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Prosthetic Accessibility for Vietnam

Industrial Design Thesis Report

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Prosthetic Accessibility for Vietnam

by

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Submitted in partial fulfillment of the requirements for the degree of

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Abstract

The amount of violence and suffering that occurs in developing countries is astonishing, but the main problem is their access to proper healthcare. It is a basic human right to have access to medical facilities, without it, citizens of these countries will continue to suffer. One of the largest problems in Vietnam is amputation, it completely changes the life of the patient. The effects of life after amputation are dependent on the quality and access of prosthetics, majority of events resulting in amputation are road accidents and war. Life in Vietnam can be difficult as living in rural villages is common, and the main sources of travel are biking, or walking, if they have money bus or taxi. These citizens lively hoods are dependent on being physically capable so that they can work on their farms to sell produce or efficiently work in manufacturing factories. The process when getting a prosthetic requires time and money, the socket must be measured and custom made, while the parts are imported, not to mention the physical therapy needed later. These crude scraps can damage the amputated limb and requires constant maintenance, while giving no guarantee for functionality for their jobs. This thesis proposes a thorough research of the daily lives of citizens in Vietnam and the challenges they face. Research methods such as data collection, surveys and interviews, this data will be analyzed to focus on improving the quality of life. Additionally, with reference to existing prosthetics and methods, a one-to-one model will be developed to understand the required ergonomics. Results from this analysis will secure a design solution that makes prosthetics accessible, improving the life of the user, and reducing strain on daily activities.

Acknowledgements

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I would like to thank Catherine Chong as my thesis professor, for the overall assistance with the styling, conceptualizing, and innovating in the pursuit of this creative direction. Thank you to James Jordan for his insight on the lifestyle and struggles of an amputee. Thank you to my peers and classmates, who have made my thesis and college experience exceptional.

Finally, I would like to thank my family, my mother Phoebe and father Ray, who have been supporting me through the years in my pursuit of becoming a designer. Thank you to my partner Brendan who has been there for me, supported and encouraged me throughout every project, pushing me to become the best designer I can be. Thank you all dearly.

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1 Problem Definition

Figure 2 - Justin Mott, Alarming Trends of Amputees in Vietnam. Retrieved from https://www.nytimes.com/slideshow/2013/06/04/world/asia/05vietnam.html

1.1 Problem Definition

Vietnam is a culturally rich and beautiful country, though they are considered a developing country. Vietnam has reported on average the highest numbers of amputees in comparison to other developing countries, these high number of amputations are a result from war violence, traffic accidents, industrial accidents, and disease (Matsen, 1999). These citizens have minimal access to medical facilities, and even less access to proper prosthetists who can assist them with getting a quality prosthetic. Income in Vietnam often comes from labor-intensive professions such as farming, manufacturing, and fishing, this unstable income is dependent on the user's ability to work. The price of a above-knee prosthetic can vary but is considerably higher than a years' worth of income from these users (Palmer 2015).

This thesis report will examine how low-income citizens in Vietnam function through their daily lives as an amputee. The research and content therein are aimed at developing a cohesive design solution that allows amputees to continue with their lives without hardship from their disability. In addition, it is essential to make a sustainably conscious and ergonomic design solution for these amputees to use.

1.2 Rational & Significance

To gain a comprehensive understanding into the daily routines and tasks of an amputee, specifically an above-the-knee amputation, several tools will be utilised to access this data and information. The scope of these research questions dives into the understanding of the daily activities that are performed, the order of it and their relevance to the research itself. Likewise, understanding how amputees interact with their prosthetic throughout their day, reducing the pain and discomfort when used, while increasing the prosthetics usability.

This thesis will use the following questions, information areas and research tools to obtain an understanding, information, and data to shape the final design.

Questions addressed in this thesis:	Information areas investigated:	Research tools utilized:
How may we make prosthetics more accessible to those in developing countries?	Lifestyle in rural Vietnam.	Literature reviews
How can the comfort of an amputee be improved upon?	Prosthetic making process and how they are obtained.	Information searches
What are the fundamental needs of an amputee?	Target demographics (primary, secondary, and tertiary).	Existing solutions
		Expert/User interviews
		Ergonomic studies

Table 1 - Investigative Approach

The essential information gathered with these research tools will assist with developing a thesis solution based around constructing a comprehensive solution that fulfills the necessary sustainability, ergonomic and functional requirements of the thesis.

1.3 Background / History / Social Context

With over half of Vietnams population living in rural areas, the main form of transportation is either walking or by scooter/bicycle (Vietnamese Travel Information, 2020). As an amputee traveling is extremely difficult especially without a quality prosthetic, while the nearest medical facility are hours away. The lack of prosthetics in Vietnam directly affects the quality of life for these amputees and jeopardizes their ability to earn income, forcing them to beg. Though there are various groups working to supply prosthetics to developing countries such as Vietnam, due to the millions of amputees around the world, only a small percentage are supplied with prosthetics.

Agriculture is the most critical economic sector in Vietnam, their major crops include sugarcane, cassava, corn, sweet potatoes, fruits, nuts and rice, while a majority of this farming is done by hand instead of machines (Jamieson, 2020). Working in agriculture forces the user to be dependent on their physical ability so that they can grow their produce and haul it to their local market to sell. Vietnam also depends on manufacturing for developed countries as their cost of production is significantly lower. Working at these facilities entails; long intensive work ours, forced to work overtime, and low wages, commuting via either scooters or bicycles (Jamieson, 2020). As an amputee, working in either of these industries are nearly impossible, even with a prosthetic these industries would not be suitable because their prosthetic limits their abilities and if they push beyond that they could seriously injure themselves. Unfortunately, this issue here is not only is there a lack of accessibility of prosthetics in Vietnam, but there is also the lack of a design that improves the quality of life for these amputees.

