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One Knee Stair Negotiator

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University of Missouri–St. Louis ▪ Washington University in St. Louis

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The design-to-prototype process for a One Knee Stair Negotiator, designed to reduce or eliminate the weight on one leg while climbing stairs. The decision-making processes, fabrication plan, engineering analysis, safety concerns, and risk assessments are documented. Pertinent photographs, drawings, and video links are included for clarification.

JME 4110
Mechanical Engineering
Design Project

One Knee Stair Negotiator

Naomi Marciante
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1 INTRODUCTION

1.1 VALUE PROPOSITION / PROJECT SUGGESTION

In an age of an increasing population of elderly people, the needs of these individuals should be considered. In the past, the elderly were often left at home and cared for by their descendants. However, the new age allows them to live their own lives. One common hinderance to this life after retirement is an increase in pain in one or both of their knees. Stairs are particularly problematic for people with knee issues and can even force the elderly to downsize their homes. Our goal is to create a cheap, simple, discreet and comfortable means of easing the plight of those whose knees are or knee are failing them and preventing their access to higher planes and elevations. To solve this problem, we hope to either modify already currently existing stairs, or, more likely, through personal equipment. We hope to help not only the aging community, but also many people that have lost mobility through permanent or short-term injury. This design will reduce or eliminate the pain of climbing and descending stairs by focusing on eliminating weight on one of the legs. The device will be human powered.

1.2 LIST OF TEAM MEMBERS

Naomi Marciante
Seth Trevino

2 BACKGROUND INFORMATION STUDY

2.1 DESGIN BRIEF

A modified crutch and or semi exo-suit that assists with movement on stairs. The main goal will be to divert weight and force away from the affected knee and dispense it to other parts of the leg or directly to the ground. We will plan to keep the product discreet and allow for ample ability to move. The key to our success will be to create a device or product that will not force the wearer to change their gait or add any other undue stress. The two main changes are the following: we streamlined our focus to divert pressure on the knees of an individual. The second is to keep in mind how will this disrupt the natural walk of a person.

2.2 BACKGROUND SUMMARY

2.2.1 Existing Designs

There are a few traditional designs for assistance in reducing or eliminating the weight placed on one leg. These include crutches, canes, and walkers. There are adaptions of these traditional devices that are more user friendly or allow more freedom than these traditional tools. Some of these designs, like the Freedom Leg (shown in Figure 1), give the user the ability to carry objects without the need to juggle a crutch.

Figure 1 – The Freedom Leg Off-Loading Brace

Other design adaptations were specific to climbing stairs, including the stair lift, which requires a permanently mounted chair and rail in the stairwell. Other devices can be added to wheelchairs to climb or descend stairs. Many of these products, such as the Liftkar PT-U (see Figure 2), require an additional person to operate the equipment. In addition, the Liftkar PT-U powered stairlift is battery powered and requires training to use.

Figure 2 – Liftkar PT-U Powered Stairlift

Also researched were some multipurpose devices including exo-skeletons. The MAX system (shown in Figure 3) reduces muscle force required to complete tasks by as much as 60 percent. The Chairless Chair also allows for reducing force on the users legs. The only difference is that the max allows you to go up stairs and the Chairless Chair does not allow for stair travel. The MAX is a motorized product while the Chairless Chair is motorless.

Figure 3 – MAX System and Chairless Chair

2.2.2 Professional Information

In addition to researching existing designs, we spoke with Jeff Harvath PT, DPT, COMT, who is a Manager in the Division of Clinical Practice at Washington University School of Medicine. Dr. Harvath explained the biomechanics of ascending and descending stairs. He demonstrated the "up with the good, down with the bad" technique, which reduces load on the bad leg by keeping it as straight as possible. When the leg is straight, there is a vertical load on the knee. However, as the knee bends, the force is directed at the knee at an angle, which creates a shearing force. This shearing force puts strain on the knee and can cause pain.

Dr. Harvath explained some of the common tools available for knee pain in the marketplace. He explained that compression sleeves are useful in combatting swelling. Braces with a joint at the knee are able to bypass the knee loading but are typically used to prevent the knee from rotating sideways during sports. Scooters are for ankle injuries, and this kneeling position can overextend the knee and cause more pain. Walkers are not typically used on stairs because they don't have enough horizontal support.

Typically, the recommended therapy is to strengthen the glute muscles so they can absorb more of the load, and to use the "up with the good, down with the bad" while leaning on the railing(s) as much as possible.

2.2.3 Codes and Standards

A few codes and standards applied to our potential solutions. Staircase measurements are subject to building codes. In addition, the ADA has regulations for staircases for accessibility. Finally, the FDA regulates assistive devices, such as walkers, braces, and wheelchairs.

2.2.3.1 FDA Assistive Devices

Assistive devices are subject to FDA review. Most of the devices we considered would fall into a Class I device, which includes walkers, leg braces, and wheelchair accessories. According to the FDA website:

> If a manufacturer's device falls into a generic category of exempted class I devices as defined in 21 CFR Parts 862-892, a premarket notification application and fda clearance is not required before marketing the device in the U.S. however, these manufacturers are required to register their establishment.

Although the device need not be approved by the FDA, it must be registered before it can be sold. A powered exoskeleton, however, is a Class II device, so it would be subject to an FDA review before it could be placed on the market. The requirements for such a device can be found under: 21CFR890.3480, Sec. 890.3480.

2.2.3.2 Building Codes

Most local codes will reference an authority in building for acceptable measurements for staircases. There are a variety of building codes available, all with different requirements for stairways. To further complicate matters, codes are revised on a regular schedule. The most commonly used building codes were researched. The International Building Code (IBC), Residential Building Code (IRC), and Americans with Disabilities Act Standards for Accessible Design (ADASAD), and Code of Federal Regulations Title 29 (OSHA) were determined to apply and be widely accepted references for stair construction. The information in these documents is further explored in Section 7.

2.2.4 Summary

There were quite a few devices available for assistance with negotiating stairs, there is not currently an excellent solution for negotiating a narrow stairwell. The current devices, such as walkers, are not stable enough to be a good support on stairs. The advice of medical professionals, including our interviewed Physical Therapist, is to use stair railing as much as possible. However, this can be difficult for people who don’t have good coordination and upper body strength. In addition, most stairways only have one handrail available.

3 CONCEPT DESIGN AND SPECIFICATION

3.1 USER NEEDS AND METRICS

3.1.1 Record of the User Needs Interview

Table 1 – User Needs Interview

Product/Project Name: One Knee Stair Negotiator Customer: Dr. Mark Jakiela Address: Washington University Willing to do follow up? Yes Type of User: People with arthritis		Interviewers: Naomi Marciante, Seth Trevino Date: June 17, 2016 Currently Uses: Nothing	
Question	Customer Statement	Interpreted Need	Importance
What are you looking for?	A way to go up and down steep narrow staircase. The staircase is 1 m wide and quite steep.	Pain reduction.	5
Where will it be used?	At home primarily on one staircase, going up and down when arthritis is bad.	Pain reduction; Discreet.	5
Do you want to avoid putting any weight on the knee, or is reducing the weight on the knee ok?	Ideally no weight on one leg, but minimally reducing the load by 50%.	Decrease in weight on bad leg.	5
If it slows down your walk, is that ok?	should take no longer than 50% more time	Quick to use.	5
How much time are you willing to spend putting on / taking off the device	It should be as easy to put on/remove as putting the foot in a bicycle pedal. The device should be usable with shoes, socks, or barefoot.	Quick to use.	3
Are you willing to learn how to use the device?	It should be simple and require no thought.	Easy to use.	3
Can battery power be used? If so, how long must it last?	Ideally the device would be kinetically powered. If a battery is used, it must last 12 hours between charges.	Low maintenance.	2
Do you have any emergency safety concerns, such as use in a fire?	Not for emergency use.	Low Cost.	1

Question	Customer Statement	Interpreted Need	Importance
What are you looking for?	A way to go up and down steep narrow staircase. The staircase is 1 m wide and quite steep.	Pain reduction.	5
Where will it be used?	At home primarily on one staircase, going up and down when arthritis is bad.	Pain reduction; Discreet.	5
Do you want to avoid putting any weight on the knee, or is reducing the weight on the knee ok?	Ideally no weight on one leg, but minimally reducing the load by 50%.	Decrease in weight on bad leg.	5
If it slows down your walk, is that ok?	should take no longer than 50% more time	Quick to use.	5
What is the ideal cost of the final product? What is the min-max?	The device should cost no more than $300 for an elite version.	Low Cost.	3
Is it important that it lasts a long time?	It should last as long as a coffee maker.	Replacement no greater than every 5 years.	2
How much maintenance are you willing to do?	No more than shining a pair of shoes.	Repair/maintenance no greater than once per month.	2
Do you have any concerns about the long-term effects of using this product?	Immediate relief not rehabilitation.	Pain reduction.	1
Is it ok if you have to go a separate route (different staircase)? What would keep you from using it?	Ok, but cost of installation and the space utilized would be a concern.	Easy to use.	1
Would you prefer this device stay at one location, or move with you?	Ideally it would stay in the stairwell.	Discreet.	2
How much installation are you willing to do?	There can be no mounting of hardware.	Easy to use.	2
Does it need to look nice?	5 to 6 on the "nice looking" scale.	Discreet.	1
Would you be open to wearing it? Velco ok? Tie ok? Multiple straps ok? How light?	If worn, it needs to be comfortable, able to be worn under clothing, concealable, lightweight, and easy to put on/take off.	Discreet.	1
What would stop you from wearing it?	Can't be ski boot bulky.	Diameter increase of leg.	2

Question	Customer Statement	Interpreted Need	Importance
Are you willing to modify your gait/ way of walking?	If worn, the gait should be indistinguishable from normal when travelling on flat ground.	Gait modification.	1
Are you ok with carrying something that is only usable when going up stairs?	I am willing to carry something if light.	Easy to use.	1
Do you need it to be storable? If so, what are the max dimensions?	Storage space no greater than upright vacuum cleaner.	Easy to store.	2
Are you ok with being on an incline?	A 10-15° incline is the max.	Easy to use.	1
Would multiple people use the same device?	Primarily it would be for one user.	Easy to use, Low cost.	1

Table 2 – Initial Needs Table for One Knee Stair Negotiator

Need Number	Need	Importance*
1	Pain Reduction	5
2	Easy to Use	4
3	Quick to use stairs	4
4	Low maintenance	1
5	Inexpensive	2
6	Discreet when worn	1
7	Comfortable when worn	1
8	Easy to Store	1

*1-least important, 5 most important

3.1.2 List of identified metrics

Table 3 – Identified Matrix

Metric Number	Associated Needs	Metric	Units	Worst Value	Best Value
1	1	Weight on Bad Leg	%	0	50
2	1	Pain Level	integer	0	10
3	2	Time to Put On / Remove	s	0	10
4	2, 7	Number of Fasteners	integer	0	5
5	3	Time to Use Stairs	s	10	15
6	4	Interval Between Replacement	years	10	0
7	4	Interval Between Recommended Maintenance	months	6	0
8	5	Sell Price	$	0	300
9	6	Change in Appearance?	integer	0	10
10	6, 7	Change in Gait on Flat Ground?	binary	0	1
11	6, 7	Increase in Diameter of Leg	inch	0	5
12	8	Time to Store	s	0	20
13	8	Volume of Storage	ft^3	0	4

3.1.3 Table/list of quantified needs equations

Table 4 – Quantified Needs Matrix

		Metric															
		Weight on Bad Leg	Pain Level	Time to Put On / Remove	Number of Fasteners	Time to Use Stairs	Interval Between Replacement	Interval Between Recommended Maintenance	Sell Price	Change in Appearance?	Change in Gait on Flat Ground? Yes/No	Increase in Diameter of Leg	Time to Store	Volume of Storage	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Pain Reduction	0.25	0.75												1.00	0.25	0.25
2	Easy to Use			0.75	0.25										1.00	0.15	0.15
3	Quick to use stairs					1									1.00	0.20	0.20
4	Low maintenance						0.6	0.4							1.00	0.05	0.05
5	Inexpensive								1						1.00	0.10	0.10
6	Discreet when worn									0.4	0.4	0.2			1.00	0.15	0.15
7	Comfortable when worn				0.1						0.2	0.7			1.00	0.05	0.05
8	Easy to Store												0.25	0.75	1.00	0.05	0.05
Units		%	integer	s	integer	s	years	months	$	integer	binary	inch	s	ft^3	Total Happiness		1.00
Best Value		0	0	0	0	10	10	6	0	0	0	0	0	0			
Worst Value		50	10	10	5	15	0	0	300	10	1	5	20	4			
Actual Value		0	0	0	0	0	10	6	0	0	0	0	0	0			
Normalized Metric Happiness		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			

3.2 CONCEPT DRAWINGS

Concept #1:

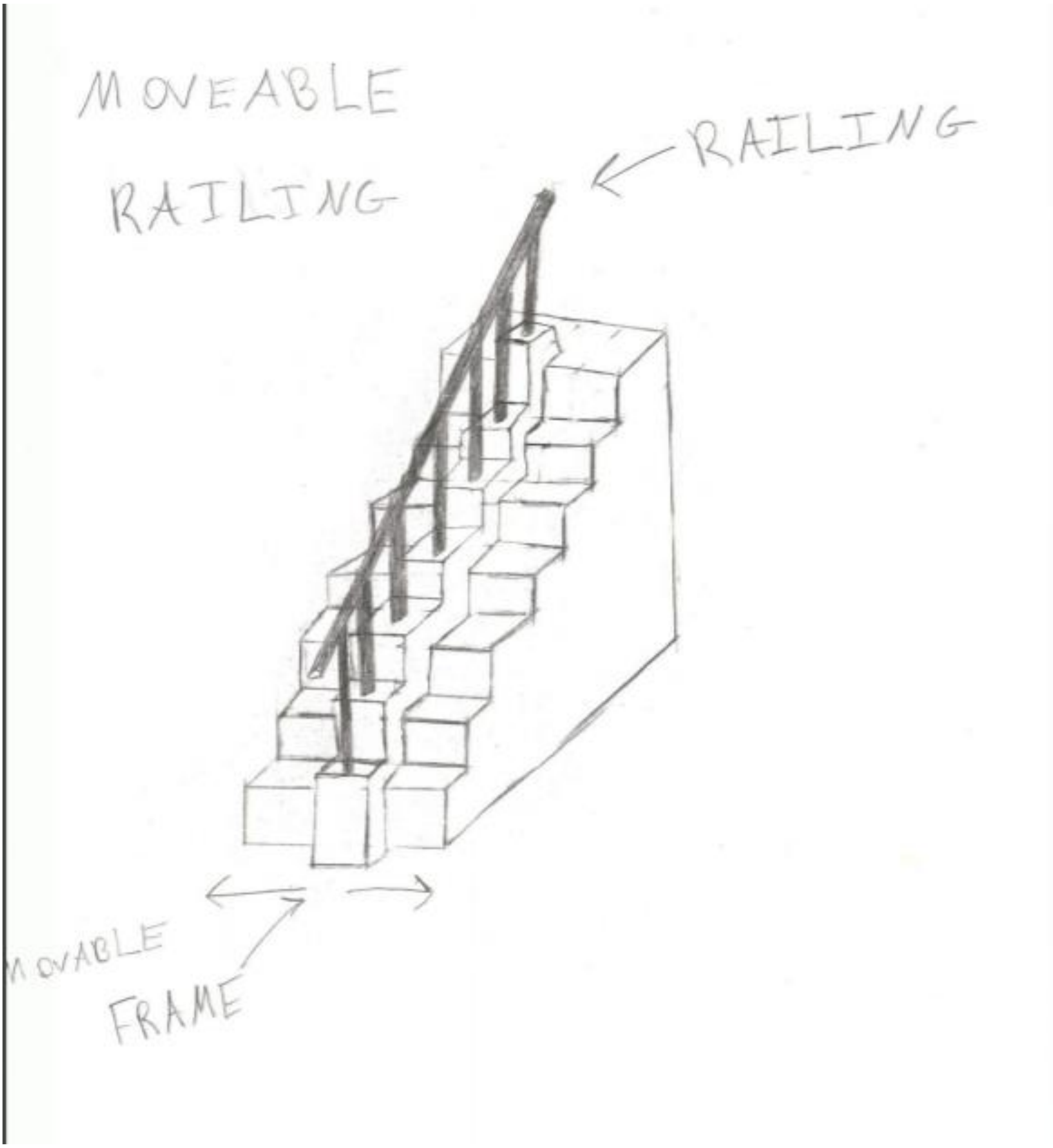


Figure 4 – Movable Railing

Concept #2:

