

Surplus DoD Equipment Removal Device

**a report done for
Vermillion Rise Mega Park
Hillsdale, Indiana**

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**ME472-03
Capstone Design
Professor Z. Chambers**

**DEPARTMENT OF MECHANICAL ENGINEERING
ROSE-HULMAN INSTITUTE OF TECHNOLOGY**

Executive Summary

The client for the Capstone Design project is Bob Grewe. Mr. Grewe is the Executive Director of Vermillion Rise Mega Park, a 7,000-acre industrial facility located in Hillsdale, Indiana. [1] The overall need that the client communicated is an economically feasible method of removing surplus equipment from a basement. The opportunity for the team is to accurately capture the needs of the client, to conceive solutions that satisfy these needs, and to effectively communicate the results of the team's work with the client.

The key needs that were explicitly identified by our main stakeholder, Mr. Grewe, are that the solution is safely operable, inexpensive, and capable of removing objects from any location in the basement. See Table 2 for the specific and measurable numbers associated with these technical specifications.

Statics analyses were conducted on the cart, winch bracket and pulley. The statics analyses in Appendix C – Deflection Calculations, Appendix F- Winch Mount Analysis and Appendix H- Pulley Static Analysis show that the parts should not fail.

The prototype cart and winch system were completely constructed within the allotted time frame. On-site testing was performed with multiple successful tests being completed. The cart, however, failed the last test with the backboard splitting and the uprights failing.

Despite initial setbacks due to material acquisition, the team was able to meet all deadlines set out at the beginning of the academic year. This resulted in a fully completed workplan. We successfully completed our spring workplan which contained two test and refine phases before project handoff.



Figure 1: Final Design

Nomenclature

- VR: Vermillion Rise
- SPTV: Self-Propelled Tracked Vehicle
- CAD: Computer-Aided Design

Disclaimer

The contents of this report were prepared by senior mechanical engineering students at Rose-Hulman Institute of Technology. We feel confident in our work as students. However, all material should be reviewed by an appropriate professional before implementation.

Executive Summary	1
Nomenclature.....	2
Disclaimer	2
Table of Tables	5
Table of Figures.....	Error! Bookmark not defined.
Problem Definition	7
Project Needs and Technical Specifications.....	9
Conceptual Design	12
Conceptual Design Refinement to Convergence	12
Functional Prototype and Preliminary Testing.....	13
Functional Prototype.....	13
Prototype Testing	15
Design Modifications Resulting from Prototype Testing	17
Design Verification.....	19
Appendix A - Design Checklist.....	23
Appendix B – Prior Art (EZ-Climber 1300)	24
Appendix C – Deflection Calculations	25
Case 1: 125 kg Load at the Center Point of Beams 3 and 4	26
Case 2: 250 kg Load at the Center of Beam 4.....	29
Appendix D – Bill of Materials.....	32
Appendix E- Design Drawings.....	36
Appendix F- Winch Mount Analysis.....	47
Appendix G - Rationale for Technical Specification Values & Subsequent Evaluation Methodology	48
Appendix H- Pulley Static Analysis	52
Appendix I – Set-up Instructions	53
Appendix J – Cart Conversion Instructions.....	56
Appendix K – Safe Operating Instructions.....	57
K.1 - Loading Small Items	57

K.2 – Loading Large Items	57
Appendix L – Lessons Learned	61
Appendix M – Acknowledgements	62
Appendix N – Battery Care.....	63

Table of Tables

Table 1: Client Needs	9
Table 2: Needs to Metrics Map	11
Table 3: Design Verification	19
Figure 1: Final Design	1
Figure 2: Example Equipment Needing Removal	7
Figure 3: Possible Exit Paths	7
Figure 4: Representative Obstructions to Exit	8
Figure 5: Initial Prototype.....	13
Figure 6: Prototype Testing Failure.....	16
Figure 7: Swivel Locks	17
Figure 8: Redesigned Ramps.....	17
Figure 9: Wedge Ramps.....	18
Figure 10: Final Cart Design.....	18

Problem Definition

The client of this Senior Capstone Project is Bob Grewe. Mr. Grewe is the executive director of Vermillion Rise Mega Park, a 7,000-acre industrial facility located in Hillsdale, Indiana [1]. Mr. Grewe has tasked us to **design a system that can be used to safely remove obtrusive equipment from a basement**. The main stakeholders affected by this project are the Vermillion Rise Management, as they are the beneficiaries of the project, and Rose-Hulman Institute of Technology, since the quality of the results of the Senior Capstone Team directly reflect on the quality of Rose-Hulman's education. Within the Mega Park, this project focuses on a single building which is not currently leasable to clients because the basement contains large amounts of unwanted equipment. This equipment includes old desktop computers, printers, battery backups, and computer accessories among other things. Representative pictures of the items present are below in Figure .

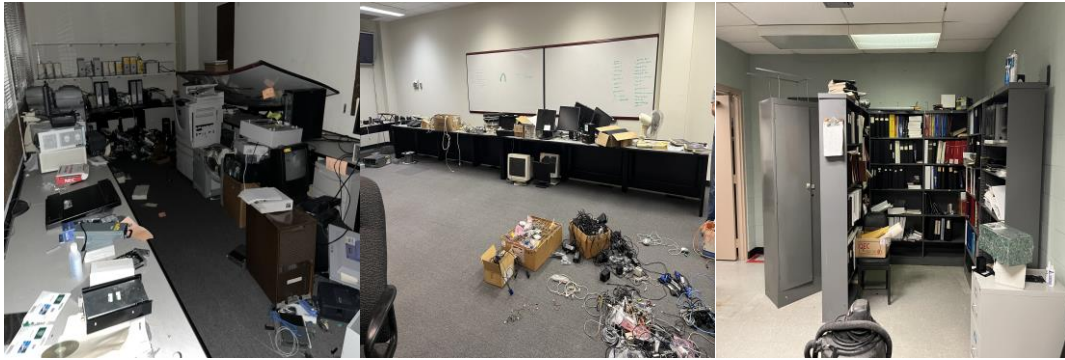


Figure 2: Example Equipment Needing Removal

The facility does not contain an elevator to remove the items, so they must be removed through one of three stairways exiting from the basement. These three options are depicted in Figure below.

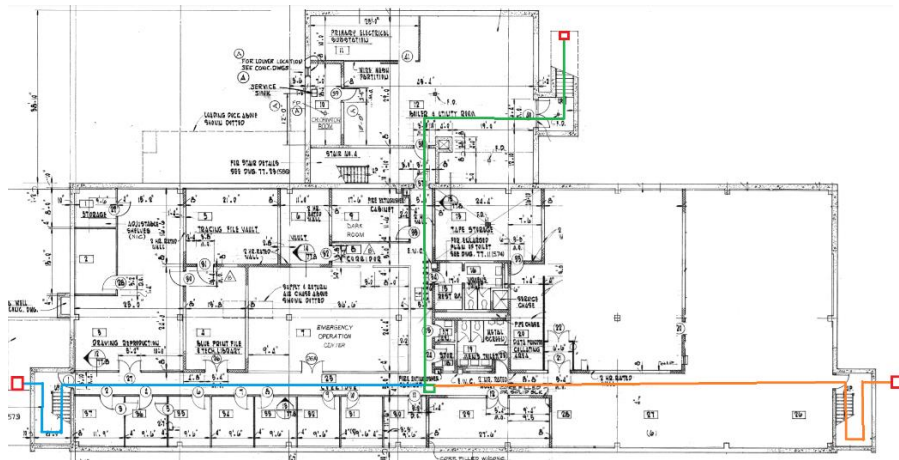


Figure 3: Possible Exit Paths

Of the three possible exits, the one denoted by the green path is the only one that does not require the solution to navigate a stairwell with a turn. For this reason, it was chosen to be the exit path that the solution was designed to be used on. Figure below shows representative pictures of the doorways and hallways the solution must move through as well as a picture of the selected stairwell.



Figure 4: Representative Obstructions to Exit

The top-level functional requirements of the solution include that it must be able to maneuver a wide range of equipment sizes from the various locations within the basement to the targeted exit. The solution must then be able to move the equipment up this stairwell to the ground level. After our project is completed, Mr. Grewe will facilitate recycling or disposing of said equipment. One of the two ways the success of the project will be measured by grading the solution delivered to the client against the Needs to Metrics Map located in Table 2. The second of the two ways the success of the project will be measured is by how our client rates our delivered solution and whether he thinks that the delivered solution accomplishes all he set out to accomplish when he informed the team of the project at the beginning of the fall quarter.

The successful completion of this project has potential for four positive external effects. Firstly, the opportunity to lease this space should help aid in the development of the vast Vermillion Rise complex. Secondly, the associated increase in jobs should have a positive impact on the local economy through increased local demand and purchasing. Next, the successful completion of this project helps to facilitate the process of return on investment for Vermillion Rise Development. Lastly, the successful and safe removal of this equipment allows for it to be recycled into new and useful materials and items preventing its environmentally dangerous decay.

Project Needs and Technical Specifications

Table 1 below details the client's needs associated with this project. These needs guide the analysis of design concepts in terms of safety, cost, compatibility, convenience, functionality, performance, experience, and reliability.

Table 1: Client Needs

#	Need	Category
1	Safely operable	Safety
2	Inexpensive	Cost
3	Fit through the doors, hallways, and staircases in the existing building without modification	Compatibility
4	Removable and reassemble-able	Convenience
5	Able to move the items present	Functionality
6	Storable in supply closet	Compatibility
7	Capable of quick assembly/disassembly	Performance
8	Operable by few people	Experience
9	Able to transport items across uneven ground	Performance
10	Able to be loaded and unloaded quickly	Efficiency
11	Able to navigate sharp corners	Performance
12	Reliable	Reliability
13	Capable of moving things up and down stairs	Performance

Needs one, two, three, four, and six from Table 1 come directly from the client. The remaining needs are determined to be basic requirements for the solution to fulfill its purpose. Need five is the very basic requirement that the solution be able to move the range of items present in the facility. This range includes large printers, desktop computer towers, battery backup units, and a range of smaller office equipment and accessories. Need seven is a performance based need that ensures setup and teardown of the solution is not inhibitive to regular operation of the facility. Need eight constrains the number of people required to operate the solution as to not further disrupt normal operation of the facility. Need nine serves to ensure that the solution can traverse the bumps and cracks in the floors of the facility, as well as the outdoor concrete. Need ten is an efficiency need that serves to ensure the overall task of cleaning out the facility doesn't take an inhibitive amount of time. Need eleven is a performance requirement that will aid in ease of mobility throughout the facility. Need twelve helps constrain the operating lifetime of the solution such that it doesn't fail before the objective task is completed successfully. Lastly, need thirteen is a performance need that will allow for the solution to be utilized by potential leasers of the space to move equipment back into the space. Together, these needs will

ensure that the solution will be able to successfully complete the objective task and fulfill the client's needs.

The needs are ranked in order of importance first by client input, and then by pertinence to successful completion of the target objective. The "safety" and "inexpensive" needs are both ranked as the highest priority based on the client's direct input. Needs three through six are ranked as the second highest priority because they ensure the device has the bare minimum capacity to carry the present items and navigate the space. Needs seven and eight are ranked third because they do not pertain to the bare minimum requirements but ensure that use of the device does not induce an excessive time or maintenance cost. Needs nine through twelve are ranked fourth because they pertain primarily to the setup and teardown of the device, not its critical functions. Lastly, need thirteen is ranked fifth because the physical appearance of the solution is of little to no importance for this application.

To quantify the degree to which these needs are met, metrics are developed. Each metric is then combined with an associated target based on measurements of the facility, client input, standards, and regulations. This creates a set of technical specifications. The needs and their associated technical specifications are then ranked in order of importance. The summary result of this process is provided in Table 2 on the following page.

The rationale for the target values selected in the Needs to Metrics Map are in Appendix G. Also, the plan for evaluating the competency of the final solution by measuring it against each technical specification is in Appendix G. No changes were made to the project needs or technical specifications since the team's last report because the team decided that the needs and technical specifications continued to accurately represent the client's needs.

Table 2: Needs to Metrics Map

Need		Metric	Units	Target	
#	Rank				
1	5	Safe	a tray height	cm	≤ 24 (9.5 in.)
			b edge radius	mm	< 0.5 (0.02 in.)
			c # of exposed pinch points	N/A	0
2	5	Inexpensive	a cost	\$	$< \$2500$
3	4	Fit doors and hallways	a device length	m	< 1.22 (48 in.)
			b device width	m	< 0.81 (32 in.)
			c device height	m	< 1.83 (72 in.)
4	4	Carry the present items	a lifting capacity	kg	> 250 (550 lb.)
			b object length	m	< 1.75 (69 in.)
			c object width	m	< 0.82 (32 in.)
			d object height	m	< 1.70 (67 in.)
5	4	Maneuverability	a traverse bumps (height)	cm	≥ 2 (0.75 in.)
			b traverse gaps (width)	cm	≥ 3 (1.2 in.)
			c turning radius	m	< 0.6 (23.5 in.)
			d move things down	Yes/No	Yes
6	4	Move things upstairs	a ability to mv. upstairs	Yes/No	Yes
7	3	Reliability	a objects moved	objects	> 250
8	3	Efficiency	a load time	min.	< 5
			b unload time	min.	< 3
9	2	Store in closet	a storage length	m	< 0.91 (36 in.)
			b storage width	m	< 0.82 (32 in.)
			c storage height	m	< 1.83 (72 in.)
10	2	Few operators	a operators	people	≤ 2
11	2	Quick assembly/disassembly	a assembly time	min.	< 90
			b disassembly time	min.	< 90
12	2	Assembly	a constructible	Yes/No	Yes
			b deconstructible	Yes/No	Yes
13	1	Design	a visual appeal	N/A	Acceptable

Conceptual Design

Conceptual Design Refinement to Convergence

The cart design underwent multiple changes since the initial design at the end of the fall quarter. These design changes include changing out the tracks for casters and the body of the cart being made of 80/20 extrusions. These and other changes were made to simplify operation and manufacturing of the cart.

The first major design change was the change from tracks to pneumatic casters. This design change was made for two reasons. Firstly, ease of operation. The tracks would have made the cart difficult to push and turn. This is due to the large contact patch of the tracks that provides a large amount of friction. Also, assuming that the tracks do not stretch, they would not allow the front and rear guide wheels to move at different speeds. This would further impair maneuverability in certain situations. Pneumatic casters were chosen at the clients request as they preferred the pneumatic casters to normal plastic casters. The casters were spec'd from McMaster-Carr to be over engineered for our heaviest load. Since casters were chosen instead of the tracks, a set of ramps were designed so that the cart could navigate the stairs. This is because the casters are too small to traverse the stairs without a ramp.

The second major design change of the cart was the change from a sheet metal construction to a wood and 80/20 construction. This design change both simplified fabrication and allowed for the cart to become more modular. The 80/20 extrusions eliminated the need for sheet metal bending at awkward angles and allows for an overall simpler construction. The 80/20 construction also makes it easier to take the cart apart and replace old or damaged components should the need arise. The 80/20 also allowed for the construction of a modular cart that can be quickly modified for both large and small objects. According to the statics analysis in Appendix C, the cart should only deflect 17mm in the worst-case scenario.

The anchoring mechanism for the winch was also redesigned. The original design included a weighted sled that would provide the reaction force to allow the winch to pull the cart up the stairs. It was decided to utilize a concrete wall on the property near the stairs to anchor the winch to. This means that the winch assembly will be easier to store and a whole sled does not need to be produced. A static analysis was done on the anchoring of the winch this way (See Appendix F- Winch Mount Analysis). The required reaction force exerted by the concrete anchor is 1469 N. The concrete anchors can handle 4890 N in pull-out, being well over the needed 1469 N.

A design addition from our fall design was the pulley at the crest of the top stair. This pulley was added to keep the winch cable from rubbing against the edge of the stair, damaging both the stair and the cable. A static analysis of the pulley was done using the supplier's rating.

Functional Prototype and Preliminary Testing

Functional Prototype

Fabrication of the first functional prototype was completed during Winter quarter. It is shown below in Figure 5. The prototype was built within desired specifications. The main categories for the building of the cart were the machining of the metal parts and the woodworking.



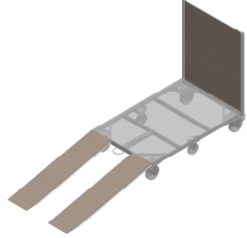
Figure 5: Initial Prototype

For the machining, the team used a bandsaw to cut all the 80/20 pieces referenced in Appendix E- Design Drawings (E3-E14). These cut pieces were then drilled and faced using the two mills in the BIC Machine shop. After machining was finished, all the parts were sanded and deburred. The parts that needed tapping were tapped with a hand tap. Fitment was then tested prior to full assembly. The entire skeleton of the cart was then assembled along with the winch mount, pulley mount and rails for the loading ramps.