A major challenge with supply prosthetics to Vietnam is the fact that the current prosthetic design is highly reliant on the socket. The socket casted to fit the user's residual limb and modified multiple times by making test forms for the user to try on to find any areas of discomfort. If the socket does not fit the user's residual limb perfectly, it can cause the user extreme discomfort and even cause damage to the residual limb itself (UCTV, 2018). The process of making the socket is long and requires continuous visits to medical facilities in order to ensure that the socket properly fits the user's residual limb.

2

Research

Figure 3 - Kim Gregory, A Sustainable Journey Around Rural Vietnam, Retrieved from https://theculturetrip.com/asia/vietnam/articles/how-to-sustainably-see-the-best-of-rural-vietnam/

2 Research

Figure 4 - Justin Mott, Alarming Trends of Amputees in Vietnam. Retrieved from https://www.nytimes.com/slideshow/2013/06/04/world/asia/05vietnam.html

2.1 User Research

The objective of this thesis and the research found is to determine a specific research topic using scholarly and consumer tools. The research topic in question is, determining ways to make above-knee leg prosthetics more accessible to citizens living in rural Vietnam. "Citizens of Vietnam continue to lose their limbs at an alarming rate. Immediately after the Vietnam War, war victims accounted for 75% of amputees; by 1996, war victims comprised only 46% of the total Vietnamese amputee population" (Matsen, 1999). In order to gain a deeper understanding of this topic and problems that are associated with it, research tools such as Humber Library Search Engine, Library Databases and Google Scholar will be used.

The focus areas for the information research will include user needs, user demographics, benchmarked products, surveys, and interviews, including an investigation for full bodied human interaction design. "Vietnamese people with disabilities experience higher rates of poverty relative to the wider Vietnamese population when accounting for the additional costs of disability" (Palmer, 2015).

2.1.1 User Profile – Persona

Figure 5 - Penta Prosthetics, Retrieved from https://pentaprosthetics.org/impact-stories

Name:	Đinh Quang Dũng
Age:	56 (Vietnamese)
Occupation:	Shop owner
Income:	$1,700 CAD/year
Education:	Elementary
Relationship Status:	Married with 3 children
Location:	Đà Nẵng, Vietnam
Cause of Amputation:	Traffic Accident
When Prosthetic was Obtained:	2015
Price of Prosthetic:	$2,000 CAD
Use of Prosthetic:	10 hours/day

Table 2 - Fictitious User Profile

This prosthetic user is a developed, fictitious persona, that fit the user demographic, motivation and background based off the demographic research. The use of this persona's intent is to redirect the design intent from merely the product to the actual end user. A fictional breakdown of the user's profile is described below:

> *"Đinh worked most of his life on his families rice farm in Đà Nẵng, he mended the paddy field throughout the seasons so that it could be sold at the local market. As he grew older, Đinh inherited the farm and the land, he continued his work with his wife and 3 children, who later would also inherit the land. In 2013, when Đinh was in the city, he was struck by a vehicle, the doctors were forced to amputate his right leg due to extreme trauma. After 6 months, when his residual limb had fully healed his doctors had informed him about the possibility of getting a prosthetic. Đinh and his family saved their money for two years to be able to afford a rudimentary prosthetic, and to pay off his medical bills but were unable to afford any physical therapy. Even with the prosthetic, Đinh was no longer able to work the paddy fields, his body could not handle the labor. Therefore, Đinh and his wife gave their children the farm and moved to the city to find work for Đinh. Presently, Đinh works in a small convenience shop with his wife, barely able to afford the small apartment they live in. Though Đinh's life is difficult he still feels lucky to live it as he often sees other amputees begging on the streets."*

Based off research, lower-limb amputees tend to be males between the ages of 45 years old to 65 years old. Accidents, and disease are responsible for non-congenital amputations, these events can happen at any time.

Being an amputee requires major adjustments in the user's lifestyle, the user needs to consistently exercise the rest of their body to support their residual limb. The reality is that their life becomes significantly more difficult because there are many activities that they can no longer do even if there was accessibility to obtain a prosthetic. When the user is at an older age, it is more difficult to adapt to their new lifestyle as their body is not as resilient as a user between the ages of 20 years old to 35 years old.

When living in a rural village, the average level of income is considered low. The average income in Vietnam is $2,200 CAD per year, while in comparison the average income for farmers in Vietnam is $1,450 CAD per year (Xinhua, 2018). This income goes towards, food, housing, clothing, travel, and other necessities. When faced with the event of amputation many other costs arise such as medical bills, physical therapy, medication, mobility aids and if possible, a prosthetic.

To earn this minimal income, these citizens lives are dedicated to their work, living in a rural village limits the type of work that is available. Main forms of work include fishing, farming, or working in manufacturing facilities (Jamieson, 2020). These are jobs that are highly labor intensive taking up 8 hours to 10 hours per day and will often need to be done by hand instead of having mechanical aids.