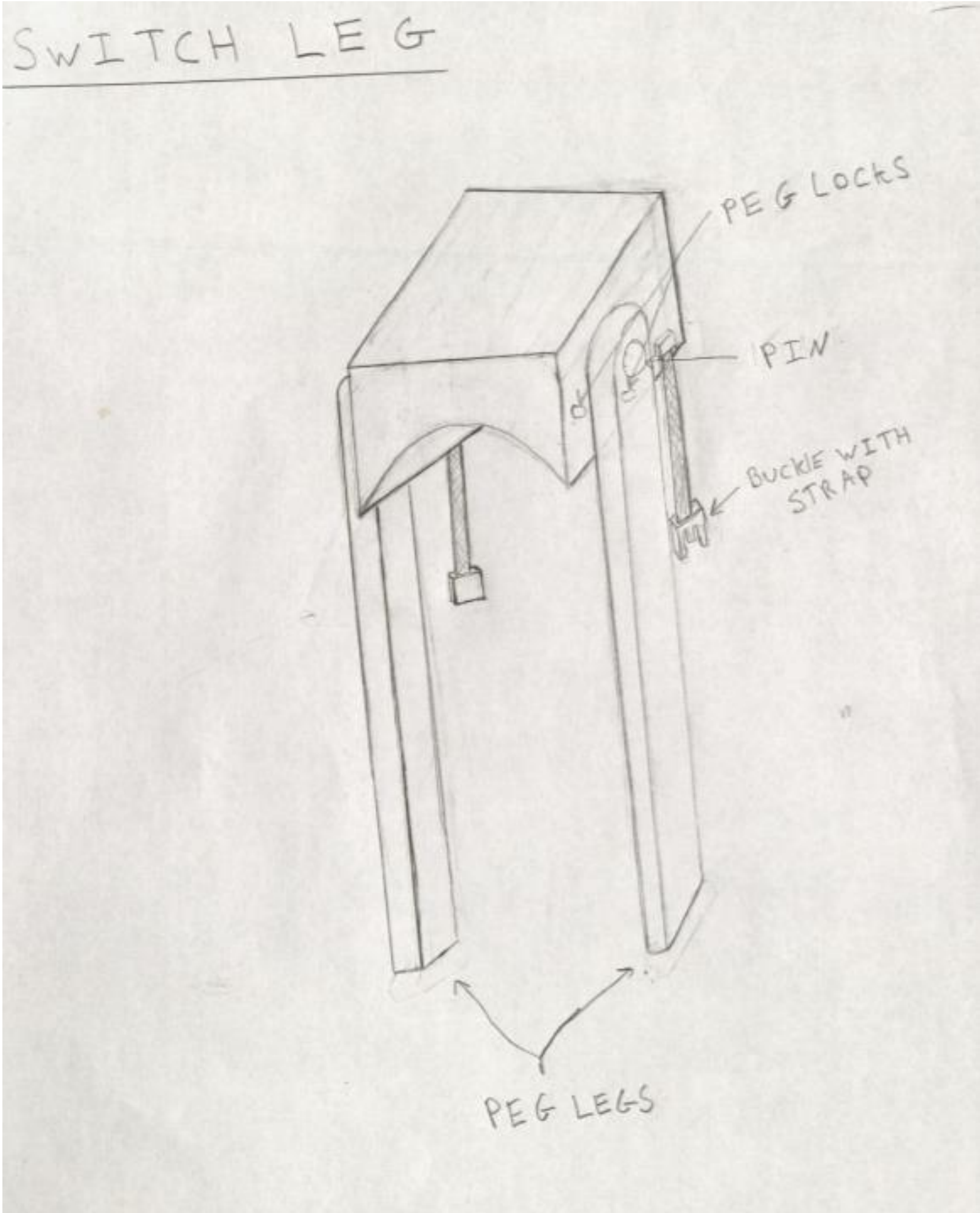


Figure 5 – Switch Leg

Concept #3:

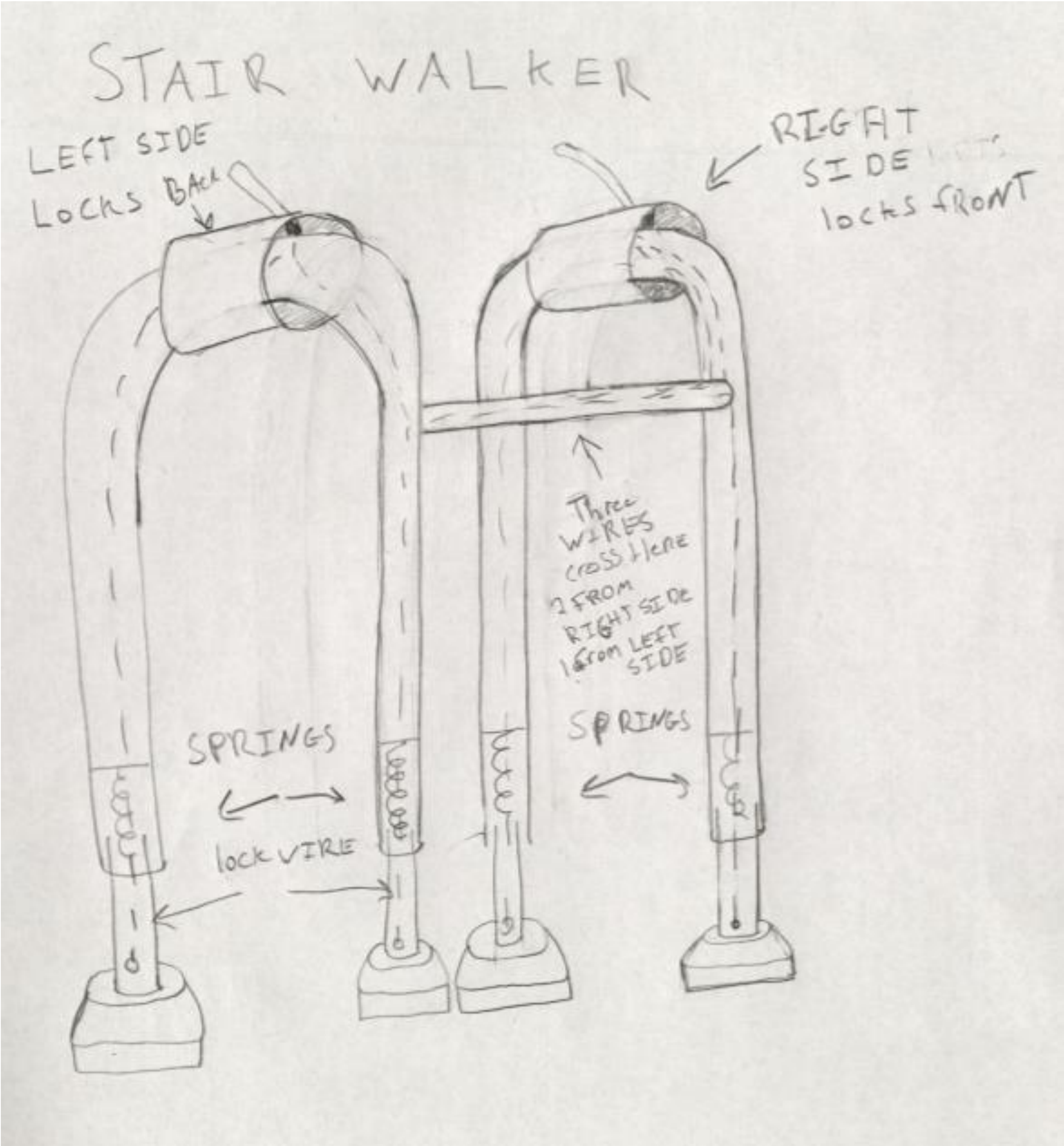


Figure 6 – Stair Walker

Concept #4:

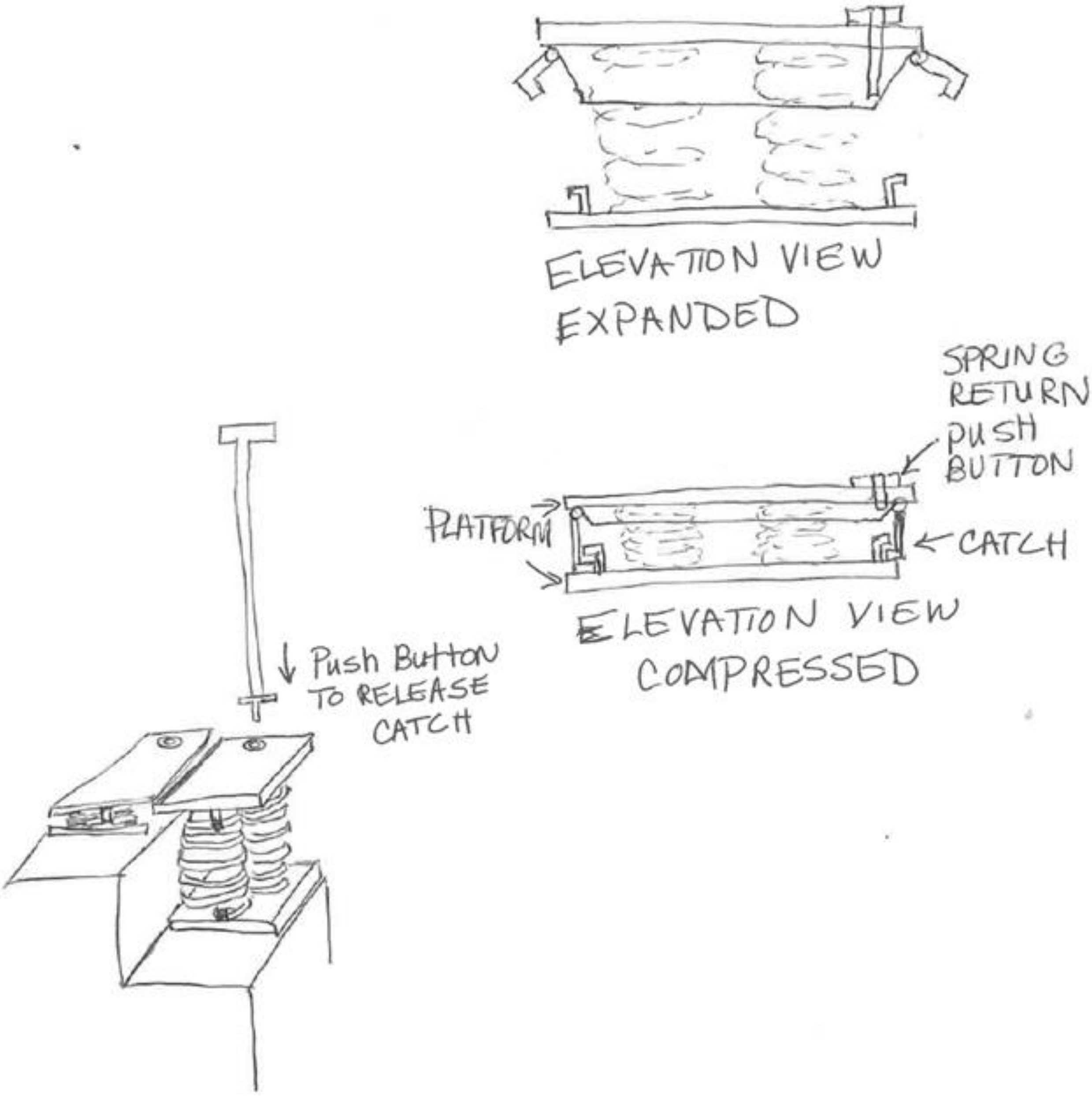


Figure 7 – Spring Stairs

3.3 A CONCEPT SELECTION PROCESS.

3.3.1 Concept scoring

Concept #1:

Table 5 – Concept #1 Metrics Table

Moveable Railing		Metric															
		Weight on Bad Leg	Pain Level	Time to Put On / Remove	Number of Fasteners	Time to Use Stairs	Interval Between Replacement	Interval Between Recommended Maintenance	Sell Price	Change in Appearance?	Change in Gait on Flat Ground? Yes/No	Increase in Diameter of Leg	Time to Store	Volume of Storage	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Pain Reduction	0.25	0.75												0.88	0.25	0.22
2	Easy to Use			0.75	0.25										1.00	0.15	0.15
3	Quick to use stairs					1									0.00	0.20	0.00
4	Low maintenance						0.6	0.4							0.87	0.05	0.04
5	Inexpensive								1						0.50	0.10	0.05
6	Discreet when worn									0.4	0.4	0.2			0.60	0.15	0.09
7	Comfortable when worn				0.1						0.2	0.7			0.80	0.05	0.04
8	Easy to Store												0.25	0.75	0.25	0.05	0.01
Units		%	integer	s	integer	s	years	months	$	integer	binary	inch	s	ft^3	Total Happiness		0.60
Best Value		0	0	0	0	10	10	6	0	0	0	0	0	0			
Worst Value		50	10	10	5	15	0	0	300	10	1	5	20	4			
Actual Value		10	1	0	0	15	10	4	150	0	1	0	0	4			
Normalized Metric Happiness		0.80	0.90	1.00	1.00	0.00	1.00	0.67	0.50	1.00	0.00	1.00	1.00	0.00			

Concept #2:

Table 6 – Concept #2 Metrics Table

Switch Leg		Metric															
		Weight on Bad Leg	Pain Level	Time to Put On / Remove	Number of Fasteners	Time to Use Stairs	Interval Between Replacement	Interval Between Recommended Maintenance	Sell Price	Change in Appearance?	Change in Gait on Flat Ground? Yes/No	Increase in Diameter of Leg	Time to Store	Volume of Storage	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Pain Reduction	0.25	0.75												0.83	0.25	0.21
2	Easy to Use			0.75	0.25										0.05	0.15	0.01
3	Quick to use stairs					1									1.00	0.20	0.20
4	Low maintenance						0.6	0.4							0.45	0.05	0.02
5	Inexpensive								1						0.00	0.10	0.00
6	Discreet when worn									0.4	0.4	0.2			0.52	0.15	0.08
7	Comfortable when worn				0.1						0.2	0.7			0.36	0.05	0.02
8	Easy to Store												0.25	0.75	0.31	0.05	0.02
Units		%	integer	s	integer	s	years	months	$	integer	binary	inch	s	ft^3	Total Happiness		0.55
Best Value		0	0	0	0	10	10	6	0	0	0	0	0	0			
Worst Value		50	10	10	5	15	0	0	300	10	1	5	20	4			
Actual Value		5	2	10	4	10	3	4	300	8	0	4	10	3			
Normalized Metric Happiness		0.90	0.80	0.00	0.20	1.00	0.30	0.67	0.00	0.20	1.00	0.20	0.50	0.25			

