Final Report
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EZ Sit

An ergonomic standing wheelchair with sitting and standing assistance

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Executive Summary

Our proposed product is the EZ Sit, an ergonomic standing wheelchair that provides passive support in the sitting and standing motions, to assist users suffering from injuries and physical ailments to more comfortably move around. Our inspiration for the design came from our experiences with our respective grandparents, most of whom rely on wheelchairs for mobility in their daily lives, yet struggle with continually deteriorating condition and ability to sit and stand unassisted.

Our grandparents are not alone. As of 2023, there are more than 65 million wheelchair users worldwide, according to the World Health Organization. Despite almost 1 in 10 people depending on wheelchairs for mobility, most commercial wheelchairs do not provide any sitting or standing assistance for users, confining them to the wheelchair as their physical condition deteriorates. This dependency on wheelchairs for mobility only exacerbates the issue, as prolonged sitting has been found to cause various health complications, such as osteoporosis, muscle atrophy, and cardiovascular conditions. That's not to mention the detriments to the mental health of users, who may suffer from insecurity and lack of social interactions due to the restraints of wheelchair dependency. Using a wheelchair should not be a death sentence.

Although there are standing and assistive wheelchairs available in the market, many of these range from several hundred to a few thousand dollars, which is a large investment for many people just looking for some small relief from the confines of their seats. These high end wheelchairs advertise their complex, proprietary technologies for assistive standing support as the reason for the absurd cost of their products, making these products inaccessible to populations that need accessible assistive technology.

Our solution to this issue, the EZ Sit, uses a simple design that allows for a transformable manual wheelchair, able to convert from a standing to a seated wheelchair, that is manipulated entirely by mechanical energy and a little bit of user input. We achieved this through first, creating a robust wheelchair design manufactured out of wood that is both durable and cost effective, with a seat that is capable of pivoting about its frame in order to extend to a vertically reclined chair or fold back into a regular seat. Instead of relying on motors or the user to manually manipulate the chair into these positions, we rely on high strength elastic bands strong enough to support the weight of the chair and a person in the standing wheelchair position. The user simply has to recline back on the chair while it is in the standing position, and the resistive force from the tensioned elastic bands provides a smooth descending motion into the seated position. The user can now manipulate it just like a standard manual wheelchair to move around. Whenever they want to stand back up, instead of struggling to support themselves up, if they apply just a slight amount of force to push themselves upwards, they will find themselves comfortably carried up into the standing position by the tensioned elastic bands, which provide a smooth transition upwards back into the standing position.

Our product is a truly innovative and cost effective approach to supporting and improving the well-being of wheelchair users, by giving them the option to move more freely and interact with the world as they please.

User Scenario

"*In standing you can get a real hug; you can look over a crowd and you feel like a human being*"

- Quote from participant of Permobil's Powered Standing Wheelchair Study

It is easy to take things for granted, especially those that feel most permanent and familiar in our lives. But what happens when those things are taken away from you, or are so far that reaching them is a constant struggle?

Our ability to sit and stand seems like such a basic, common part of our everyday lives that most people will never really appreciate the complexity of moving and pulling our joints, muscles and tendons in a way that lets you stand up to greet your friends, and sit back and relax when you enjoy coffee with them at your favorite cafe.

For some people, these simple actions can be a painful struggle, or even completely out of reach. People with disabilities or suffering from injuries to their lower body may lack the stability, strength or even coordination to safely and easily sit down and stand up from chairs. As we grow older, the degeneration of our joints and soft tissues means these complications are an impending reality for all people.

As of 2023, there are more than 65 million wheelchair users worldwide, according to the World Health Organization. That is almost 1 in 10 people who depend on wheelchairs for mobility assistance. Despite almost 1 in 10 people requiring wheelchairs, most commercial wheelchairs do not provide sitting or standing assistance to users who may struggle with these tasks due to injuries and ailments. Prolonged sitting can also lead to health complications such as osteoporosis, muscle atrophy, and cardiovascular conditions, which only exacerbate the deterioration of your health and well being over time.

For our team, these struggles reminded us of our loved ones. Our own grandparents, many of whom depend on wheelchairs for mobility, struggle immensely with sitting and standing from their wheelchairs and also chairs in general. For them, performing these actions is a struggle, and the risk of falling and injury is a fear that pervades every movement. This stops them from moving as often as they want, and prevents them from doing the simple things they enjoy, like cooking meals or standing up to give their loved ones a hug.

Our dream is a product that can make these movements simple and comfortable again, while providing the support and mobility of traditional wheelchairs, so that users can feel empowered with the options and ability to move around and interact with the world around them how they want.

To this end, we designed the EZ Sit: an ergonomic standing wheelchair that provides passive support in the sitting and standing motions, to assist users suffering from injuries and physical ailments to more comfortably move around.

Design Solution

Our final product, the EZ Sit, is a standing wheelchair boasting a robust wooden frame, with nylon upholstery seats and industry standard composite wheels with neoprene tires. It features a pioneering seat design that allows the seat to pivot about the wheelchair arms, and enables the wheelchair to transform from a standard seat to a reclined, standing chair. This feature incorporates elastic bands that provide the necessary support to pull the chair into standing position and smoothly recline back into a seated position with minimal user input. Our design will allow anybody to comfortably sit and stand from the wheelchair, with the aim of making the lives of wheelchair users with disabilities or injuries much easier, and give them the option to stand supported by our product.

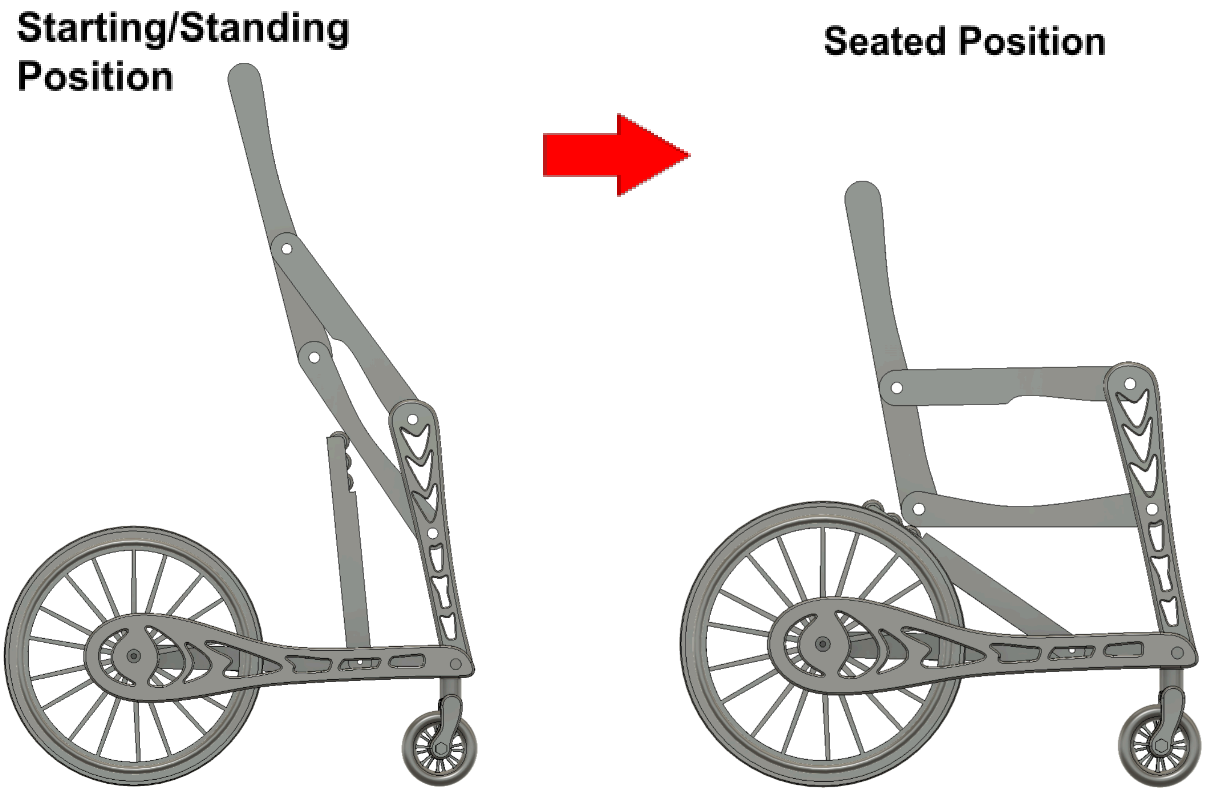


Figure 1: Functionality of Standing and Sitting Wheelchair Feature

To use it, just simply lean back into the chair while it is in its starting standing position with its built in rear wheel brakes engaged to prevent it from moving. Nothing to fear, the attached elastic bands have a load specification of over 200 lbs, meaning they can easily support the weight of the chair and a person leaning on it, just enough to allow you to smoothly recline with the chair into its seated position. This makes it easy for you to get into the chair, even if you have limited joint strength or mobility due to injury or disability.

Once in the seated position, the EZ Sit acts just like any other manual wheelchair, with the user able to move the wheelchair by turning the outer push rings of the large rear wheels. The small front wheels provide maneuverability, allowing for easier turning. The sturdy wooden frame's structure is optimized to minimize weight while maintaining high strength in its load bearing members, creating a lightweight yet durable chair. The seat is outfitted with nylon upholstery, which was chosen for its water resistant design and comfortability.

When you want to get up from the chair, simply engage the wheel brakes again and apply a slight force to lift yourself up from the chair, just a little bit of movement will be enough to activate the elastic bands and they will pull you and the chair up the rest of the way back into its standing position.

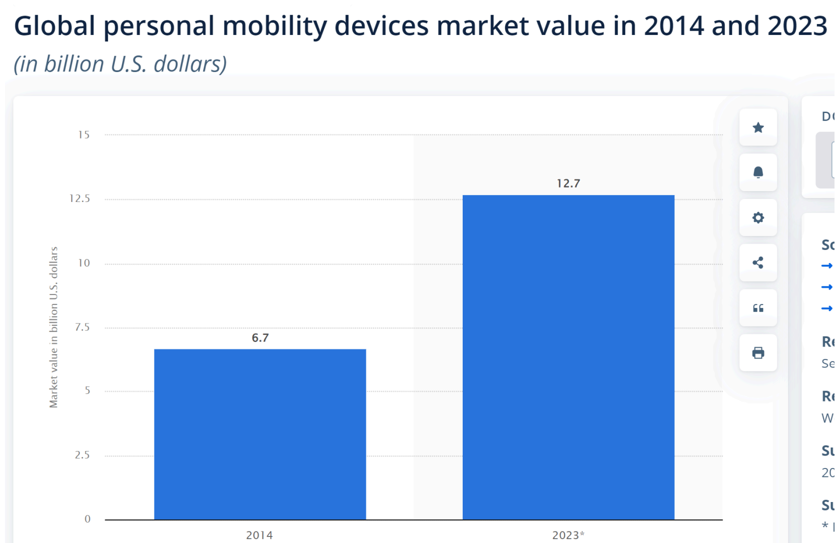
There is little reason for concern with the dynamic movements of the chair, we designed it so that the weight and center of gravity is focused near the center and bottom of the chair such that it will not easily tip or shake when it is moving. We also chose elastic bands because of their simplicity, and because they will naturally provide less force when they are less stretched. This means that in the wheelchair's standing position, where the bands are least stretched, they will provide the least amount of force while in the seated position they provide the most. That means in the sitting and standing motions of the chair the amount of force changes as the bands are less stretched, so that anybody using them won't be forcefully pushed out of the chair when sitting or abruptly fall straight down when sitting.