Becoming an amputee can send the user into a shock of emotions, it is a major event that completely changes the user's life, psychologically effecting the user. It can be expected for the user to go through phases of depression, anxiety, anger, or somatization (Durmus et al., 2015). These psychological effects influence the quality of life for the user, whether they have the ambition to participate in recreational activities or the way they view themselves. Users with above-knee amputations have a low view of their body image, and low self-esteem. The loss of a body part disrupts the integrity of the body and affects the physical and psychological condition of the user.

When a limb is removed, the mind can trick the user into thinking their original limb is still there, this can be in the form of tingles of sensation, itchiness, or physical pain. With information gathered from a survey, these feelings of phantom limb symptoms can last for either a few months or over a decade, it is dependent on the user itself. Regardless of the duration, these sensations or pains effects the user's quality of life.

Demographic		*User Behavior*	
Age	55 - 65	*Psychological Effects*	High
Gender	Male	*Lifestyle*	Laborious
Income	Low	*Body Image*	Low
Location	Rural	*Self-Esteem*	Low
Ethnicity	Vietnamese	*Physical Activities*	Low

Table 3 - Primary User Profile

2.1.1.1 Primary User

The primary users are the amputees who are obtaining the prosthetic.

2.1.1.2 Secondary User

The secondary users are the prosthetist who work with the primary user to obtain the prosthetic.

2.1.1.3 Tertiary User

The tertiary user are they physical therapists who work with the primary user to adjust them physically to their new lifestyle.

2.1.2 User Observation – Current User Practice

2.1.2.1 Introduction

The purpose of obtaining this data is to assist in the understanding of various uses and product scenarios experienced by above-knee amputees living in rural Vietnam. Further understanding how and why they use specific products and the context of events they are in. This information and data will dictate the design process for this thesis solution.

2.1.2.2 Method

User research was conducted in form of interviews both over the phone and by email. A survey was also organized and shared with other prosthetists to get an average consensus of the process of obtaining a prosthetic.

The socket of a prosthetic is a time-consuming portion of the product, as it is fitted specifically to the user's residual limb. When the user's residual limb has fully healed post-surgery, a prosthetist will work with the user to obtain a prosthetic fitted for the user's lifestyle. The socket is an extremely import portion because if the fitting is not efficient, it will cause the user great discomfort when using their prosthetic and could even damage the residual limb.

The experience when fitting for a socket is as follows:

Intimate relationship with the prosthetist.

- The user's residual limb is measured in depth by hand.
- Sensitive points on the residual limb are identified.
- Working closely together to determine what is the best course of action that benefits the user.

There are multiple versions of the socket that would be made in this process, initial casting, tests sockets and the final socket. The initial casting is made by plastering the user's residual limb in order to create a negative, which would be filled with liquid plaster, creating the positive. When making test sockets, acrylic sheets are vacuum formed over the positive casting and cleaned up.

The testing process with the sockets are as follows:

- Testing the initial test socket while wearing a liner on the residual limb, the user would let the prosthetist know where the areas of discomfort are.
- Testing the sockets requires the user to have the socket connected to a prosthetic pylon and foot, so that the user could see how it feels walking with it.
- Adjustments are made as many times as necessary so that the user feels comfortable when walking with the socket, so that the final socket can be made.

During theses meetings with the prosthetist, the user would be taught, in depth, the tasks required to maintain their prosthetic, the duration of time that the prosthetic should be worn and other details.

The interview with James Jordan, an upper limb amputee and War Amps Canada employee, was conducted over the phone. James had agreed to speak for an interview and discussion about his work at War Amps Canada. James has experience as the primary user and as a secondary user, therefore being able to give accurate information.

Name	*Email*	*Basis of Expertise*
James Jordan	James.Jordan@waramps.ca	Working with War Amps Canada for 10+ years. Congenital upper limb amputee.

Table 4 - User Interview Contact.

Questions were prepared prior to the interview, targeted at gaining exclusive individual insight from personal experience working in this industry, interacting with others in the community and hands on experiences with prosthetics. In context of this interview, the questions were specified towards the interviewee, in terms of his work and background. The questions used in the interviews are as follows:

- What is your name and work title?
- How did you get involved working in this industry?
- How long have you been working in this industry?
- Would you be able to explain the process in getting a prosthetic?
- What are some common problems you have seen others experience?
- How long does it take for the user to receive the prosthetic?
- Have you ever met a user who has given up on using their prosthetic?
- Would you be able to describe the daily activities of an amputee and the challenges they would often face?

These questions were asked in a simple manor between the interviewer and interviewee, James Jordan. Answers from the interview has been paraphrased as requested by the interviewee and additional questions were asked. The key takeaways from the interview which shaped the thesis design are listed in the table below.