Concept #3:

Table 7 – Concept #3 Metrics Table

Stair Walker		Metric: Weight on Bad Leg	Pain Level	Time to Put On / Remove	Number of Fasteners	Time to Use Stairs	Interval Between Replacement	Interval Between Recommended Maintenance	Sell Price	Change in Appearance?	Change in Gait on Flat Ground? Yes/No	Increase in Diameter of Leg	Time to Store	Volume of Storage	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Pain Reduction	0.25	0.75												0.83	0.25	0.21
2	Easy to Use			0.75	0.25										0.75	0.15	0.11
3	Quick to use stairs					1									1.00	0.20	0.20
4	Low maintenance						0.6	0.4							1.00	0.05	0.05
5	Inexpensive								1						0.80	0.10	0.08
6	Discreet when worn									0.4	0.4	0.2			0.20	0.15	0.03
7	Comfortable when worn				0.1						0.2	0.7			0.76	0.05	0.04
8	Easy to Store												0.25	0.75	0.13	0.05	0.01
Units		%	integer	s	integer	s	years	months	$	integer	binary	inch	s	ft^3	Total Happiness		0.72
Best Value		0	0	0	0	10	10	6	0	0	0	0	0	0			
Worst Value		50	10	10	5	15	0	0	300	10	1	5	20	4			
Actual Value		5	2	2	2	10	10	6	60	10	1	0	10	4			
Normalized Metric Happiness		0.90	0.80	0.80	0.60	1.00	1.00	1.00	0.80	0.00	0.00	1.00	0.50	0.00			

Concept #4:

Table 8 – Concept #4 Spring Stair Metrics Table

Spring Stair		Metric: Weight on Bad Leg	Pain Level	Time to Put On / Remove	Number of Fasteners	Time to Use Stairs	Interval Between Replacement	Interval Between Recommended Maintenance	Sell Price	Change in Appearance?	Change in Gait on Flat Ground? Yes/No	Increase in Diameter of Leg	Time to Store	Volume of Storage	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Pain Reduction	0.25	0.75												0.70	0.25	0.18
2	Easy to Use			0.75	0.25										1.00	0.15	0.15
3	Quick to use stairs					1									0.00	0.20	0.00
4	Low maintenance						0.6	0.4							0.57	0.05	0.03
5	Inexpensive								1						0.00	0.10	0.00
6	Discreet when worn									0.4	0.4	0.2			0.60	0.15	0.09
7	Comfortable when worn				0.1						0.2	0.7			0.80	0.05	0.04
8	Easy to Store												0.25	0.75	0.00	0.05	0.00
Units		%	integer	s	integer	s	years	months	$	integer	binary	inch	s	ft^3	Total Happiness		0.48
Best Value		0	0	0	0	10	10	6	0	0	0	0	0	0			
Worst Value		50	10	10	5	15	0	0	300	10	1	5	20	4			
Actual Value		0	4	0	0	20	5	4	600	0	1	0	45	20			
Normalized Metric Happiness		1.00	0.60	1.00	1.00	0.00	0.50	0.67	0.00	1.00	0.00	1.00	0.00	0.00			

3.3.2 Preliminary analysis of each concept's physical feasibility

3.3.3 Concept #1:

The Moveable railing will have three main components. The first is the frame that will sit on top of a given staircase. This frame will need to be able to stay in place and not fall over when leaned upon. The second is for a railing to be attached to the frame and allow the user to climb the stairs regards of going up or down, or if the bad knee is the right or left knee. The third is for it to be easily disassembled and moved. This will possibly be accomplished with smaller modular frame pieces that can be combined and interchanged as needed. Initially we will need to know the rise and run of the user's stairs for our product to function. Some future iteration may make it one-size-fits-all or something that will be able to adjust on the spot. The key will be to not be evasive in any way to the structure of the stairs themselves.

3.3.4 Concept #2:

The Switch leg has four main components. The first is the two peg leg extensions that will extend from the thighs to the floor. The material for this will need to be sturdy similar to a cane but will need to be thing to adhere closer to the leg than a standard crutch. Lightweight material will also be needed since the user will be wearing it. The second component will be a brace that will be attached to the thigh. This will be something that has to be thin and comfortable. Specifically, we will need to make the brace breathable in order to not smell and require more maintenance. The clasp on the brace will need to be simple, similar to a duffle bag clasp or backpack clasp. The third component will be a hinged joint that will allow the pegs to replace the users leg. This component will need to be able to lock and unlock when the user is walking normally. The hinge should be able to self-lock and then release when activated. The special requirement will be a fourth component that will be the actuator that will allow the leg to switch when in use. This device will need to be activated when the peg leg makes contact with step and release when user is fully erect on step. The actuator will need a pressure release to lock and some form of handheld activator to release.

3.3.5 Concept #3:

The Stair walker will have three main components as well. The first will be the walker itself which will be a standard non-rolling, four-legged walker. The second will be the spring-operated extenders and adjustable feet/legs that will adhere to the stairs and create the ability to be stable while traveling up and down the stairs. The third component will be the means of locking and unlocking the adjustable feet/legs. This will possibly be accomplished with a similar pulley system found in walkers with breaks and in bikes. Another option would be to have a self-locking mechanism that activates when pressure is applied and will lock in the position needed and release when no longer on the stairs. Special feet/legs will have to be designed to be either built into the walker or to be attached to a standard walker. We looked at various extending and retractable devices that had features we would like to use in our design, but the trick will be modifying it to a walker. Some examples include the toy lightsabers that extend out at a press of a button and pogo sticks.

3.3.6 Concept #4:

The Spring stairs has two major components. The first is the apparatus that will lift or descend the user. As the name implies the first example of how we would accomplish this would be with springs. Other examples would include hydraulics or pneumatics that would bring the user to the desired level. The second component is the actuator that will be activated by handheld device. Current idea is a ski pole that you press on a button that activates the device. The spring stairs would naturally stay neutral and not activated allowing others to use the stairs normally. Special modification will be needed in order to prevent injury. Considerations concerning how quickly the lift works and how much effort is needed to activate the system. Concerns of being off-balance may lead to other injuries. Another special feature will be how small the device will have to be to not affect the functionality of the stairs when not in use and still able to lift a 250lb person, which is a comfortable room for error for the average weight of a person.

3.3.7 Final summary statement

We subjected all four concepts to the decision matrix that we created. The decision matrix was based off the interview we had with our client on the needs the clients was worried about. Each of the four concepts received a happiness score.

To determine the best concept to develop, four criteria were used. The first was the score on the happiness matrix. Second was the ability for a prototype to be constructed with our limited resources. The third was that it was not already invented. The fourth was the danger involved in using the product, which would increase the risk of the product going to market. A summary of the weighted results for our decision is presented in Figure 8. The text following describes the weighting of the different concepts.

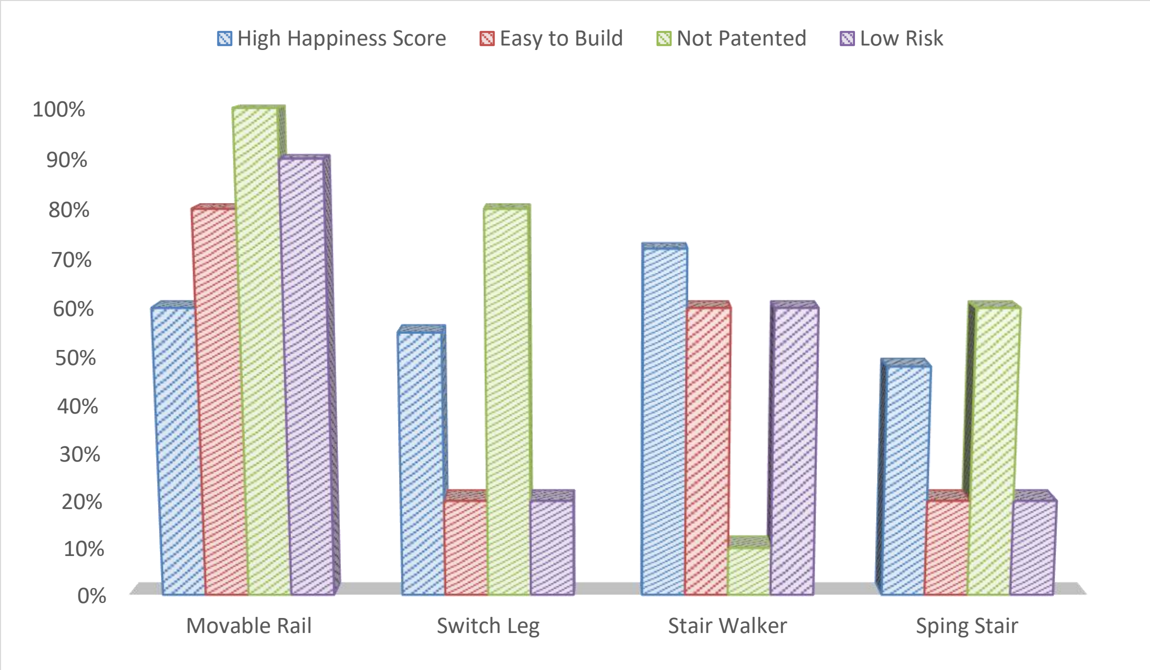


Figure 8 – Design Selection

3.3.8 Criteria #1: High Happiness Score

The Spring Stair scored a 48% on the happiness matrix. The Switch Leg scored a 55%. The Movable Railing scored a 60%, and the Stair Walker scored 72%. The Stair Walker and the Movable Rail scored the highest on the happiness matrix and were both considered in depth as good choices for the project.

3.3.9 Criteria #2: Easy to Build

The Spring Stair and the Switch Leg were considered the most difficult to fabricate and therefore didn't fit out second criteria. On the other hand, the Movable Railing and Stair Walker required less fabrication.

3.3.10 Criteria #3: Not Patented

Several different iterations of the Stair Walker were found that were similar to our conceptual design. This made the Stair Walker less desirable for development because it would require some innovation to make it stand out. In addition, there were a few student designs that were not patented, but also did not have a commercially available product. This indicated that the desire for this type of device was low. The Movable Railing is a new way to modify the normal stair railing that did not require fastening to the stairs or wall. We were convinced it would be safe from patent issues.

3.3.11 Criteria #4: Low Risk

3.3.12 Final Decision

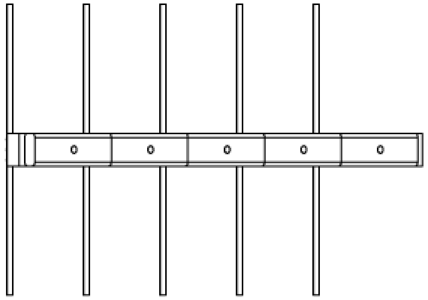
Even though the Stair Walker had a higher happiness score, the Movable Rail was chosen for two reasons. The first reason was that the fabrication of the Movable Railing was significantly easier than the walker. This would make cost and modifications cheaper and easier for us and our client. The second reason was because we found very little existing innovations of simple modifications to stairs.

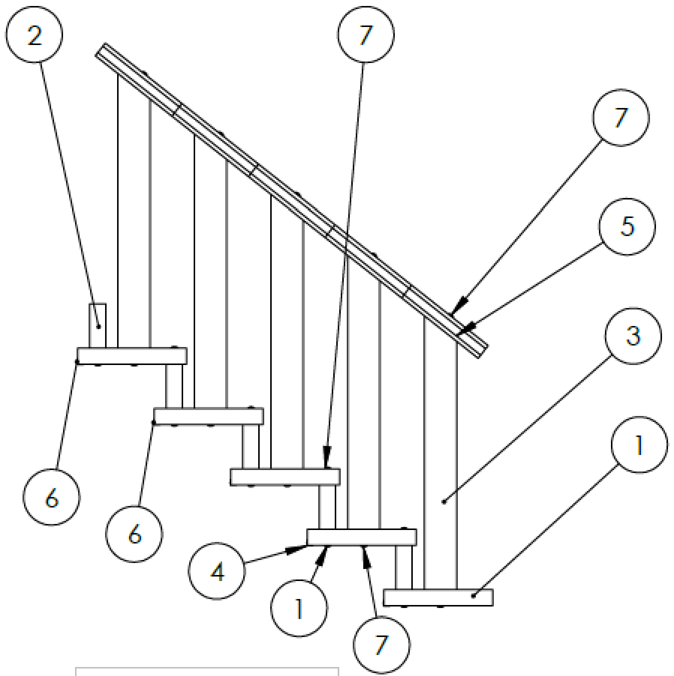
3.4 PROPOSED PERFORMANCE MEASURES FOR THE DESIGN

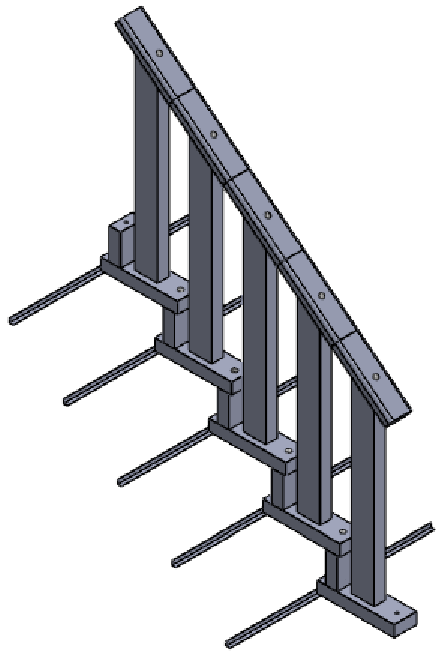
Decrease in pressure/ pain on the bad leg is our overall deciding factor in success. If the device minimizes the pain to half of that felt without the aid of the device, it will meet the minimum requirements. We hope to reduce the pain to a quarter or zero. We believe the Moveable Railing will be successful at accomplishing our goal.