Apart from making these movements easier for users, our wheelchair's standing function means that users can experience improvements to their physical, mental, and social well being. Many studies have found that prolonged sitting can cause a variety of health complications, such as osteoporosis, while the limitations of using a wheelchair also has negative consequences on the amount and quality of social interactions and consequently the user's mental health. On the other hand, incorporating periods of standing for wheelchair users has been found to reduce these complications while improving their overall well being, which is discussed in our market research.

We designed the EZ Sit to be a safe, affordable, and impactful product that can enable wheelchair users to move unrestricted and comfortably, with the potential to prevent extended deterioration of their health from prolonged sitting.

Market Analysis

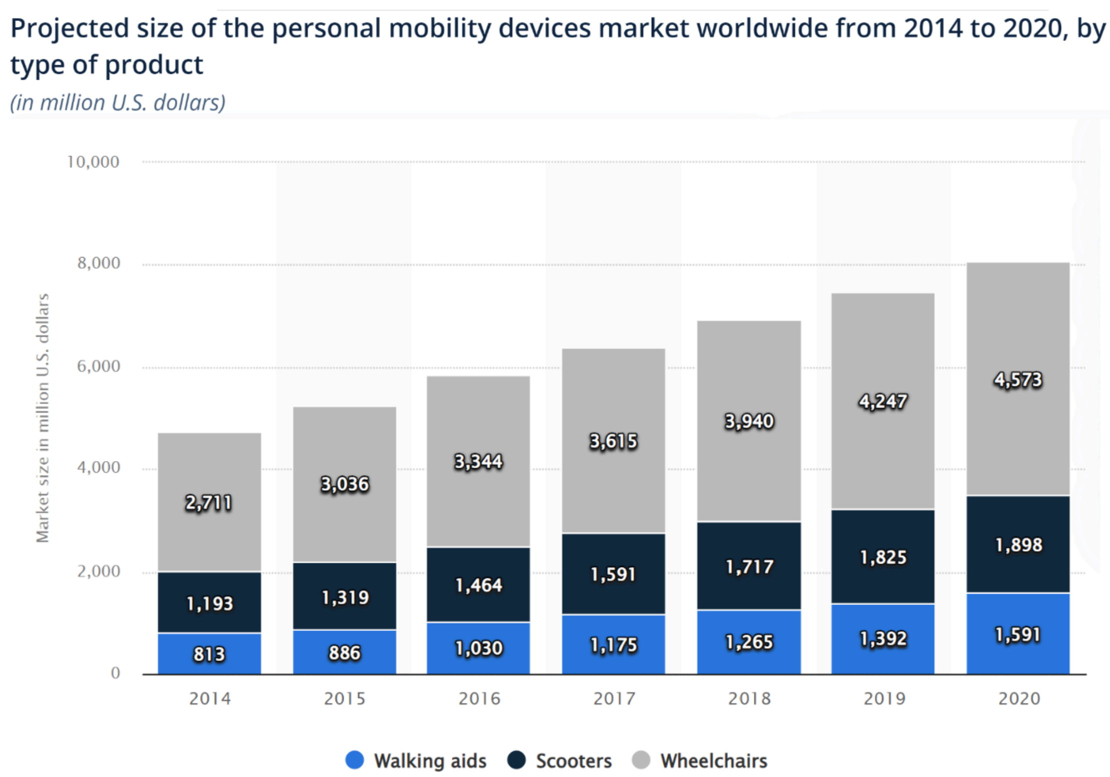
To get a better understanding of the market for assistive mobility devices and wheelchairs specifically, we looked at statistics on the market value and number of users of assistive technology. We found that the global personal mobility devices market value has seen a significant increase in the past decade, according to the following figure acquired from Statista[1].



[1] Figure 2: Global Personal Mobility Devices Market Value in 2014 and 2023

From Figure 2 we can see that the market value of personal mobility devices has nearly doubled from 2014 to 2023, growing from 6.7 to 12.7 billion U.S. dollars. This is indicative of a growing market and need for personal mobility devices like wheelchairs, although the exact types of mobility devices are not stated in this study.

To supplement the findings from Figure 2, we found another study from Statista[2], which elaborated on specific types of personal mobility devices and their approximate and predicted market shares between 2014 and 2020. The projected findings are as follows:



[2] Figure 3: Projected Size of the Personal Mobility Devices Market Worldwide from 2014 to 2020, by Type of Product

From Figure 3, we can see that wheelchairs make up the greatest percentage of the market in personal mobility devices, with an estimated 4,573 million dollar market value projection for 2020, and an overall increasing trend over time.

With this understanding of the market value and potential for wheelchairs, we looked into the specific needs of wheelchair users and caretakers to get a sense of what our top stakeholder product needs are. A 2023 study[3] provides valuable insight into the needs of our target market, which is wheelchair users or caretakers. The following table shows their collected customer statements and interpreted customer needs:

Table 2. Customer needs interpretation.

Customer Statements	Interpreted Customer Needs
Large body size can sit.	The wheelchair can fit person with a large body size
Comfortable to use.	The wheelchair is comfortable to use.
Reduce weight of wheelchair	Less weight of wheelchair.
Can withstand for oversized user.	The wheelchair able to withstand for oversized user.
No fifth hand while moving the wheelchair manually.	The wheelchair is motorized.
Reduce pushing force.	The wheelchair able to reduce pushing force.
Wheelchair can be fold.	The wheelchair must be foldable.
Low price.	The price of wheelchair must be affordable.
Safety while using wheelchair.	The wheelchair must have safe precaution. (brakes, stable and etc.)
Reduce problem to use.	The wheelchair able to reduce problem to use.

[3] Figure 4: Table of Customer Needs Interpretations

From these collected customer needs, the authors were able to further organize the needs into a list of metrics, ranked in order of importance, which are summarized into the following:

Table 4. The list of metrics for wheelchair.

Metric	Customer needs no.	Metric	Important	Units
1	1,2	Size	4	mm
2	3	Weight	5	kg
3	4,5,6	Strength	2	N/m²
4	7,8,9	Design	1	Subject
5	10	Price	6	RM
6	11,12	Safety	3	Subject

[3] Figure 5: List of Metrics for Wheelchair

We can see that customers found the most important aspect of their wheelchair to be its design, encompassing aspects like the functionality of the wheelchair and its accessibility to differently abled populations. Furthermore, the strength and safety of the wheelchair closely followed in terms of importance to customers, being second and third respectively. Finally, the size, weight and price of the wheelchair were found to be the least important aspects of a prospective wheelchair. Based on these findings, we can conclude that when designing our wheelchair product we would need to place emphasis on the actual functionality of our design, as well as its strength and safety to ensure that stakeholders are comfortable using our product. The size, weight and price of the wheelchair are less important to users, but still important to consider in the design process.

Finally, we wanted to investigate the prospect of a supported standing feature in an assistive wheelchair, as that is a major focus of our designs. While there is much research and anecdotal evidence on the detrimental effects of prolonged sitting and inactivity, we wanted to look into the benefits of standing for wheelchair users specifically. According to "Standing Tall: Examining the Evidence for Standing Power Wheelchairs" [4], some of the possible benefits to supported standing are: increased range of motion, better bladder and bowel function, improved respiration and circulation, increase in bone density and more health and quality of life benefits. Overall, there are many benefits to the health and well being of wheelchair users who take advantage of supported standing features and functions in their wheelchairs.

Based on our research, we summarized our main stakeholder product needs for our wheelchair:

- Functional design
- Accessible for variety of backgrounds and situations
- Strong and durable
- Safe for users
- Reasonable weight, not too heavy
- Reasonable size, can accommodate users of different sizes
- Agreeable price, not too expensive
- Can provide support or assistance when standing or sitting
- Increases or improves mobility of users
- Comfortable
- Allows users to perform necessary tasks such as moving around and accessing different spaces

Competitor Product Analysis

Knowing the main stakeholder product needs for our wheelchair, we can look into competition in the wheelchair and standing wheelchair market to determine how our product compares to existing competitors.

Our first competitor product would be the traditional manual wheelchair, with one market competitor being the Drive Medical Folding Transport Wheelchair[5], which can be bought from Amazon retailing at $129.99. The competitor product is shown below in Figure 6:

Figure 6: Drive Medical Folding Transport Wheelchair

The Drive Medical Wheelchair is highly rated on Amazon, with an average 4.6/5 star rating out of over 6000 ratings (as of May 2, 2024). Its advertised features include:

- Lightweight, at 37.6 lbs
- Folding design

- Easy to transport
- Superior support with nylon upholstery
- Durable steel frame with urethane tires mounted on composite wheels
- Overall product dimensions of 24"D x 43.5"W x 36"H
- Seat dimensions of:
    - Seat Width: 18 inches.
    - Seat Depth: 15.75 inches.
    - Back of Chair Height: 16 inches

Amazon's AI-generated customer insight aggregated from customer reviews suggests that customers find the value, portability, ease of movement, folding, comfort, and overall quality of the wheelchair to be positive, while the one detriment was the size of the wheelchair not accommodating different demographics of users.

Comparing our design to the Drive Medical Wheelchair, our product offers many of the same features. This includes a lightweight design, at around 40 lbs, folding capability, durable frame with the same types of wheels for maneuverability, and supportive nylon upholstery.
In addition to these features, our product also provides supportive standing and sitting features, which assist the user in sitting down and standing up comfortably from the chair. Our chair dimensions, specifically the seat height and depth, are greater than those of the Drive Medical Wheelchair, at around 28 and 21 inches, respectively.
However, our product price range may be slightly higher than that of the Drive Medical, at around $150 to $200, due to wood manufacturing and material costs.
Despite the potential cost difference, the additional features of our product make it a viable competitor to highly rated market competitors like this Drive Medical Folding Transport Wheelchair.