Key Takeaways – James Jordan Interview
An artificial limb can be extremely expensive in North America depending on what type of limb it is, lower-limb prosthetics tend to be more expensive ranging from $20,000 CAD to $30,000 CAD.
During the users first visit to the prosthetist, they take the measurements of the user's residual limb and cast it in plaster to get an exact replica of the residual limb. They fill this mold with plaster and file down any areas that need adjustments. This plaster mold will then have melted plastic draped over it to create the test socket, this test socket is to make sure that it fits properly and to ensure there are not any pressure points. Many adjustments need to be made to the test socket because if not it can misalign the prosthetic, affecting the users back.
The alignment of the prosthetic is important because if there are any misalignments it can negatively affect the user's body and the user will not be able to use the prosthetic. If this is the case the only options available for the user is a wheelchair or hopping around on their sound limb, which can destroy it before the user is 20 years old.
The final socket is made using layers of fabric coated in liquid plastic that is absorbed into the fibers of the fabric. This makes the socket incredibly durable to the point where it could only be intensively smashed with a hammer in order to break it. These sockets must be extremely durable as it is going through everyday use.
It is common that over 50% of the time the user will have to go back to their prosthetist to have adjustments made to their socket, so that it is functioning perfectly and not causing the user any pain. There are many variables that come into play; maintenance, external physical stresses, and alignment issues.
The mentality of an amputee is very dependent on the individual themselves, those born with congenital limb loss have minimal psychological issues with their prosthetic in comparison those who suffered trauma causing them to lose their limb. Depending on the age of the user they may be more accepting of their amputation if they were younger. It is a major mental change for the user and can be mentally devastating, it takes time for the user to accept their amputation after a traumatic event. Though there are users who give up on using their prosthetic, if they are motivated and determined, they will find a way to function with or without a prosthetic.

Table 5 - User Interview Key Takeaways

Keywords and phrases extracted from the interviews are:

Socket – Device that joins the user's residual limb to their prosthetic, specifically made and shaped to the user's residual limb.

Residual Limb – The portion of the arm or leg left remaining after an amputation, could also be referred to as a stump or residuum.

Sound Limb – The users opposing limb that has not been amputated.

Alignment of the Prosthetic – Consistent centering of the socket, knee joint, pylon, and foot in the prosthetic.

Water Leg – A prosthetic leg designed for use in water.

Tendonitis – The inflammation of a tendon, common from the overuse of a joint.

2.1.3 User Observation – Activity Mapping

Information and data from the socket process were gathered and organized to develop potential improvements in the user experience.

- Measuring the residual limb.
- Covering the residual limb with plaster to create a negative.
- Trying on the test socket.
- Walking with the test socket.
- Learning how to use and maintain the gel liner.
- Trying on the final socket.
- Learning how to use the prosthetic from the prosthetist and physical therapist.
- Walking with the final socket.

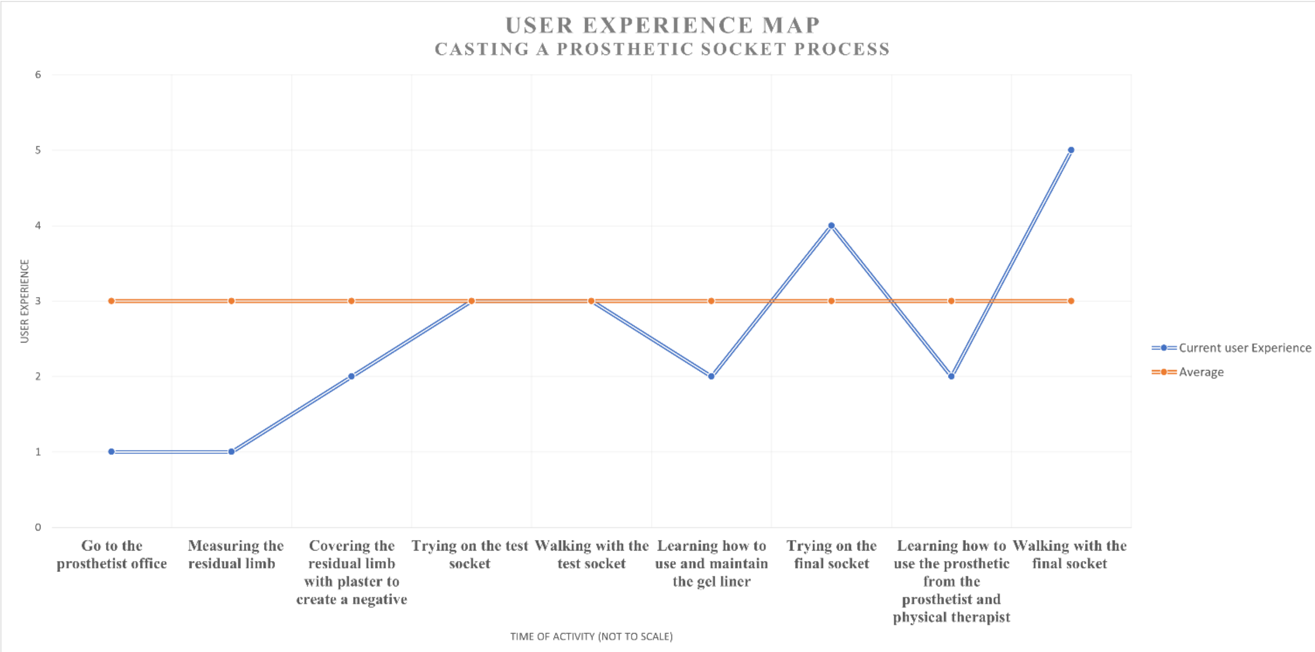


Figure 6 - Current User Experience Map for Casting a Prosthetic Socket Process

1 (Very Poor), 2 (Poor), 3 (Average), 4 (Good), 5 (Very Good)

2.1.4 Human Factors – Research of Existing Products

Ergonomics associated with above-knee prosthetics are extremely important and is researched in depth, but it is common for these researchers to not publish their findings. "Throughout the world, the major objective of prosthetics is to restore, as close as possible, the functional capacity formerly held by a limb deficient person, while attaining the best cosmetic result afforded to, and deemed necessary by the patient. On the surface, there would be very little difference in the design and manufacture of prosthetic solutions with respect to the approaches taken by Western and third world countries. "(Strait, 2006). Looking into existing prosthetics and methods used by amputees will help in understanding the fundamental features and abilities needed to be integrated and innovated for the design solution.