4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT/ASSEMBLY DRAWINGS

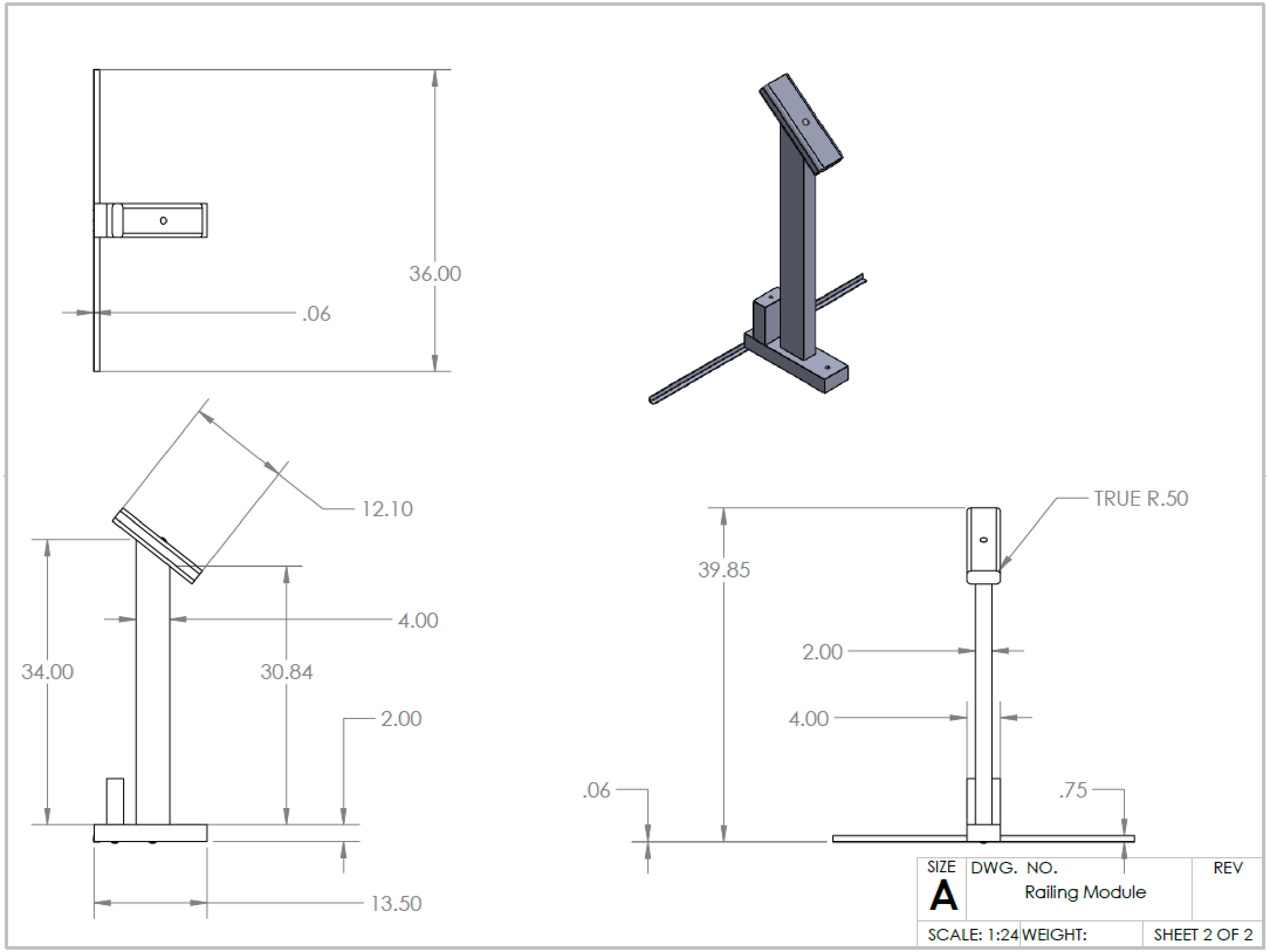






ITEM NO.	PART NO.	DESCRIPTION	QTY./ UNIT
1	W001	2"x4"x8' PINE 13.5"L	5
2	W002	2"x4"x8' PINE 5.5"L	5
3	W003	2"x4"x8' PINE 34"L	5
4	L001	ANGLE IRON 3/4" X 3/4" 30"L	5
5	R001	HANDRAIL 1.5" X 12.1"	5
6	S001	18-8 Stainless Steel, Number 0 Size, 5/8" Long	15
7	S002	Medium-Strength, 3/8"-16 Thread Size, 3-1/2" Long	19

SIZE	DWG. NO.	REV
A	Railing final assembly	
SCALE: 1:20	WEIGHT:	SHEET 1 OF 2


36.00
.06
12.10
4.00
34.00
30.84
2.00
13.50
TRUE R.50
39.85
2.00
4.00
.06
.75
SIZE
A
DWG. NO.
Railing Module
REV
SCALE: 1:24
WEIGHT:
SHEET 2 OF 2

4.2 PARTS LIST

Table 9 – Initial Parts List

ITEM NO.	PART NO.	DESCRIPTION	QTY.	QTY/assembly	VENDOR	VENDOR NO.	PRICE/QTY	COST FOR MODULE	COST FOR ASSEMBLY
1	W001	2"x4"x8' PINE 13.5"L	1	5	HOME DEPOT	161640	$0.32	$0.32	$1.60
2	W002	2"x4"x8' PINE 5.5"L	1	5	HOME DEPOT	161640	$0.32	$0.32	$1.60
3	W003	2"x4"x8' PINE 34"L	1	5	HOME DEPOT	161640	$0.32	$0.32	$1.60
4	L001	ANGLE IRON 3/4" X 3/4" 30"L	1	5	HOME DEPOT	800897	$1.66	$1.66	$8.30
5	R001	HANDRAIL 1.5" X 12.1"	1	5	HOME DEPOT	10000734	$1.67	$1.67	$8.35
						RAW MTRL. TOTAL=		$4.29	$21.45

ITEM NO.	PART NO.	DESCRIPTION	QTY.	QTY/assembly	VENDOR	VENDOR NO.	PRICE/QTY	COST FOR MODULE	COST FOR ASSEMBLY
6	S001	18-8 Stainless Steel, Number 0 Size, 5/8" Long	3	30	McMastercar r	92470A041	$0.15	$0.45	$4.50
7	S002	Medium-Strength, 3/8"-16 Thread Size, 3-1/2" Long	3	19	McMastercar r	90185A638	$0.65	$1.94	$12.26
						HARDWARE TOTAL=		$2.39	$16.76

4.3 DESCRIPTION OF THE DESIGN RATIONALE

The overall shape of the product was designed to be modular, so that it could fit to any number of stairs. Also, with minor adjustments to the 2x4 members, the device could be adjusted to fit any tread or riser dimensions. The length and height of the base were estimated in accordance with IBC code requirements for a tread length of 12" with a 1.5" extension for the nosing, and a riser height of 7".

1. 2x4 Tread Base: This component was chosen for low cost, high availability, and ease of manufacturing. The strength of the material was deemed sufficient to withstand any loads applied. The length of the base was selected to stretch the length of the tread and extend to the riser of the next module.

2. 2x4 Riser: Chosen for the same rational as 1. 2x4 Tread Base. The height was selected to extend between modules. The placement on 1. was designed to avoid any nosing on the stairs.

3. 2x4 Baluster: Chosen for the same rational as 1. 2x4 Tread Base. The height was selected to extend 34" from the tread. The placement on 1. was designed to center the load on the base. The angle of the cut at the top of the baluster is 38.29 degrees, this was done to have continuous flow of the railing as required by code.

4. Angle Support: 3/4" x 3/4" x 1/16" angle iron was chosen for the support to prevent the assembly from tipping. The code standard was that the structure must resist 200 lbs. of force applied at the handrail in both the vertical and horizontal direction. This created a significant moment (600 ft lbs.) at the base of the Movable Railing where it sits on the stairs. In order to balance this moment, it was necessary to have a long structure that would stretch across the stairs. Angle was chosen because it can sit at the base of the riser at the connection to the tread without creating a trip hazard. Plywood that would cover the stair treads was also considered but was deemed less desirable due to aesthetics and weight. Calculations will be needed to determine the best material for the angle.

5. Handrail: Wooden pine handrail 2X4 with .5 fillet radius on the sides, with flat bottom and 12.1 inches in length was chosen to provide a secure handhold. The wood will provide strength and allow it to be easily combined with other modules. Each railing will line up with each module and therefore create a seamless railing.

6. Screws 5/8": These screws connect the angle iron to the base. Three screws are equally spaced in the center of the leg on the tread. The length was chosen to avoid penetrating the top of the base. The quantity was chosen to resist the moment arm shearing out the screws from the wood.

7. Bolts: Chosen for strength and ease of use. The length of the bolt was chosen to give adequate penetration into its connecting member. All the bolts are the same for ease of assembly and lower inventory/cost needed to build the product.

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 Signed engineering analysis contract

MEMS 411 / JME 4110
MECHANICAL ENGINEERING DESIGN PROJECT
ANALYSIS TASKS AGREEMENT
PROJECT: One-Knee Stair Negotiator NAMES: Naomi Marciante NM
Seth Trevino ST INSTRUCTOR: Dr. Jakiela

The following engineering analysis tasks will be performed:

Analysis before prototype:

1. Bending on Angle Support:
   Calculated by hand using maximum loading conditions of 200 lbs on the rail in the vertical and horizontal position.

2. Slipping vs. Bending
   Calculated by hand using maximum loading conditions, assumed coefficients of friction, and estimated weight.

Analysis after prototype:

1. Slipping vs. Bending on finished wood, carpet, and aluminum stairs to confirm coefficient of friction is adequate to prevent sliding.
   Push/pulling in multiple axes and on the listed surfaces to determine if sliding occurs.

2. Reducing overall weight.
   Calculations of strength for heavy components to determine if lighter materials can be used.

The work was divided among the group members in the following way:

All tasks are discussed every week and are distributed to individuals based on time and skills.

Seth:

- Responsible for weight load calculations.
- Responsible for reviewing bending and slipping calculations.
- Responsible for testing actual model for slipping vs. bending with Naomi.

Naomi:

- Responsible for bending and slipping calculations..
- Responsible for testing actual model for slipping vs. bending with Seth.

Instructor Signature: ____________ Print Instructor Name: JAKIELA.

(Group members should initial near their names above.)

5.2 ENGINEERING ANALYSIS RESULTS

5.2.1 Motivation

The analyses chosen for the project were selected to verify critical components of the design and to identify potential improvements. Commonly used building codes require a railing to be capable of withstanding a 200 lb. force applied at the handrail. This force creates a large moment arm acting on the Movable Railing. Bending calculations were made for the angle support. These were to verify the angle support was sufficient to resist the bending moment produced by weight applied to the top of the railing. In addition, the bending calculations were used to decide if any changes to material could reduce the cost or weight of the final design.

Tipping and sliding were also of concern but were more difficult to model because there were so many moving parts. A rigid body analysis would indicate a substantial force would be required to resist tipping and sliding. However, rigid body analysis was not valid for the structure, since each module was free to move somewhat independently of the others. The movement between the pieces would absorb some of the force. It was, therefore, determined to build a prototype and subject it to forces to determine the stability under load.

5.2.2 Summary statement of analysis done

All analyses were performed using the worst-case-scenario for the force applied to the handrail. Per code, the Movable Railing should be able to withstand a 200 lb. force applied to the handrail. The bending force was compared to the selected material for the angle support.

In addition, it was important that the module be as light as possible to reduce the hassle of installation. The materials were analyzed to ensure the module was light enough to be easily installed. The calculations and formulas used are summarized below.

5.2.3 Methodology

Calculations were performed using published engineering equations and mechanics of materials commonly accepted values. In addition, physical tests of the protype were performed.

Bending of Angle Support

Code requirements state that a handrail must resist a load of 200 lbs from any direction. The design of the Movable Railing included an angle support to go along the back of the tread and provide resistance to the moment created by this application of force. For the angle support to resist this moment, the bending stress needed to be less than the yield strength of the material. Figure 9 shows a simplified free body diagram of one module of the Movable Railing.

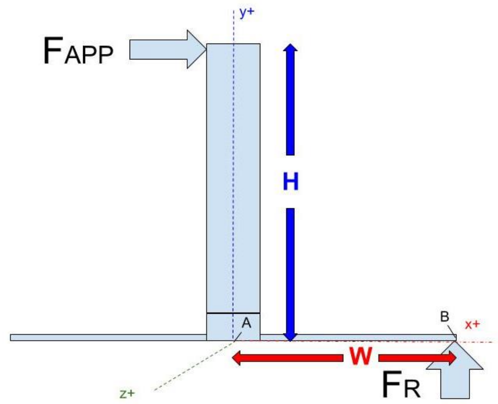


Figure 9 – Free Body Diagram – Movable Railing Module

The moment created by application of pressure at the top of the handrail was determined by the formula:

$$M_A = F_{app}(H) = 200\ lbs.(36\ in) = 7200\ in\ lbs. \quad (1)$$

where M_A is the moment produced at A, F_{app} is the force applied at the top of the handrail, and *h* is the height from the angle support. The counterforce moment needed to be equal to the moment at A. This resisting moment was produced by the tread resisting the angle at point B, and was determined from the formula:

$$M_B = F_R(W) = \ 7200\ in\ lbs., \quad (2)$$

where M_B is the moment produced at B, F_R is the resisting force, and *x* is the distance from the point of application to the end of the angle support. The Moment at B is resisted by all the angle supports in the structure. The free body diagram which shows the resistance provided by the entire assembly is represented in **Figure 10**.

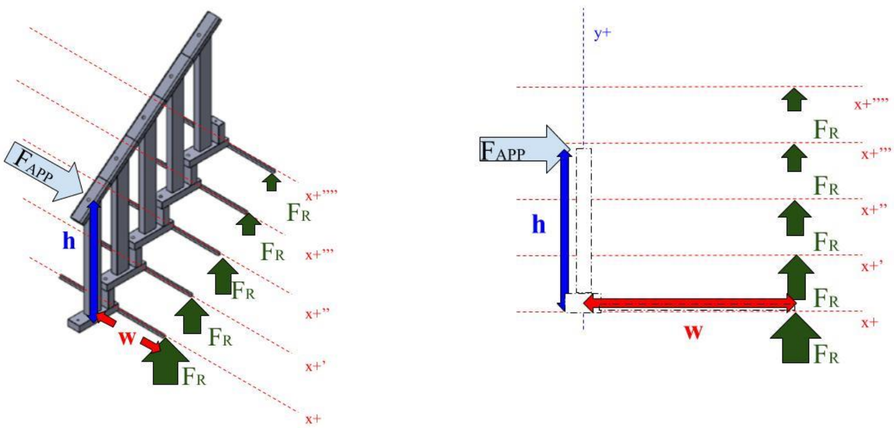


Figure 10 – Free Body Diagram – Movable Railing Assembly

Based upon the shared loading, the load for any individual angle support was less than the total load. It was estimated that, at worst case, any individual angle would not support more than 2/3 of the total load. The bending stress was calculated from the following formula:

$$\sigma_B = \frac{M}{S}, \quad S = \frac{c}{I_c}, \tag{3}$$

where σ_B is the allowable bending stress, M is the maximum moment, *S* is the Section Modulus, *c* is the distance from the neutral axis to the outside of the angle, and I_c is the Moment of Inertia for the angle support. The Section Modulus allows different sizes and shapes of materials to be easily compared. The above equation was rearranged to find the minimum Section Modulus required. The maximum allowable bending stress per angle support was determined by using 60% of the yield strength of the material and 2/3 of the total bending moment.

$$S_{min} = \frac{M_{max}}{\sigma_B} = \frac{\frac{2}{3} * 7200 \text{ in lbs}}{\sigma_Y * 0.6}, \tag{4}$$

where σ_Y is the yield strength of the material. This formula was used to determine the minimum section modulus for commonly used angle materials.

Two materials were considered for the angle support. Initially steel was chosen because it is strong and inexpensive. Aluminum was also considered because it is lighter than steel. Hot Rolled A-36 Steel Angle has a yield strength of 36,300 psi. 6063 Aluminum has a yield strength of 23,000 psi, and 6061 Aluminum has a yield strength of 40,000 psi. Taking 60% of these numbers for a safety factor, the minimum section modulus for each material is shown in Table 10:

Table 10 – Minimum Section Modulus

Material	Yield Strength (σ_Y)	Minimum Section Modulus (S_{min})
6061 Aluminum	40,000 psi	0.200 in^3
A-36 Steel	36,000 psi	0.222 in^3
6063 Aluminum	23,000 psi	0.347 in^3

An angle support, when viewed from the side, has the shape shown in Figure 11. The height of the angle is represented by *h*. The depth is represented by *d*. The thickness is designated *t*. The centroidal or neutral axis is shown by x_c and y_c.