Looking at the market for standing wheelchairs, wheelchair88's Leo[5] is a high end product priced at US $3,500 that serves as competition to our EZ Sit. The Leo is shown below:

Seat Width	Seat depth adjustable range
14"	16", 17", 18"
16"	16", 17", 18"
18"	18", 19", 20"

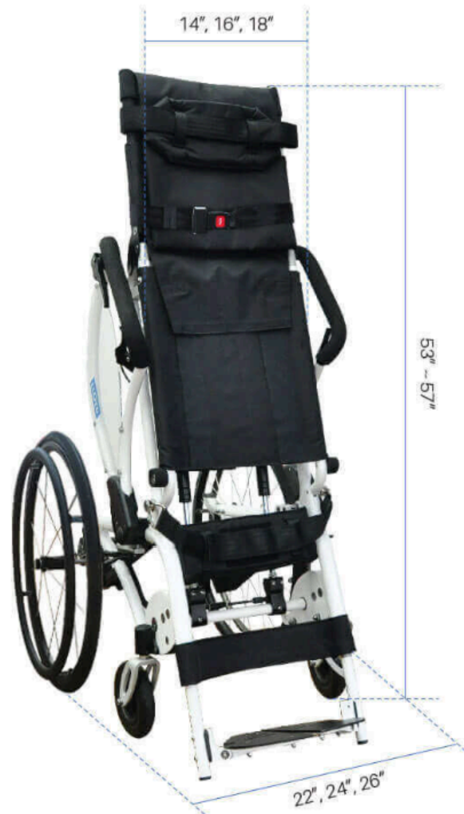


Figure 7: wheelchair88's Leo Standing Wheelchair

The Leo is advertised to have the following features:

- Proprietary user-controlled stand-sit mechanism, the user can control the stand or sit movement at their own pace
- Very safe, and no worries of falling forward due to their patented mechanism
- Adjustable seat depth & footrest height to suit users of different sizes and leg lengths.
- Equipped with rear wheel suspension by polyurethane blocks for more comfortable rides.
- Footrest angle is adjustable to stretch the calf muscles and tendons as the user stands up.
- Quick-release front and rear wheels with a foldable backrest to become a very compact size so that it can fit in a regular car trunk.
- Total weight at only 27 kg (59 lb) and can reduce to 21.5 kg (47 lb) after detaching the 4 wheels by quick-release function.
- Uses only high-grade aircraft quality aluminum alloy to ensure lightweight, durability, and safety standards.
- Available in 14″, 16″, 18″ seat width with multiple adjustable parts to suit different body sizes.

- Comes with different straps for the knee, ankle, chest, and safety belt

There are also a variety of add-ons that are available for an additional price.

The Leo clearly boasts a variety of features that wheelchair88 advertises to justify its incredibly high price point, at around 17 times the price of our wheelchair given our range of $150 to $200.

Comparing our EZ Sit to the Leo, the Leo includes more customization options and some higher quality design features, such as their anti-tilt mechanism for stability and user controlled stand-sit mechanism. The high grade frame material is also used as justification for the high price. However, our product offers many similar features, such as an assistive stand-sit mechanism with user control, and a lightweight and sturdy design.

Overall, it is clear when comparing our product with the Leo that we are appealing to different target populations. Our EZ Sit is meant to be an affordable option for users who want a safe and comfortable wheelchair that also provides them with the option and benefits of supported standing and sitting functions, while the Leo is a higher end version of the same concept that provides additional customization, comfort, and safety features for its customers. We believe that our product will be successful in the standing wheelchair market due to the lack of affordable and effective options.

Production and Retail Considerations

Item	Count	Cost (USD)
8’ x 4’ Birch Plywood	1	90.00
8’ x 4’ Particle Board	1	30.00
½” Bolts and Nuts 8” Length	12	21.99
5” Box of Screws	1	8.00
8’ 2’ x 4’ Dimensional Lumber	2	8.00
60” x 40” Nylon Fabric	2	15.99
Composite Rear Wheels	1	67.95
Front Caster Wheels	1	39.95
Total Cost:	**281.88**	

For our EZ Sit, we are looking at a production volume of around 10000 units per year. This is based on the availability and manufacturability of the components, with most parts being commercially available or easily manufactured, such as CNC for the wooden frame. Our total cost for all of the material and components is only about $281.88 USD, which is reasonable considering we had to buy the material and individual components such as wheels for our product. If we scale this to our proposed production volume and factor in the reduction in costs from mass manufacturing and production, we could easily achieve a much lower production cost per unit compared to our standalone prototype. Because of this, our proposed retail price is $200, this price allows us to make profit while also meeting market expectations for an affordable standing wheelchair.

Future Market Research

In the future, it would be important to monitor and further research on the topic of standing as it relates to the health and well being of wheelchair users, so that a more concrete relationship can be established. Adjustments to the design of our wheelchair may be necessary to accommodate any new findings in this field, and as the market for standing wheelchairs becomes more popular and competitive we should look into continuous improvement of our designs to meet stakeholder needs as the market changes.

Design Documentation

EZ Sit Full Assembly Drawing

An assembly drawing of the entire wheelchair is shown below in Figure 8, with relevant dimensions:

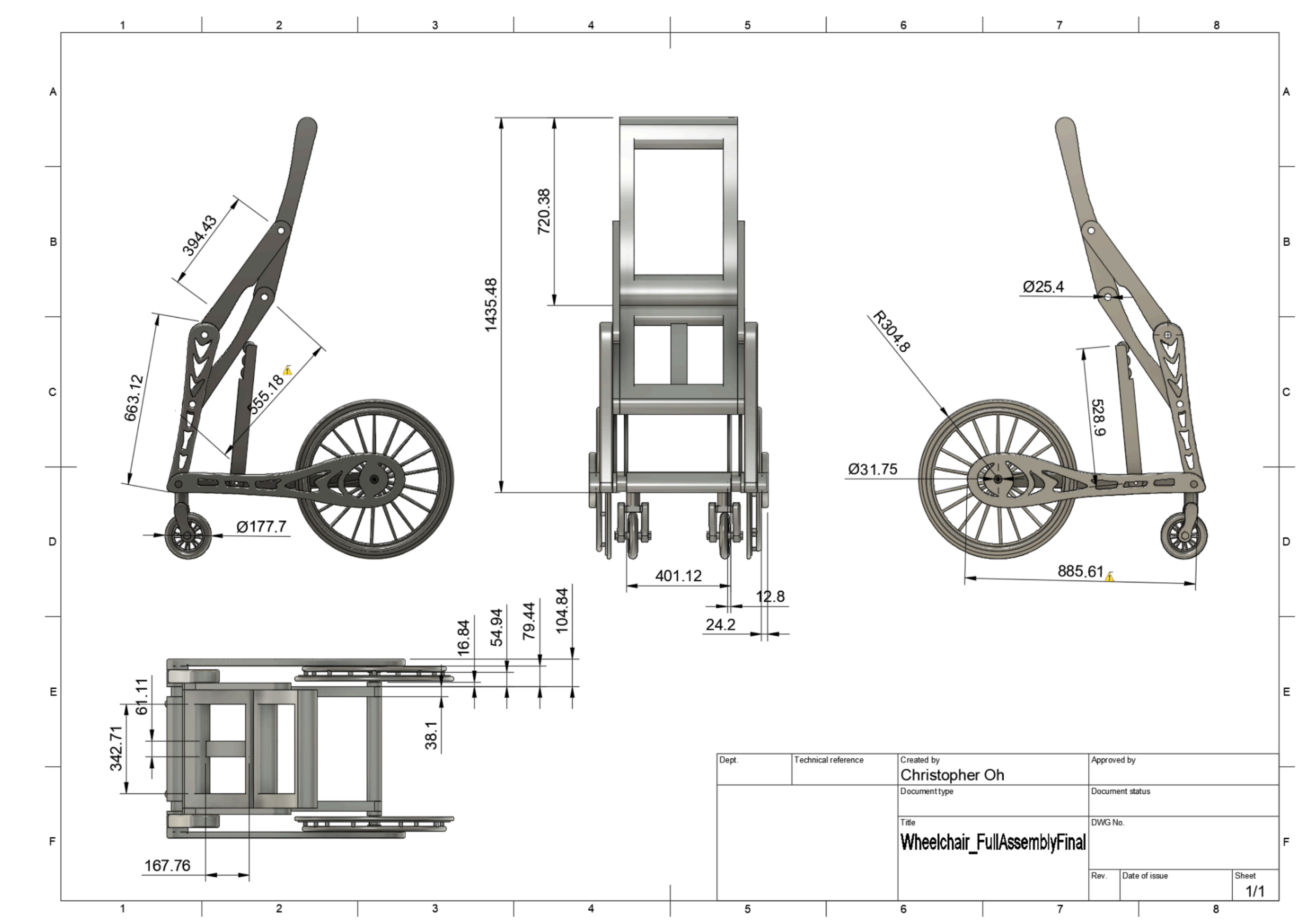
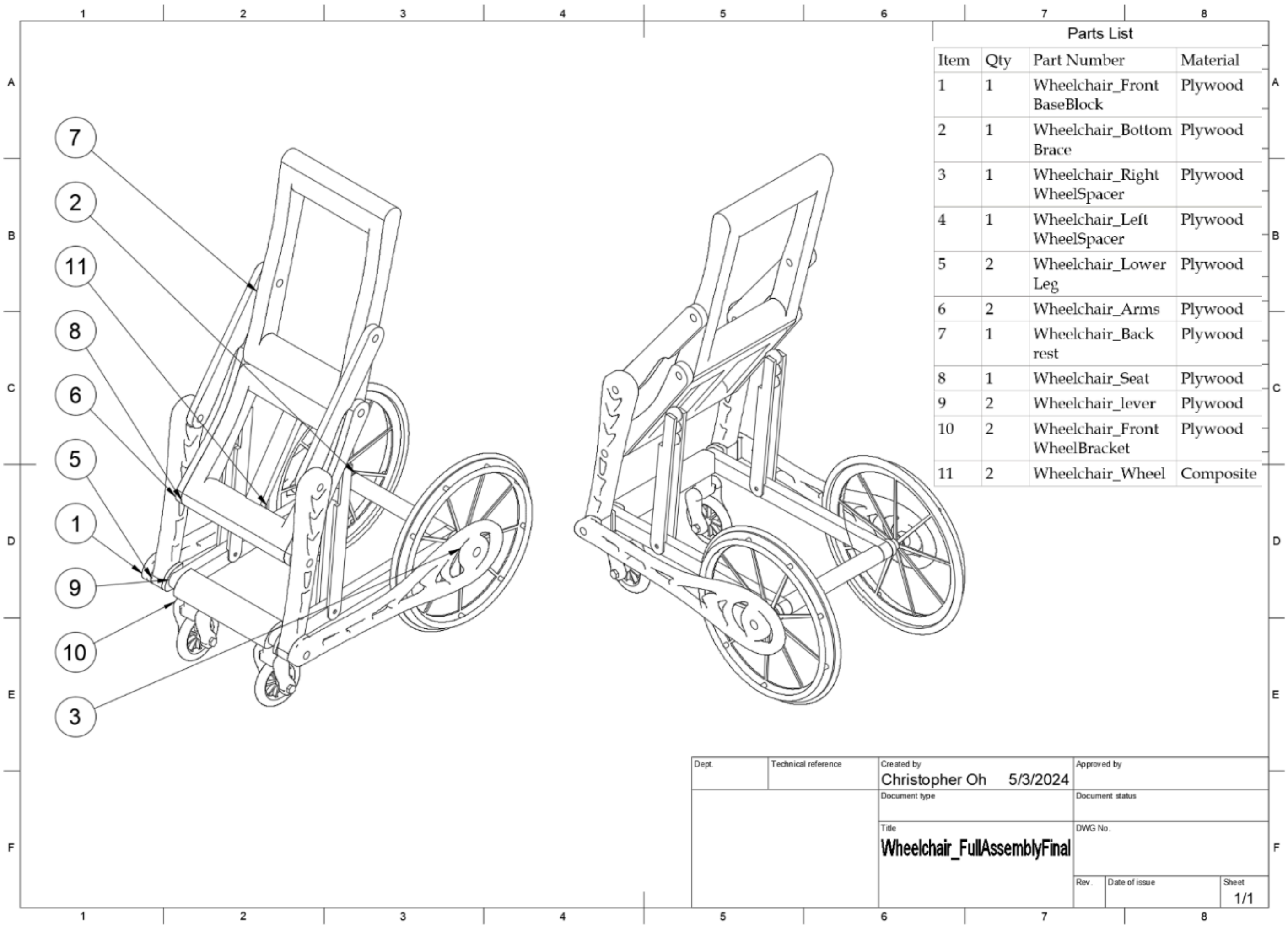