The average day correlates to three primary types of scenarios; exercise/training, water-based activities, and daily wear. An average workday in Vietnam operates for 8-10 hours a day, when additional work is required may occasionally operate upwards of 12-15 hours per day. Work in Vietnam is commonly individual compared to a team setting.

2.1.5 Safety and Health – Research of Existing Products

Safety from unstable or polished terrain and durability are crucial elements to above-knee prosthetics. Common elements identified from current benchmarked products are as follows:

- Traction
- Durability
- Waterproof
- Cost-effective
- Lightweight
- Easy to Maintain

Health and safety for a user's prosthetic is extremely important. Any flaws or threats could potentially injure the user further. Daily activities can range from a walk on a dirt path to having to navigate on a road through a monsoon, emphasizing the importance of having a prosthetic that can withstand these elements. When using an above-knee prosthetic, it will take time for the user to be able fully function, the possibility of falling or injury is high in this initial phase.

2.2 Product Research

The following section of this thesis report is to examine various prosthetics and accessories used by amputees, to identify key benefits and features, while highlighting areas for innovation. When researching various prosthetics, companies broke down the prosthetic to 3 main pieces that are featured on their site; the knee joint, pylon, and prosthetic foot. A pool of 10 products were initially selected, with the following 4 being critically analyzed for this report. Below is a table identifying the 4 selected products.

Product Name	*Product Image*	*Product Reference*
Aqualine Water Leg		Figure 7 - Aqualine Water Leg, Retrieved from https://www.ottobock.ca/en/prosthetics/lower-limb-prosthetics/solution-overview/aqualine-waterproof-above-knee-system/
C-Leg		Figure 8 - C-Leg, https://www.ottobock.ca/en/prosthetics/lower-limb-prosthetics/solution-overview/c-leg-above-knee-system/
Ottobock's Fitness Prosthetic		Figure 9 - Ottobock's Fitness Prosthetic, Retrieved from https://www.ottobock.ca/en/prosthetics/lower-limb-prosthetics/solution-overview/above-knee-fitness-prosthesis/
LIMBox		Figure 10 - LIMBox, Retrieved from https://www.limbsinternational.org/technology-development.html

Table 6 - Current Benchmarked Products

2.2.1 Benchmarking – Benefits and Features

The pool of products was selected due to their; main functions/features, price range, and ergonomic characteristics that can be improved upon later in the thesis process. Using literature and data provided from the existing products, features and benefits have been organized and highlighted. The full breakdown of the benefits and features is highlighted in ***Appendix C***, along with the benchmarked products.

The key benefits and key features have been organized in the table below as follows:

Key Benefits	*Key Features*
Comfort	Foot
Stability	Knee
Efficiency	Leg
Ease	Pylon
Use	

Table 7 - Benchmarked Products Key Benefits and Key Features

2.2.2 Benchmarking – Functionality

After being broken down to their most fundamental form, 2 distinct product categories arose during the benchmarking process. On a primary level, the pool of benchmarked products offers the ability of being high functioning and the other being cost effective. Both categories have their own specialized features and benefits which can be applied to a uniform design solution. Basic functionality allows users to conduct their daily routine with efficiency and the ability to do so in comfort.

On a practicality scale, products that offer high functioning features are often higher in price as well. The pool of benchmarked products is spread throughout the X-Y axis as seen in Figure 11, a design opportunity zone has been highlighted, indicating the most ideal features and functions of the design for this thesis.

The solution for this thesis should be developed in an area where opportunity for a high functioning prosthetic is available at a cost-effective price.

As per the X-Y graph measuring functionality and cost-effectiveness, a design opportunity zone has been highlighted, indicating the most ideal features and functions of the design solution for the thesis. In this graph there are 10 benchmarked products shown measured based on their price range and the number of features that are included in the design as well.

The solution should be developed in an area where opportunity for a high functioning prosthetic is provided to the user at a pricing that suits the user's lifestyle.