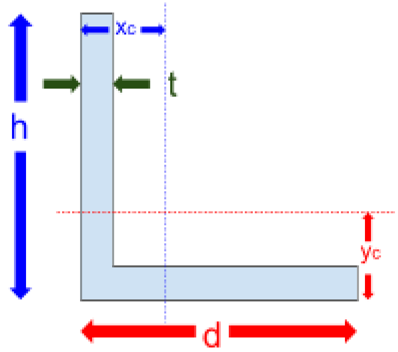


Figure 11 – Angle Shape Variables

The Second Moment of Inertia about the x-axis can be found using the parallel axis theorem. The formula is:

$$I_x = \frac{1}{3}[hd^3 - (h-t) * (h-t)^3] - A\,(h - y_c)^2, \tag{5}$$

$$y_c = (h^2 + bt - t^2)/(2(h + d - t)), \tag{6}$$

where I_x is the Second Moment of Inertia about the x-axis, h is the height of the angle, d is the depth of the angle, t is the thickness of the angle, and A is the area of the angle. For an angle shape, the Section Modulus can be found by dividing the Second Moment of Inertia about the x-axis by the distance from the centroid to the outside of the angle. The minimum section modulus for an angle is found by using the material farthest from the neutral axis, which is at the top of the angle (S_{Xtop}). However, there were several safety factors in the calculations, and the maximum load would be along the bottom of the angle support. Therefore, the maximum section modulus (S_{Xbot}) was used. This is found by using the material at the bottom of the angle, which is closer to the neutral axis. Therefore,

$$S_{Xbot} = I_x / y_c, \tag{7}$$

The section modulus was calculated for multiple angle measurements. The results are shown in Table 11.

Table 11 – Section Modulus of Different Angles

Angle	h [in]	b [in]	t [in]	I_x [in^4]	A [in^2]	y_c [in]	S_{xbot} [in^3]
3/4 x 3/4 x 1/8	0.750	0.750	0.125	0.009	0.172	0.233	0.037
1 x 1 x 1/8	2.000	0.750	0.125	0.136	0.328	0.777	0.175
2 x 1 x 1/8	**2.000**	**1.000**	**0.125**	**0.150**	**0.359**	**0.715**	**0.210**
2 x 1.25 x 1/8	2.000	1.250	0.125	0.163	0.391	0.663	0.245
2 x 1.5 x 1/8	2.000	1.500	0.125	0.173	0.422	0.618	0.280
2 x 2 x 1/8	2.000	2.000	0.125	0.190	0.484	0.546	0.348
3 x 3 x 1/8	3.000	3.000	0.125	0.661	0.734	0.797	0.830

The smallest angle that would support the load was 2x1x1/8 6061 Aluminum. Other options were 2x1.5x1/8 steel, or 2x2x1/8 6063 Aluminum.

Weight Reduction

In order to properly support the Movable Railing, the angle support needed to be at least 2x1x1/8 6061 Aluminum, 2x1.5x1/8 steel, or 2x2x1/8 6063 Aluminum and was to be 36 inches in length. The three materials are compared in Table 12.

Table 12 – Weight of Available Angle Sizes/Materials

Angle Size	Angle Material	Cross Sectional Area [in^2]	Density [lb/in^3]	Weight [lbs.]
2 x 1 x 1/8	**6061 Aluminum**	**0.359**	**0.098**	**1.26**
2 x 1.5 x 1/8	A-36 Steel	0.422	0.280	4.25
2 x 2 x 1/8	6063 Aluminum	0.484	0.098	1.70

For the minimum cross section of a given material, the 2x1x1/8 6061 Aluminum was the lightest.

Tipping and Slipping

Tipping and sliding were also of concern but were more difficult to model because there were so many moving parts. A rigid body analysis would indicate a substantial force would be required to resist tipping and sliding. However, rigid body analysis was not valid for the structure, since each module was free to move somewhat independently of the others. The movement between the pieces would absorb some of the force. It was, therefore, determined to build a prototype and subject it to forces to determine the stability under load.

5.2.4 Results

The calculations indicated that the 3/4x3/4x1/8 angle support was not strong enough to the applied force. This result was surprising, but it was verified by using smaller angles on the prototype, which yielded to the stress of bending. The bending moment was significant due to the long moment arm. The decision was made to change the size of the angle to give it more resistance to bending. In addition, the material was changed to make the angle support as small and light as possible.

In order to properly support the Movable Railing, the angle support needed to be 2x1x1/8 6061 Aluminum, 2x1.5x1/8 steel, or 2x2x1/8 6063 Aluminum. The materials were compared and the 2x1x1/8 6061 Aluminum had the least weight.

The prototype was assembled and subjected to loads to test for tipping or slipping. It was determined that the Movable Railing was very secure for loads directed straight down. However, the Movable Railing would slide if the load was at more than a 45-degree angle.

5.2.5 Significance

Several modifications of the original design were made because of the engineering analysis.

The angle support was not strong enough to resist the bending moments. A larger cross section was required. However, it was important that the weight of the module be low because it would be easier to install and store when not in use.

After a review of available materials, the angle support was changed from 3/4x3/4x1/8 steel to 2x1x1/8 6061 Aluminum. The 6061 Aluminum had the lowest weight in the size required.

The testing of the prototype showed that the assembly would slip if force was applied to the handrail at greater than a 45-degree angle. To provide more resistance to slipping, it was decided to coat the bottom of the module with slip resistant material. This change also reduced the likelihood that the angle support would scratch any hard surfaces.

6 RISK ASSESSMENT

* For context review source: http://www.mitre.org/publications/systems-engineering-guide/acquisition-systems-engineering/risk-management

6.1 RISK IDENTIFICATION

Risk is expected in three specific areas. The first is in standards and codes that are mentioned later on in section 7 will needed to be met and certified before our apparatus can be sold universally. The second risk is that while we have to match standards and codes for our apparatus and we will try our best to match the most prevalent variations of stairs cases home owners may not meet those requirements. The third risk involves providing proper safety instructions in how to use the apparatus and install the apparatus. The following are shown clearly below:

- Codes and standards.
- Universal usage.
- Safety and installment.

6.2 RISK ANALYSIS

6.2.1 Codes and standards

We believe that this will be the most probable high risk we will have in developing out product. In the end it will require showings and conversations with standard developers to come to a common ground that works for everyone.

6.2.2 Universal usage

We hope to accommodate everyone by meeting the most common variations of stairs and will offer possible specialty ones for individuals that request custom designs. We determine this to be a low impact concern.

6.2.3 Safety and installment

We will solve this one with a videos and instructions. Another possibility is to have doctors know about our products and help properly recommend how to use it for instructions and to their clients.

6.3 RISK PRIORITIZATION

6.3.1 Priority is safety

We mainly focused on safety. We made sure that the product would not collapse on the user. This involved some man handling and exploiting points of concern. We made modifications to prevent tipping and flipping.

6.3.2 Codes

We spent some time adhering to the codes that have been created in regards to stairs. This included proper height for the railing, proper tread lengths. We also made sure that our railing was continuous and able withstand the proper forces.

7 CODES AND STANDARDS

7.1 IDENTIFICATION

Building codes were explored to confirm the Moving Railing would conform to their recommendations. Codes frequently use the following terms to describe parts of a staircase. The tread is the horizontal part of the stair on which the user steps. The nosing is the portion of the tread that extends past the riser. The riser is the upright portion of the stair, which determines the height between the steps. The headroom is the distance between the top of the stair tread and the bottom of the ceiling. The landings are the areas at the top and bottom of the stairs. Bannisters are handrails along the sides of stairs or the edge of a landing. A newel post is a vertical post at the end of a bannister. Balusters are the vertical supports between the guardrail or handrail and the tread.

The International Building Code (IBC), Residential Building Code (IRC), and Americans with Disabilities Act Standards for Accessible Design (ADASAD), and Code of Federal Regulations Title 29 (OSHA) all have information on stair construction. These documents are frequently used as guidelines for local code. The recommendations for stairs are summarized below.

The following recommendations were common in the IBC, IRC, and ADASAD.

- Treads should be equal in length (within 3/8" tolerance).
- Risers should be equal in height (within 3/8" tolerance)
- Handrail assemblies and guards must be able to resist a single concentrated load of 200 pounds applied in any direction at any point along the top.
- Handrails must be between 34 - 38 inches above the stair nosing.
- Handrails can be circular or oval with 1-1/4 to 2 inch in diameter, or rectangular with a perimeter between 4 and 6-1/4 inches with a 2-1/4 inch cross-section and 1/8" minimum radius at the edges.
- Handrails should be continuous and easy to grip.
- Handrails adjacent to a wall should have a 1-1/2 inch clearance from the wall.
- Handrails along a wall should project no more than 4.5 inches into the stairwell.

The International Building Code (IBC) has the following additional guidelines:

- The tread must be 10 to 11 inches in depth.
- A nosing must be provided for stairs depth of less than 11 inches must be at least 3/4 inches and no more than 1-1/4 inches.
- The riser should be no more than 7-3/4 inches.
- Open risers are permitted.
- Handrail extensions of 12 inches are required at the bottom and top of the stairs.
- The ends of handrails should return to a wall or guard.

The International Residential Building Code (IRC) has slightly different guidelines:

- The tread must be at least 10 inches in depth.
- A nosing must be provided for stairs with solid risers and must be at least 3/4 inches and no more than 1-1/4 inches. A nosing is not required if the tread depth is more than 11 inches.
- The riser should be no more than 7-3/4 inches.
- Open risers are permitted.
- Handrail extensions at the bottom and top of the stairs are not required.

- Handrails must be provided on one side of stairs.
- The ends of handrails should return to a newel post or safety terminal.

ADA requirements also differ slightly from the IBC and IRC as follows:

- The tread must be a minimum of 11 inches in depth.
- Curved or beveled nosing should not extend more than 1-1/2 inches from the riser.
- The riser should be between 4 and 7-3/4 inches.
- Open risers are not permitted.
- Handrails must be less than 38 inches above the stair nosing.
- Handrails must be provided on both sides of stairs.
- Handrail extensions of 12 inches are required at the bottom and top of the stairs.
- The ends of handrails should return to a wall or guard.
- A center handrail is not required and does not have to comply with the guidelines for handrails.

OSHA regulations also have the following stipulations:

- The tread must be between 10 and 14 inches in depth.
- The riser should be between 6 and 7-1/2 inches.
- Handrails should be between 30 to 37 inches from the front of the tread.
- Non-permanent handrails need a minimum clearance of 3 inches between the handrail and walls or other objects.

7.2 JUSTIFICATION

The codes were chosen because they are the most widely used requirements for building construction. Although local codes may vary, they normally rely on the guidance of well-known publications. By surveying the most commonly used references and complying with their recommendations, the Movable Railing should be compliant with most local codes.

7.3 DESIGN CONSTRAINTS

The functional constraints were related to the shape and structure of staircases. The building codes reshaped the design to improve adjustability for different types of stairs. They also restricted the materials and shape for the design to comply with the requirements for handrail height. The handrail shape was changed due to code requirements. The safety design constraints were related to the requirement of resisting a 200 lb. load applied at the top of the handrail. This constraint restricted the material, shape, and length of the support that runs along the base of the tread.

7.3.1 Functional

The permissible riser and tread length vary between publications. Also, the allowed height of the handrails is different from the different references. Table 13 summarizes the recommendations.

Table 13 – Summary of Code Requirements for Stairs

	IBC	IRC	ADASAD	OSHA
Tread Depth	10 to 11 inches	At least 10 inches	At least 11 inches	10 to 14 inches
Riser Height	At most 7-3/4 inches	At most 7-3/4 inches	4 to 7-3/4 inches	6 to 7-1/2 inches
Handrail Height above Tread	34 to 38 inches	34 to 38 inches	Less than 38 inches	30 to 37 inches

The different tread depths and riser heights permitted mean that the design must be adjustable to fit many different sized staircases.

The handrail height requirements can all be met if the height of the handrail is between 34 and 37 inches above the front of the tread.

In addition, the requirements for handrail shape will influence the design. Handrails can be circular or oval with 1-1/4 to 2 inch in diameter, or rectangular with a perimeter between 4 and 6-1/4 inches with a 2-1/4 inch cross-section and 1/8" minimum radius at the edges.

7.3.2 Safety

The safety of handrails is determined by the ability to withstand a force of 200 lbs. at the top of the railing in any direction. This is a fundamental requirement of the design and determines the length and material of the angle support. In addition, the fasteners and material of the supports must be able to withstand 200 lbs of force.

7.4 SIGNIFICANCE

The wide variety of tread depths and riser heights that are allowed make adjustability important. Although the modular design permits adjustability for the number of stairs, the bolt design only allows one tread depth. The original design idea was to give inserts to adjust the riser height above a baseline. Incorporating adjustable depth and height by means of pegs or toggle bolts will solve this problem. This will modify the final design to include holes for adjustment and a means of attaching the modules. However, the modules must maintain a height of 34 to 37 inches above the tread for the handrail. This will restrict the adjustability of the modules.

The requirements for handrail shape required a modification of the initial design for the railing. Using a 2x4 will not meet the requirements because it is too large. A new handrail size and or shape will have to be used.

The safety of handrails is determined by the ability to withstand a force of 200 lbs. at the top of the railing in any direction. This is a fundamental requirement of the design and determines the length and material of the angle support. The length of the angle support should be as short as possible because it will limit the amount the Movable Railing may shift horizontally within the stairwell. A high level of adjustability will allow the railing to be positioned to reduce effort for the individual user. If the Moveable Handrail can be placed near the body, the amount of effort needed to lift up is reduced. The angle support may need to change to a tube support for better resistance to bending and torsion. Also, the materials used may be limited by this requirement, which will impact the overall weight.

8 WORKING PROTOTYPE

8.1 PROTOTYPE PHOTOS

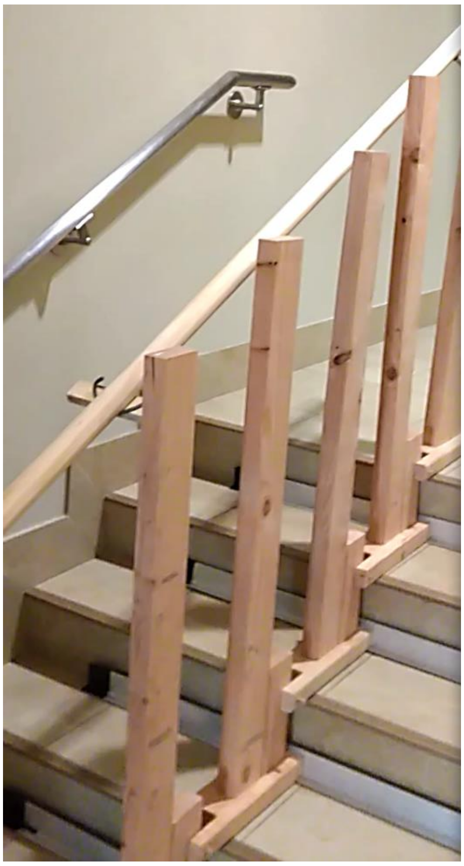


Figure 12 – The Movable Railing Side View

The Movable Railing is designed to assist a person who can only put weight on one leg. The Movable Railing provides a second rail to make climbing and descending stairs easy and safe without using the affected leg. The Movable Railing is placed near the user's body, decreasing the strength needed to lift-up and lower-down the body while negotiating stairs, because both arms can be used. Ideally, the user will have the upper body strength to take all the weight off the leg that is causing pain. If the user does not have adequate body strength to take all the weight off the leg that is causing pain, the Movable Railing can still be used to reduce the weight on the affected leg. In addition, having both sides supported by railing can help for those who are having balance issues when going up and down stairs.