Figure 8: EZ Sit Full Assembly Drawing with Dimensions

EZ Sit Full Bill of Materials (BOM)

Figure 9 below is the full Bill of Materials (BOM) for the EZ Sit:



Item	Qty	Part Number	Material
1	1	Wheelchair_Front BaseBlock	Plywood
2	1	Wheelchair_Bottom Brace	Plywood
3	1	Wheelchair_Right WheelSpacer	Plywood
4	1	Wheelchair_Left WheelSpacer	Plywood
5	2	Wheelchair_Lower Leg	Plywood
6	2	Wheelchair_Arms	Plywood
7	1	Wheelchair_Back rest	Plywood
8	1	Wheelchair_Seat	Plywood
9	2	Wheelchair_lever	Plywood
10	2	Wheelchair_Front WheelBracket	Plywood
11	2	Wheelchair_Wheel	Composite

Figure 9: EZ Sit Bill of Materials (BOM)

Parts 1 through 10 are all fabricated through CNC machining of plywood. The remaining Part 11, which are the wheels, are non-custom standard composite wheelchair wheels. These were obtained from the Drive Medical Folding Transport Wheelchair, and recreated in the CAD model. The wheels are 24 inches in diameter, and replacement wheels can be ordered online separate from the wheelchair[6].

In the future these wheels can either be bought from manufacturers or manufactured in house.

The following are the custom built component drawings.

EZ Sit Component Drawings

Figure 10: EZ Sit Part #5 Lower Leg Drawing with Dimensions

Figure 11: EZ Sit Part #6 Wheelchair Arms Drawing with Dimensions

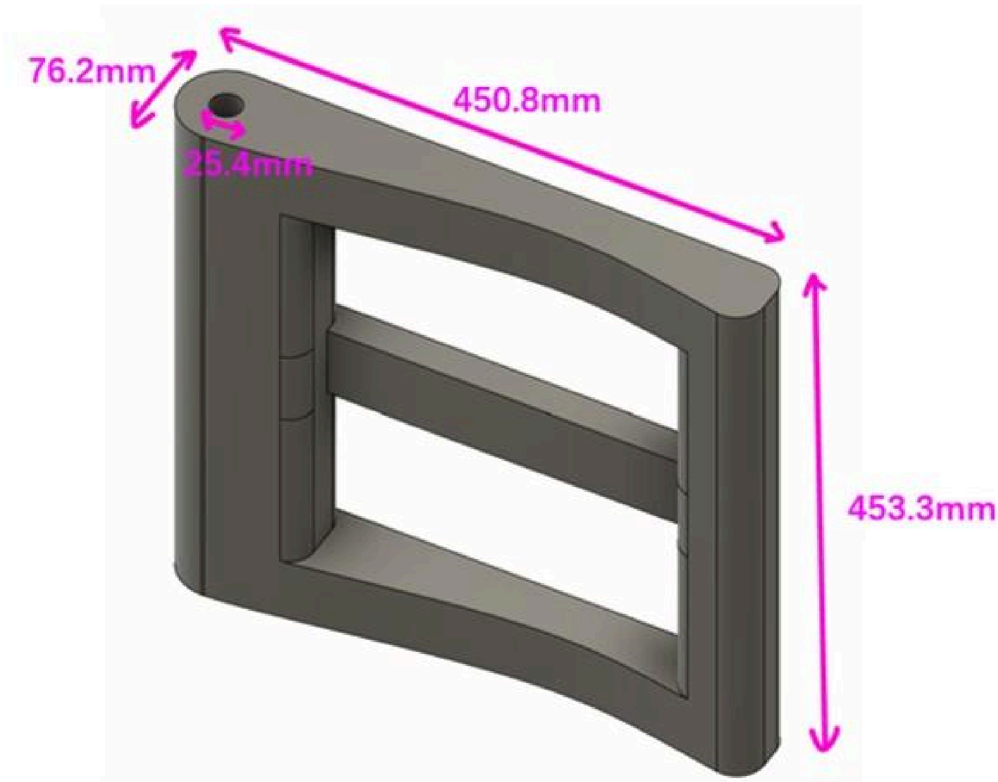


Figure 12: EZ Sit Part #8 Wheelchair Seat

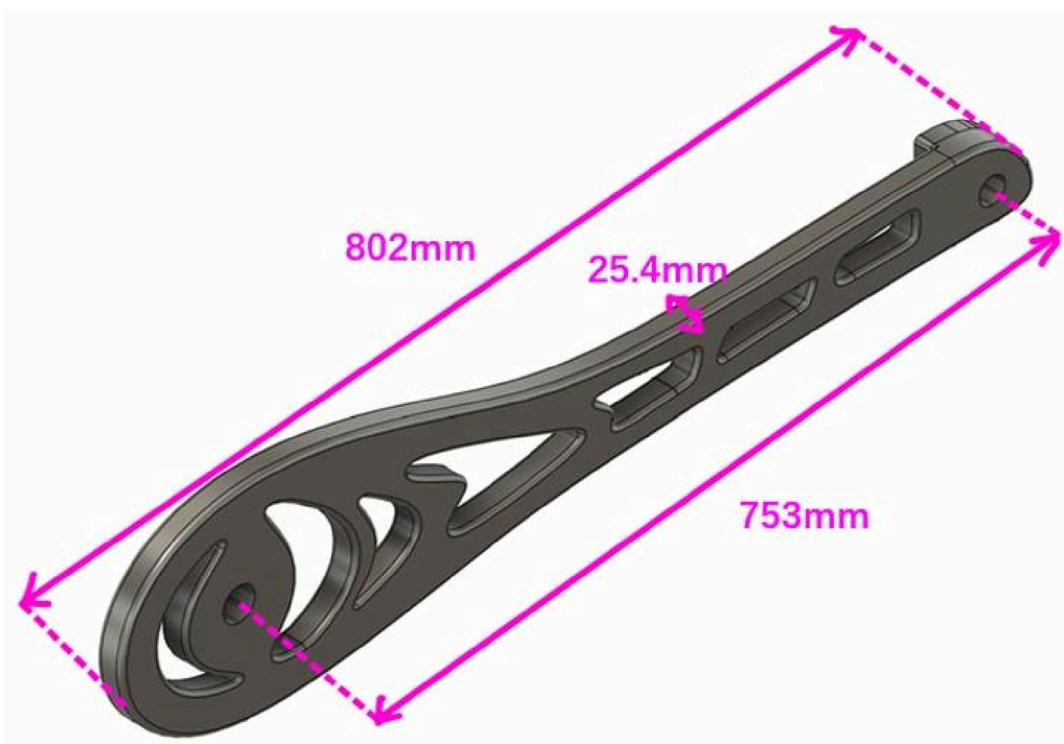


Figure 13: EZ Sit Part #1 Wheelchair Base Block

Figure 14: EZ Sit Part #11 Wheelchair Wheel

House of Quality

To determine the most important elements of our product's design and target specifications, we needed a structured approach to defining our customer needs and requirements and translating them into engineering characteristics for our assistive wheelchair product.
To this end, we decided to use the Quality Function Deployment (QFD) method, specifically employing a House of Quality (HOQ) to facilitate our group decision making process.

For our HOQ, we needed to identify our primary customer needs and requirements as well as the engineering characteristics of our product related to these customer needs that can be effectively quantified and adjusted to meet customer satisfaction.

The customer needs for our assistive wheelchair product that we established from our Market Analysis research are as follows:

- Portable
- Comfortable
- Easy to Use
- Price
- Durability
- Aesthetically Pleasing
- Easy to Maintain
- Anticorrosion
- Safety
- Accessible to Different Users
- Easy to Manufacture
- Makes Standing Up Easier
- Makes Sitting Down Easier
- Wheelchair Mobility

We then established several engineering characteristics of the design that may be relevant to these customer needs:

- Weight Frame Material
- User Weight Range
- User Height Range
- Seat Width Range
- Strength
- Assistive Standing Feature
- Assistive Sitting Feature
- Amount of User input needed for standing/sitting
- Amount of User Input needed to maneuver the wheelchair

- Foldable Frame
- Chair Seat Material

We then tabulated these established customer needs and engineering characteristics in our HOQ table to identify their correlations. From these relationships we are able to determine which design characteristics are most important to consider in our design process, as well as perform benchmarking with competitor products to see how our proposed product compares to our competition.

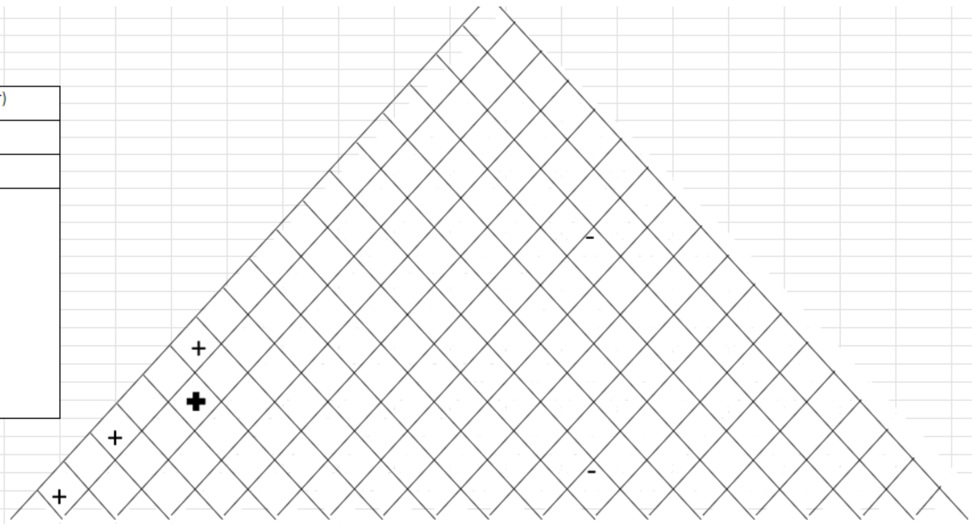
Our selected competitor products are:

- Drive Medical SSP118FA-SF Silver Sport 1 Folding Transport Wheelchair with Full Arms and Removable Swing-Away Footrest, Black (https://a.co/d/1gtq7Oi)
- DeerPlanet Folding Electric Wheelchair for Adults Seniors 30 Lbs Updated Lightweight All Terrain Motorized Wheelchair Compact Power Wheelchair with Removable Battery Liftable Armrest Airline Approved (https://a.co/d/32MVF3A)

Both products are highly rated on Amazon, with an over 4 star rating and over one hundred sales in the past month, as of May 2nd, 2024. We believe these products are representative of our main competition in our market.