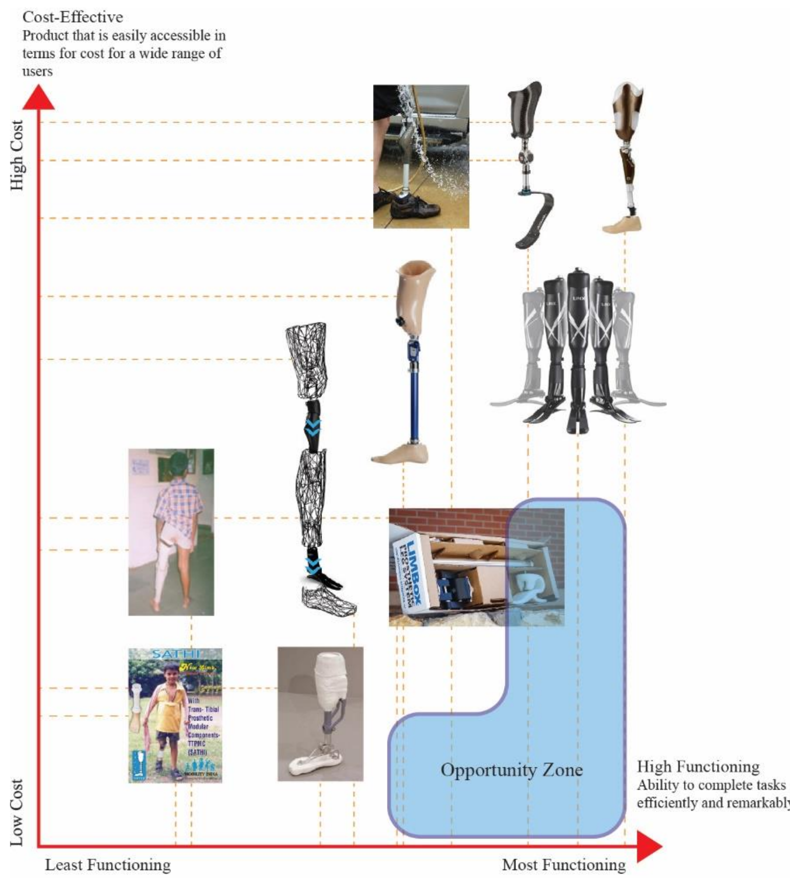


Figure 11 - XY Product Functionality Graph

2.2.3 Benchmarking – Aesthetics and Semantic Profile

Based off Figure 12, it is prominent that there is a lack of organic form in the pool of benchmarked products. It is apparent that the current designs of prosthetics and existing solutions are consistent of rudimentary or mechanical forms with a very modern aesthetic. There are minimal companies emerging designing either hyper realistic prosthetics or sci-fi robotic prosthetics, that will cost years of income saved up. 3D printed prosthetics have an aesthetic that is in-between these two categories but lacks the durability and functionality required in an above-knee prosthetic.

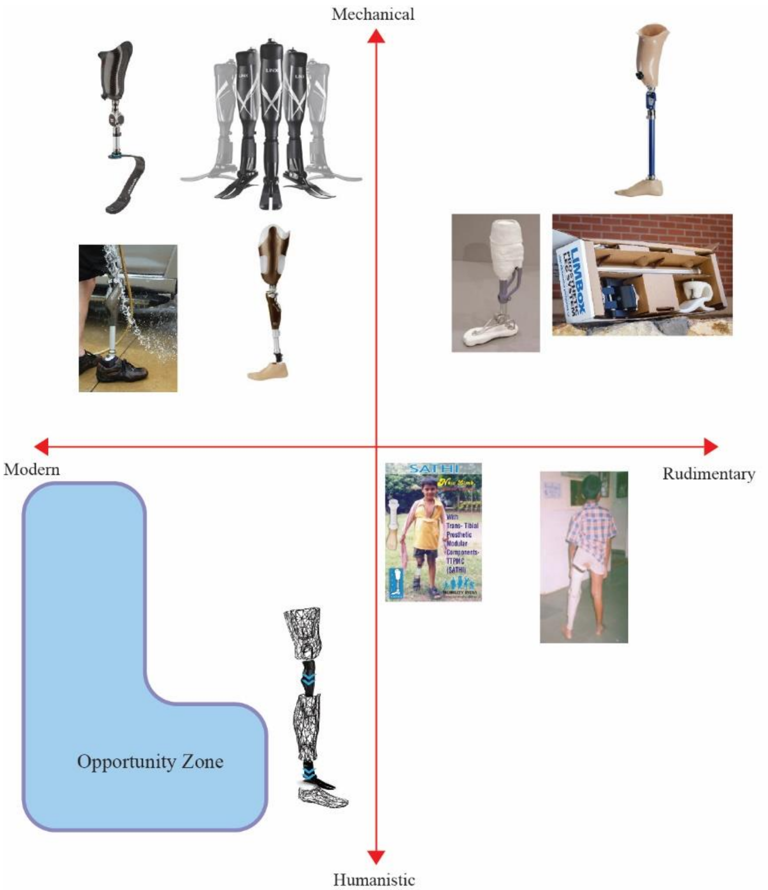


Figure 12 - XY Product Semantics Graph

The general aesthetic is mechanical and strong in appearance, with minimal availability for user customization. These benchmarked products have little emphasis on strong styling and aesthetic consideration. Visually, these designs are overly straightforward, with both implied and physical mass. Adding some more visually pleasing curvature that is humanistic while enhancing the modern mechanical visual appeal offers potential to develop an innovative solution for an above-knee prosthetic. The four main areas of aesthetic design for above-knee prosthetics in Figure 12 are, Mechanical, Humanistic, Modern, and Rudimentary styling.

Black and white monochromatic styling are used in the design styling of the benchmarked products. If not black and white, a variety of flesh tones are used to mimic the user's original limb. The surfacing for these products often appears to be smooth with either a satin or glossy finish. Soft goods are included as an accessory to the prosthetic, acting as a residual limb gel liner or a compression waist band. The benefit of the rudimentary design projects the product as lightweight and slim, making it more ideal to use day to day so that the user is not weighed down. Though the rudimentary design also lacks greater design elements to make it pleasing to the eye.