Figure 13 – The Movable Railing End View

The Movable Railing takes up very little room in the stairwell and can be moved from side to side to accommodate different shoulder widths.

8.2 WORKING PROTOTYPE VIDEO

The primary performance measure was the reduction in weight on the affected leg.

A video showing our final working prototype can be seen at:

https://youtu.be/GYbcDYPNii4 and https://youtu.be/nQYCRS2-w6g

As it demonstrates, the affected leg, whether right or left, can be completely relieved of weight while traversing the stairs.

8.3 PROTOTYPE COMPONENTS

Figure 14 – Tread Base

The tread base goes along the tread of the stairs to connect the modules. The dowel holes at the right of the picture will be used to connect the tread base to the riser, shown in Figure 15.

Figure 15 – Riser

The riser is used to adjust the module to the height of the stairs. Additional holes for dowel pins can be added for multiple riser heights. Also, by adding holes from the front to back of the riser, the tread length can be adjusted.

Figure 16 – Baluster

The baluster provides support for the handrail.

Figure 17 – Angle Support

The angle support gives side-to-side stability to the Movable Railing, which is not affixed to the stairs by bolts, screws, or other fasteners.

Figure 18 – Dowel Assembly

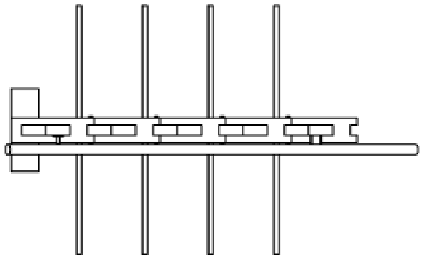
The dowel assembly allows the Modular Railing to be assembled without complicated tools. With a simple insertion of the dowel pin, the modules are joined together. Each module weights less than 10 lbs. which makes installation quick and easy.

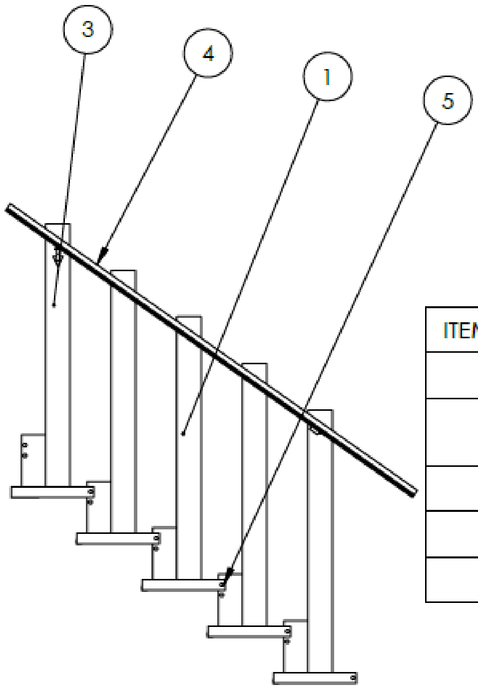
9 DESIGN DOCUMENTATION

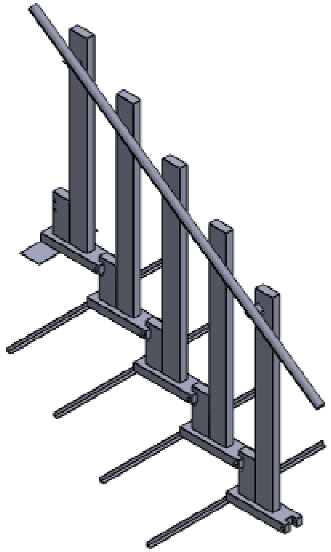
9.1 FINAL DRAWINGS AND DOCUMENTATION

9.1.1 Engineering Drawings

See Appendix C for the individual CAD models.







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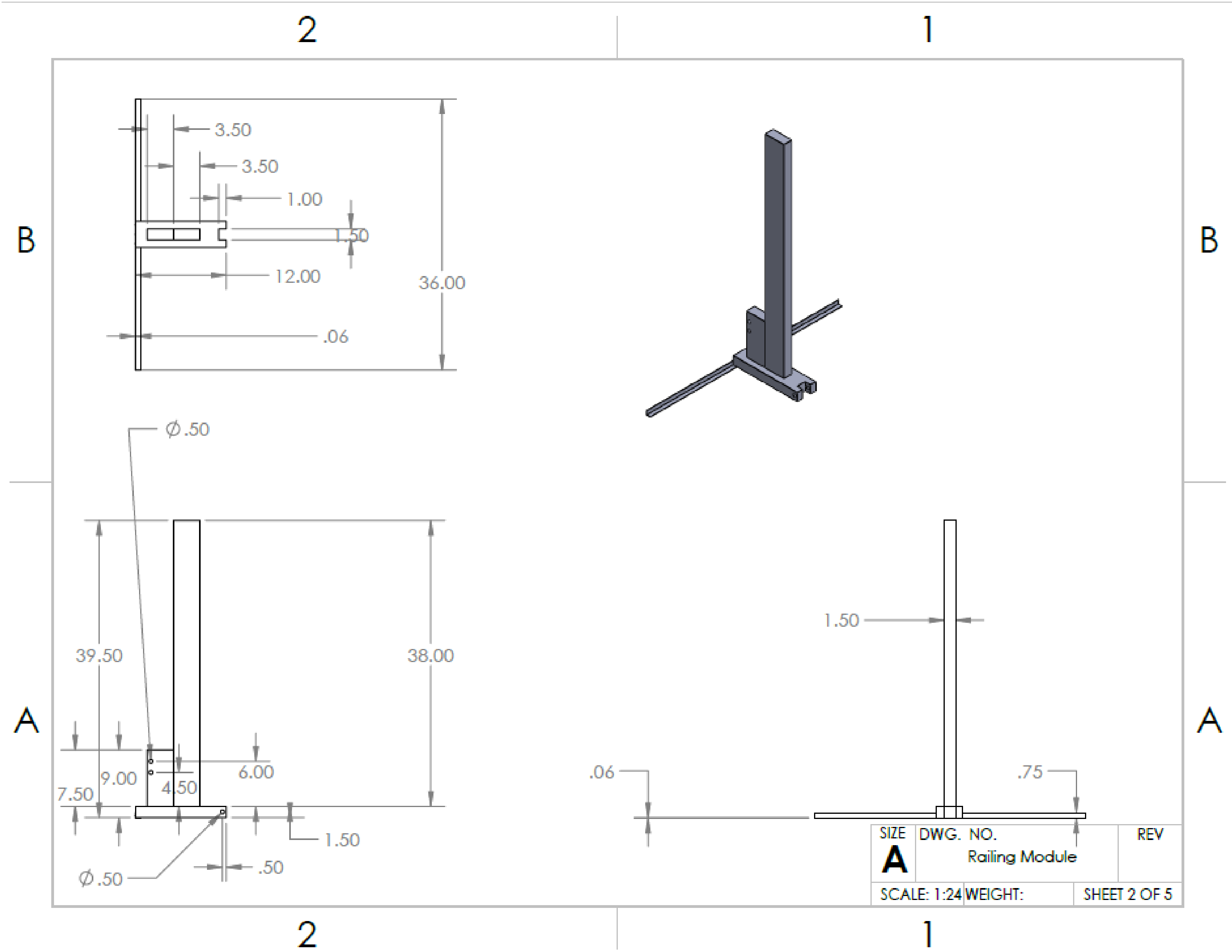
1	Railing module		3
2	Railing module bottom		1
3	Railing module top		1
4	Railing final		1
5	Dowel pin final		4

SIZE	DWG. NO.	REV
A	Railing final assembly	
SCALE: 1:20	WEIGHT:	SHEET 1 OF 5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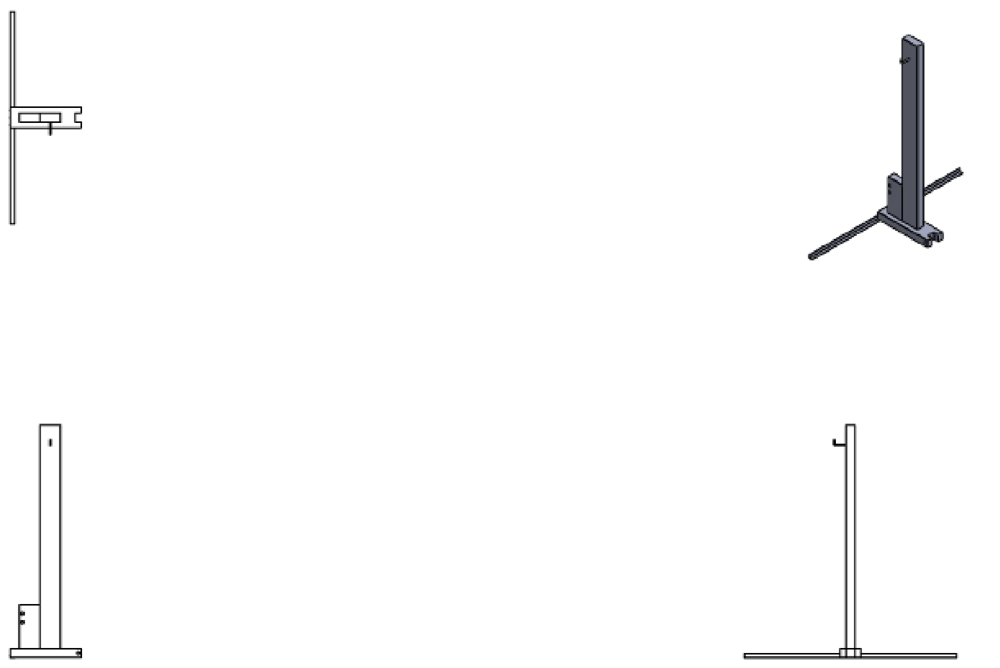

A A

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

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MFG APPR.		
Q.A.		

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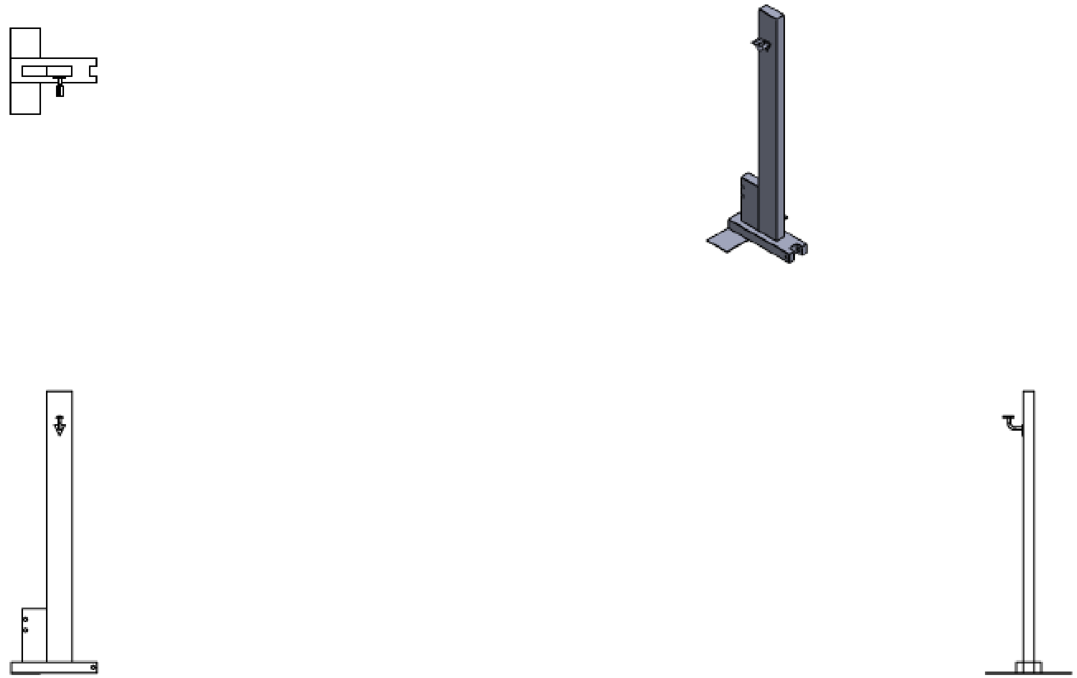

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TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

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MATERIAL

FINISH

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MFG APPR.		
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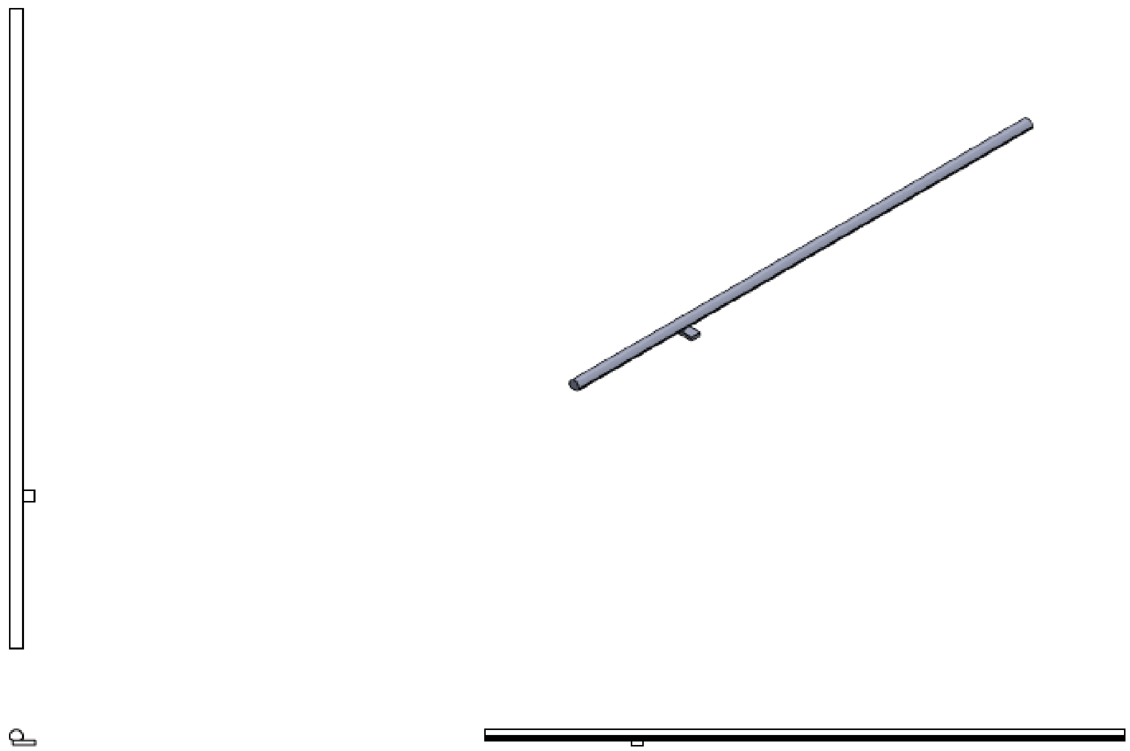

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NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	Railing	

SCALE: 1:16 WEIGHT: SHEET 5 OF 5

9.1.2 Sourcing instructions

Refer to Appendix B, utilizing the columns labeled "SOURCE" and "VENDOR PART NO." for sourcing information.