The following is our completed House of Quality (HOQ) table that summarizes our design choices, targets and specifications, relationships and benchmarking against the competition:

Product:	EZ-Sit (Assistive Wheelchair)
Team:	EZ-Sit
Date:	5/2/2024
Notes:	



Correlations	
Positive	+
Negative	-
None	

Relationships	
Strong	●
Moderate	o
Weak	v
None	

Dir. of Improvement	
Maximize	↑
Target	⇕
Minimize	↓

Weight - Stakeholder 1	Weight - Stakeholder 2	Grouping	Engineering Characteristis / Stakeholder Requirements	Weight	Frame Material	User Weight Range	User Height Range	Seat Width Range	Strength	Assistive Standing Feature	Assistive Sitting Feature	Amount of User input needed for standing/sitting	Amount of User Input needed to maneuver the wheelchair	Foldable Frame	Chair Seat Material							Our Product	Folding Transpot Wheelchair	Electric Wheelchair
			Direction of Improvement	↓	⇕	↑	↑	↑	↑	↑	↑	↓	↓	↑	⇕							Competitive Assessment		
			Portable	o										●								4	4	2
			Comfortable		o					o	o				●							4	3	3
			Easy to Use							●	●	●		o								4	4	3
			Price	v	●									o	●							4	4	1
			Durability		●				●													4	3	4
			Aesthetically Pleasing		o										o							4	3	3
			Easy to Maintain						v													4	4	3
			Anticorrosion		●										o							4	4	3
			Safety		o				o	o	o											4	3	4
			Accessible to Different Users	o		●	●	●		●	●	●	●	o								5	3	4
			Easy to Manufacture		v	v	v	v		●	●			●								4	4	2
			Makes Standing Up Easier							●												5	1	1
			Makes Sitting Down Easier								●											5	1	1
			Wheelchair Mobility	v						v			o									4	3	5

	Weight	Frame Material	User Weight Range	User Height Range	Seat Width Range	Strength	Assistive Standing Feature	Assistive Sitting Feature	Amount of User input needed for standing/sitting	Amount of User Input needed to maneuver the wheelchair	Foldable Frame	Chair Seat Material
Units	lbs		lbs	ft	in	lbs			%	%		
Target - Disgusted	>60	Heavy alloy	400+	<3 ,>6.5	>36	200	No	No	>100	>100	No	Stiff
Target - Delighted	35-50	Carbon fibe	200-400	3 - 6.5	18-28	400	Yes	Yes	25-75	25-75	Yes	Nylon
Technical Competitive Assesment: Our Product	40	Aluminum	250	3 - 6.5	24	400	Yes	Yes	50	50	Yes	Nylon
Folding Transpot Wheelchair	37.6	Steel	250	3 - 6.5	18	300	No	No	100	100	Yes	Nylon
Electric Wheelchair	57	Aluminum	300	3 - 6.5	21	400	No	No	100	100	Yes	Cushion

(1-5, 5 is best)

Figure 15: EZ Sit House of Quality (HOQ)

From our completed House of Quality, we can see that:

- Frame Material, Assistive Standing Feature, and Assistive Sitting Feature are the engineering characteristics that have the most and strongest relationships with stakeholder requirements
    - Frame material is critical in determining the price, durability and anticorrosion of the product, while also somewhat related to comfort, aesthetics, safety, and ease of manufacturing
    - Assistive Standing and Assistive Sitting have strong relationships with the product's ease of use, manufacturing, and accessibility, and also are related to its safety and comfort
- Overall, every engineering characteristic had at least one strong relationship with a stakeholder requirement, the only exception being the weight of the product
- There are strong positive correlations between the material and weight, and between the material and the strength of the product
- Our product ties or outscores the competitor products in every metric in our HOQ

From this, we have these major takeaways:

- The frame material is the most important consideration due to its effect on various stakeholder requirements and correlation with multiple other engineering characteristics
- The assistive standing and assistive sitting features are necessary characteristics of the final product due to their strong relationship with product usage and customer satisfaction
- The weight of the product only had moderate or weak relationships with stakeholder needs, so it is not a major concern of the design
- Our product has a clear advantage over its competitors in the market based on these criteria and stakeholder needs

These takeaways were major influences on our decision making during the design process, leading to our final choice of wood as the wheelchair frame material as well as the implementation of the assistive standing and sitting feature. Despite weight not being a major concern, we still reduced material where we could to cut cost and maintain a reasonable product weight. This HOQ also validated our design as a competitor to existing products in the market.

Design Analysis

The following figure shows our failure mode and effects analysis (FMEA) table, which summarizes our identified major failure modes of the main design components as well as the

24-441 Engineering Design II – Failure Mode and Effects Analysis

Team EZ sit **Product** Wheelchair with assistive standing and sitting features 5/3/2024

Item and Function	Failure Mode	Effects of Failure	S	Causes of Failure	O	Current Design Controls	D	RPN	Recommended Actions
Adjustbale Armrests: It has a self-locking mechanism that enables people to lift up the arm and then themself step by step.	Fracture	Inoperative & Potential injury risk to people	8	High load and stress Improper operation	3	Manual instruction Stress Analysis FEA Inspection	3	72	Make sure it is well-assembled Check if there is cracks from time to time Do FEA analysis and simulation in Solidworks, so we can choose a approapiate dimensions and design
	Stuck	Inoperative	3	Improper dimensioning Improper Operation Deformation from high loads	4	Inspection Manual instruction Stress Analysis	2	24	Make sure it can work when assemblied. Add force along the correct direction so it won't deform Instructions on how to use the adjustable armrest correctly. Do calculation and simulation when designing
Chair Seat	Fracture	Compromised Structural integrity	3	High load and stress	7	FEA Stress Analysis	8	168	Use FEA and stress analysis to determine appropriate dimensions and design to reduce maximum stresses and chances of failure
Chair Backrest	Fracture	Compromised Structural integrity	3	High load and stress	6	FEA Stress Analysis	6	108	Use FEA and stress analysis to determine appropriate dimensions and design to reduce maximum stresses and chances of failure
Chair Lower Leg: Supporting members that connect seat and arms to the frame	Fracture, Buckling	Compromised Structural integrity	8	High load and stress	3	FEA Stress Analysis	2	48	Use FEA and stress analysis to determine appropriate dimensions and design to reduce maximum stresses and chances of failure
Chair Base Block: Supporting members that connect wheels to the frame	Fracture	Compromised Structural integrity	7	High load and stress	2	FEA Stress Analysis	3	42	Use FEA and stress analysis to determine appropriate dimensions and design to reduce maximum stresses and chances of failure

Figure 16: EZ Sit Failure Mode and Effects Analysis Table

In general, we found that our major failure mode for all components would be fracture from high loads and stresses during operation. Some components, such as the chair lower leg, could also fail from buckling due to high compressive forces when in the standing position. Our main design controls for all of these failure modes was stress analysis calculations and finite element analysis in Solidworks and Fusion 360. Using these methods, we were able to determine appropriate dimensions and geometries for our designs to reduce maximum stresses and minimize the chances of failure.

The following tables document our design for manufacturing and assembly (DFMA) for our product:

Minimize Part Count: Eliminate fasteners/holes, part consolidation	For these components that are not rotating, we make them as a whole part and fabricate them.
Standardize Components: Take advantage of economies of scale & known component properties	When designing, we are trying to use standard bolts and nuts like M6 and M8.
Commonize Product Line: Economies of scale and minimum training and equipment	For the adjustable armrest design, we 3D print it with PLA and then assemble it with M6 bolts and nuts. It is a set-to-go process and is very easy to fabricate as long as we have the design drawing. For the transformable wheelchair, we use CNC machining with wood. It needs CNC training and a longer time to fabricate. But it is a feasible way to fabricate complex components, and CNC machining is a very high accuracy process for mass manufacturing.
Standardize Design Features: Common dimensions for fewer tools and setups	When designing, we are trying to make the holes suitable for M6 & M8 bolts and nuts. For the rotation part, we use a pin to enable the rotation between two components.
Keep Designs Simple: Simplest way to achieve needed functionality	For the adjustable seat, we will have the seat and armrests pivot about the legs of the wheelchair frame. For the assistive sitting and standing feature of this movement, we will use elastic bands to provide an assistive force, since the force can be varied depending on the elongation of the band.

Figure 17a: EZ Sit Design for Manufacturing Table 1

Multifunctional Parts: e.g.: fingernail clipper arm acts as lever, spring, and cutter	For the adjustable armrest design, the armrest acts as a self-lock slot, a pull bar and armrest to put arms.
Ease of Fabrication: Choose materials easy to work with	For the adjustable armrest design, we 3D print the components with PLA, which is easy to do because it is a set-to-go process as long as we have the design drawing. For the transformable design, we use wood, which is easy to cut and fabricate using CNC machining. (But it is not easy to bend them so we only connect them)
Avoid Tight Tolerances: Causes exponential cost increases	For the adjustable armrest design, there is approximately 0.2mm error in 3D printing. So we design the holes to be 6.25mm to fit the M6 bolts. For the rest of the wheelchair, since it is fabricated out of wood using CNC machining, which has high accuracy, we use a tolerance of around 0.125 mm on all holes.
Minimize Secondary & Finishing Operations: Only where needed	For these components that are not rotating, we make them as a whole part and fabricate them. We also connect all components using standard bolts and nuts. The wood used for the rest of the wheelchair may be polished, which is a quick treatment and requires a short time to cure.
Take Advantage of Special Process Properties: e.g.: color in injection molding	Because 3D printing prints layer by layer, we can pause it and put a nut inside during the process. The inner nut is fixed and will not get loose. CNC machining of the wood will also allow us to cut out complex shapes and geometries, enabling geometry changes for topology optimization to minimize material use and weight. It also allows us to achieve a more aesthetic design.