The prosthetic solutions are lacking in the aesthetic styling of emotion and expression. There are strong design elements with a mechanical aesthetic in mind, which is represented through the prosthetics design and form. The socket of the prosthetic can occasionally be customized, depending on the users chosen prosthetist, besides that, there are no other components that the user can dictate the aesthetic stylings.

2.2.4 Benchmarking – Materials and Manufacturing

Materials which appear in the current benchmarked products are as follows:

Material	*Benefits*	*Reference*
Titanium	Titanium is strong yet lightweight material, lighter than stainless steel but with twice the strength. This materials elasticity and coefficient of thermal expansion is identical to those of human bone. Titanium is biocompatible with the human body, inert and immune to attacks	http://titaniumthemetal.org/Resources/DataSheetMedical.pdf
Carbon Fiber	Carbon fiber is a material, that when compared to others, is a lighter load bearing material. This materials property includes high stiffness, specific strength and tensile strength, and a low thermal expansion. Prosthetics made from carbon fiber allows for heavy weighted amputees to be able to use it.	https://broncoscholar.library.cpp.edu/bitstream/handle/10211.3/193171/MotaAnissa_LibraryResearchPaper2017.pdf?sequence=1#:~:text=It%20is%20commonly%20alloyed%20with,most%20commonly%20aluminum%20and%20vanadium.&text=Being%20lightweight%2C%20strong%2C%20resistant%20to,similar%20to%20that%20of%20bone.
Crepe Neoprene/ Urethane Foam	This material is used to mimic the human foot when molded over an inner keel, then shaped. This material produces an inexpensive, durable, and almost maintenance-free prosthetic foot.	https://www.amputee-coalition.org/resources/prosthetic-feet/
DuPont Delrin	This Delrin material is ideal for parts designed to replace metal. It has a combination of low-friction, high strength, high stiffness, and high-wear resistance making it an ideal material for	https://www.dupont.com/products/delrin.html

	prosthetics. This material is also able to mate will with metals and other polymers.	
Steel	Steel is a strong, rigid, ductile, and durable material, giving it a long-life expectancy that is ideal for prosthetics.	https://musculoskeletalkey.com/materials-and-technology/
Polyethylene	Polyethylene is a flexible polymer that allows for the prosthetic to be waterproof. This material is ideally used in a large quantity	https://broncoscholar.library.cpp.edu/bitstream/handle/10211.3/193171/MotaAnissa_LibraryResearchPaper2017.pdf?sequence=1#:~:text=It%20is%20commonly%20alloyed%20with,most%20commonly%20aluminum%20and%20vanadium.&text=Being%20lightweight%2C%20strong%2C%20resistant%20to,similar%20to%20that%20of%20bone.
Ionomeric Polymer Metal Composites (IPMC)	IPMC are an electro-active polymer, this material is mechanically flexible making it easy to manipulate its shape. Due to its low density and its ability to induce electrical bending, this material is easy to fabricate.	https://broncoscholar.library.cpp.edu/bitstream/handle/10211.3/193171/MotaAnissa_LibraryResearchPaper2017.pdf?sequence=1#:~:text=It%20is%20commonly%20alloyed%20with,most%20commonly%20aluminum%20and%20vanadium.&text=Being%20lightweight%2C%20strong%2C%20resistant%20to,similar%20to%20that%20of%20bone.
Cobalt-Chromium Alloys	Cobalt-chromium alloys are a biocompatible metal that can resist wear, has a high strength and is able to mirror the physical and mechanical properties of joints.	https://www.cobaltinstitute.org/prosthetic-alloys.html

Aluminum	Aluminum has a high strength-to-weight ratio making it durable and lightweight material, well suited for prosthetics. This material is also non-corrosive ideally used for everyday use materials.	https://musculoskeletalkey.com/materials-and-technology/

Table 8 - Benchmarked Materials Table

The chosen materials and associated manufacturing processes specified in Table 9, are vital for everyday uses. Materials used in products analyzed during the benchmarking phase, include Dupont Delrin, Crepe Neoprene/Urethane Foam, and Ionomeric Polymer Metal Composites (IPMC). These materials are reliable under stress, extended periods of use and they are cost-effective, making them ideal for providing prosthetics to users who do not have access. In addition to their raw qualities, many of these materials can handle constant usage, therefore when used in manufacturing prosthetics, giving the prosthetic a long product lifetime. With a longer product lifetime, the user's income is spared from having to replace major components of their prosthetic, saving their expenses for more dire needs.

2.2.5 Benchmarking – Sustainability

Sustainability is an essential element to consider when designing the prosthetic, as there will be a direct impact on the user, Vietnam is currently suffering from air pollution. Vietnam is considered one of the top 10 countries in the world with the worst air pollution (Vietnam, 2018), this pollution is due to Vietnams low energy prices for manufacturing. This high demand for low-cost manufacturing pushes there to be an excessive number of factories in Vietnam, producing air pollution. The prosthetic designed for this thesis will have to be able to be produced without causing further harm to the environment.

"Postwar economic improvements have brought Vietnam a long way, but some are pausing now to reflect on the trade-offs made in that time. Gross domestic product expands 6 to 7 percent every year. Meanwhile, though, the frequency of days when Ho Chi Minh City's air is considered unhealthy for sensitive groups has doubled compared to two years ago. Scarier yet, 66,300 Vietnamese died from causes linked to bad air in 2013. "(Vietnam, 2018).

The use of materials and manufacturing processes which have minimal to no negative impact on the environment, will be an added benefit to the success of providing accessible prosthetics to users living in rural Vietnam.

