<u>Concept Selection</u>

Evaluation of Concepts

In order to determine the requirements that each of the concepts must meet, customer requirements and needs would need to be analyzed and converted into quantifiable variables. The House of Quality (HoQ) method was implemented to create a chart that indicates the requirements that the concepts should meet. In order to begin HoQ, we first must determine the 'Importance Weight Factors' for each 'Customer Requirement'. This was done by completing a Binary Comparison Matrix, which separately compares each customer need to the others.

Pugh charts will then be used to gauge the concepts relative to one another and determine the most optimal concept. Each Pugh chart will eliminate at least one concept, and this process will be repeated until we are left with an acceptable number of concepts. Next, the Analytical Hierarchy Process (AHP) evaluation was implemented to methodically analyze and weigh the criteria of the concepts. After completing the evaluation of the concepts, the most promising design was chosen to accomplish the task.

Binary Comparison Matrix

The binary comparison chart is used to determine the importance of the specified customer needs and their relative weight to obtain an 'Importance Weight Factor' (IWF), highlighted in blue. The Importance Weight Factor can then be applied to the Engineering Characteristics in our HoQ to determine the relative weight and rank order.

Interpreted Customer Needs	1	2	3	4	5	**Row Totals (IWF)**
1. Lightweight		0	0	0	1	1

2. Clean Panels	1		1	1	1	4
3. Autonomous	1	0		0	1	2
4. Power	1	0	1		1	3
5. Solution tank	0	0	0	0		0

The Importance Weight Factors for each need, shown in blue, highlight that ‘Clean Panels’ is our most vital need. This is not surprising, as it is included in the name of our project. Automated non-destructive cleaning of solar panels cannot be accomplished without a dependable power source, which suggests why ‘Power’ ranked above ‘Autonomous’ or ‘Lightweight’.

Based on these weight results, these were placed in the house of quality under the importance weight factor. Now that the importance weight factor had been determined, the House of Quality chart can be created using the engineering characteristics.

House of Quality

A house of quality chart translates the customer’s requirements into quantifiable variables in the design process. This incorporates the weight factors from the binary comparison chart to emphasize the importance of customer needs. The ‘Engineering Characteristics’ are taken from our Targets and Metrics Analysis. This part of the process infuses the voice of the customer into the design.

	Engineering Characteristics					
	Units	kg	panels/hou r	# sensors	Voltage	Gallons
Customer Requirements	Importanc e Weight Factor	Weigh t	Speed	Navigation / Movement	Reliabl e Power Source	Solutio n Storage
1. Lightweight	2	9	3		1	3
2. Clean Panels	5	1	1		3	3
3. Autonomous	3		3	9	1	
4. Power	4	3	1	1	9	
5. Solution tank	1	9	1			9
Raw Score ()	176	44	25	31	72	4
Relative Weight %		25%	14%	17%	41%	2%

Rank Order		**2**	**4**	**3**	**1**	**5**

Pugh Chart Method of Selection

In this portion of the document the team will use a series of Pugh charts to aid with the concept selection of the autonomous solar panel cleaning robot. The initial Pugh chart will contain the medium and high-fidelity concepts that have been generated to begin designing the system. Once Pugh chart 1 is completed, the team will eliminate concepts that have been outweighed when in comparison. The values with the highest score will then be moved to proceeding Pugh charts until there are three or less designs. With the remaining designs, the team will be granted the best design concepts to utilize or combine in the design process.

Pugh Chart - 1

This Pugh chart is a comparison of the “GEKKO Bot” vs. All Options that are under consideration. The GEKKO Bot was chosen as our datum to compare to because we felt it was a good median design to compare our concepts to. Each option in the charts will consist of medium (M) and high (H) fidelity concepts shown below the list of Pugh charts. Each of the options will be denoted as M or H with the number of the concept shown below attached to represent which concept is being evaluated.