Figure 17b: EZ Sit Design for Manufacturing Table 2

Minimize Part Count: Eliminate unnecessary parts	For these components that are not rotating, we make them as a whole part and fabricate them. We also add some space inside the bars and levers as long as they are strong enough. This helps to reduce the weight and the cost.
Minimize Assembly Surfaces: and sequence them	Our design works through several leverage and rotation joints. After fabrication, the only thing we need to do is just connect them using bolts and nuts.
Use Subassemblies: can be assembled and tested separately, can be outsourced	For the adjustable armrest design, we have already tested it as a subassembly and found out it works as we expected. It includes a well-designed slot to provide a self-lock mechanism that allows the user to lift it up step by step and release it from any point. It stays horizontal at initial condition and provides a maximum of 45 degree lifting angle. The wheels can also be outsourced, since wheelchair wheels are standard and mass manufactured.
Mistake-Proof: unambiguous, unique assembly orientation	For the adjustable armrest design, the slot is half the width of the armrest. The rest half is the space for the sliding rods and is easy to recognize during assembly. Because we have minimized the part count as well, the assembly is not complex and therefore not easy to make mistakes when assembling the components based on the CAD models and drawings.
Minimize Fasteners: snap fits and part consolidation	For the adjustable armrest design, we only have a single place that needs fasteners. The rest of the parts are rotation joints that are connected by bolts and nuts.

Figure 18a: EZ Sit Design for Assembly Table 1

Minimize Handling: position for insertion or joining is easy to achieve	It is easy to assemble them since we use standard design using M6 & M8 bolts and nuts. Also, the slot is 11mm, enabling the M10 bolts to slide smoothly inside.
Minimize Assembly Direction: ideal is to add each component from top to base	For the adjustable armrest design, it is very easy to assemble it because we only have 4 components. The key to the design is the design of the slot and the length of the leverage, which are both calculated to achieve certain performance. For the transformable wheelchair design, it is assembled from bottom to top. So, it can always stay stable on the ground when we assemble them.
Provide Unobstructed Access: consider assembly path (e.g.: oil filter)	For the transformable wheelchair design, we assembled them from middle to sides. So, it won't get stuck. We also need to put the leverage in before we fasten the nuts on both sides(wheels).
Maximize Assembly Compliance: chamfers and radii help assemble parts with variance	For the adjustable armrest design, we add chamfer to the connecting rods at both ends. So, it can rotate smoothly and won't get stuck by edges.
Features in your product that have no functionality in the use phase but are there instead to support assembly	For our transformable wheelchair design, we include extra rods in the mainframe to support assembly and increase the strength of the wheelchair. Because it should be able to support a person's weight.

Figure 18b: EZ Sit Design for Assembly Table 2

From our design for manufacturing tables, we concluded that it would be most efficient and beneficial to manufacturing if we made all non-rotating parts in the assembly as whole parts to minimize the total number of parts and reduce manufacturing costs. We also decided to standardize the connections and fasteners in our design by using M6 and M8 bolts only to reduce the need for multiple different hole dimensions. Because we decided to use wood and PLA for most of the design, it also greatly reduces our manufacturing time and costs because we can use effective fabrication methods like CNC machining and 3D printing. These manufacturing methods also allow for a degree of customization of our design, such as machining complex geometries with the wood in CNC machining and printing full parts using 3D printing. We also require minimal finishing operations because of our material and manufacturing choice, only requiring some sanding and polishing for the wood after fabrication.

According to our design for assembly tables, we can conclude that our assembly should be relatively efficient based on our design choices. We minimized part count by keeping our design simple, composed of just a few components. The parts are also easily assembled together with just a few fasteners, mostly just M6 and M8 bolts. Because of these design choices, the assembly is simple and the entire chair can be assembled from the base to the top with little issue due to its simple connections and small number of total components.

Mechanical Analysis

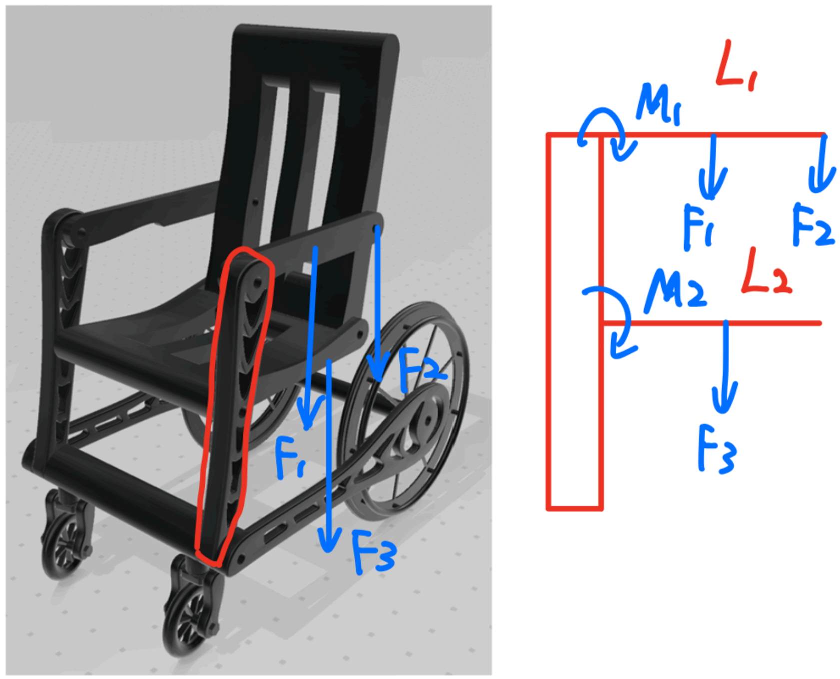
In order to validate the structural integrity of our design and identify points of mechanical failure and areas for improvement, we performed both hand calculations for stress analysis as well as Finite Element Analysis(FEA) in Fusion 360 and Solidworks.

Because the assistive standing and standing feature is one of the most significant components of our design, we wanted to confirm that our design is structurally sound and capable of withstanding the loads associated with having the full weight of a person in sitting and standing. For this purpose, we performed hand calculations to determine the moments and forces on the arms and armrests of the chair.

We chose to focus on the legs of the chair because they would bear the most load during regular operation of our design. Connecting the front of the wheelchair frame to the seat and armrests, the legs of the chair support much of the weight of the person and the chair in the sitting position and should support the majority of any applied loads in the standing position, since they essentially become two force members supporting the entire combined weight of the seat and the person.

We also chose to perform stress analysis on the armrests of the chair to validate our hypothesis that they would not support much of the load from the chair or person in regular operation. This is because they are only connecting the chair to the legs and do not experience much load, apart from a person resting their arms on them.

For the legs of the chair, we decided to analyze the forces and moments caused by the weight of the connected parts, those being the seat of the chair and the armrests. Our hand calculations for the legs of the chair are as follows in Figure 19:



$$F_N = F_1 + F_2 + F_3 = 4.64\ kg \times 9.8\ N/kg$$
$$= 45.472\ N$$

$$M_1 = F_1 \cdot \tfrac{1}{2} L_1 + F_2 \cdot L_1 = 17.2\ N \cdot m$$

$$M_2 = F_3 \cdot \tfrac{1}{2} L_2 = 7.62\ N \cdot m$$

Figure 19: Hand Calculated Forces and Moments for Lower Legs of Wheelchair Design

F1 represents the gravitational force of the arms and F2 represents the partial combined gravitational force of the seat back and the seat, while F3 represents the partial gravitational force of the seat. All of them are multiplied by a safety factor of 1.7. Fn is the total force exerted on the lower leg (depicted by the red circle in the picture), and M1 and M2 are the torsion caused by the forces mentioned above.

For the armrests of the chair, we decided to analyze the forces and moments caused by its own weight, those being the seat of the chair and the armrests. Our hand calculations for the armrests of the chair are as follows in Figure 20:

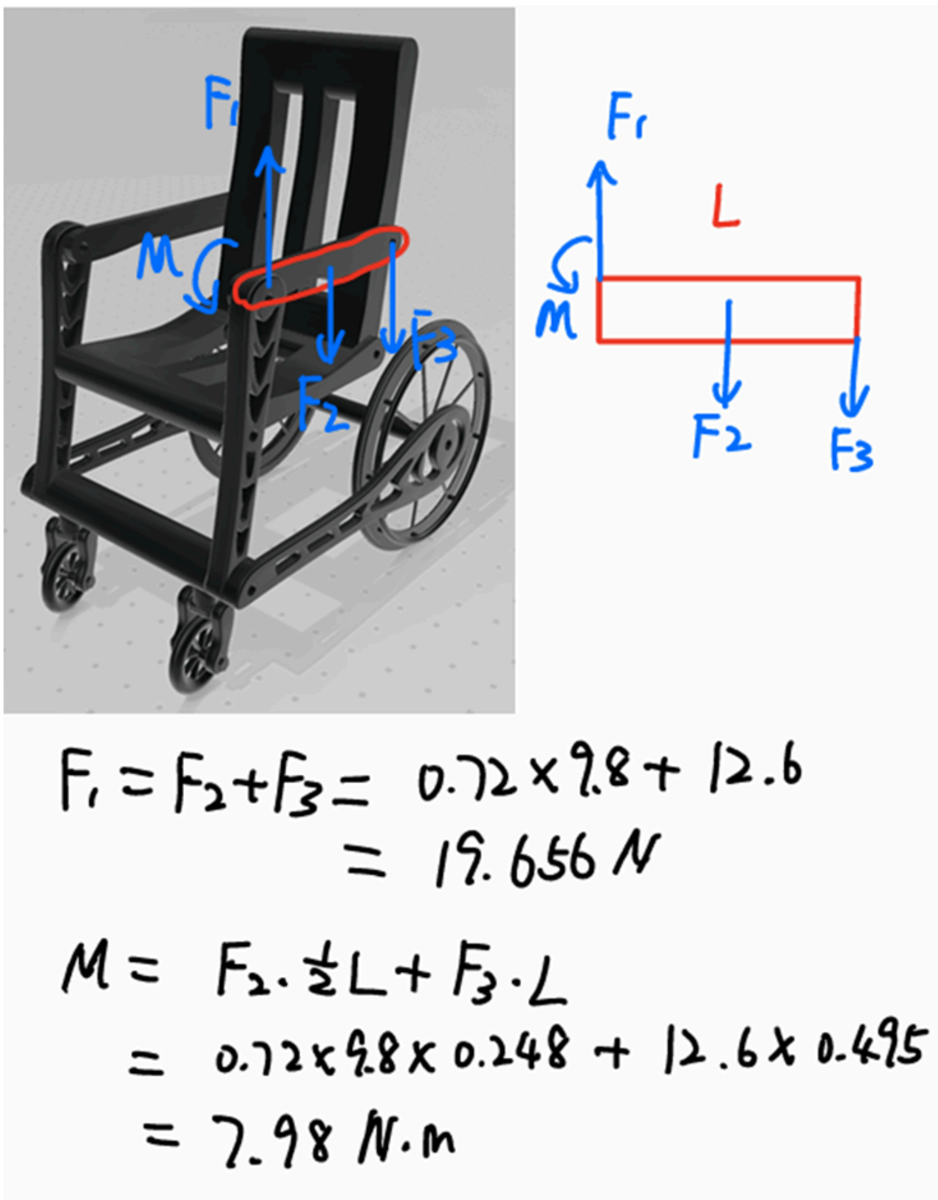


Figure 20: Hand Calculated Forces and Moments for Arms of Wheelchair Design

F1 represents the supporting force from the lower leg and F2 represents the gravitational force of the arm itself, while F3 represents the partial gravitational force of the seat back and the seat. All of them are multiplied by a safety factor of 1.7. M is the reaction moment from the lower leg to the torsions caused by the forces mentioned above.