9.2 FINAL PRESENTATION

A video displaying our final presentation can be viewed at:

Multiple user Presentation:

https://www.youtube.com/watch?v=MZMMRAbqfD4

Assembly Presentation:

https://www.youtube.com/watch?v=7HYea_kK30c

Power Point Presentation:

https://youtu.be/6_xdC8Kd8b0

10 TEARDOWN

TEARDOWN TASKS AGREEMENT

PROJECT: One Knee Stair Negotiator NAMES: Seth Trevino INSTRUCTOR: Jakiela
Naomi Marciante

The following teardown/cleanup tasks will be performed:

The modules will be disassembled into their component parts and the materials will be placed in the appropriate section of Jolly's workroom to be available for future projects.

Instructor comments on completion of teardown/cleanup tasks:

OK. INCREASE ORGANIZATION OF PARTS STORAGE

Instructor signature: [signature] Print instructor name: JAKIELA

Date: 8/10/19

11 APPENDIX A - PARTS LIST

* This is an initial list of parts for the cost of raw materials, components, assemblies etc.

Table 14 – Final Parts List

ITEM	PART NO.	DESCRIPTION	QTY
1	RAILING MODULE		3
2	RAILING MODULE BOTTOM		1
3	RAILING MODULE TOP		1
4	RAILING FINAL		1
5	DOWEL PIN FINAL		4

12 APPENDIX B - BILL OF MATERIALS

Table 15 – Final BOM with Sourcing Information

MATERIAL DESCRIPTION	SOURCE	VENDOR PART NO.	QTY	PRICE/UNIT	EXTENDED PRICE
2"X4"X8' PINE	HOME DEPOT	161640	4	$2.52	$10.08
2"X1"X0.125"x36" 6061-T6 ALUMINUM ANGLE	SPEEDYMETALS.COM	61a.125x1-36	4	$9.07	$36.28
3/8" X 48" WOOD ROUND DOWEL	HOME DEPOT	204354371	1	$0.98	$0.98
HANDRAIL 1.5" X 13.5" X 60"	HOME DEPOT	10000734	1	$10.02	$10.02
HANDRAIL BRACKET	HOME DEPOT	15101	1	$2.98	$2.98
SPAX #6 x 5/8"	HOME DEPOT	4101010350161	1	$2.17	$2.17
SPAX #10 x 3-1/2"	HOME DEPOT	4191670500906	1	$10.39	$10.39
				TOTAL	$72.90

13 APPENDIX C – COMPLETE LIST OF ENGINEERING DRAWINGS

A complete set of Solidworks part, assembly and drawing files can be found as a link at the bottom of the open scholarship web page or at the following link:

Seth and Naomi models.zip

14 APPENDIX D - PROJECT MANAGEMENT AND COLLABORATION

14.1 PRELIMINARY: TEAM ORGANIZATION

1. Write a group summary explaining how you ended up on the same team.

We ended up on the same team by luck. We were both looking for a teammate and asked the same third person who already had a team. . We officially met for the first time on Thursday after the first class.

2. Write a group summary explaining how you made your project picks

Our project pics were made by Naomi, since Seth was not able to attend the first class. Naomi made a list of potential projects, and when selected in the lottery chose the one at the top of the list that wasn't already selected. The first choice would have been the smoothie stirrer, second choice was the shower car wash blower.

The one leg stair extender was my third choice, but we are both excited about the project. It was selected because it was interesting and beneficial. I liked the idea of overcoming a problem that is widespread and doesn't have a good current solution. The videos demonstrated ideas of using pulley or gear systems. It looked like building a prototype was possible. It was interesting to me because many of my family members have struggled with limited mobility, whether due to illness, surgery, or injury. The idea of helping them move safely and painlessly was appealing.

3. If your group does not have three (3) people, justify why not.

Seth and Naomi asked many different people if they wanted to form a group, but they had already committed to another group. During the class when teams were being chosen, Naomi looked around to see if there were any people who were still forming a group. However, everyone seemed to have a team already.

4. If you have already made plans re subdividing the work, please describe them.

Sub-dividing the work will be a collaborative process throughout the design. On the Thursday after class we met up at school and went over what happened in class and discussed our ideas for the project. We initially went through a few ideas what were the possibilities of the project. From there we created of list of details and ideas to help curtail our project into the direction we want to go into. At the end of the meeting we determined six things to look up to further our knowledge in the subject and split the work up evenly. We also determined how to split up the home work and scheduled a time to reconvene and see how well we are progressing. We will in the future probably continue to meet and discuss how we split the work over time and continue to create secondary meeting times as checkpoints to see that were are on task and making progress in a healthy way.

5. As a team, develop and write a project description.

To create a cheap, simple, discreet and comfortable means of easing the plight of those whose knees are or knee are failing them and preventing their access to higher planes of elevations. To solve this problem, we hope to either modify already currently existing stairs or more likely through personal equipment. We hope to help not only the aging community but also many people that have lost haves suffered other injuries whether they be permanent or short term.

14.2 BACKGROUND INFORMATION STUDY

1. List and explain any preliminary design decisions made even before doing the background information study.

Before doing the background study, we had an idea that we wanted something that would be portable, since the user will have trouble with stairs wherever they go. We also wanted to have something discreet so that it wouldn't draw unnecessary information to the user. Examples of our ideas were along the lines of crutches and peglegs.

2. Do you feel that there are any implied constraints limiting the scope of the design? Describe them.

The constraint of human power implies that a mechanical solution rather than an externally powered solution must be found. We assumed that any battery powered devices would be outside the defined scope. The scope is not hindered but it will be less effective than possible with external forces playing a role. In our mind the more manual the better but some small motors could take the edge of how bulky are design will be.

14.3 SPECIFICATION AND CONCEPTUAL DESIGN STUDY

1. Did you originally have more than 4 ideas?

We had many ideas (at least 12) that we considered during the brainstorming phase. After completing the interview, there was a slight change to our focus. Firstly, we changed our focus from a universally usable product to one that was more specific to our user's needs. Secondly, we re-examined our focus on having a wearable device, since the user is primarily having trouble negotiating one narrow, steep staircase.

2. How were some ideas ruled out? Are things unanimous?

We ruled out some ideas by picking the best of similar designs. We then rated each design using the happiness rating from the decision matrix. The table below shows each design, the criteria used, and the score of each design. The movable railing ranked highest in our criteria, and was chosen as the primary design. The stair walker was in second place and was developed in parallel but with far less focus.

Table 16 – Design Decision Table

	Happiness Rating	Easy to Fabricate	Not Patented	Low Risk	Score
Movable Railing	X	X	X	X	4
Stair Walker		X		X	2
Spring Stairs				X	1
Switch Leg					0

3. Describe briefly how work was partitioned according to the assignment subtasks.

Naomi and Seth both recorded their observations from the interview on a notes page. From the observations, Seth did a rough draft of his interpretation of the user needs. Naomi edited those needs and created the template for the decision matrix. Seth reviewed the decision matrix and approved it.

A brainstorming session on possible designs was completed before the interview. Both parties came up with 4 different design ideas that were different. Also, we collaborated on the interview questions based upon our initial research and design ideas.

After the interview, we re-evaluated our designs. Some of the designs were very similar, so we each developed alternate designs. We met after developing these designs independently and decided which designs to present to our sponsor. The final four designs were chosen and subjected to the design decision table in question 2.

Naomi adapted the interview questions to the template and did the tables for Assignment 3. Each person developed a final sketch of their designs and did the happiness decision matrix for each. Seth described each of the four options and completed the rationale for choosing the final design.

14.4 EMBODIMENT AND FABRICATION PLAN

1. Explain clearly how the work was subdivided

The work was subdivided according to ability. Seth had more experience with Solidworks, so he did the drawings. Naomi did the bill of materials. There were four areas of needed research identified during our weekly group meeting, and these were divided equally. Seth researched materials and the sliding mechanism for the stairs. Naomi researched making the stairs modular and keeping them from tipping.

In addition, Naomi contacted and met with a physical therapist at Washington University's Physical Therapy Office on Forest Park. She recorded the observations from the meeting and reported back to Seth.

2. Make the instructor a "go to" list: "If a problem here, go to . . . ."

Table 17 – Responsibility Matrix

Task	Responsible	Approval	Support
1- Project Selection	Naomi	-	-
1- Brainstorming	Seth	-	Naomi
1- HW Background Search Existing Product 1, Risk Assessment, Revised project description	Seth	-	-
1- HW Background Search Project description Existing Product 2, Codes and Standards	Naomi	-	-
2- Background Search Submitted	Naomi	-	-
3- Concept Design and Specification Draft 1 - 4 independent ideas	Naomi / Seth	-	-
3-User needs interview notes	Naomi / Seth	-	-
3-Happiness matrix categories	Seth	Naomi	-
3-Happiness matrix template	Naomi	Seth	-

3- Concept Design and Specification Draft 2 - 4 more independent ideas	Naomi / Seth	-	-
3- Concept Design - Choosing winning concept	Naomi / Seth	-	-
3- Draw Concepts 1-3 and do happiness matrix on each.	Seth	-	-
3-Draw Concept 4 and do happiness matrix	Naomi	-	-
3-Description of each concept, explanation of concept chosen and reasons, identification of primary metric for project.	Seth	Naomi	-
3- Concept Design Submitted	Seth	-	-
4- Embodiment and Fabrication Plan Research materials, sliding concept	Seth	-	Naomi
4-Research tipping and modular	Naomi	-	Seth
4-Embodyment Drawing	Seth	-	-
4- BOM and Justification of parts chosen	Naomi	Seth	-
4- Embodiment Plan Submitted	Seth	-	-
7- Parts Obtained	Seth/Naomi	-	-
5- Engineering Analysis Proposal Draft	Naomi	-	Seth
5- Engineering Analysis Tipping and Sliding	Naomi	-	Seth
5- Engineering Analysis Initial Prototype	Naomi	-	-
5- Engineering Analysis Weight Reduction	Seth	-	-
6- Codes and Standards Draft	Naomi	Seth	-
5- Engineering Analysis Calculations	Naomi/Seth	-	-
6- Codes and Standards Submitted	Naomi	-	-
5- Engineering Analysis Submitted	Naomi	-	-
8- Risk Assessment	Seth	-	-
7- Working Prototype Build	Naomi/Seth	-	-
7- Working Prototype Demo	Naomi/Seth	-	-
8- Final Drawings	Seth	-	-
9- Gannt Chart Complete	Naomi	-	-
9- Final Report Compiling Assignments into Final Document	Naomi	-	-
9-Final Report Completing Additional Sections	Seth	-	Naomi

9- Final Report Submitted	Naomi	-	-
10- Final Teardown	Naomi/Seth	-	-
10 - Final Teardown Submitted	Naomi	-	-

14.5 ENGINEERING ANALYSIS

1. Now that you can identify every part in the design, revise the go-to list.

See above.

2. Clearly explain if there is any work subdivision related to building testable early prototypes.

Naomi built some early prototypes to get an idea of the overall scale and to physically experiment with the angle support. A plastic angle was used to get a better idea of the forces to which the angle support would be subjected and the best way to model these forces. In addition, the fastening method for the angle was tested on these early partial builds.

Seth and Naomi reviewed the results of the early rough prototype to better envision the design and identify potential issues.

14.6 CODES AND STANDARDS

1. Describe if any conflicts arose, and how they were resolved.

Since Naomi had started looking at codes and standards during assignment 2, she took the lead on this assignment. Seth reviewed the writeup and didn't have any issues with it.

The conflicts identified were the restrictions on dimensions for the product to comply with code. The dimensions were adjusted to comply with code. In addition, the handrail was redesigned to allow a continuous run.

14.7 WORKING PROTOTYPE

1. Advise the instructor if you want another week to work on the prototype.

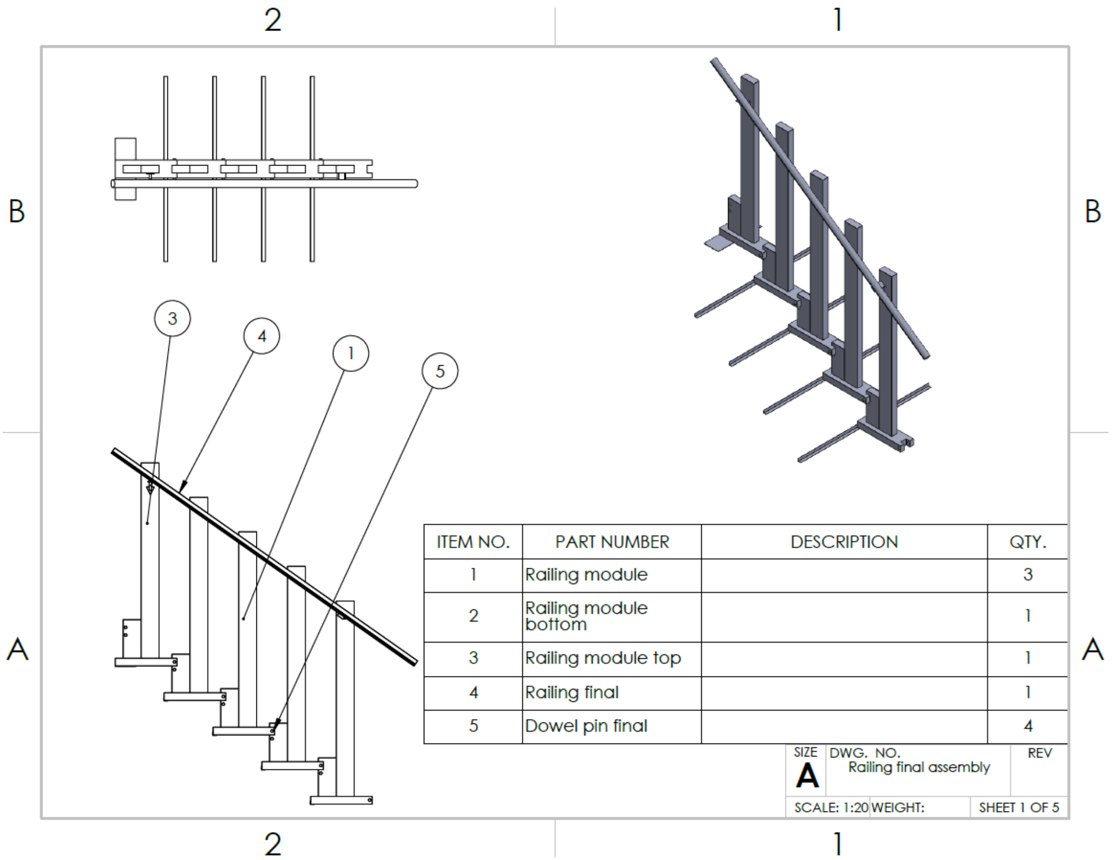
Not needed.

2. All team members should be responsible for building some hardware. Provide explanation and revise the go-to list.

Naomi prepared the angle and some preliminary wood components. Seth and Naomi met at Wash U and built the prototype together.