For the woodworking section, the plywood for the floor and walls of the cart were cut to length and the ends were routed to fit the slots in the 80/20. These drawings can be found in Appendix E- Design Drawings (E19, E20 and E21). Holes were then drilled by hand in the floor board and ramp boards. The floor board and ramp boards were then secured to the metal pieces for the respective boards. The final part of the woodworking was the fabrication of the stair ramps. The boards were cut down from 120 inches to 104 inches. All four boards then had an 8-inch-wide, 0.75-inch-deep route created up the entire length using the CNC router in the KIC.

Additional Parts

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	30-3030	30mm x 30mm x 940mm TSP	2
2	backPanel	plywood	1
3	91292A192	M5x0.8x30 mm SHCS	4
4	25-2525	25mm x 25mm x 1110mm TSP	4
5	6000N124	T-Slotted Framing Fasteners	20
6	91294A194	M4x0.7x16mm FHS	20
7	rampPanel	plywood	2



Additional Purchases

ITEM NO.	PART NUMBER	Source	DESCRIPTION	QTY.	Unit Cost	Total Cost
1	30-3030	8020.net	30mm x 30mm x 990mm TSP	2	\$13.56	\$27.12
2	25-2525	8020.net	25mm x 25mm x 1160mm TSP	4	\$14.13	\$56.52
3	6000N124	McMaster Carr	T-Slotted Framing Fasteners	20	\$0.91	\$18.20
4	91294A194	McMaster Carr	M4x0.7x16mm FHS (100 pk.)	1	\$7.57	\$7.57
5	1251061	Menards	4'x8'x3/8" Plywood	1	\$35.99	\$35.99
					Total	\$145.40
					+15%	\$167.20

Total Additional Cost: \$167.20

Abbreviations
TSP - T-Slot Profile
SHCS - Socket Head Cap Screw
Pneu. - Pneumatic
FHS - Flat Head Screw

RHIT A LANDSCAPE	
Dimensions are inches and degrees	Large Items Cart Additional Parts and Purchases
Default Tolerances	
.X ±0.1	Drawn by: Team 53
.XX ±0.03	
.XXX ±0.005	
Angles ±2	Scale: 1:35 Date: 12/9/2021

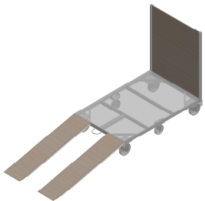
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The final parts to be made were 3-D printed inserts on the ends of the ramps. One was a wedge at the leading edge to help the objects get onto the ramp. The second part was an insert to bridge the gap between the ramps and the cart.

The team learned quite a bit throughout the fabrication process. Firstly, the team learned that plywood that is not properly stored can cause problems. After the plywood sections

were cut, moisture caused the plywood to curl even after weights were added to flatten it out. This led to the rear wall having to be fabricated from particle board and not plywood. We also learned to better schedule with the ME techs as we cut it close routing the stair ramps with the CNC router. We learned that machining odd angles is more difficult to mill with the current machines we have. The team also learned to design parts that are better suited for the available machines.

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Angles ±2	

Abbreviations
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 SHCS - Socket Head Cap Screw
 Pneu. - Pneumatic
 FHS - Flat Head Screw

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Prototype Testing

The preliminary testing was done on site at Vermillion Rise. The holes for the concrete anchors for mounting the winch, pulley, and ramps were drilled and the components were mounted. Five different tests were performed to test carrying capacity of the cart and the compatibility of the cart with the basement. There was one issue with mounting all the components. The width between the wheels of the cart is less than the tracks in the ramps on the stairs. So, the planned mounting method could not be done for both ramps.

The first test performed was taking the cart without any other load up and down the stairs using the winch. This test was a success. The winch had no trouble pulling the cart and the pulley worked as planned to prevent the cable from dragging on the top of the stairs.

The next test was to check the compatibility of the cart with the doorways of the basement and the cart's ability to take corners and traverse bumps and gaps. We maneuvered the cart throughout the basement, checking to make sure it fit through the smallest doorways indicated on the blueprints and moving the cart over bumps and gaps the team noted during the first visit to the facility. This test was a success. The cart fit through all doorway and was able to turn corners and traverse all bumps and gaps with no problems.

After this, the cart was pulled up the stairs with increasing amounts of weight. 50-pound salt bags were used as weights. Three trials were run. The first trial was 100 pounds, the second was 200 pounds, and the third was 250 pounds. All three trials were successes. All components worked as designed.

The next test performed was loading one of the larger items that needs to be removed, a printer, onto the cart using the plywood ramps to see if the plywood ramps would handle the weight and could be easily attached and detached from the cart. This test was a partial success. The ramps successfully handled the weight of the printer being rolled up them, but once the printer was on the cart it was difficult to remove them because the printer is slightly longer than our cart and the ramps needed to be lifted up out of the C channel to be removed. Changes were made to the cart so the ramps can be slid in from the side to eliminate this issue.

The final test ran was attempting to take the printer previously loaded onto the cart up the stairs using the winch. This test was unsuccessful and resulted in a component failure. As the back wheels of the cart reached the ramp, the swivel wheels on the back of the cart turned horizontally, imparting an impulse to the cart which caused the particle board on the back of the cart to snap and the bolt heads holding the vertical uprights partially pulled through the 80/20. The aftermath of this incident is shown in Figure 6 below.



Figure 6: Prototype Testing Failure

Design Modifications Resulting from Prototype Testing

To correct for the violent rotation of the rear wheels, we developed custom pin locks that restrict the swivel of the rear casters without prevent the rotation of the wheels. These are shown in Figure 7 below.



Figure 7: Swivel Locks

Also shown in Figure 7 is the use of c-channel to mount the rear panel of the cart for additional strength over routing the edges down to 7mm. Triangular bracing, shown in Figure 10, was also added in order to further support the back panel of the cart.

This modification proved successful in our both our second and third onsite testing days. Additionally, we redesigned the stair ramps to be made out of MDF covered with clear coat for longevity. A close-up view of the redesigned ramps is provided in Figure 8 below.



Figure 8: Redesigned Ramps

These ramps are far wider than the original ones which allows for L-Channel mounting on both sides for stability. The effectiveness of the clear coat was also put to the test on our second day of onsite testing when the ramps experienced rainfall without any noticeable damage. We also added metal plates to the back sides of the ramps at the seams to prevent deflection between sections.

Lastly, we build wedge ramps for the top of the stairs so that the cart could travers the approximately four-inch bump. We were able to develop these using scrap material from the initial ramp design, alleviating any additional expense for our client. The wedge solution is shown in Figure 9 below.



Figure 9: Wedge Ramps

The final cart design after these changes is shown in below.



Figure 10: Final Cart Design

Additional pictures of the final design are shown in the instructional appendices I through K.

Design Verification

The systematic evaluation of our technical specifications is described in Appendix G. The results of our evaluation are summarized in Table 3 below.

Table 3: Design Verification

Project Need	Technical Specification	Rationale	Achieved?
Safe	Tray height of 24cm	Allows for ease of loading	Yes
	No sharp edges	Injury prevention while operating	Yes
	No pinch points	Injury prevention while operating	Yes
Inexpensive	Costs less than \$2500 USD	Client requirement	Yes
Fit doors and hallways	Device length less than 1.22 m	Allows cart to maneuver through building	Yes
	Device width less than 0.81 m		Yes
	Device height less than 1.83 m		Yes
Carry items within building	Able to lift 250 kg	Measurements of largest item found in building	Yes
	Carry object 1.75 m long		Yes
	Carry object 0.82 m wide		Yes
	Carry object 1.70 m tall		Yes
Maneuverability	Traverse bumps at least 2 cm tall	Measurements taken onsite	Yes
	Traverse gaps at least 3 cm wide		Yes

	Turning radius of less than 0.6 m	Measurements taken within building	Yes
	Take things down stairs	Goal to increase utility of solution	Yes, Not advised
Move items up stairs	Move items from the basement to the ground level using stairs	Client requirement	Yes
Reliability	Complete 250 cycles	Estimate of number of trips to complete task	Predicted to be Yes, minimal wear observed in testing
Efficiency	Load time of less than 5 min	Goals set to minimize time required to operate	Yes
	Unload time of less than 3 min		Yes
Storage	Solution length of less than 0.91 m	Measurements taken in building	No
	Solution width of less than 0.82 m		Yes
	Solution height of less than 0.83 m		Yes
Crew size	Require only 2 operators	Buddy system and taking minimum number from other tasks	Yes
Assembly/Disassembly time	Solution fully assembled in less than 90 min	Minimize time required to use solution	Yes
	Solution fully disassembled in less than 90 min		Yes
Assembly	Able to be put together with common tools	Allows for maintenance	Yes

	Able to be taken apart with common tools		Yes
Design	Design is visually acceptable	Builds client confidence in build quality	Yes

The only technical specification that was not met was the storage length of the device due to the stair ramps. These ramps are longer than the specified 0.91 m. This has been deemed acceptable by the team and client as a new storage space was found to accommodate the device.

The other questionable specification is the ability of the cart to move things down the stairway. The team experimentally determined that the device was physically able to move things down the stairs. However, this operation is risky as the cart has to be guided over the top step of the stairs. The team feels that it is not advisable to complete this operation due to safety concerns.

Works Cited

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- [5] 8020 Inc., "20-2040," [Online]. Available: <https://8020.net/20-2040.html>. [Accessed 27 12 2021].

Appendix A - Design Checklist

Consideration	Cite evidence in your report that your team has accounted for each consideration, where applicable (include section name and page number)
Global	This consideration is not applicable to our project because our work only affects a single business entity.
Economic	<ul style="list-style-type: none"> - ... the opportunity to lease this space should help aide in the development of the vast Vermillion Rise complex. (Problem Definition, Page 8) - ... the associated increase in jobs should have a positive impact on the local economy through increased local demand and purchasing. (Problem Definition, Page 8) - ... the successful completion of this project helps to facilitate the process of return on investment for Vermillion Rise Development. (Problem Definition, Page 8)
Environmental	- ... the successful and safe removal of this equipment allows for it to be recycled into new and useful materials and items preventing its environmentally dangerous decay. (Problem Definition, Page 8)
Societal	This consideration is not applicable to our project because our work only affects a single business entity.
Ethical	This consideration is not applicable to our project because there are no ethical dilemmas present.
Engineering Standards	<ul style="list-style-type: none"> - A conversation with a Journeyman Machinist suggested a minimum edge radius of 0.5 mm [2]. (Appendix G, Page 4) - OSHA guidelines require that all pinch points be either guarded or avoided through procedural methods like two-handed tripping devices [3]. (Appendix G, Page 44)

Appendix B – Prior Art (EZ-Climber 1300)



Appendix C – Deflection Calculations

Simplifying the complete frame assembly shown in Figure C-1 below:

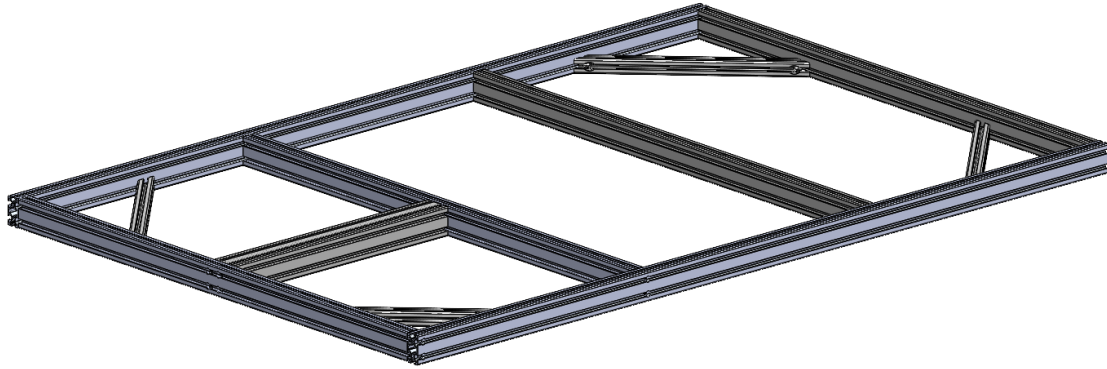


Figure C-1: Complete Frame

to that in Figure C-2 below:

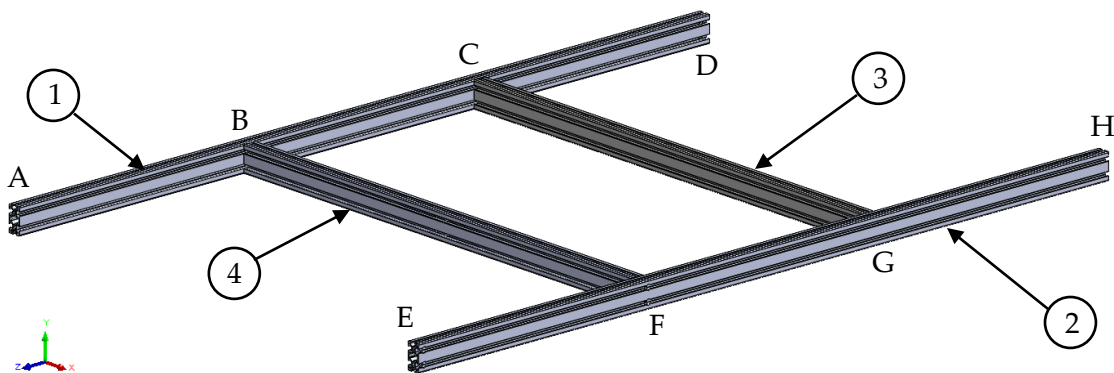


Figure C-2: Simplified Frame

allows for deflection to be determined via a simple statics calculation. This simplification is likely to produce a worst-case scenario deflection, and thus is significant in validating the design. In this calculation, all beams will be modeled as if they were simply supported as shown in Figure C-3 below.

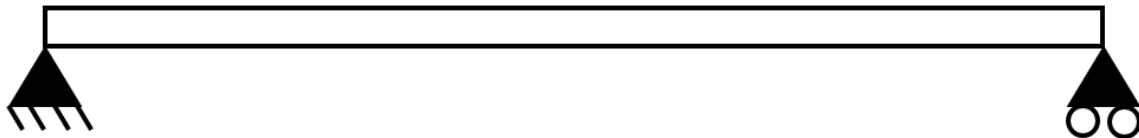


Figure C-3: Beam Model

This model is suitable because the bolt interactions are insignificant to the deflection. Deflections in the x- and z-directions will also be ignored because they are insignificant relative to deflections in the y-direction. Lastly, the mass of the beams will be neglected because the heaviest member is 0.765 kg and the maximum expected load is 250 kgs. Two loading scenarios will be evaluated in this analysis.

- Case 1: 125 kg load at the center point of beams 3 and 4
- Case 2: 250 kg load at the center point of beam 4

The deflections for each case are provided in Table C-1 below.

Table C-1: Deflection Summary

Case	Maximum Deflection (mm)	Maximum Bending Stress (Gpa)	Factor of Safety
1	15.0	0.108	2.23
2	17.6	0.203	1.19

Detailed calculations for each case follow. The length of members 1 and 2 is 1.200 m and the length of members 3 and 4 is 0.750 m. The material properties of the 20mm X 40mm extrusions used are provided below in Table C-2.

Table C-2: Material Properties

A_c (m ²)	σ_{yield} (Gpa)	E (Gpa)	I (m ⁴)
0.275×10^{-3}	0.2411	70.326	4.5357×10^{-8}

Case 1: 125 kg Load at the Center Point of Beams 3 and 4

The loading scenario for this case is shown in Figure C-4 below.

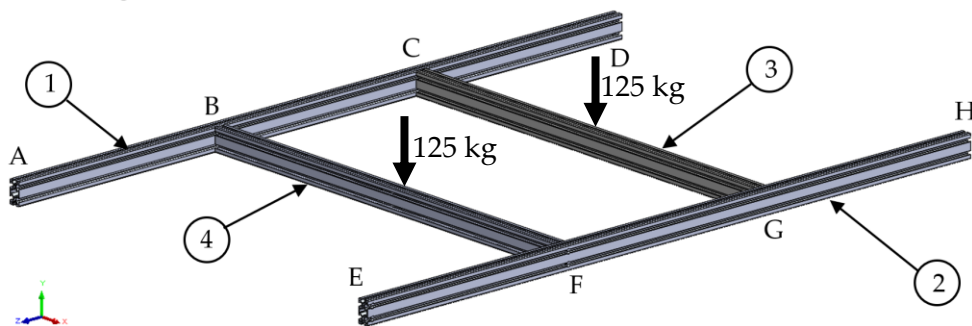


Figure C-4: Case 1 Loading

The loading scenario of beams 3 and 4 is identical in this case, so only one beam needs to be analyzed. The free body diagram (FBD) for member 3 is given in Figure C-5 below.