		Concepts?								
Selection criteria		**DATUM** **[1] GEKKO BOT**	**Option 2** **H1**	**Option 3** **H 2**	**Option 4** **H3**	**Option 5** **M1**	**Option 6** **M2**	**Option 7** **M3**	**Option 8** **M4**	**Option 9** **M5**
Criteria 1	Cleaning Capabilities	-	+	**s**	**-**	+	**-**	+	+	**-**
Criteria 2	Weight	-	**s**	+	**s**	+	**-**	+	+	**-**
Criteria 3	Cost	-	**s**	+	**s**	+	**-**	**-**	+	+
Criteria 4	Speed of cleaning	-	-	-	-	s	-	-	s	-
Criteria 5	Ability to Navigate	-	+	+	**-**	+	+	**-**	+	**-**
Criteria 6	Support	-	+	+	+	+	+	+	+	+
Criteria 7	Ease of Use	-	**-**	+	**-**	+	+	**-**	+	**-**
Score			**1**	**4**	**-3**	**6**	**-1**	**-1**	**6**	**-3**
Continue?			**Yes**	**Yes**	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**No**

Reference

[1] "GEKKO Solar High-Tec Robot," SERBOT Swiss Innovations, [Online]. Available: https://www.serbot.ch/en/solar-panels-cleaning/gekko-solar-robot. [Accessed 26 10 2021].

Pugh Chart- 2

For the Pugh chart below, "H3" and "M5" have been eliminated due to a substantially low score in comparison to the GEKKO BOT[1]. With that, the team will compare the remaining Medium and High Fidelity concepts to the High fidelity concept 2, shown as "H2".

		Option 1 H2	**Option 2 H1**	**Option 3 M1**	**Option 4 M2**	**Option M3**	**Option M4**
Criteria 1	Cleaning Capabilities	**-**	**-**	+	**s**	**s**	+
Criteria 2	weight	**-**	**-**	+	**s**	**-**	**s**
Criteria 3	cost	**-**	**-**	+	**-**	**-**	**s**
Criteria 4	Speed of cleaning	**-**	+	+	**-**	**-**	+
Criteria 5	Ability to navigate	**-**	**s**	**s**	**s**	**s**	**s**
Criteria 6	support	**-**	+	+	**s**	+	+

Criteria 7	Ease of use	**-**	**-**	**-**	**s**	**-**	**-**
Score			**-2**	**4**	**-2**	**-2**	**3**
Continue?			**No**	**Yes**	**No**	**No**	**Yes**

After completing two Pugh charts, the team has determined that the concepts M1, M4 and H2 will be used to create a final design. From the chart, each of the concepts that are remaining have two design characteristics in common. The first characteristic each design shares is utilizing tank tracks to create a high enough coefficient of friction due to the amount of surface area of the method of movement. With this the robot will be able to navigate across the array seamlessly. The second characteristic that all remaining concepts share is an unlimited amount of power that can be utilized. Without a limited amount of power, the robot will be able to eliminate all levels of soil that are present on the array. Though the robot will not be limited to a defined ampacity, the amount of power consumed will remain in consideration.

High Fidelity Concepts

1. Lithium Polymer Battery - Circle Brushes - Arduino controlled with sensors - Clamps - External solution storage
2. DC Power - dry/wet brushes - Arduino controlled with sensors - Tank wheels with suction cups - External solution storage
3. Lithium Polymer Battery - dry/wet brushes - Arduino controlled with sensors - rails on sides of panel - external solution storage

Medium Fidelity Concepts

1. AC Power OR Generator - dry/wet brushes - Arduino - sensors - tank wheels with suction cups - clamps-solution stored in external tank
2. Solar powered - Circular brushes - Arduino controlled with sensors - Suction/ negative pressure - external solution
3. Magnetic power - circular brushes - Arduino - sensors - Rails-solution in external tank
4. Interchangeable battery packs-circle brushes-Arduino controlled with sensors- Tank track with adjustable clamps-Solution in external tank with pump
5. Lithium Polymer Battery - Air - Arduino controlled with sensors - suction/negative pressure - no solution- rails

AHP

Final Selection

Shown below are the graphs and methods used for the analytical hierarchy process (AHP). The purpose of the AHP is to break down the evaluation criteria for our project. Our criteria consisted of cleaning capabilities, weight, cost, speed ability to navigate, support and ease of use. Each criteria was compared to one another based on a scale of importance. If one was more important than the other, then that criteria was given a higher weight, this is shown in Figure 1.