14.8 DOCUMENTATION

1. Remember that this is the main documentation that would allow someone else to build a version of your design.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
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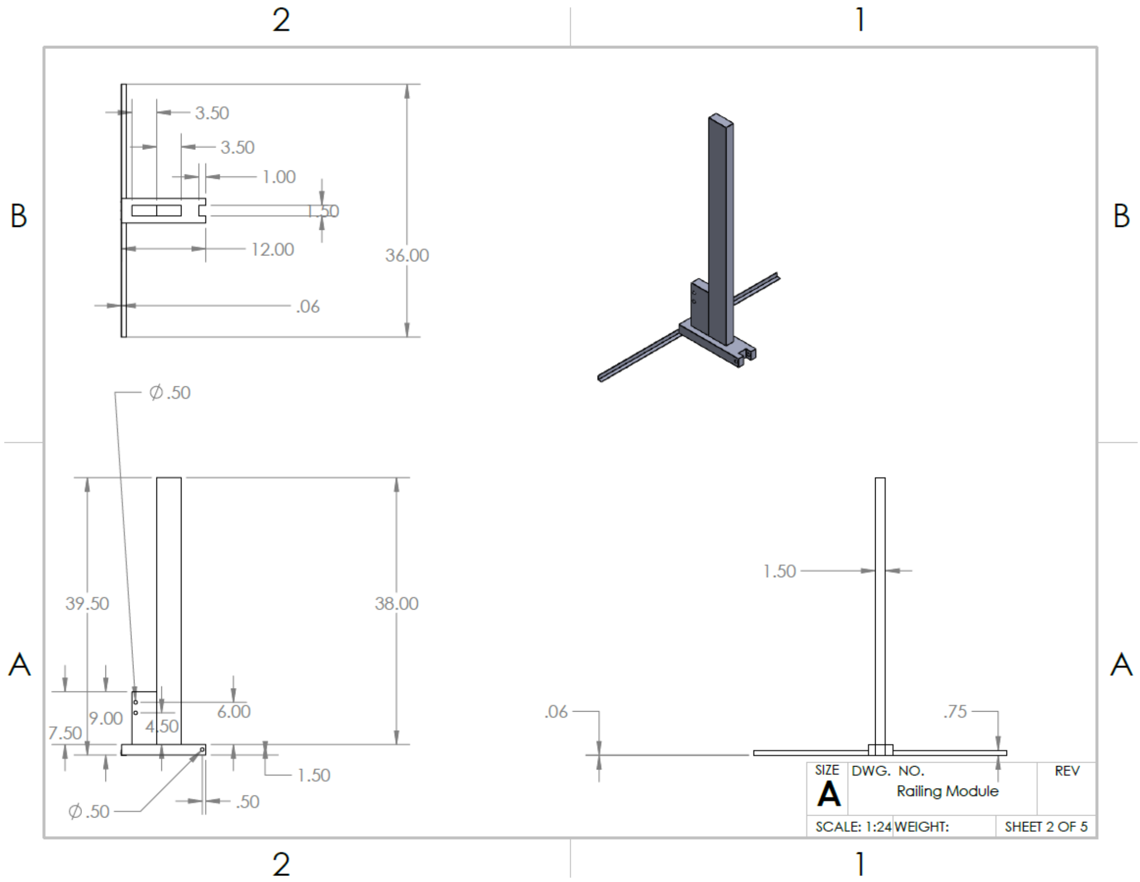
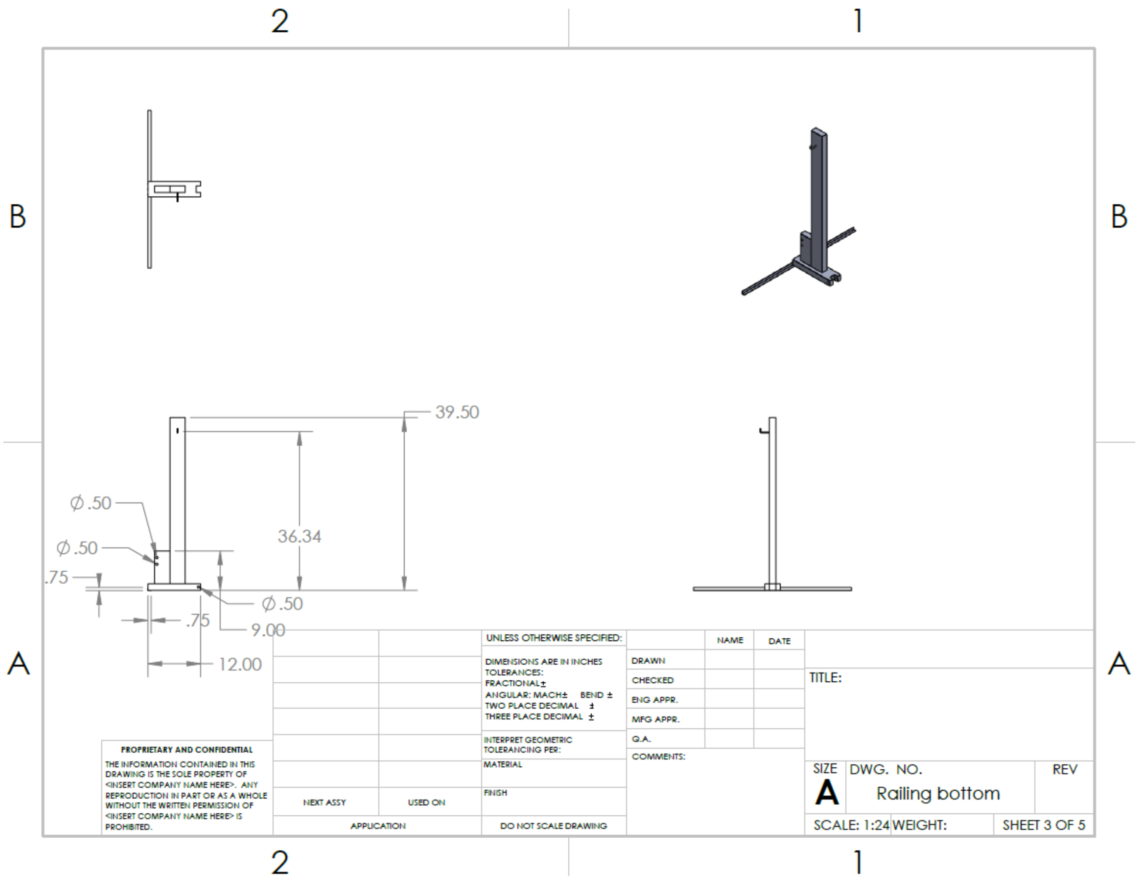
2	Railing module bottom		1
3	Railing module top		1
4	Railing final		1
5	Dowel pin final		4

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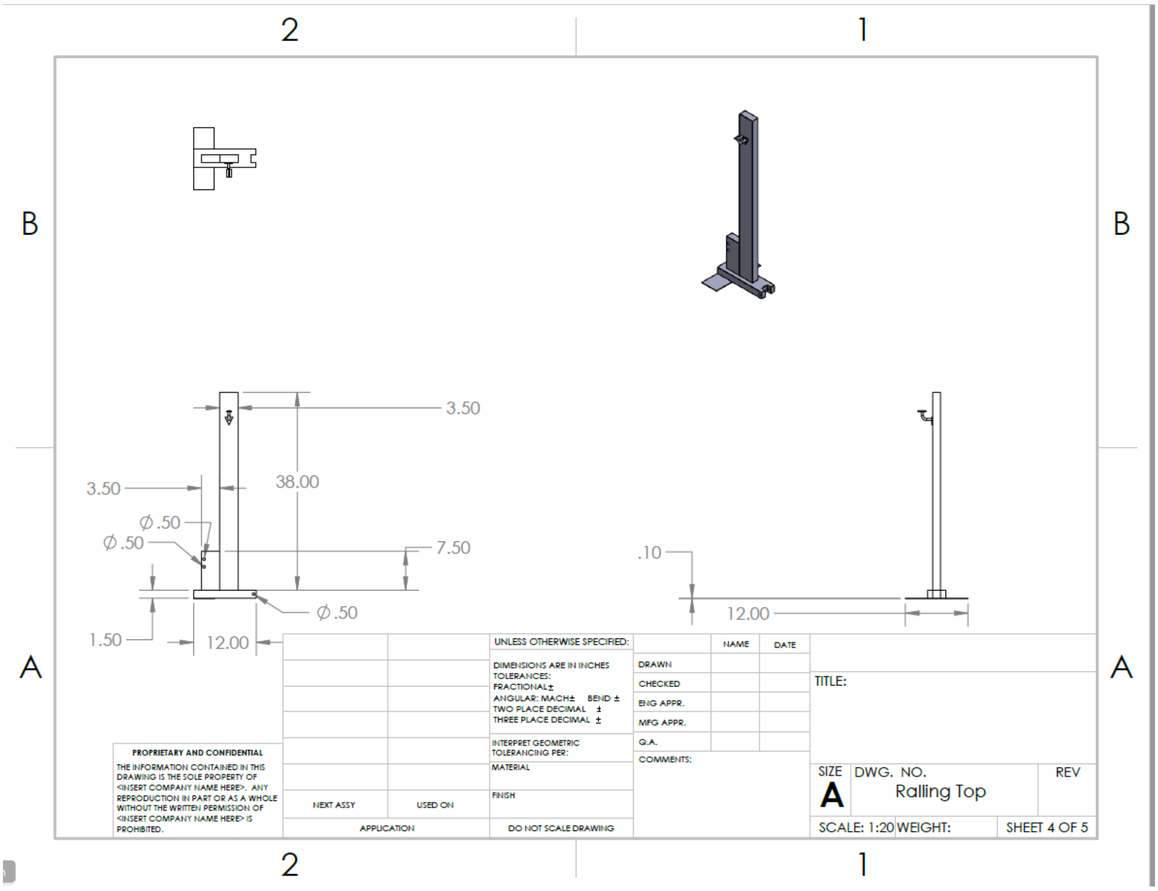
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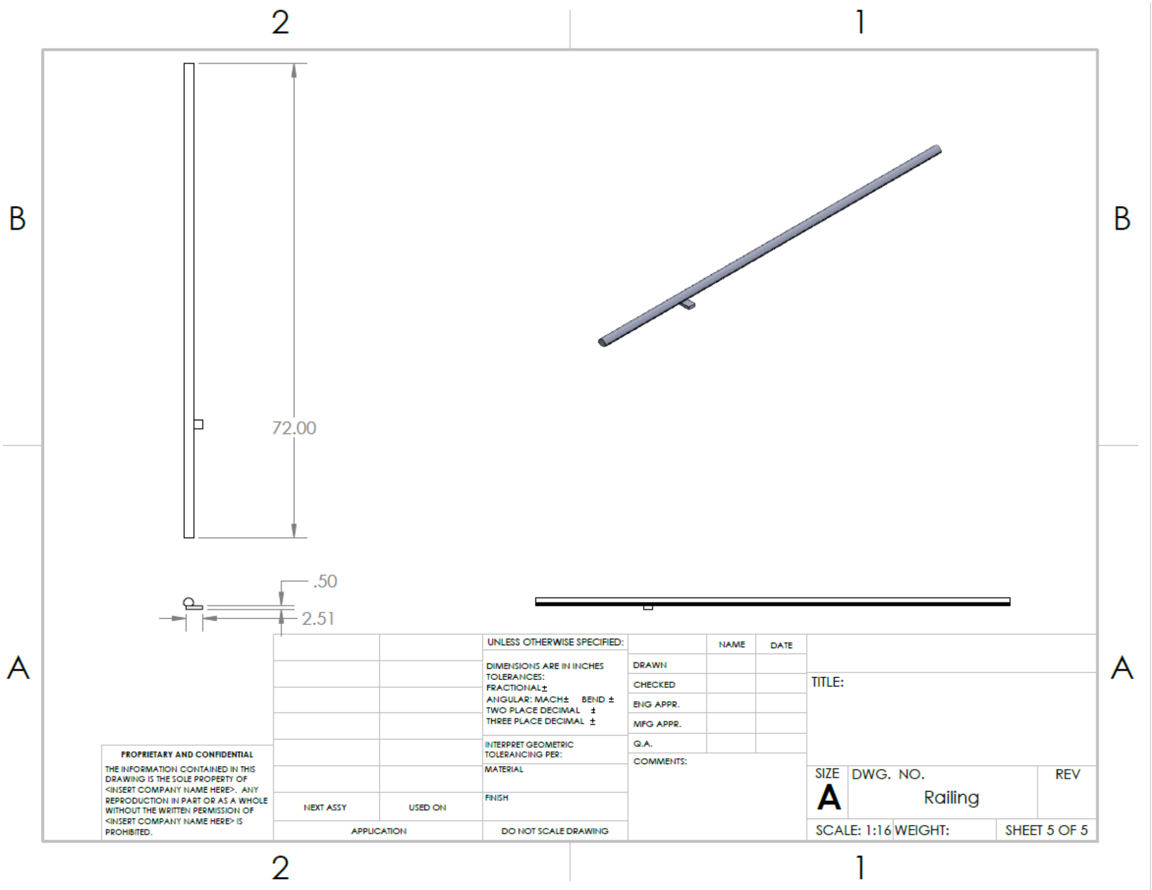

14.9 PUBLICATION

1. Try to get your report done as soon as possible to allow Lauren Todd time to review it.
2. Remember, your report will get downloaded around the world.

14.10 TEAR DOWN

1. You must contact the instructor if you want to keep the prototype.
2. If you don't keep your design, it will be absorbed back into the "morgue."

Done.

14.11 TEAM PERFORMANCE

1. Although this is extra credit, it is very important!
2. Also, please do not forget course evaluations.

Done.

15 ANNOTATED BIBLIOGRAPHY

21CFR890 Standard No. 3840, Food and Drug Administration, United States Government, 4/1/2018. Web. 4 August 2019. https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm?fr=890.3480

Although we did not finally go with a wearable device, this code provided guidance on registering such a device and complying with FDA regulations.

2012 International Building Code® - Section 1009 Stairways, International Code Council, Inc., 4051 West Flossmoor Road, Country Club Hills, IL 60478-5795, https://www.iccsafe.org/

2009 International Residential Building Code, International Code Council, Inc., 4051 West Flossmoor Road, Country Club Hills, IL 60478-5795, https://www.iccsafe.org/

2010 ADA Standards for Accessible Design - 504 Stairways, United States Department of Justice – Americans with Disabilities Act, 950 Pennsylvania Avenue, NW, Civil Rights Division, Disability Rights Section - NYA, Washington, D.C. 20530, https://www.ada.gov/regs2010/2010ADAStandards/2010ADAstandards.htm#c5

OSHA Regulation 29 CFR 1926.1052 Stairways, United States Department of Labor - Occupational Safety & Health Administration, 200 Constitution Ave NW, Washington, DC 20210, https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.1052

The International Building Code (IBC), Residential Building Code (IRC), and Americans with Disabilities Act Standards for Accessible Design (ADASAD), and Code of Federal Regulations Title 29 (OSHA) had information relating to the construction of staircases and handrails, which we applied to our design. Although there is no current regulation on movable or intermediary railing, we attempted to comply to the regulations as much as possible.

J. Harvath, "Physical Therapist Interview," 05-Jun-2019.

Jeff Harvath PT, DPT, COMT, Doctor of Physical Therapy and Certified Orthopedic Manual Therapist was interviewed. Dr. Harvath, is the Manager of the Division of Clinical Practice at Washington University School of Medicine. He provided critical insight into how patients with problems putting weight on one leg were treated.