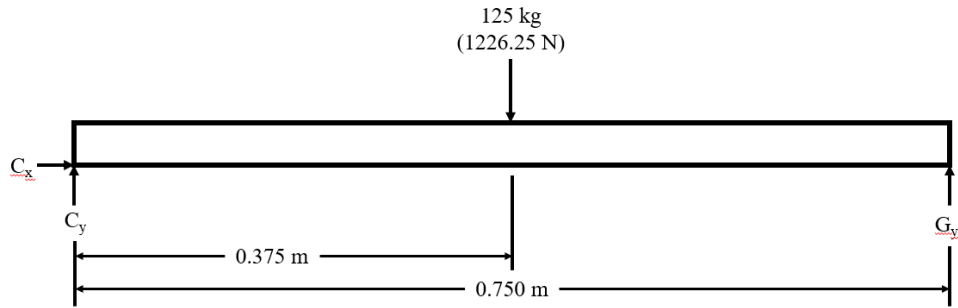


Figure C-5: Member 3 FBD

The sums of forces in the x and y directions and the sum of moments about point C are given in equations C.1, C.2, and C.3 below.

$$\sum F_x = 0 = C_x, \quad \text{C.1}$$

$$\sum F_y = 0 = C_y - 1226.26 + G_y, \quad \text{C.2}$$

$$\sum M_C = 0 = -1226.26(0.750) + G_y(0.750), \quad \text{C.3}$$

The solution to these equations is $C_x = 0$ N, $C_y = 613.125$ N, and $G_y = 613.125$ N. From symmetry, it can be concluded that $B_x = 0$ N, $B_y = 613.125$ N, and $F_y = 613.125$ N. The maximum deflection in for this loading scenario is given by

$$\delta_{\max,3} = \frac{PL^3}{48EI} = \frac{(1226.25 \text{ N})(0.750 \text{ m})^3}{48(70.326 \times 10^9 \text{ Pa})(4.5357 \times 10^{-8} \text{ m}^4)} = 3.38 \text{ mm}. \quad \text{C.4}$$

The maximum bending moment for this loading scenario is given by

$$M = \frac{WL}{4} = \frac{(1226.25 \text{ N})(0.75 \text{ m})}{4} = 229.92 \text{ N} \cdot \text{m} \quad \text{C.5}$$

This corresponds to a maximum axial stress of

$$\sigma_{\text{axial}} = \frac{My}{I} = \frac{(229.92 \text{ Nm})(0.020 \text{ m})}{4.5357 \times 10^{-8} \text{ m}^4} = 0.101 \text{ Gpa}. \quad \text{C.6}$$

The FBD for member 1 is given in Figure C-6 below.

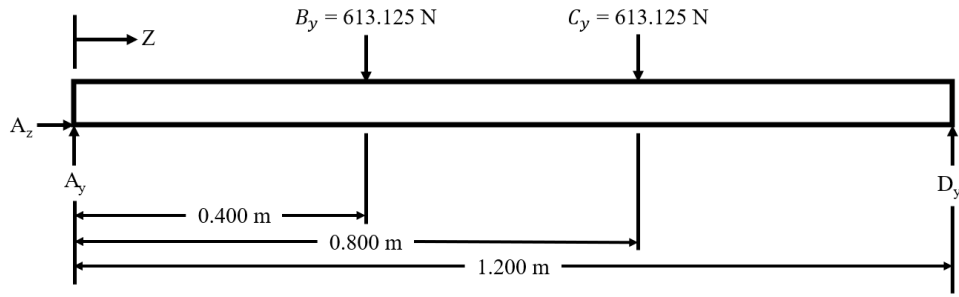


Figure C-6: Member 1 FBD

The sums of forces in the y and z directions and the sum of moments about point A are given in equations C.7, C.8, and C.9 below.

$$\sum F_z = 0 = A_z, \quad \text{C.7}$$

$$\sum F_y = 0 = A_y - 613.125 - 613.125 + D_y, \quad \text{C.8}$$

$$\sum M_C = 0 = -613.125(0.400) - 613.125(0.800) + D_y(1.200), \quad \text{C.9}$$

The solution to these equations is $A_z = 0$ N, $A_y = 613.125$ N, and $D_y = 613.125$ N. From symmetry, it can be concluded that $E_x = 0$ N, $H_y = 613.125$ N, and $G_y = 613.125$ N.

The deflection of this member is more easily analyzed using singularity functions than superposition. The progression of singularity functions is:

$$q(x) = A_y \langle z \rangle^{-1} - B_y \langle z - 0.400 \rangle^{-1} - C_y \langle z - 0.800 \rangle^{-1} + D_y \langle z - 1.200 \rangle^{-1} \quad \text{C.10}$$

$$v(x) = A_y \langle z \rangle^0 - B_y \langle z - 0.400 \rangle^0 - C_y \langle z - 0.800 \rangle^0 + D_y \langle z - 1.200 \rangle^0 + C_1 \quad \text{C.11}$$

$$v(0) = A_y \rightarrow C_1 = 0$$

$$M(x) = A_y \langle z \rangle^1 - B_y \langle z - 0.400 \rangle^1 - C_y \langle z - 0.800 \rangle^1 + D_y \langle z - 1.200 \rangle^1 + C_2 \quad \text{C.12}$$

$$M(0) = 0 \rightarrow C_2 = 0$$

$$\theta(x) = \frac{1}{EI} \left[\frac{A_y}{2} \langle z \rangle^2 - \frac{B_y}{2} \langle z - 0.400 \rangle^2 - \frac{C_y}{2} \langle z - 0.800 \rangle^2 + \frac{D_y}{2} \langle z - 1.200 \rangle^2 + C_3 \right] \quad \text{C.13}$$

$$y(x) = \frac{1}{EI} \left[\frac{A_y}{6} \langle z \rangle^3 - \frac{B_y}{6} \langle z - 0.400 \rangle^3 - \frac{C_y}{6} \langle z - 0.800 \rangle^3 + \frac{D_y}{6} \langle z - 1.200 \rangle^3 + C_3 x + C_4 \right] \quad \text{C.14}$$

$$y(0) = 0 \rightarrow C_4 = 0$$

$$y(1.200) = 0 \rightarrow C_3 = -109$$

$$y(x) = \frac{1}{EI} \left[\frac{A_y}{6} \langle z \rangle^3 - \frac{B_y}{6} \langle z - 0.400 \rangle^3 - \frac{C_y}{6} \langle z - 0.800 \rangle^3 + \frac{D_y}{6} \langle z - 1.200 \rangle^3 - 109z \right] \quad \text{C.15}$$

Evaluating equation C.15 at $z = 0.400\text{m}$ and $z = 0.600\text{m}$ yields -11.6 and -13.8 mm respectively. Combing the maximum deflection in member 3 calculated in C.4 with the deflection in member 1 at $z = 0.400\text{m}$ yields an overall maximum deflection of 15mm . The maximum bending moment on member 1 is calculated by evaluating C.12 at $z = 0.600\text{m}$. This gives a maximum bending moment of $245.25 \text{ N} \cdot \text{m}$. This corresponds to a maximum axial stress of

$$\sigma_{\text{axial}} = \frac{My}{I} = \frac{(245.25 \text{ Nm})(0.020 \text{ m})}{4.5357 \times 10^{-8} \text{ m}^4} = 0.108 \text{ Gpa.} \quad \text{C.16}$$

This axial stress is greater than that found in equation C.6 and equates to an overall factor of safety in yielding of 2.23 .

Case 2: 250 kg Load at the Center of Beam 4

The loading scenario for this case is shown in Figure C- 7 below.

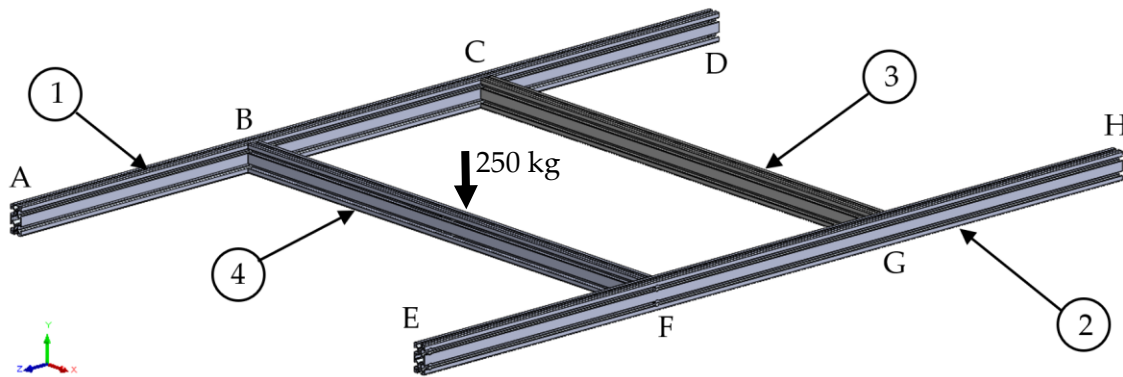


Figure C- 7: Case 2 Loading

Member 3 does not experience any load in this loading scenario so C_y and G_y are both 0 N. The FBD for member 4 is given in Figure C- 8 below.

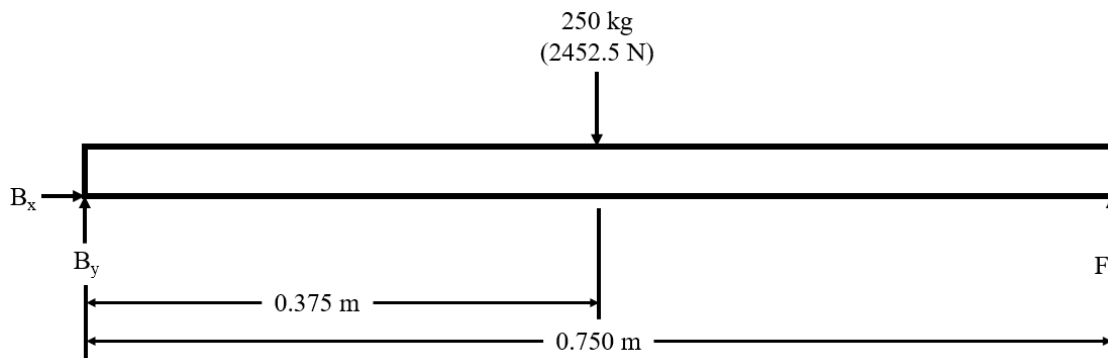


Figure C- 8: Member 4 FBD

The sums of forces in the x and y directions and the sum of moments about point B are given in equations C.1, C.2, and C.3 below.

$$\sum F_x = 0 = B_x, \quad \text{C.17}$$

$$\sum F_y = 0 = B_y - 2452.5 + F_y, \quad \text{C.18}$$

$$\sum M_B = 0 = -2452.5(0.750) + F_y(0.750), \quad \text{C.19}$$

The solution to these equations is $B_x = 0 \text{ N}$, $B_y = 1226.25 \text{ N}$, and $F_y = 1226.25 \text{ N}$.

The maximum deflection in for this loading scenario is given by

$$\delta_{\max,3} = \frac{PL^3}{48EI} = \frac{(2452.5 \text{ N})(0.750 \text{ m})^3}{48(70.326 \times 10^9 \text{ Pa})(4.5357 \times 10^{-8} \text{ m}^4)} = 6.76 \text{ mm}. \quad \text{C.20}$$

The maximum bending moment for this loading scenario is given by

$$M = \frac{WL}{4} = \frac{(2452.5 \text{ N})(0.75 \text{ m})}{4} = 459.84 \text{ N} \cdot \text{m} \quad \text{C.21}$$

This corresponds to a maximum axial stress of

$$\sigma_{\text{axial}} = \frac{My}{I} = \frac{(459.84 \text{ Nm})(0.020 \text{ m})}{4.5357 \times 10^{-8} \text{ m}^4} = 0.203 \text{ Gpa}. \quad \text{C.22}$$

The FBD for member 1 is given in Figure C- 9 below.

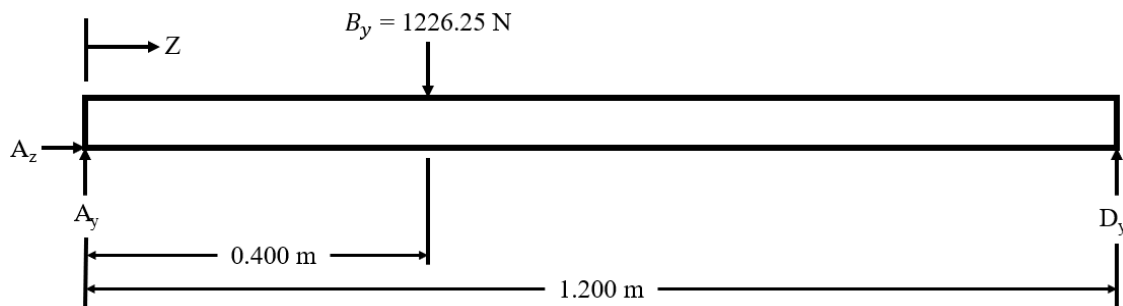


Figure C- 9: Member 1 FBD

The sums of forces in the y and z directions and the sum of moments about point A are given in equations C.23, C.24, and C.25 below.

$$\sum F_z = 0 = A_z, \quad \text{C.23}$$

$$\sum F_y = 0 = A_y - 1226.25 + D_y, \quad \text{C.24}$$

$$\sum M_C = 0 = -1226.25(0.400) + D_y(1.200), \quad \text{C.25}$$

The solution to these equations is $A_z = 0$ N, $A_y = 817.5$ N, and $D_y = 408.75$ N. From symmetry, it can be concluded that $E_x = 0$ N, $H_y = 817.5$ N, and $G_y = 408.75$ N. The deflection of this member is more easily analyzed using singularity functions than superposition. The progression of singularity functions is:

$$q(x) = A_y \langle z \rangle^{-1} - B_y \langle z - 0.400 \rangle^{-1} + D_y \langle z - 1.200 \rangle^{-1} \quad \text{C.26}$$

$$v(x) = A_y \langle z \rangle^0 - B_y \langle z - 0.400 \rangle^0 + D_y \langle z - 1.200 \rangle^0 + C_1 \quad \text{C.27}$$

$$v(0) = A_y \rightarrow C_1 = 0$$

$$M(x) = A_y \langle z \rangle^1 - B_y \langle z - 0.400 \rangle^1 + D_y \langle z - 1.200 \rangle^1 + C_2 \quad \text{C.28}$$

$$M(0) = 0 \rightarrow C_2 = 0$$

$$\Theta(x) = \frac{1}{EI} \left[\frac{A_y}{2} \langle z \rangle^2 - \frac{B_y}{2} \langle z - 0.400 \rangle^2 + \frac{D_y}{2} \langle z - 1.200 \rangle^2 + C_3 \right] \quad \text{C.29}$$

$$y(x) = \frac{1}{EI} \left[\frac{A_y}{6} \langle z \rangle^3 - \frac{B_y}{6} \langle z - 0.400 \rangle^3 + \frac{D_y}{6} \langle z - 1.200 \rangle^3 + C_3 x + C_4 \right] \quad \text{C.30}$$

$$y(0) = 0 \rightarrow C_4 = 0$$

$$y(1.200) = 0 \rightarrow C_3 = -109$$

$$y(x) = \frac{1}{EI} \left[\frac{A_y}{6} \langle z \rangle^3 - \frac{B_y}{6} \langle z - 0.400 \rangle^3 + \frac{D_y}{6} \langle z - 1.200 \rangle^3 - 109z \right] \quad \text{C.31}$$

Evaluating equation C.31 at $z = 0.400$ m and $z = 0.600$ m yields -10.9 and -11.8 mm respectively. Combing the maximum deflection in member 3 calculated in C.20 with the deflection in member 1 at $z = 0.400$ m yields an overall maximum deflection of 17.7 mm. The maximum bending moment on member 1 is calculated by evaluating C.28 at $z = 0.400$ m. This gives a maximum bending moment of 327 N · m. This corresponds to a maximum axial stress of

$$\sigma_{\text{axial}} = \frac{My}{I} = \frac{(327 \text{ Nm})(0.020 \text{ m})}{4.5357 \times 10^{-8} \text{ m}^4} = 0.144 \text{ Gpa}. \quad \text{C.32}$$

This axial stress is less than that found in equation C.22. The maximum axial stress of 0.203 Gpa equates to an overall factor of safety in yielding of 1.19 .