Figure 1 – Weighing each criteria to one another based on importance

	Criteria Comparison Matrix								*note: use 1, 3, 5, 7, 9
	Cleaning capabilities	Weight	Cost	Speed	Ability to Navigate	Support	Ease of use		
Cleaning capabilities	1	0.142857	0.2	0.333333	0.333333333	1	0.2		1 3 5 7 9
Weight	7	1	0.2	0.333333	3	3	5		
Cost	5	5	1	1	9	7	3		
Speed	3	3	1	1	5	5	5		
Ability to Navigate	3	0.333333	0.111111	0.2	1	1	0.3333333		
Support	1	0.333333	0.142857	0.2	1	1	0.2		
Ease of use	5	0.2	0.333333	0.2	3	5	1		
Sum	25	10.00952	2.987302	3.266667	22.33333333	23	14.733333		

	Normalized Criteria Comparison Matrix							Criteria Weights	
	Cleaning capabilities	Weight	Cost	Speed	Ability to Navigate	Support	Ease of use		
Cleaning capabilities	0.04	0.014272	0.06695	0.102041	0.014925373	0.043478	0.0135747	0.042177327	0.0421
Weight	0.28	0.099905	0.06695	0.102041	0.134328358	0.130435	0.3393665	0.164717911	0.1647
Cost	0.2	0.499524	0.33475	0.306122	0.402985075	0.304348	0.2036199	0.321621398	0.3216
Speed	0.12	0.299715	0.33475	0.306122	0.223880597	0.217391	0.3393665	0.263032241	0.263
Ability to Navigate	0.12	0.033302	0.037194	0.061224	0.044776119	0.043478	0.0226244	0.051799914	0.0517
Support	0.04	0.033302	0.047821	0.061224	0.044776119	0.043478	0.0135747	0.040596659	0.0405
Ease of use	0.2	0.019981	0.111583	0.061224	0.134328358	0.217391	0.0678733	0.11605455	0.116
Sum	1	1	1	1	1	1	1	1	

Once each criteria was compared to one another, we compared the top three concepts that came out of our Pugh charts from above. Each concept was weighed based on each criteria. For example, shown in figure 2, the “cleaning capabilities” criteria were compared to each concept that came out of the Pugh charts seen in figure 3. All the comparisons can be seen in the appendix.

Figure 2 – Concepts compared to one another based on the “cleaning capabilities” criteria

	Cleaning Capabilities			
	M1	M4	H2	
M1	1	0.333333	0.333333	
M4	3	1	3	
H2	3	0.333333	1	
Sum	7	1.666667	4.333333	
		Normalized		
	M1	M4	H2	Priority
M1	0.142857	0.2	0.076923	0.139927
M4	0.428571	0.6	0.692308	0.573626
H2	0.428571	0.2	0.230769	0.286447
Sum	1	1	1	1

Figure 3 – Concepts from Pugh Carts

M1	1. AC Power OR Generator - dry/wet brushes - arduino - sensors - tank wheels with suction cups - clamps-solution stored in external tank
M4	1. Interchangeable battery packs-circle brushes-Arduino controlled with sensors- Tank track with adjustable clamps-Solution in external tank with pump
H2	1. DC Power - dry/wet brushes - Arduino controlled with sensors - Tank wheels with suction cups - External solution storage

After all the criteria was weighed out to each concept, the final concept was calculated and is shown in Figure 4. Based on the figure below and based on how we calculated the weights for each criteria, the concept that was chosen was the one with the smallest decimal number. Due to how the sum was calculated in Figure 2, calculated from the columns now the rows, the concepts with the highest priority ended up being represented by the lowest decimal number.

Figure 4 – Final Generation of Concept

	Concepts		M1	M4	H2
Critera	Criteria Weights				
Cleaning Capabilites	0.0421	0.0421	0.139927	0.573626	0.286447
Weight	0.1647	0.1647	0.2	0.6	0.2
Cost	0.3216	0.3216	0.071855	0.696531	0.231614
Speed of Cleaning	0.263	0.263	0.106156	0.633346	0.260498
Ability to Navigate	0.0517	0.0517	0.333333	0.333333	0.333333
Support	0.0405	0.0405	0.088675	0.252898	0.658428
Ease of Use	0.116	0.116	0.454545	0.454545	0.090909
	Weighted Sum		0.16341	0.593747	0.242443

Shown in Figure 4, our final concept ended up being M1. M1 consists of AC Power OR a generator, dry/wet brushes, Arduino, sensors, tank wheels with suction cups, clamps and solution stored in external tank.