Based on hand calculations and overall structure analysis, our group decided that the arms, base blocks, and lower legs have the highest risk of failure. Thus we conducted FEA on these parts, as shown in figures below.

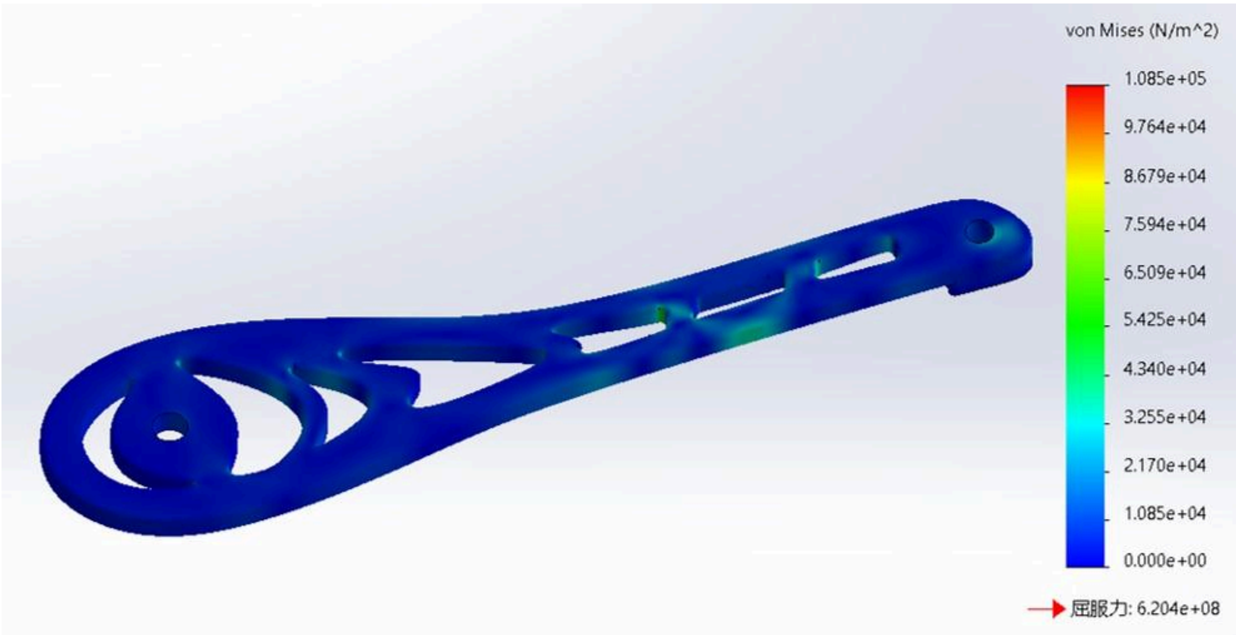


Figure 20a: Static Simulation Stress Contour for Base Blocks

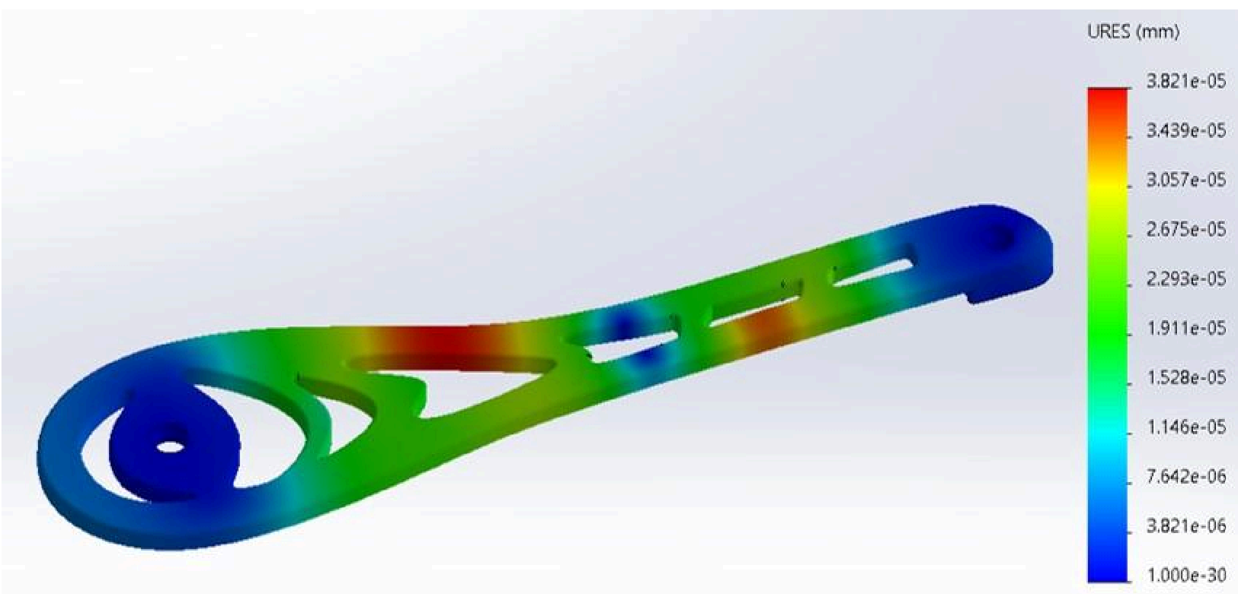


Figure 20b: Static Simulation Displacement Contour for Base Blocks

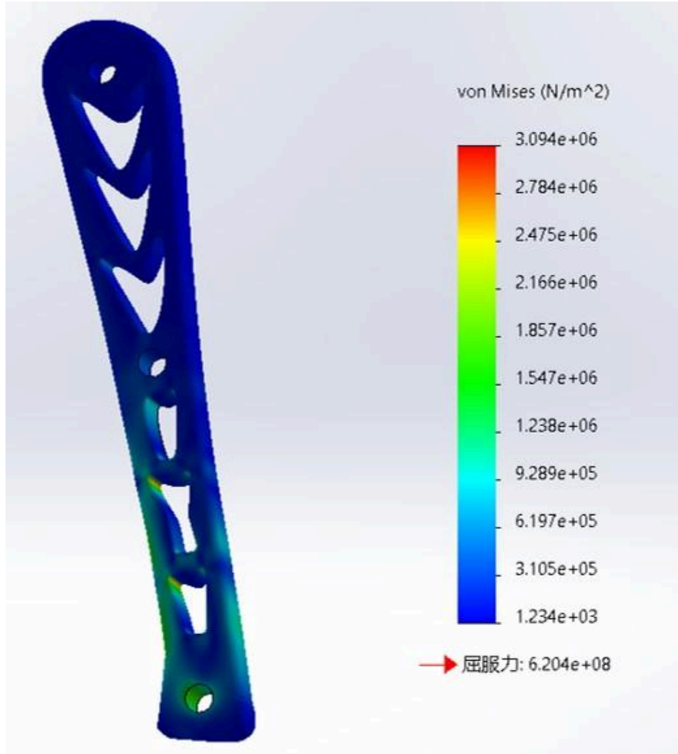


Figure 21a: Static Simulation Stress Contour for Lower Legs

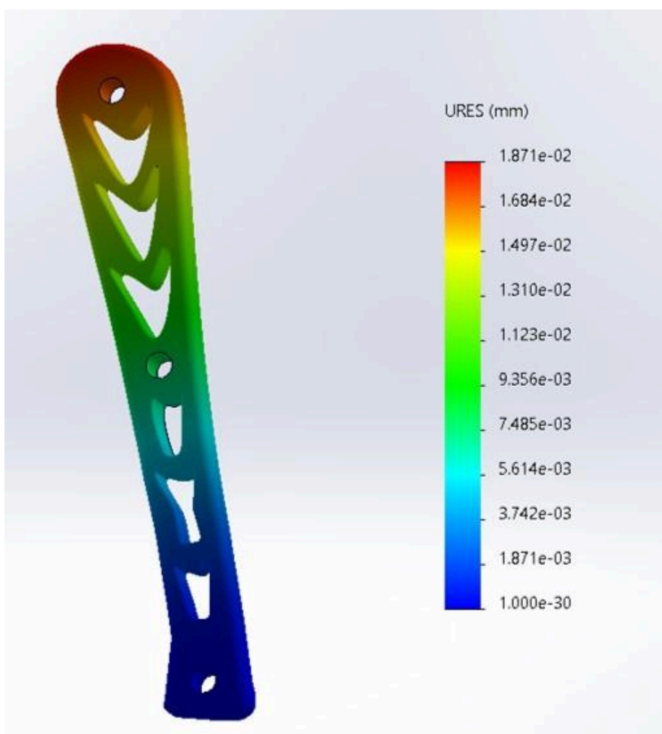


Figure 21b: Static Simulation Displacement Contour for Lower Legs

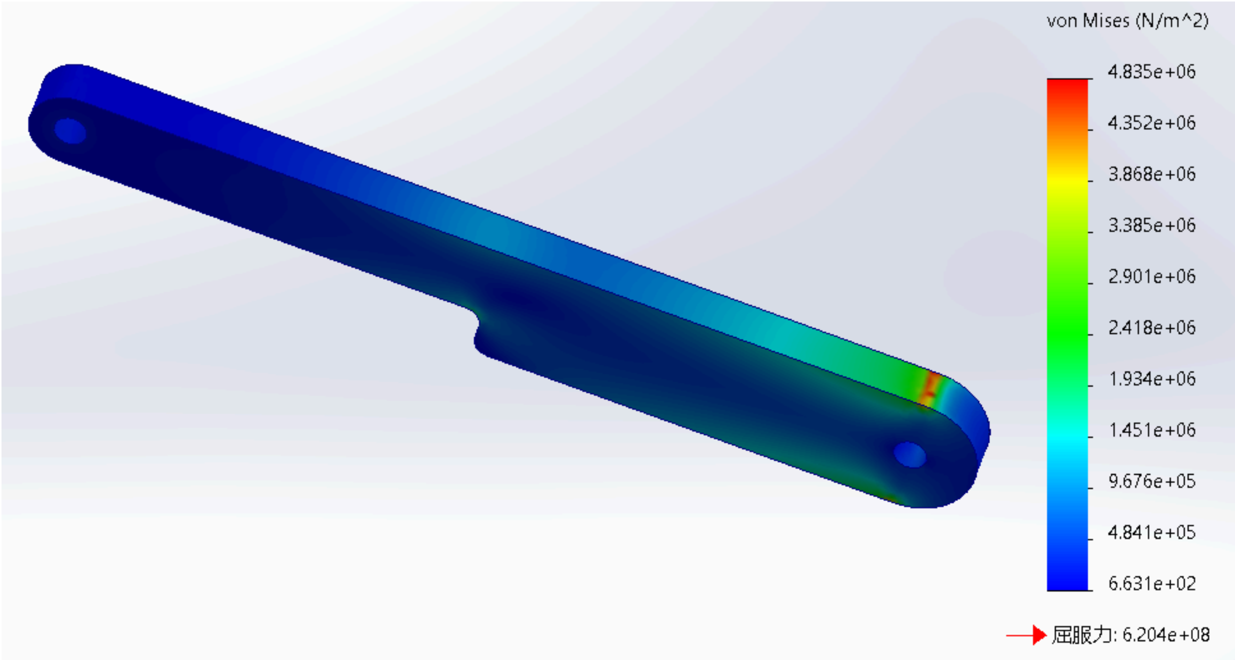


Figure 22a: Static Simulation Stress Contour for Arms

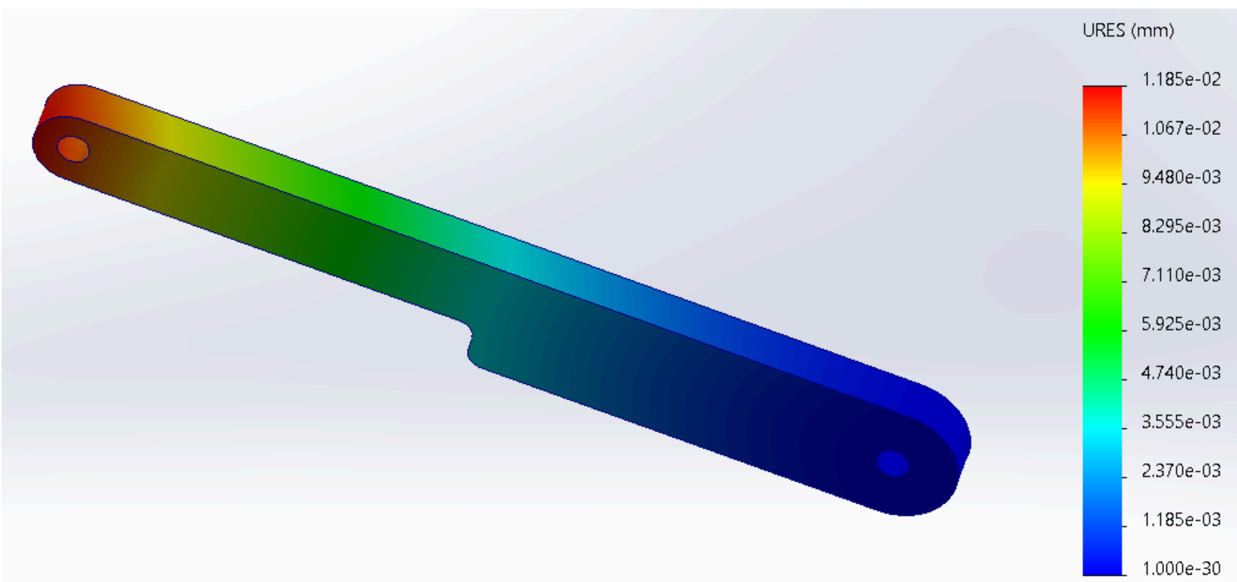


Figure 22b: Static Simulation Displacement Contour for Arms

From our static simulations, we can see that under the assumed loading conditions, none of the components experience a peak stress greater than 4.835 MPa. This is the highest stress we observe out of the simulations, and it happens in the armrests of the wheelchair. This is still much lower than the maximum yield stress of our wheelchair material, plywood, which is around 27.6 - 34.5 MPa[7]. This means that, even assuming the lower end of yield stress for plywood, we have a factor of safety of around 5.7 for the armrests, 8.92 for the lower legs, and 254 for the base blocks. From this, we can conclude that our designed components will not fail under our expected load conditions.

Prototype Documentation

Our final prototype is shown below:

Figure 23: Final EZ Sit Wheelchair Design Prototype

Our final prototype implements many of the intended features of our design, including:

- CNC wooden frame for structural strength, authentic feel and aesthetics
- Material cut out from frame based on topology optimization to minimize overall weight while maintaining performance and structural integrity
- Nylon seat fabric for comfort, easy maintenance and water resistance
- Pivoting joints on wheelchair arms that allow for chair seat to extend into standing position and fold back into sitting position
- Supports under the seat that provide stability and structural support to the chair frame and seat
- Large rear wheels with outer push rings for rotating the wheels and moving the wheelchair

However, we were unable to complete some features of our design that we intended to. These include:

- Attaching the front wheels of the wheelchair
- Implementing the elastic bands for supporting standing and sitting motions

Despite not being able to fully implement these features, we were still able to test their functionality with our design.

By fastening elastic bands to the armrests and wrapping them around the seat of the chair, we were able to simulate the assistive standing and sitting feature that we meant to implement using the bands. By manually pulling and tensioning the bands, we were able to pull and hold the wheelchair seat in its standing position, and also simulate the sitting motion of the wheelchair with added resistive forces of the elastic bands. This demonstrates that our concept for the assistive standing and sitting using the elastic band works, and we just need stronger elastic bands and an optimal attachment location and method to achieve the functionality that we desired.

Although the front wheels were not attached to the wheelchair, based on our design we believe that the wheelchair would be operable and mobile once they are attached. This is because the rear wheels are attached to the frame and stable, and attaching the front wheels by bolting them to the front of the wheelchair frame would enable movement of the wheelchair assuming the connection is stable.

Comparing our final prototype to our final design intended for mass production, it is definitely not complete, but we were able to prove that our design concepts are feasible and implementable, we just needed more time to fully implement them into our design. This was partly due to the manufacturing time of the wheelchair delaying the final assembly, but we can assume that with mass production the manufacturing process would be much more efficient.

User Testing and Feedback

Despite the final prototype not being representative of our desired final product, we were still able to test the prototype and receive valuable user feedback from different users during the design exposition.

The majority of users felt that the chair was very comfortable and felt sturdy, the wood construction of the wheelchair felt stable and many people commented that the aesthetics of the design were very appealing.
Despite the assistive standing feature not being fully implemented, by manually demonstrating the function of the feature by tensioning the elastic bands by hand, we were able to successfully demonstrate our intended functionality to users, some who also manually tested it themselves. The general consensus was that the idea is very innovative and plausible, and most users wanted to see the feature be fully implemented into the design to see its full potential.