Appendix D – Bill of Materials

D.1

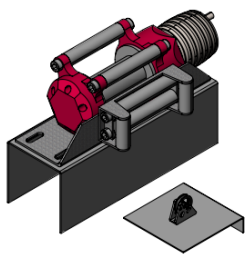
Bill of Materials

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	77-53112BW	Winch	1
2	92188A143	Concrete Stud Anchor	18
3	3211T32	Mounted Pully	1
4	24M-AGM	Deep Cell Battery	1
5	022-0209-BT-WH	Battery Tender	1
6	8982K4	1"x1" aluminum L-Channel (4ft)	1
7	1022161	2'x12'x10' Southern Yellow Pine	4

Purchases

ITEM NO.	PART NUMBER	Source	DESCRIPTION	QTY.	Unit Cost	Total Cost
1	77-53112BW	Northern Tool	Winch	1	\$339.99	\$339.99
2	92188A143	McMaster Carr	Concrete Stud Anchor (10pk.)	2	\$40.89	\$81.78
3	3211T32	McMaster Carr	Mounted Pully	1	\$65.22	\$65.22
4	24M-AGM	Autozone	Deep Cell Battery	1	\$180.83	\$180.83
5	022-0209-BT-WH	Auto Store	Battery Tender	1	\$102.67	\$102.67
6	8982K4	McMster Carr	1"x1" aluminum L-Channel (4ft)	1	\$13.12	\$13.12
7	1022161	Menards	2'x12'x10' Southern Yellow Pine	4	\$16.98	\$67.92
					Total	\$851.53
					+15%	\$980

Total Cost: \$980




RHIT A LANDSCAPE	
Dimensions are inches and degrees Default Tolerances .X ±0.1 .XX ±0.03 .XXX ±0.005 Angles ±2	Winch Assembly, Pully, and Ramps Bill of Materials Drawn by: Group 53 Scale: 1:10 Date: 12/14/2021


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D.2

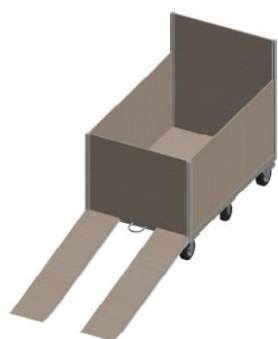
Large Items Cart Small Items Cart Hybrid Cart



\$870



\$800



\$895

There are three very similar cart designs presented here. All three share the same base and back panel, but the "Large Items", "Small Items", and "Hybrid" carts have differing side panel and ramp attachments based on their intended uses.

RHIT A LANDSCAPE	
Dimensions are inches and degrees Default Tolerances .X ±0.1 .XX ±0.03 .XXX ±0.005 Angles ±2	Cart Summary Drawn by: Group 53 Scale: 1:25 Date: 12/9/2021

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D.3




RHIT A LANDSCAPE	
Dimensions are inches and degrees Default Tolerances .X ±0.1 .XX ±0.03 .XXX ±0.005 Angles ±2	Base Frame Multi-View Drawn by: Group 53 Scale: 1:20 Date: 12/9/2021

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D.4

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20_2040_1200_CL	20mm x 20mm x 1200 mm TSP	2
2	20_2040_750_CL	20mm x 40mm x 750 mm TSP	3
3	91292A192	M5x0.8x30 mm SHCS	8
4	13184	20 Series M4 Anchor Assembly	8
6	22925T18	6" Rigid Pneu. Caster	2
7	22925T19	6" Total Lock Swivel Pneu. Caster	2
9	2835T19	5" Rigid Rubber Caster	2
11	91251A382	5/16"-24-7/8" SHCS	8
12	95615A170	5/16"-24 Lock Nut	8
13	91251A426	3/8"-24x1 1/8" SHCS	16
14	95615A150	3/8"-24 Lock Nut	16
15	91251A197	8-32x3/4" SHCS	16
16	1251062	48"x32"x1/2" ACX Sanded Plywood	1
17	5537T368	TSP Diagonal Brace - 12"	4
18	20_4040_370_CL	40mm x 40mm x 420mm TSP	1
19	91251A347	10-32x1" SHCS	8
20	5537T161	Slide in T-Nut with Fastener	50
21	3043T47	2000 lb. capacity U Bolt	1
22	91294A212	M5-0.8x16mm FHS	22



RHIT A LANDSCAPE	
Dimensions are inches and degrees Default Tolerances .X ±0.1 .XX ±0.03 .XXX ±0.005 Angles ±2	Base Fram Bill of Materials (Actual Counts) Drawn by: Group 53 Scale: 1:20 Date: 12/9/2021

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Abbreviations
 TSP - T-Slot Profile
 SHCS - Socket Head Cap Screw
 Pneu. - Pneumatic
 FHS - Flat Head Screw

ITEM NO.	PART NUMBER	Source	DESCRIPTION	QTY.	Unit Cost	Total Cost
1	20-2040	8020.net	20mm x 20mm x 1250 mm TSP	2	\$18.99	\$37.98
2	20-2040	8020.net	20mm x 40mm x 790 mm TSP	3	\$12.83	\$25.66
3	91292A192	McMaster Carr	M5x0.8x30 mm SHCS (50 pk.)	1	\$10.85	\$10.85
4	13184	8020.net	20 Series M4 Anchor Assembly	8	\$3.30	\$26.40
6	22925T18	McMaster Carr	6" Rigid Pneu. Caster	2	\$37.12	\$74.24
7	22925T19	McMaster Carr	6" Total Lock Swivel Pneu. Caster	2	\$63.98	\$127.96
9	2835T19	McMaster Carr	5" Rigid Rubber Caster	2	\$20.26	\$40.52
11	91251A382	McMaster Carr	5/16"-24-7/8" SHCS (25 pk.)	1	\$7.37	\$7.37
12	95615A170	McMaster Carr	5/16"-24 Lock Nut (100 pk.)	1	\$8.42	\$8.42
13	91251A426	McMaster Carr	3/8"-24x1 1/8" SHCS (25 pk.)	1	\$11.96	\$11.96
14	95615A150	McMaster Carr	3/8"-24 Lock Nut (100 pk.)	1	\$13.71	\$13.71
15	91251A197	McMaster Carr	8-32x3/4" SHCS (100 pk.)	1	\$16.71	\$16.71
16	1251062	Menards	Premium ACX Sanded Plywood	1	\$62.98	\$62.98
17	5537T368	McMaster Carr	TSP Diagonal Brace - 12"	4	\$19.47	\$77.88
18	20-4040	8020.net	40mm x 40mm x 420mm TSP	1	\$11.85	\$11.85
19	91251A347	McMaster Carr	10-32x1" SHCS (50 pk.)	1	\$10.59	\$10.59
20	5537T161	McMaster Carr	Slide in T-Nut with Fastener (4 pk.)	13	\$2.45	\$31.85
21	3043T47	McMaster Carr	2000 lb. capacity U Bolt	1	\$3.88	\$3.88
22	91294A212	McMaster Carr	M5-0.8x16mm FHS (100 pk.)	1	\$10.56	\$10.56
					Total	\$611.37
					+15%	\$703.08

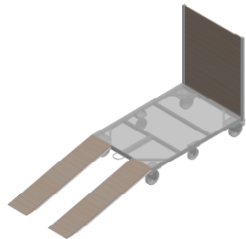
Base Cost: \$703.08

Abbreviations
TSP - T-Slot Profile
SHCS - Socket Head Cap Screw
Pneu. - Pneumatic
FHS - Flat Head Screw

RHIT A LANDSCAPE	
Dimensions are inches and degrees	Base Frame Bill of Materials (Purchase List)
Default Tolerances	Drawn by: Group 53
.X ±0.1	Scale: 1:15 Date: 12/9/2021
.XX ±0.03	
.XXX ±0.005	
Angles ±2	

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Additional Parts			
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	30-3030	30mm x 30mm x 940mm TSP	2
2	backPanel	plywood	1
3	91292A192	M5x0.8x30 mm SHCS	4
4	25-2525	25mm x 25mm x 1110mm TSP	4
5	6000N124	T-Slotted Framing Fasteners	20
6	91294A194	M4x0.7x16mm FHS	20
7	rampPanel	plywood	2



Additional Purchases						
ITEM NO.	PART NUMBER	Source	DESCRIPTION	QTY.	Unit Cost	Total Cost
1	30-3030	8020.net	30mm x 30mm x 990mm TSP	2	\$13.56	\$27.12
2	25-2525	8020.net	25mm x 25mm x 1160mm TSP	4	\$14.13	\$56.52
3	6000N124	McMaster Carr	T-Slotted Framing Fasteners	20	\$0.91	\$18.20
4	91294A194	McMaster Carr	M4x0.7x16mm FHS (100 pk.)	1	\$7.57	\$7.57
5	1251061	Menards	4'x8'x3/8" Plywood	1	\$35.99	\$35.99
					Total	\$145.40
					+15%	\$167.20

Total Additional Cost: \$167.20

Abbreviations
TSP - T-Slot Profile
SHCS - Socket Head Cap Screw
Pneu. - Pneumatic
FHS - Flat Head Screw

RHIT A LANDSCAPE	
Dimensions are inches and degrees	Large Items Cart Additional Parts and Purchases
Default Tolerances	Drawn by: Team 53
.X ±0.1	Scale: 1:35 Date: 12/9/2021
.XX ±0.03	
.XXX ±0.005	
Angles ±2	

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D.7

Additional Parts

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	30-3030	30mm x 30mm x 640mm TSP	2
2	30-3030	30mm x 30mm x 940mm TSP	2
3	frontPanel	Plywood	1
4	side panel	Plywood	2
5	backPanel	Plywood	1
6	91292A192	M5x0.8x30 mm SHCS	8



Additional Purchases

ITEM NO.	PART NUMBER	Source	DESCRIPTION	QTY.	Unic Cost	Total Cost
1	30-3030	8020.net	30mm x 30mm x 690mm TSP	2	\$10.14	\$20.28
2	30-3030	8020.net	30mm x 30mm x 990mm TSP	2	\$13.56	\$27.12
3	1251061	Menards	4'x8'x3/8" Plywood	1	\$35.99	\$35.99
					Total	\$83.39
					+15%	\$95.90

Total Additional Cost: \$95.90

Abbreviations
 TSP - T-Slot Profile
 SHCS - Socket Head Cap Screw
 Pneu. - Pneumatic
 FHS - Flat Head Screw

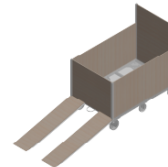
RHIT A LANDSCAPE	
Dimensions are inches and degrees	Small Items Cart Additional Parts and Purchases
Default Tolerances	
.X ±0.1	
.XX ±0.03	Drawn by: Group 53
.XXX ±0.005	
Angles ±2	Scale: 1:35 Date: 12/9/2021

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D.8

Additional Parts

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	30-3030	30mm x 30mm x 640mm TSP	2
2	30-3030	30mm x 30mm x 940mm TSP	2
3	frontPanel	3/8" Plywood	1
4	side panel	3/8" Plywood	2
5	backPanel	1/2" Plywood	1
6	91292A192	M5x0.8x30 mm SHCS	8
7	25-2525	25mm x 25mm x 1110mm TSP	4
8	6000N124	T-Slotted Framing Fasteners	20
9	91294A194	M4x0.7x	20
10	rampPanel	3/8" Plywood	2



Additional Purchases

ITEM NO.	PART NUMBER	Source	DESCRIPTION	QTY.	Unit Cost	Total Cost
1	30-3030	8020.net	30mm x 30mm x 690mm TSP	2	\$10.14	\$20.28
2	30-3030	8020.net	30mm x 30mm x 990mm TSP	2	\$13.56	\$27.12
3	25-2525	8020.net	25mm x 25mm x 1160mm TSP	4	\$14.13	\$56.52
4	6000N124	McMaster Carr	T-Slotted Framing Fasteners	20	\$0.91	\$18.20
5	91294A194	McMaster Carr	M4x0.7x16mm FHS (100 pk.)	1	\$7.57	\$7.57
6	1251061	Menards	4'x8'x3/8" ACX Plywood	1	\$35.99	\$35.99
					Total	\$165.68
					+15%	\$190.53

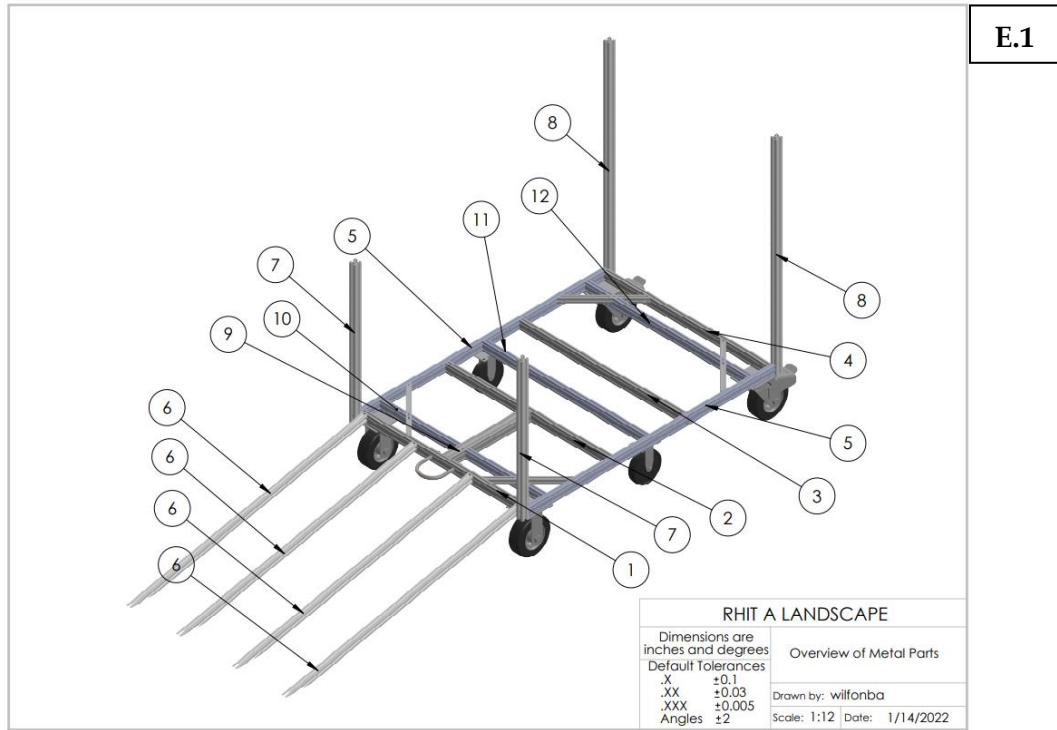
Total Additional Cost: \$190.53

Abbreviations
 TSP - T-Slot Profile
 SHCS - Socket Head Cap Screw
 Pneu. - Pneumatic
 FHS - Flat Head Screw

RHIT A LANDSCAPE	
Dimensions are inches and degrees	Hybrid Cart Additional Parts and Purchases
Default Tolerances	
.X ±0.1	
.XX ±0.03	Drawn by: Group 53
.XXX ±0.005	
Angles ±2	Scale: 1:50 Date: 12/9/2021