Appendix

AHP Charts

Figure 5 – “Weight” Criteria compared to concepts

	Weight			
	M1	M4	H2	
M1	1	0.333333	1	
M4	3	1	3	
H2	1	0.333333	1	
Sum	5	1.666667	5	
	Normalized			
	M1	M4	H2	Priority
M1	0.2	0.2	0.2	0.2
M4	0.6	0.6	0.6	0.6
H2	0.2	0.2	0.2	0.2
Sum	1	1	1	1

Figure 6 – “Cost” Criteria compared to concepts

	Cost			
	M1	M4	H2	
M1	1	0.142857	0.2	
M4	7	1	5	
H2	5	0.2	1	
Sum	13	1.342857	6.2	
	Normalized			
	M1	M4	H2	Priority
M1	0.076923	0.106383	0.032258	0.071855
M4	0.538462	0.744681	0.806452	0.696531
H2	0.384615	0.148936	0.16129	0.231614
Sum	1	1	1	1

Figure 7 – “Speed of Cleaning” Criteria compared to concepts

	Speed of Cleaning			
	M1	M4	H2	
M1	1	0.2	0.333333	
M4	5	1	3	
H2	3	0.333333	1	
Sum	9	1.533333	4.333333	
	Normalized			
	M1	M4	H2	Priority
M1	0.111111	0.130435	0.076923	0.106156
M4	0.555556	0.652174	0.692308	0.633346
H2	0.333333	0.217391	0.230769	0.260498
Sum	1	1	1	1

Figure 8 – “Ability to Navigate” Criteria compared to concepts

	Ability to Navigate			
	M1	M4	H2	
M1	1	1	1	
M4	1	1	1	
H2	1	1	1	
Sum	3	3	3	
		Normalized		
	M1	M4	H2	Priority
M1	0.333333	0.333333	0.333333	0.333333
M4	0.333333	0.333333	0.333333	0.333333
H2	0.333333	0.333333	0.333333	0.333333
Sum	1	1	1	1

Figure 9 – "Support" Criteria compared to concepts

	Support			
	M1	M4	H2	
M1	1	0.2	0.2	
M4	5	1	0.2	
H2	5	5	1	
Sum	11	6.2	1.4	
		Normalized		
	M1	M4	H2	Priority
M1	0.090909	0.032258	0.142857	0.088675
M4	0.454545	0.16129	0.142857	0.252898
H2	0.454545	0.806452	0.714286	0.658428
Sum	1	1	1	1

Figure 10 – "Ease of Use" Criteria compared to concepts

	Ease of Use			
	M1	M4	H2	
M1	1	1	5	
M4	1	1	5	
H2	0.2	0.2	1	
Sum	2.2	2.2	11	
		Normalized		
	M1	M4	H2	Priority
M1	0.454545	0.454545	0.454545	0.454545
M4	0.454545	0.454545	0.454545	0.454545
H2	0.090909	0.090909	0.090909	0.090909
Sum	1	1	1	1

Engineering Characteristics

An average residential array consists of 20-30 panels (IGT). At 0.5 gallons of solution required for each panel (Duke) that's 10-15 gallons of water. One gallon is 8.3 pounds. (That's 80+ lbs). So basically, we have to cut water usage (which I think can be done by implementing dry light cycles and using soaker brushes for heavy cycles).

- Let's assume we can cut it in half (0.25 gallons/panel) and that we are designing for about 20 panels right now. That's 5 gallons of water which is still 40 lbs.
  - We either clean without water or we need a hose (we can use a hose that is attached to a solution tank outfitted with a mixture value, so the amount of water on the roof at one given point is ideal). Light cycle will not require water and thus no hose, so the hose spool must be detachable.

- Storing solution: requires about a 1:4 ratio of vinegar to water. If we use 10-15 gallons of water (20-30 panels max water usage) then we need 2.5-3.75 gallons of vinegar