Some potential areas of improvement that users mentioned include finishing the prototype to see if our proposed features are truly functional. In addition to this, there were some concerns about stability and safety of the design since it is intended for populations with disabilities or injuries. Users identified the standing position of the chair to be potentially unsafe because of the motion and shift in center of gravity making the chair unstable, as well as the lack of leg and lower body support in the standing position. This lack of support may be an issue if users are not prepared for the standing position, and because of possible disabilities or injuries they may not be able to support themselves once standing and fall over. This prompts the implementation of lower body supports such as leg braces or straps in future iterations of our design to address these issues. Another suggestion was implementing more supports to improve wheelchair stability.

Overall, user feedback on our final prototype was generally positive, as users liked our aesthetics and the sturdiness of the design. They also saw the potential in the assistive standing and sitting feature of the design, but wanted the functionality to be fully implemented to judge its viability. Finally, there were concerns about the stability and support that the wheelchair provides in the standing position and sitting to standing motions, prompting the implementation and testing of more features in the future to address these issues.

Design Process

Our team design process philosophy is to leverage our individual strengths and skill sets, and integrate our efforts by setting realistic goals and timelines which are facilitated by regular team meetings. We wanted to emphasize communication and collaboration, and so we communicated project updates regularly through iMessage and scheduled weekly meetings to convene and share any ideas or concerns in progressing our project. All of our project materials and documents were shared in a central folder in Google Drive, and CAD files were shared through Fusion 360 because of its collaborative project features.

Responsibilities and tasks were delegated in our regular meetings, and were decided based on team consensus and our individual skill sets. Timelines for each task and goal were also decided according to team consensus based on the complexity of the task and our expectations for the semester timeline of completion for the project.

Our individual roles and responsibilities were as follows:

Team Member Roles	
Chris Oh	Manufacturing, CAD, Prototyping
Yunhuan Wu	Manufacturing, CAD, Prototyping, Hand Calculations
Jingbo Zhang	CAD, FEA, Prototyping, Hand Calculations
Eric Zhao	Documentation, Prototyping

<u>Chris Oh</u>:

- Responsible for most manufacturing tasks, since the final prototype was designed out of wood, Chris took responsibility for its manufacturing due to his proficiency in woodworking and CNC as an Architecture additional major
- Contributed to CAD modeling of prototype because of his role in manufacturing the design, providing expert knowledge and insight into how to best design the prototype for efficient manufacturing

<u>Yunhuan Wu</u>:

- Owns and can operate a 3D printer, so assisted in manufacturing parts for small prototypes and final parts
- Modeled parts in CAD for printing and also performed stress analysis hand calculations for components in the prototypes

Jingbo Zhang:

- Performed hand calculations for stress analysis of major structural components such as wheelchair arm and armrests
- Responsible for FEA of prototypes and final designs
- Contributed to CAD modeling of prototypes and final design

Eric Zhao:

- Responsible for documentation of design and project deliverables
- Assisted in prototyping and assembly of prototypes

Design Status

Currently, our documented design is ready for large scale production. We have all the necessary CAD models and design files to reproduce the prototype as a finished product, through CNC machining of the wooden frame and assembly of the components.

However, our design does still require some additional testing, as mentioned in the user feedback of the Prototype Documentation section. While we are confident in the integrity and reliability of our wheelchair design, we have yet to determine the effectiveness of our proposed assistive standing and sitting feature using elastic bands. This is definitely an area for improvement and future testing, as we would like to fully implement the feature to see whether we can create a standing wheelchair with built in support for the standing and sitting motions. While we were able to manually manipulate the wheelchair into the standing and sitting positions with weak elastic bands, we would like to test this function with much stronger bands. If these bands are reliable, we would then move into user testing to validate the effectiveness of the assistive standing and sitting feature.

We definitely hope to continuously improve our design by gathering user feedback on the fully finished product and data from regular usage. Combined with research into the exact relationship between standing and health for wheelchair users, we could create an even more effective product that provides high end functionality to support the health and well-being of wheelchair users while maintaining a simple and low cost design.

If we determine our fully implemented design to be successful, we will look into pursuing intellectual property assessment to see whether we can secure the rights to our design and achieve even greater growth in the assistive technology market.

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