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Appendix E- Design Drawings



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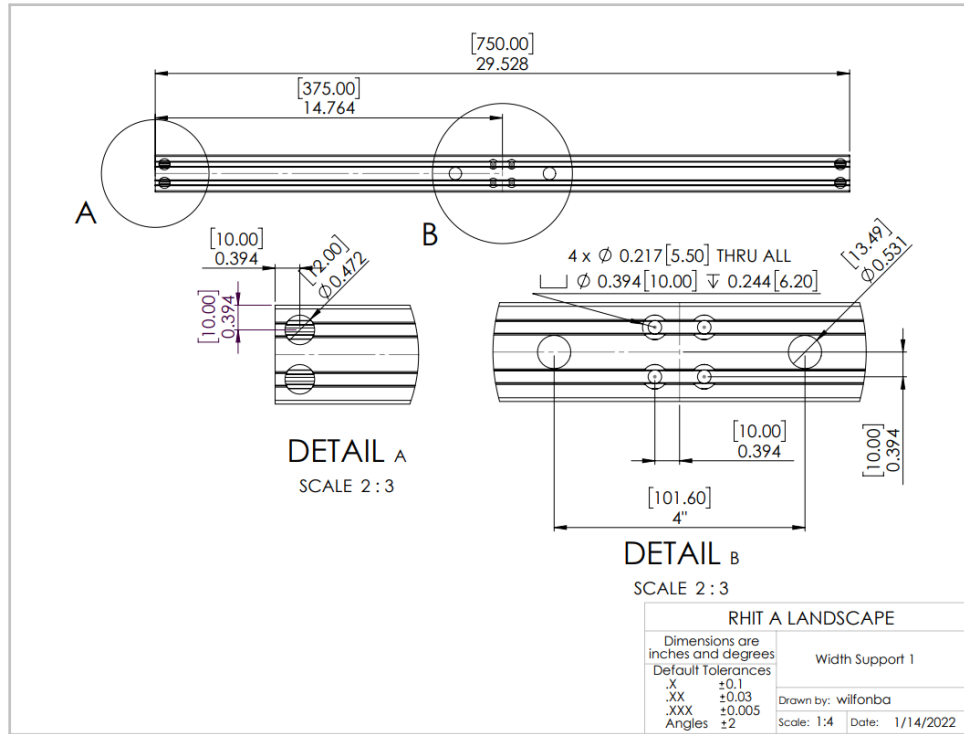
E.2

Part #	Name	Quantity	Stock
1	Width support 1	1	20-2040
2	Width support 2	1	20-2040
3	Width support 3	1	20-2040
4	Width support 4	1	20-2040
5	Length Support	2	20-2040
6	Ramp Support	4	25-2525
7	Front vertical	2	30-3030
8	Back support	2	30-3030
9	Load Support Member	1	20-4040
10	Width support 5	1	20-2040
11	Width support 6	1	20-2040
12	Width Support 7	1	20-2040

RHIT A LANDSCAPE	
Dimensions are inches and degrees	Metal Parts List
Default Tolerances	Drawn by: wilfonba
.X ±0.1	Scale: 1:12 Date: 1/14/2022
.XX ±0.03	
.XXX ±0.005	
Angles ±2	

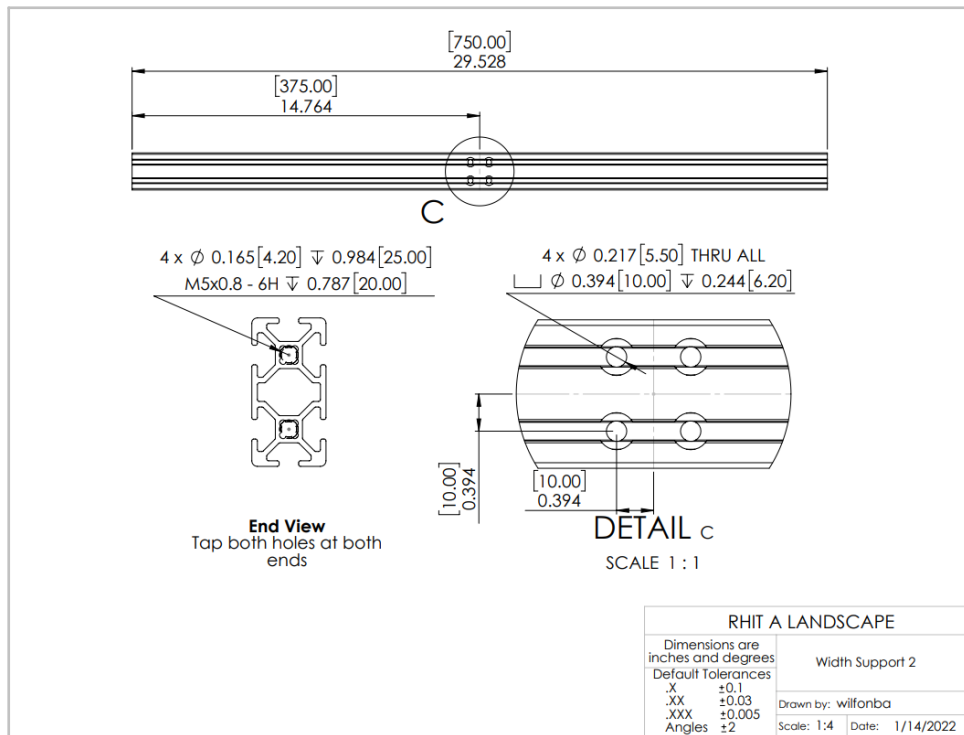
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E.3



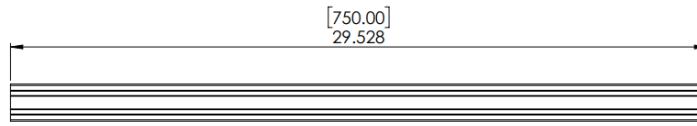
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E.4

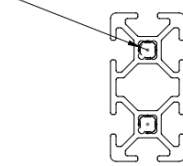


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E.5



4 x \varnothing 0.165 [4.20] ∇ 0.984 [25.00]
 M5x0.8 - 6H ∇ 0.787 [20.00]

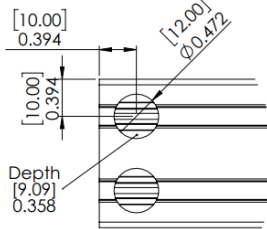
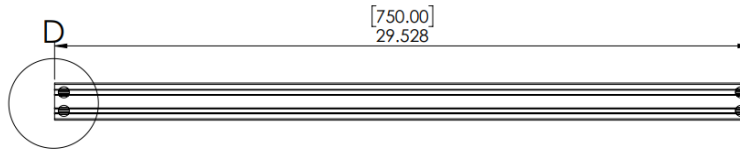


End View
 Tap both holes at both ends

RHIT A LANDSCAPE	
Dimensions are inches and degrees	Width Support 3
Default Tolerances	Drawn by: wilfonba
.X ±0.1	Scale: 1:4
.XX ±0.03	Date: 1/14/2022
.XXX ±0.005	
Angles ±2	

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E.6

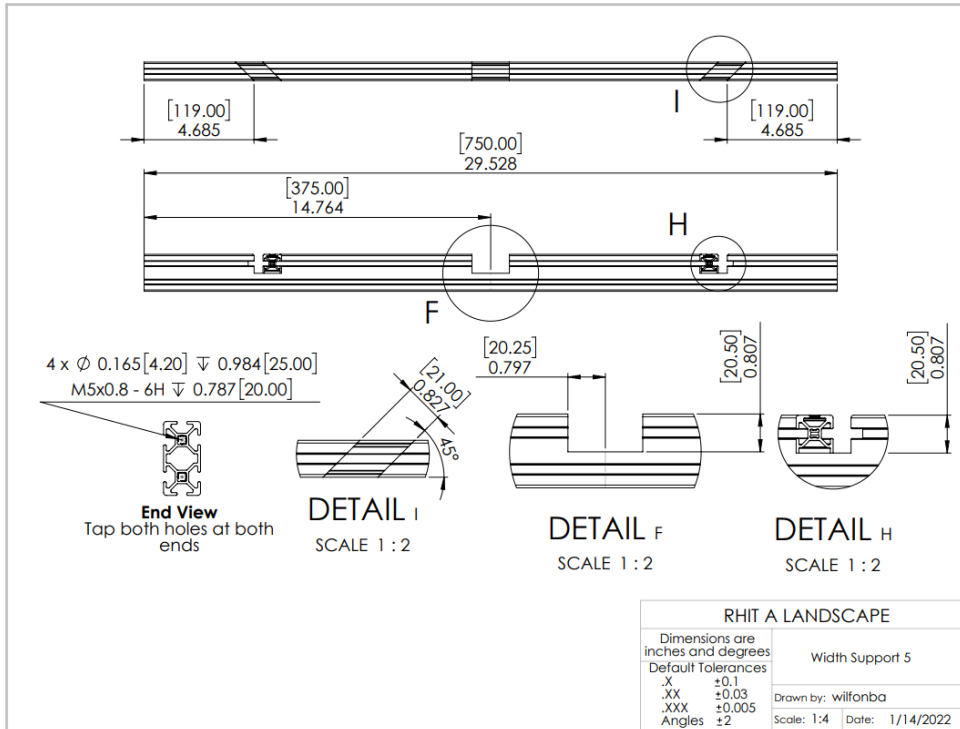


DETAIL D
 SCALE 1 : 1

RHIT A LANDSCAPE	
Dimensions are inches and degrees	Width Support 4
Default Tolerances	Drawn by: wilfonba
.X ±0.1	Scale: 1:4
.XX ±0.03	Date: 1/14/2022
.XXX ±0.005	
Angles ±2	

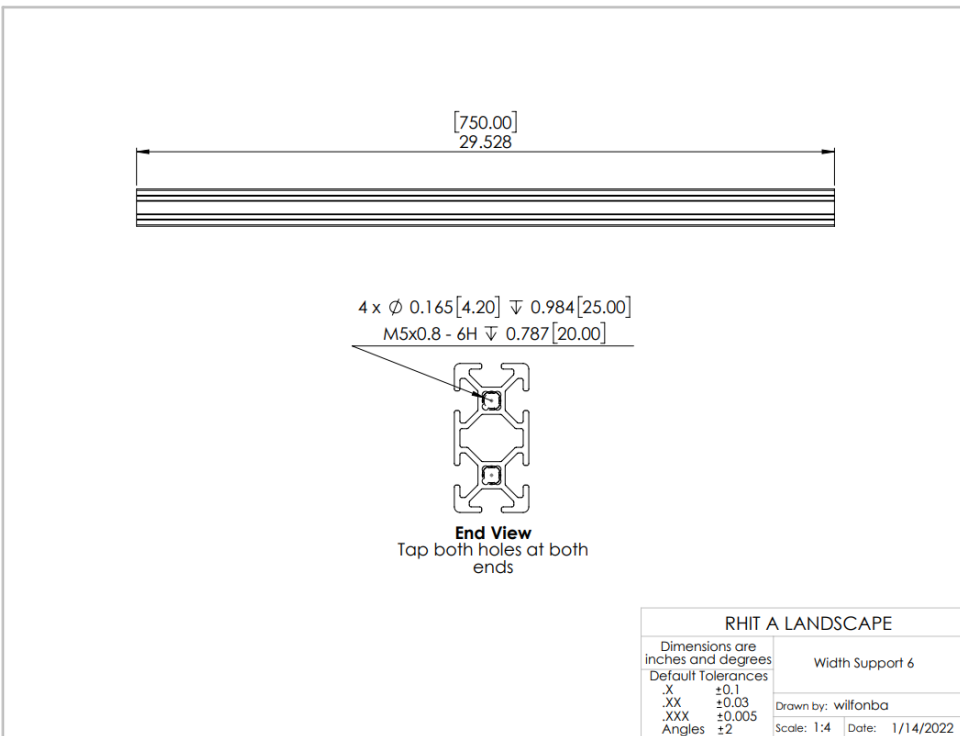
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E.7

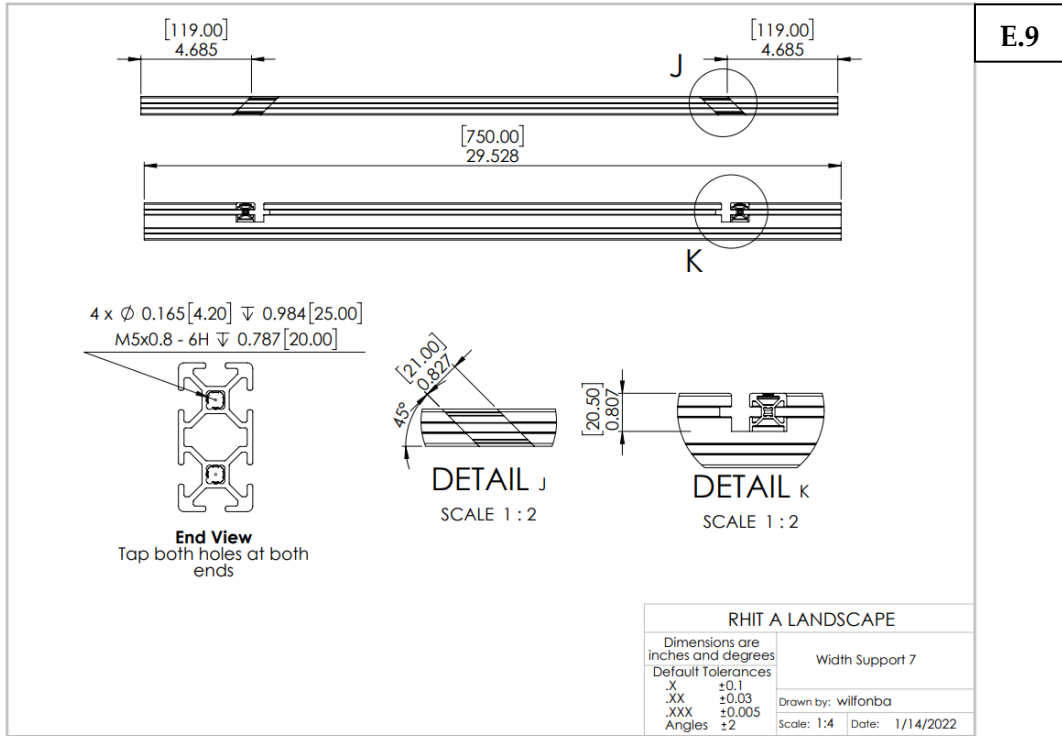


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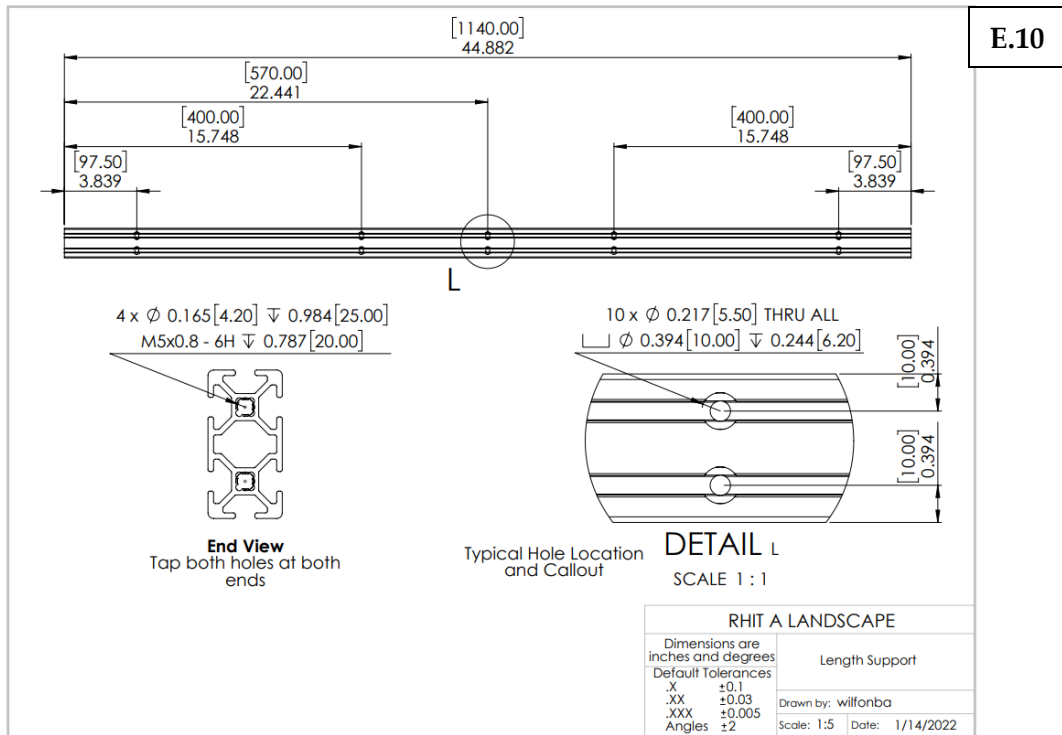
E.8



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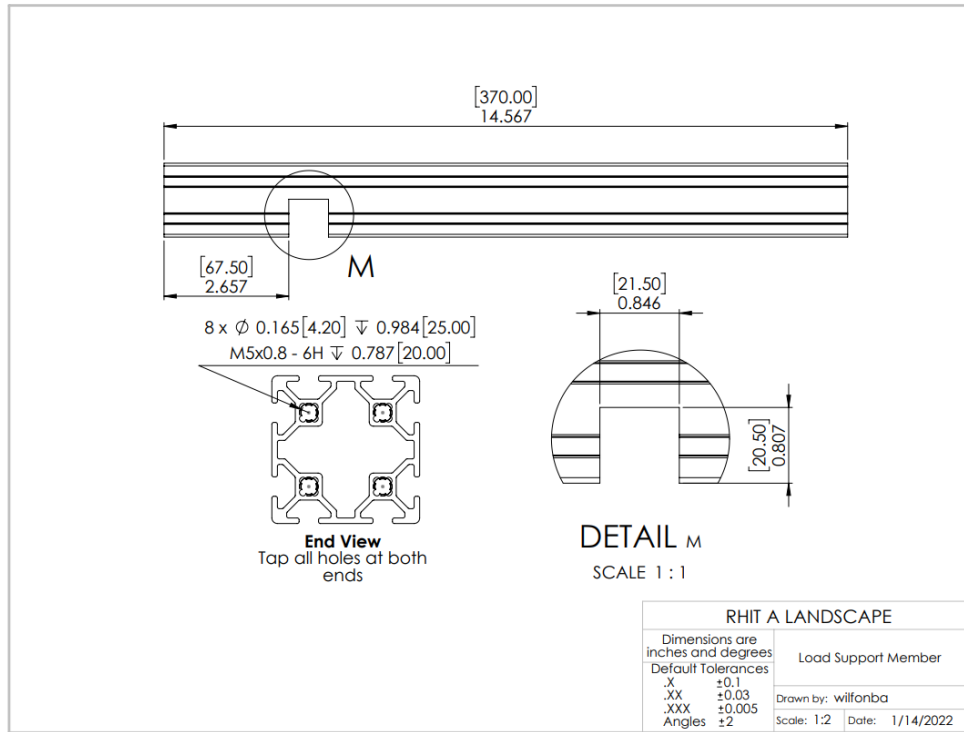


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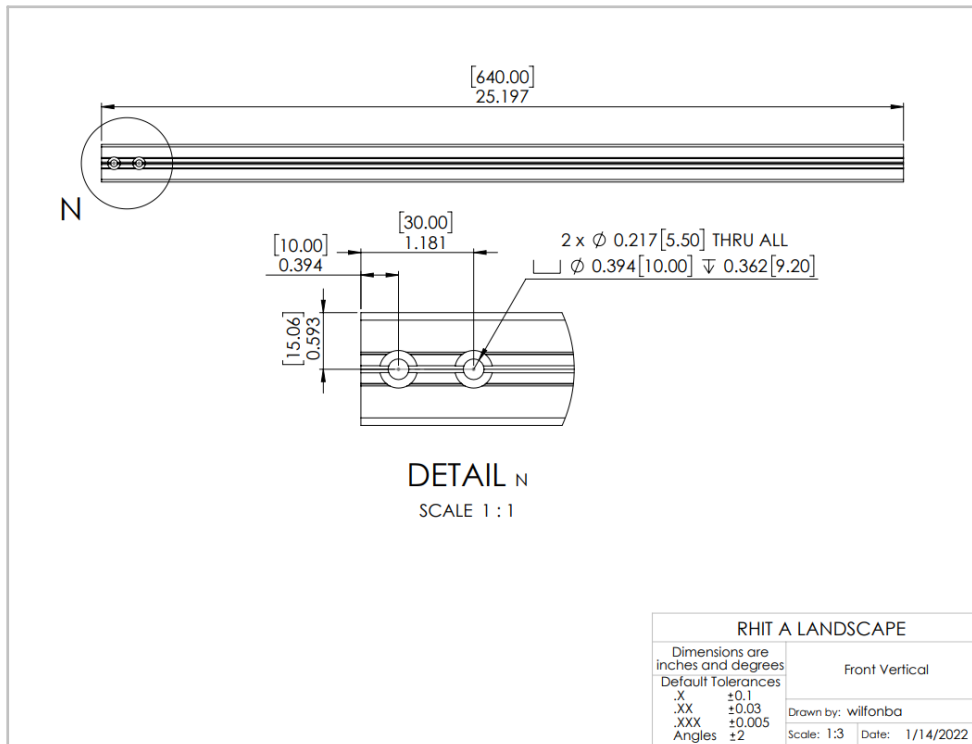
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E.11



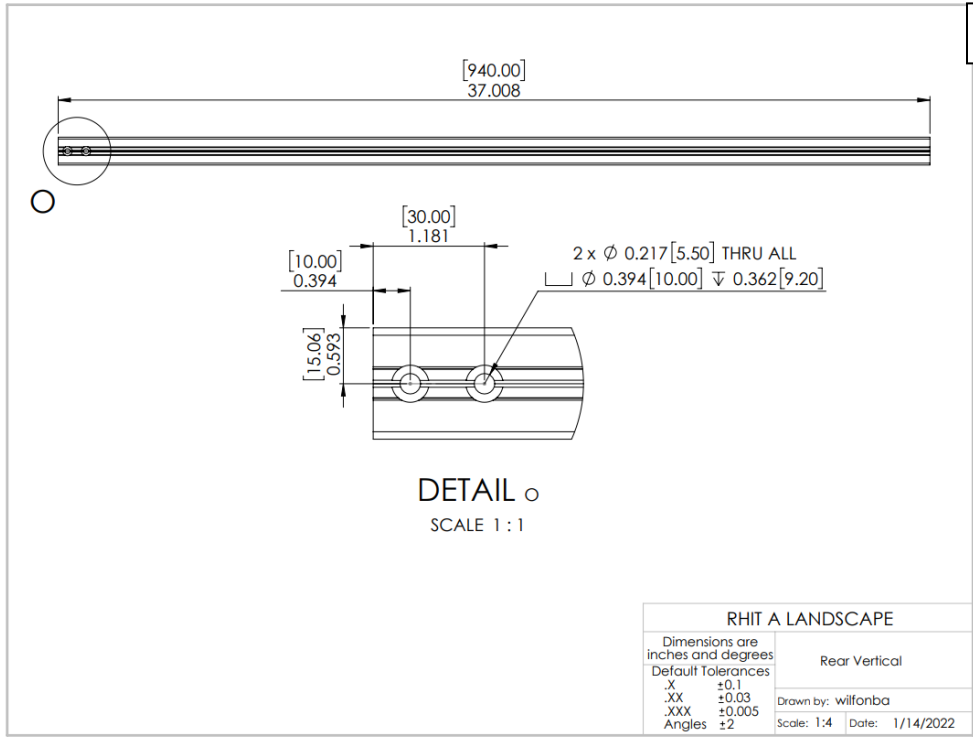
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E.12



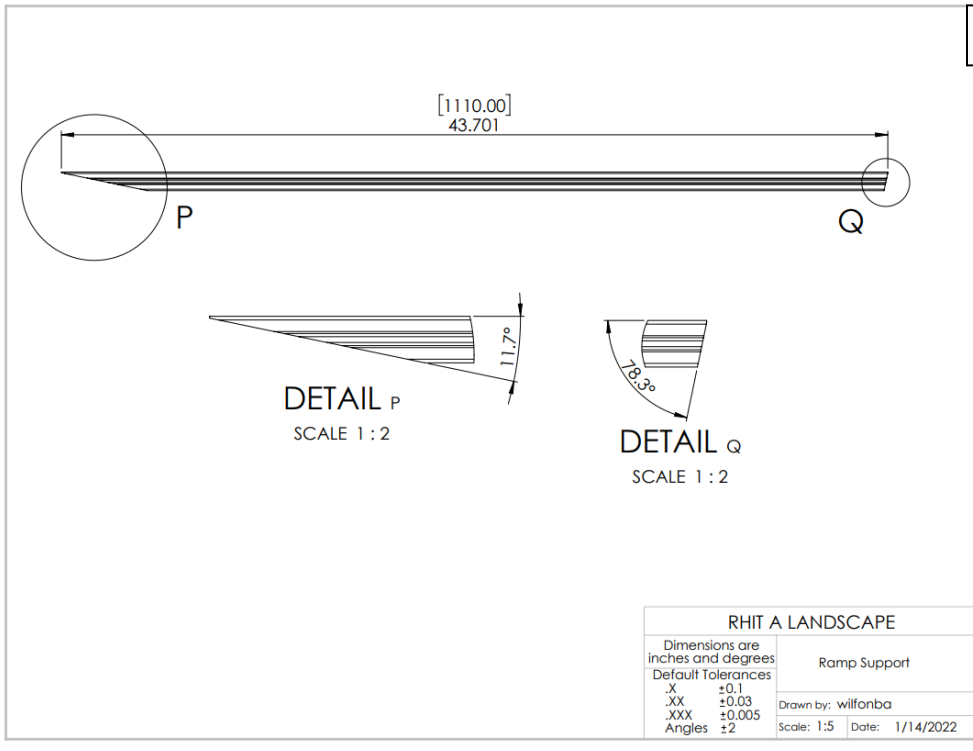
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E.13



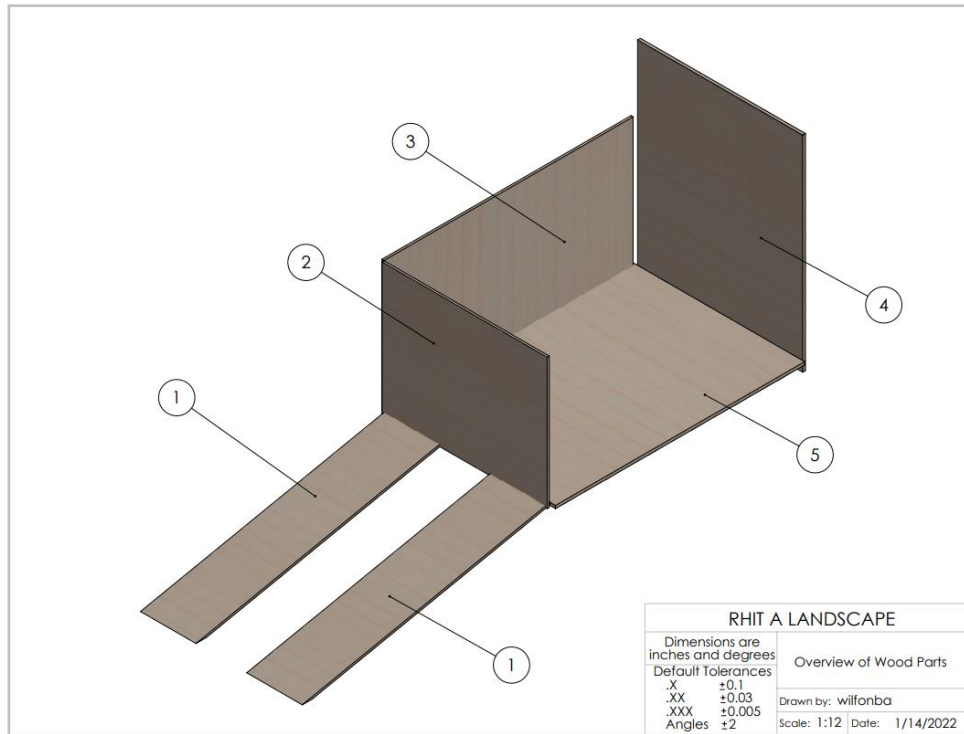
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E.14



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E.15



RHIT A LANDSCAPE	
Dimensions are inches and degrees	Overview of Wood Parts
Default Tolerances	Drawn by: Wilfonba
.X ±0.1	Scale: 1:12 Date: 1/14/2022
.XX ±0.03	
.XXX ±0.005	
Angles ±2	

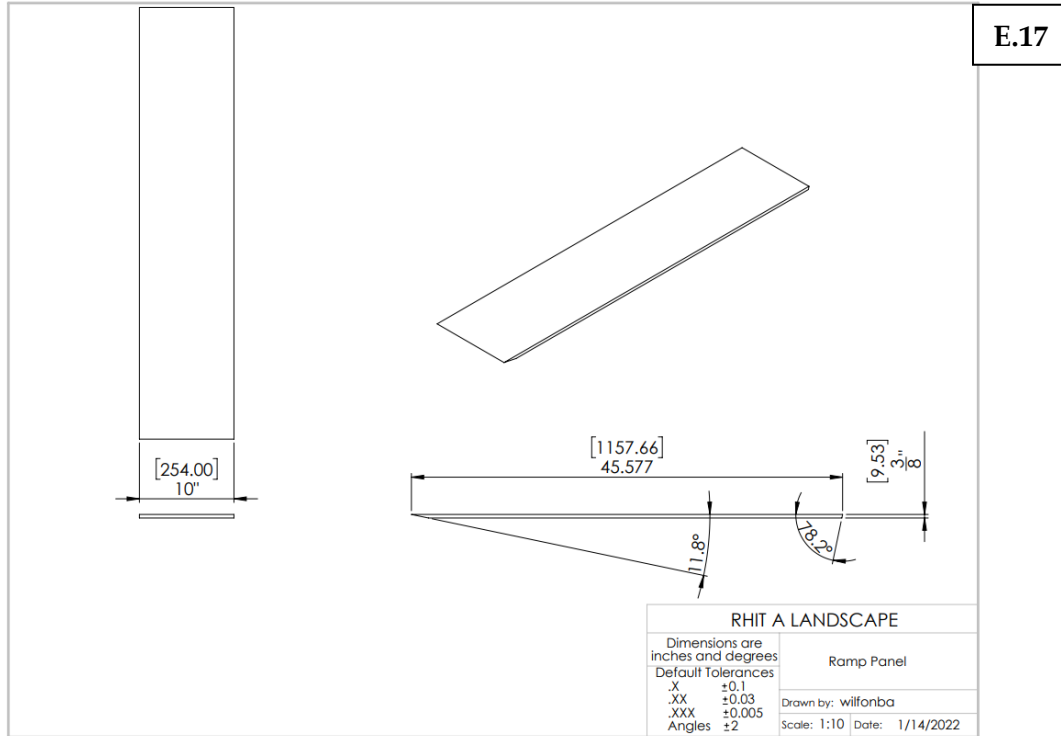
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E.16

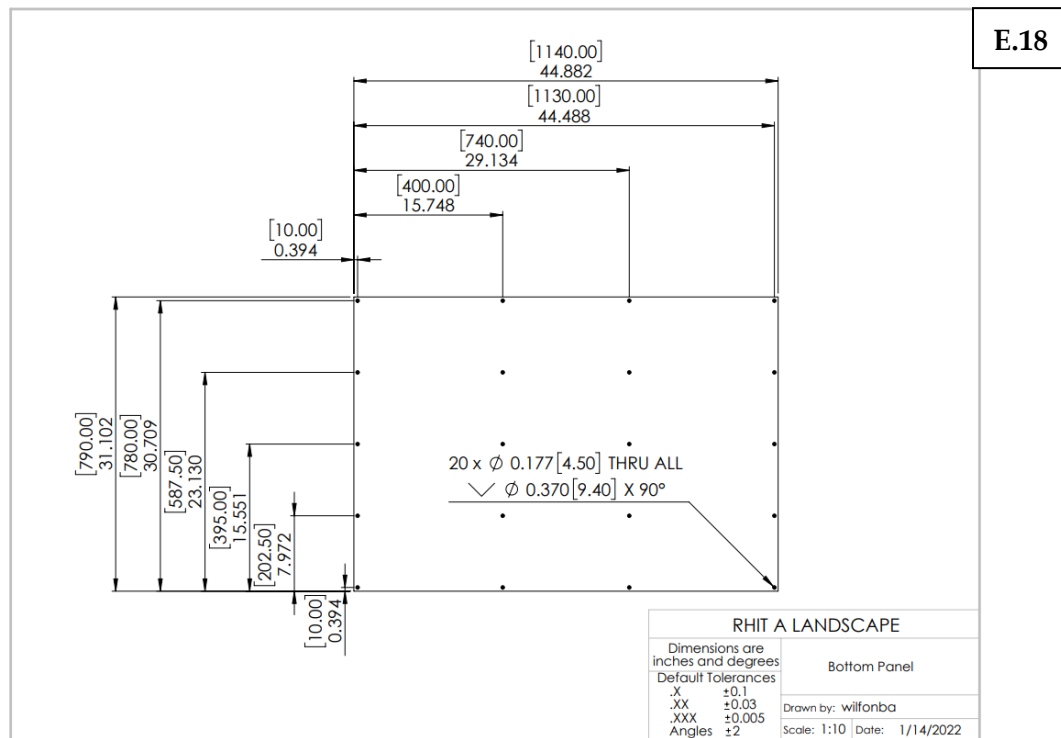
Part #	Name	Quantity	Stock
1	Ramp panel	2	1/2"
2	Front Panel	1	1/2"
3	Side Panel	1	1/2"
4	Back Panel	1	3/4"
5	Back Panel	1	3/4"

RHIT A LANDSCAPE	
Dimensions are inches and degrees	Wood Parts List
Default Tolerances	Drawn by: Wilfonba
.X ±0.1	Scale: 1:12 Date: 1/14/2022
.XX ±0.03	
.XXX ±0.005	
Angles ±2	

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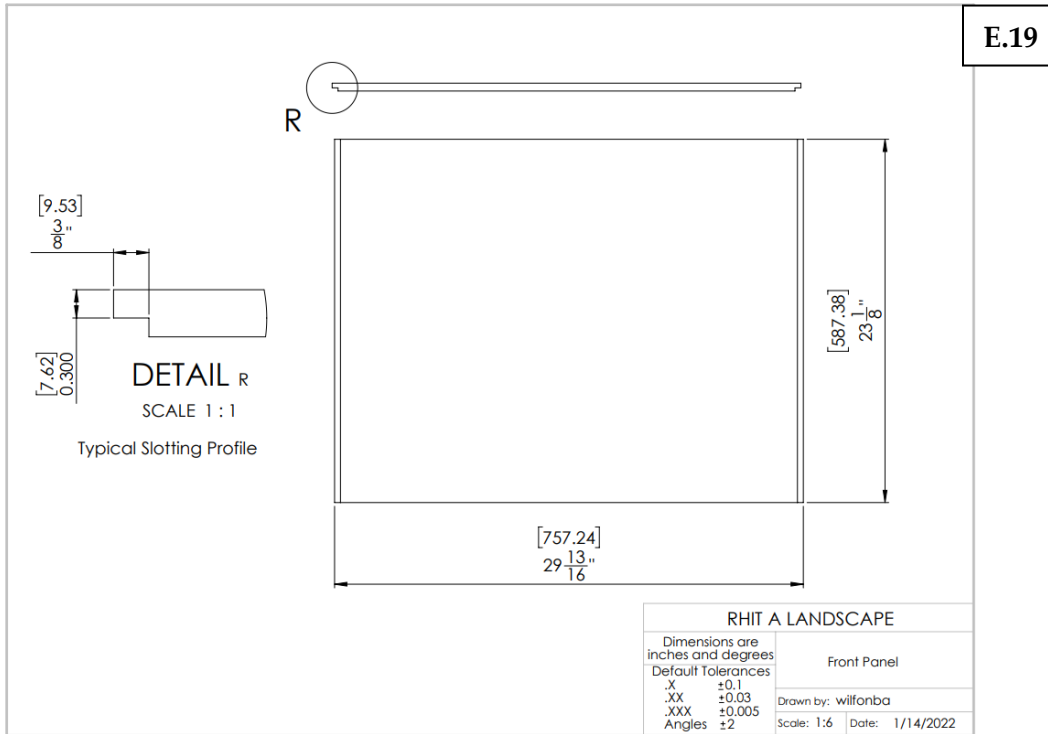


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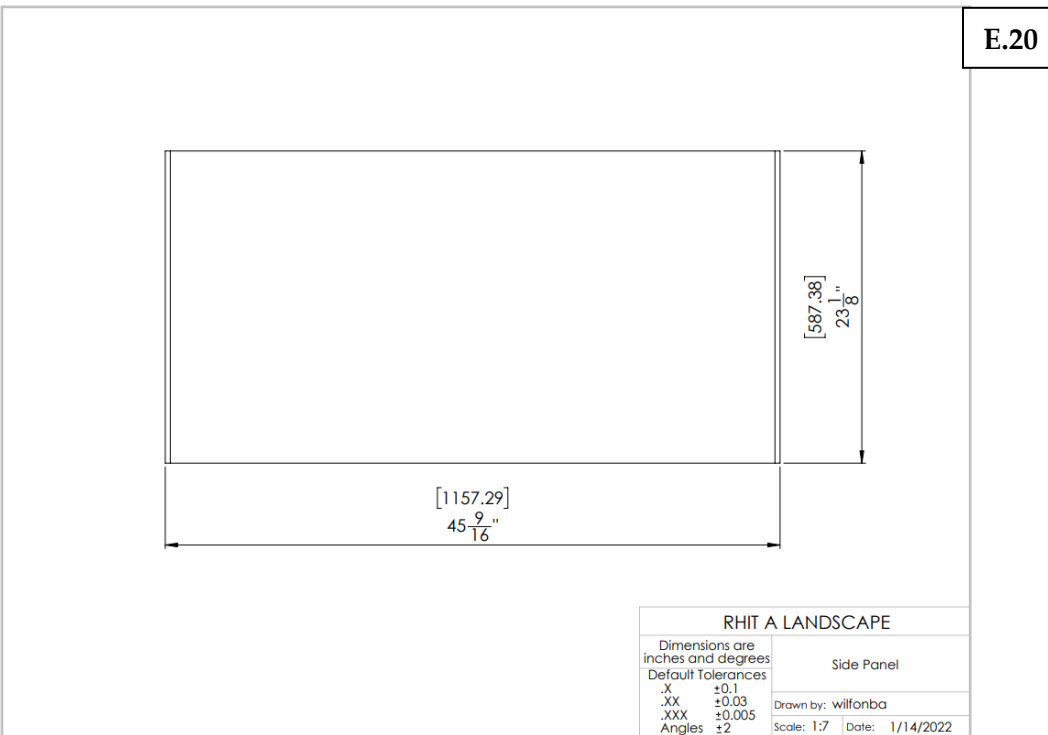
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E.19



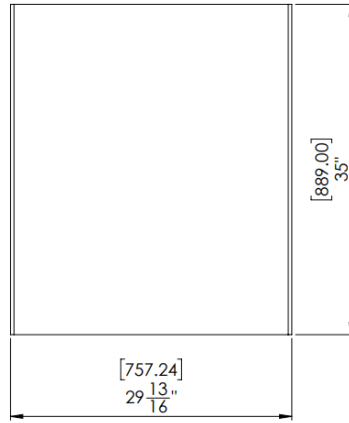
SOLIDWORKS Educational Product. For Instructional Use Only.

E.20



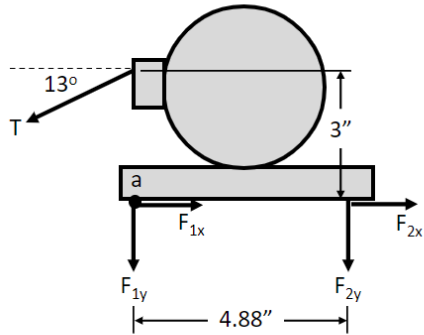
SOLIDWORKS Educational Product. For Instructional Use Only.

E.21



RHIT A LANDSCAPE	
Dimensions are inches and degrees	Back Panel
Default Tolerances	Drawn by: wilfonba
.X ±0.1	Scale: 1:10
.XX ±0.03	Date: 1/14/2022
.XXX ±0.005	
Angles ±2	

Appendix F- Winch Mount Analysis



$$\sum F_x = 0 = F_{1x} + F_{2x} - T \cos(13)$$

$$\sum F_y = 0 = -F_{1y} - F_{2y} - T \sin(13)$$

$$\sum M_a = 0 = T \cos(13) (3) - F_{2y}(4.88)$$

$$F_{2x} = F_{1x}$$

$$F_{1y} = -2021 \text{ N} \quad F_{2y} = 1469 \text{ N}$$

$$F_{1x} = F_{2x} = 1195 \text{ N}$$

Appendix G - Rationale for Technical Specification Values & Subsequent Evaluation Methodology

The “safety” need is easily deconstructed into three metrics: tray height, edge radius, and number of pinch points. The tray height directly effects how high heavy objects in the space must be lifted. An existing solution to moving heavy items upstairs is the EZ-Climber 1300/H shown in Appendix B- OSHA guidelines require that all pinch points be either guarded or avoided through procedural methods like two-handed tripping devices . (Appendix G, Page 44). Technical specifications from its data sheet indicate a minimum platform height of 14.5 in. or approximately 37 centimeters [4]. These devices are self-propelled and have a platform tilting mechanism to aid in loading items. The solution developed may or may not have such a tilting mechanism or internal power, so tray height will be limited to 24 cm (approximately 9.5 in.) to make the loading process easier. This metric will be evaluated by measuring the tray height of the final solution with a ruler or tape measure. The metric of edge radius ensures that the final solution doesn’t have dangerously sharp corners. A conversation with a Journeyman Machinist suggested a minimum edge radius of 0.5 mm [2]. This metric will be evaluated by using a radius gauge at several points on the edges of each part. The third metric, number of exposed pinch points, influences how likely it is for an end user to injure themselves in a pinch related accident. Occupational Safety and Health Organization (OSHA) guidelines require that all pinch points be either guarded or avoided through procedural methods like two-handed tripping devices [3]. This guides the decision to not allow any unguarded pinch points in the final solution. This metric will be evaluated through visual inspection of the final solution. These three metrics are all requirements of the solution.

The “inexpensive” need has one simple metric of cost. The budget provided by the client is \$2500 dollars. This metric will be evaluated through careful monitoring of the cumulative cost as the project progresses. This metric is a goal of the solution.

The “fit doors and hallways” need has three metrics relating to the operating length, width, and height of the solution. These dimensions assume that the items that require moving fit through the doors and hallways. The values for operating length, width, and height are determined by taking measurements of the doors and hallways in the facility. It was determined that the length, width, and height of the solution should be limited to 1.22, 0.81, and 1.83 meters respectively (approximately 48x32x72 in.). These values allow for approximately six cm. (approximately 2.3 in.) of total clearance through the smallest

doorways. These metrics will be evaluated by measuring the final solution with a tape measure. These three metrics are all requirements of the solution.

The “carry the present items” need has four metrics relating to the size and weight of the items needing removed. The value for lifting capacity was determined by searching the manuals of what appeared to be the heaviest items for their weight. The heaviest item found with a clear indication of weight was a large printer at 388 lbs. or approximately 176 kgs. This informed a limit on the minimum lifting capacity of 250kgs (approximately 550 lbs.). This extra capacity allows for the possibility that some items of similar type and size may have differing internals and weigh more than those with detailed manuals. This metric will be evaluated by applying a load to the solution and ensuring it operates as expected. Careful design with a generous factor of safety will help ensure that the final solution meets this metric. The metrics for object length, width, and height were determined by measuring a variety of the larger objects in the facility and taking the largest length, width, and height found. The maximum object length, width, and height were found to be 1.75, 0.82, and 1.70 m. respectively (approximately 69x32x67 in.). This metric will be evaluated by making a temporary box (likely out of cardboard), loading it onto the solution, and ensuring it operates as expected. These four metrics are all requirements of the solution.

The “maneuverability” need has four metrics critical to the solutions ability to navigate the facility. The metrics traverse bumps, and traverse gaps ensure that the solution can navigate about the facility. Target values for these metrics were determined by measuring different gaps and bumps at the facility and adding 1 cm. as a factor of safety. Target values of 2 and 3 cm. (approximately 0.75 and 1.2 in.) were assigned to bump height and crack width respectively. These metrics will be evaluated by creating model cracks and bumps from scrap material and maneuvering the solution over them. The metric of turning radius was determined by overlaying a model of the largest configuration of the solution on the blueprint and measuring the largest possible turning radius. This value was determined to be 0.6 m (approximately 23.5 in.) measured at the center of the solution. This metric will be evaluated by measuring turning radius of the solution. These three metrics are all requirements of the solution. The metric moves things downstairs is a goal for the solution. This goes above and beyond the requirements given by the client. This was added with the intention of extending the useful life of the solution to future users of space during move in. This metric will be evaluated by moving items of varying weight downstairs with the solution before the final handoff to the client.

The “move things upstairs” need has one simple metric, ability to move things upstairs. The target of this need is determined to be yes based on the definition of the problem. This metric will be evaluated by testing the devices ability on site with loads of varying size and weight before the final handoff of the solution. This metric is a requirement of the solution.

The “reliability” need has one metric, objects moved. Objects moved should be interpreted as the number of round trips required to clear the basement. The target for this metric of 250 objects was determined by visual inspection of the quantity and type of items in the facility. This metric will be evaluated through fatigue analysis of the solutions moving parts. This is a requirement of the solution.

The “efficiency” need has two metrics, loading and unloading time. The value for each was determined by estimates made by the group. These numbers are representative of the large objects that will be carried one at a time. Collecting a full load of the smaller battery backups and office accessories will likely exceed the specified times, but these items will be moved in bulk rather than one at a time. Target values were assigned to be less than five and three minutes for loading and unloading time respectively. These metrics will be evaluated by loading actual items on the solution and timing the process. These metrics are both goals of the solution.

The “store in closet” need has three metrics relating to the storage length, width, and height of the solution. The values for storage length, width, and height are determined by taking measurements of standard closet spaces from the blueprints of the facility. It was determined that the storage length, width, and height of the solution should be limited to 0.91, 0.81, and 1.83 m respectively (approximately 36x32x72 in.). These metrics will be evaluated by measuring the storage configuration of the final solution with a tape measure. These three metrics are all goals of the solution.

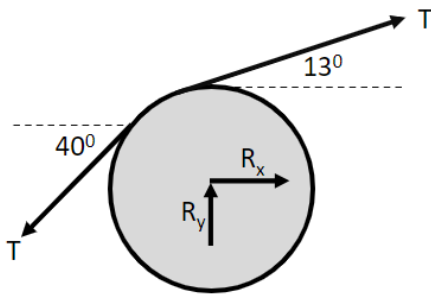
The “few operators” need has one metric, number of operators. The target for this metric was chosen to be two operators. This was chosen because it is the minimum number of operators that enables having a backup operator. This goal will be evaluated by physically attempting to load items onto and maneuver the solution with two people before the final handoff to the client.

The “quick assembly” need has two metrics of assembly and disassembly time. The targets for these metrics were chosen to be a respectable ninety-minute goals. This metric will be evaluated by physically assembling and disassembling the device on site and

timing how long it takes. The similar “assembly” need has two metrics of constructible and deconstructible. The target for these needs is yes and based on the client’s input. These are both requirements of the solution and will be evaluated by a successful demonstration of assembly and disassembly of the solution.

Lastly, the “design” need has a single metric of visual appeal with a target of acceptable. This will be evaluated by asking the client their opinion of the personal appearance of the solution. This metric is a goal of the solution.

Appendix H- Pulley Static Analysis



$$\sum F_x = 0 = T(\cos(13) - \cos(40)) + R_x$$

$$\sum F_y = 0 = T(\sin(13) - \sin(40)) + R_y$$

$$R = (-511.0 \hat{i} + 1024.7 \hat{j}) \text{ N}$$

$$|R| = 1145 \text{ N}$$

$$FOS = \frac{17167 \text{ N}}{1145 \text{ N}} = 15$$

$$17,167 \text{ N} = 1750 \text{ lbs.} \\ \text{(pulley rating)}$$

Appendix I – Set-up Instructions

Step 1: Remove the yellow caps unscrewing the $\frac{3}{4}$ " nuts by hand.



Figure I.1: Safety Cap Removal

Step 2: Lay ramp section L1 at the bottom left side of the stairs, ensuring the brackets circled in blue in Figure I.2a align with the concrete anchors as shown in Figure I.2b. Secure by finger tightening the $\frac{3}{4}$ " nuts circled in yellow in Figure I.2b.

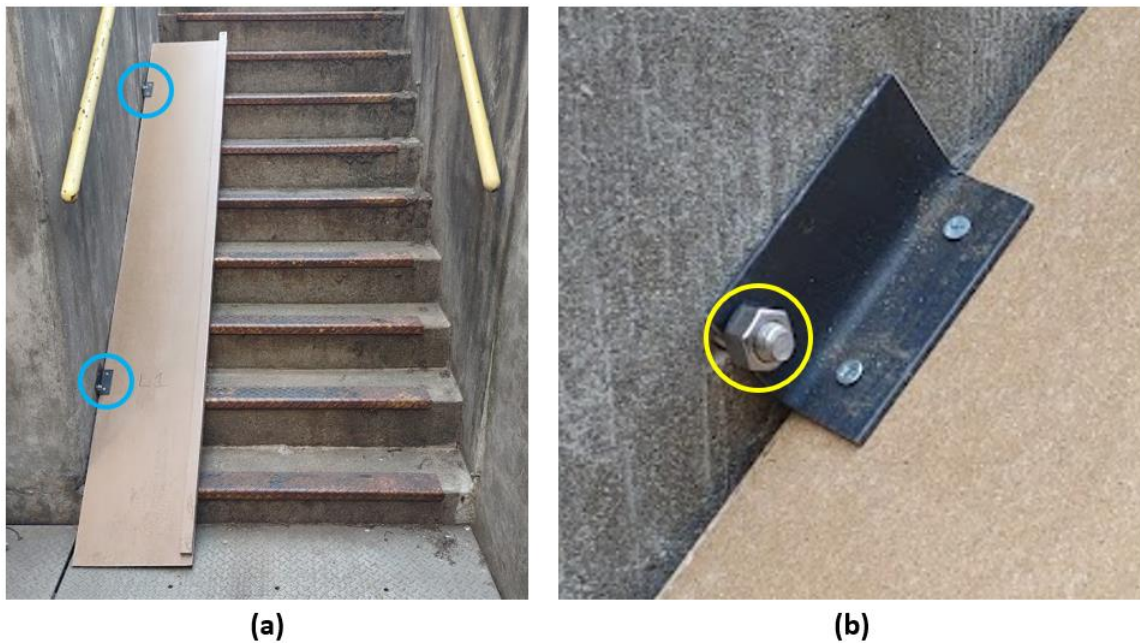


Figure I.2: Installation of Ramp Section L1

Step 3: Lay and secure the remaining ramp panels L2, L3, R1, R2, and R3 in the locations shown in Figure I.3, ensuring all brackets are aligned with the concrete anchors and all $\frac{3}{4}$ " nuts are finger tightened.

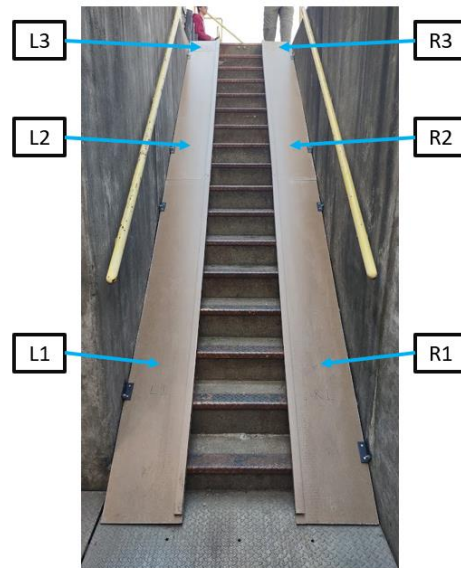


Figure I.3: Ramp Panel Placement

Step 4: Attach the winch by placing it over the three concrete anchors on the wall at the top of the stairs. Tighten the three nuts circle in blue with a $\frac{3}{4}$ " wrench or socket.

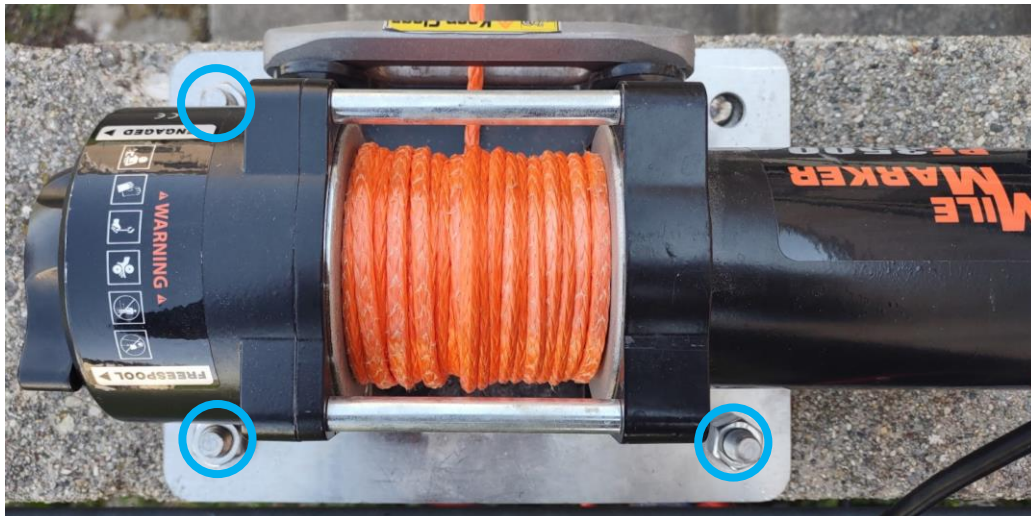


Figure I4: Winch Attachment

Step 5: Attach the red winch cable to the positive terminal of the battery and the black winch cable to the negative terminal of the battery. See Figure I5 for appropriate wiring.

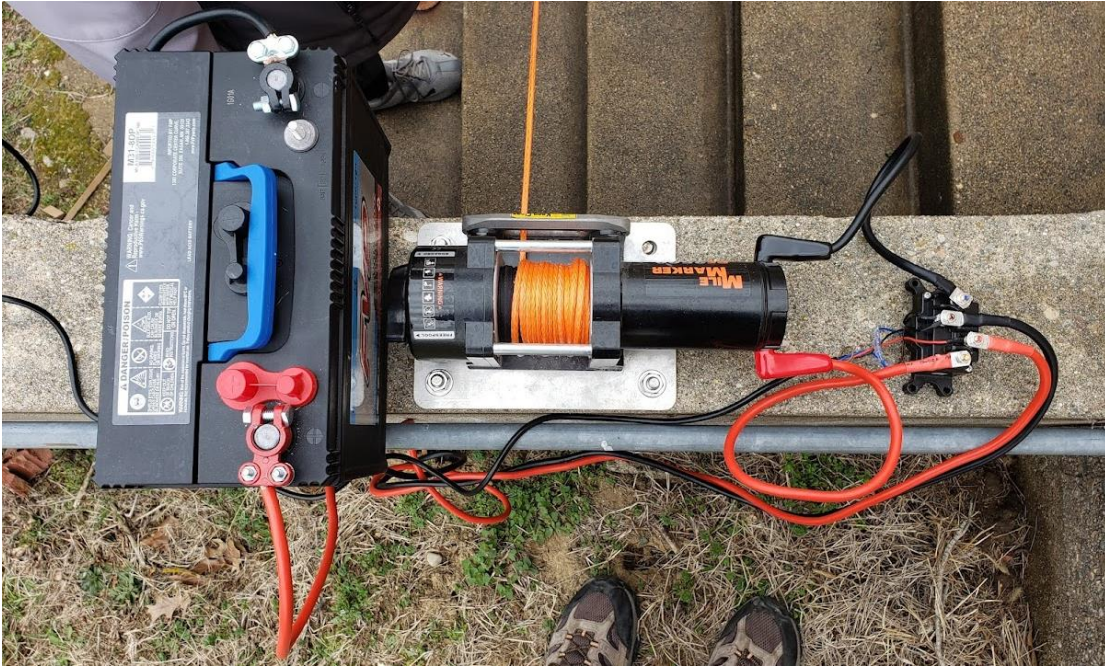


Figure I5: Winch Wiring

Step 6: Place the wedge ramps at the top of the stairs so that they align with the inside of the MDF stair ramps.

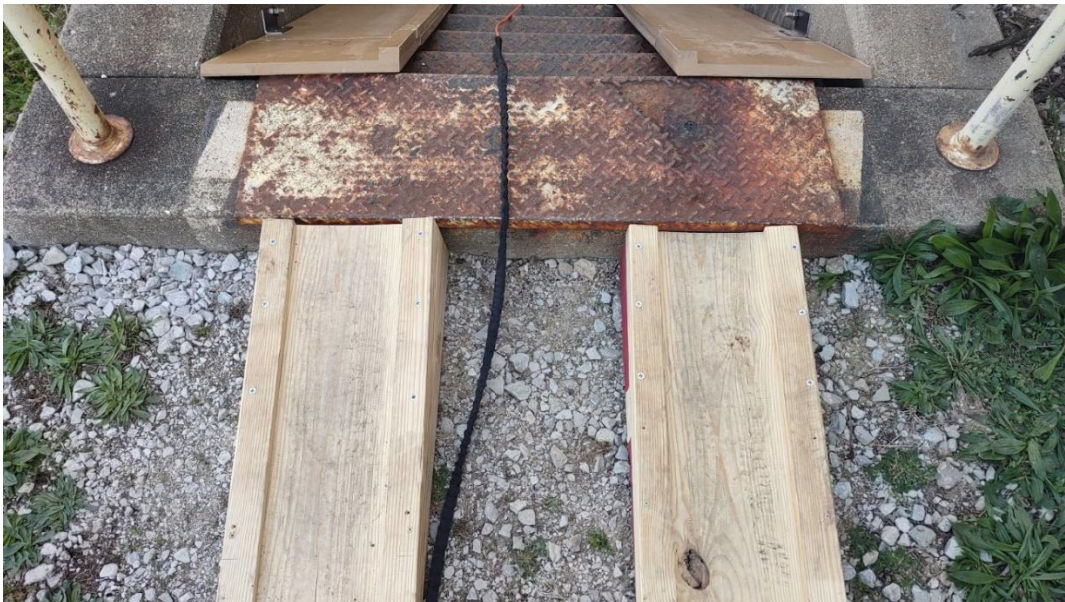


Figure I6: Wedge Ramp Placement

Step 7: Attach the pulley at the top of the stairs, tightening the two nuts with a $\frac{3}{4}$ " wrench/socket. So that the pulley rests on top of the top step.

Complete

Appendix J – Cart Conversion Instructions

Step 1: Remove the two side panels and front panel from the cart. Lift from the top of the panels to avoid pinch points.



Step 2: Remove the three bolts circled in blue from each side of the cart with a 4mm allen wrench to detach the front uprights.



Complete

Appendix K – Safe Operating Instructions

K.1 - Loading Small Items

Place, don't throw, small items in the cart in its small-items configuration.

K.2 – Loading Large Items

Step 1: Place the ramps in the slots at the front of the cart, ensuring the L and R align.



Figure K.1: Cart Ramp Installation

Step 2: Align the wheels of the large item you intend to load with the ramps of the cart.

Step 4: Completely lock the casters by pressing down on the built-in brake.

Step 5: With one person braced behind the cart, carefully push the large item up the cart's ramps.



Figure K.2: Large Item Loading

Step 6: Attach ratchet straps as shown in Figure K.3. The large flat hooks of the yellow ratchet straps should go over the 80/20 extrusions that made up the frame and the orange straps should be hooked to the u-bolt at the front of the cart. Take care not to place your fingers and the pinch points of the ratchet straps or between the ratchet straps and their attachment point.



Figure K.3: Large Item Strapping

Step 6: Roll the excess yellow ratchet straps and tuck them under on top of the large item.

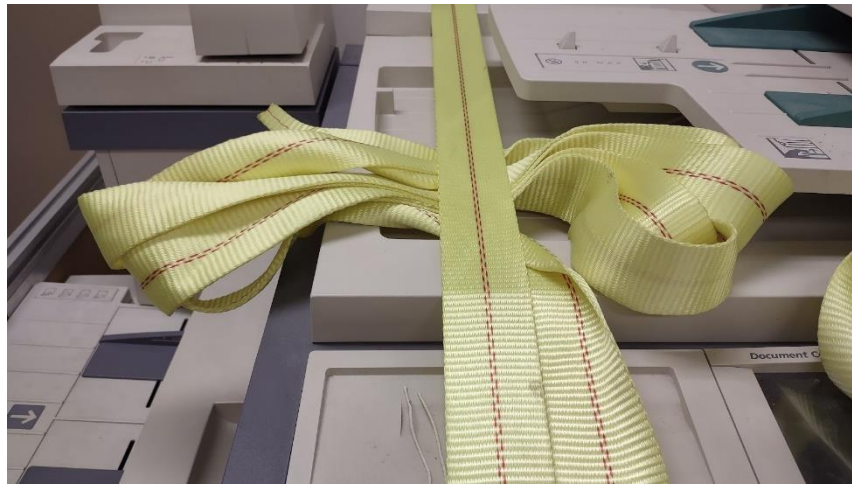


Figure K.4: Strap Retainment

Step 6: Remove the cart ramps by sliding them sideways out of their slots.

Step 7: Hand check the tightness of the ratchet straps by ensuring that the entire length of the ratchet straps are in tension.

Step 8: Push the cart to the stairwell and align the wheels with the ramps.

Step 9: Lock the swivel of the rear casters by dropping the metal pins in the holes in the aluminum blocks attached to the casters.



Figure K.5: Swivel Locks

Step 10: Attach the hook on the winch cable to the u-bolt on the front of the cart.

Step 11: Use the remote of the winch to pull the cart up the ramps until it crests the top of the stairway. During operation, no one should be right of the yellow line in Figure K.6 below.



Figure K.6: Safety Line

Step 11: Unload the cart in the opposite order in which it was loaded before reattaching it to the winch, pushing it past the crest at the top of the stairs, and winch it back down.

Complete

Appendix L – Lessons Learned

Over the 30 weeks that our team spent in Senior Capstone, we have overcome many foreseen and unforeseen challenges. Some of the unforeseen challenges included a back panel failure, a reduction in team size from five to four members, a snowy testing day, and some materials not being dimensionally stable. Some of the foreseen challenges included the arduous hours in the BIC spent machining and cutting materials for our project, the difficulty of communicating with client virtually, having to machine parts at odd angles, and deciding on a design that was able to meet the cornucopia of needs that our team and client devised.

The first lesson that we learned in our project is to test early and to test often. Our team spent the last seven weeks of the fall quarter understanding the needs of our stakeholders, proposing three concepts that met those needs, and then deciding on a concept to move forward with purchasing materials for and constructing. Going into the start of the winter quarter with no actual on-site testing was concerning as it didn't seem like there was going to be a lot of time left in the academic year to not only purchase supplies, but entirely build, test, and refine our project. Our team benefited greatly from testing early and testing often as our team carried out three days of on-site testing: one in winter quarter and two in spring quarter. While our team had to put in a lot of effort to construct our solution in time to get in a testing day in winter quarter, we were able to gain great insights into the weak points of our solution including learning of a weak back panel, the necessity of two extra ratchet straps, and the lack of alignment of our stair ramps. Not only did we uncover weak points of solution, but we learned about them early enough when we still had the time to adequately address them before delivering the solution to our client.

Another lesson that became evident later in our project was the importance of following the principle of Occam's razor which emphasizes the simplicity of the solution as opposed to the number of features in the solution. When our team set out to decide on which concept to move forward with, we followed the principle of Occam's razor as part of the rationale for choosing a concept that utilized off-the-shelf electronics as opposed to choosing a concept that required our team to design and build all the electronic components which would've included a transmitter, receiver, electronic speed controller, battery, wiring, and DC motors. While the concept that required all the in-house designed electronics seemed to be a more enjoyable project, we were thankful that we utilized Occam's razor as it meant our team could focus our efforts on the mechanical components of our project. Not only was the off-the-shelf solution more reliable, but if the electronic components were to fail, it will be much simpler for our client to just purchase the off-the-shelf components again.

Appendix M – Acknowledgements

Throughout the course of the academic year completing the Mechanical Engineering Senior Capstone Project, our team has been fortunate to have worked with and worked for a group of individuals that exemplify the qualities of professionalism. We would like to start by thanking our professor for the Mechanical Engineering Senior Capstone course, Dr. Chambers, as he was a great resource along the way to keep our team on-track and helped facilitate the principal requirements of the course over the three quarters in which our team was enrolled in it. Next, we want to thank the Mechanical Engineering Department for coordinating professors to take part in external reviews to ensure that our capstone project was sound and on-track and for planning out the Mechanical Engineering curriculum such that the members of our team were adequately prepared for the challenges we faced to complete the Senior Capstone Project. Finally, we would like to extend a great thank you to Bob Grewe, the Executive Director of the Vermillion Rise Mega Park who provided the funding for the materials which made up our project and was graciously willing to donate his time to meet with us at Rose-Hulman and facilitate on-site testing days.

Appendix N – Battery Care

For maintaining the battery, we would recommend fully charge the batter before putting it in storage and then charging the battery with battery charger every 1-2 months that it has been in storage (not being used). Do not charge the battery while using it to power anything. When charging the battery, make sure it is in a well-ventilated room. To prepare to use the device, fully charge the battery the day before use.

I found the links to the specific battery and charger that he bought:

- <https://www.menards.com/main/tools/automotive/automotive-batteries/fvp-reg-voltege-reg-m31-8dp-dual-purpose-marine-battery/2609721/p-4364363665510480.htm>

- <https://www.schumacherelectric.com/products/50a-12v-fully-automatic-battery-charger-engine-starter/>
 - <https://store-zm80kkpa03.mybigcommerce.com/content/manuals/0099001890-R0.pdf>