2.3 Summary

To summarize, the prosthetic designed for this thesis will be aimed towards users between the ages of 55 years old to 65 years old, living in rural Vietnam. The primary user is the amputee, the secondary user is the prosthetist, and the tertiary use will be the physical therapist. The information gathered for the user data is based off user/expert interviews and surveys conducted within the community. Obtaining a prosthetic can be an in-depth process as the socket is specified for every individual user by being a casted replicate of the user's residual limb with adjustments made to avoid pressure points and discomfort during use. When researching benchmarked products, two main categories of product functionality arose, having the product be cost-effective and high functioning as well. In terms of the aesthetics, the aim for the prosthetic design is to be a humanistic and modern design, taking advantage of the sustainable materials such as Dupont Delrin, Crepe Neoprene/Urethane Foam, and Ionomeric Polymer Metal Composites (IPMC). Sustainability is a major factor for this thesis, as any negative effects will have impact on Vietnam.

3

Analysis

Figure 13 - Justin Mott, Alarming Trends of Amputees in Vietnam. Retrieved from https://www.nytimes.com/slideshow/2013/06/04/world/asia/05vietnam.html

3 Analysis

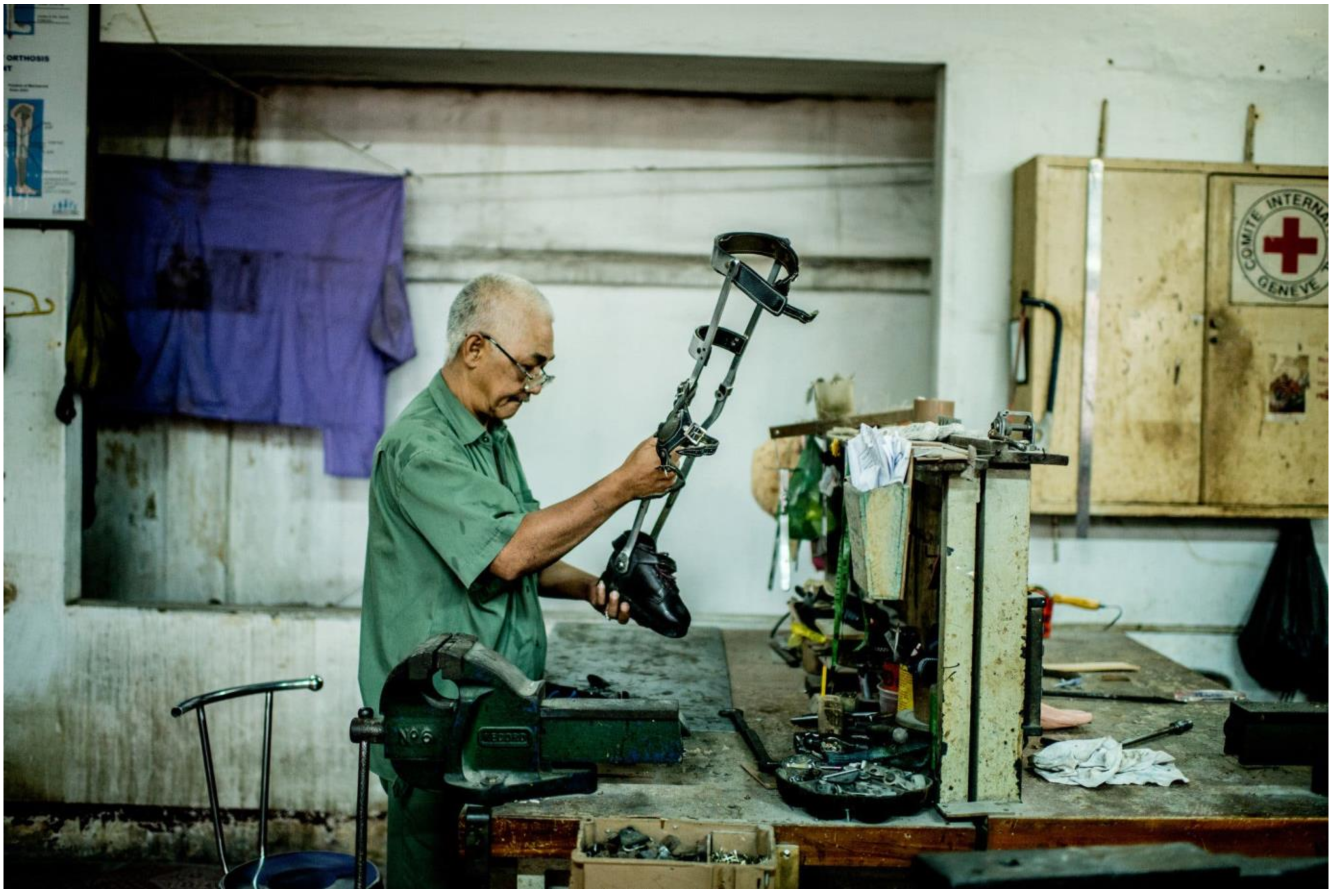


Figure 14 - Justin Mott, Alarming Trends of Amputees in Vietnam. Retrieved from https://www.nytimes.com/slideshow/2013/06/04/world/asia/05vietnam.html

3.1 Analysis – Needs

Living in rural Vietnam is a difficult life, there must be a high work ethic to live a good life in these villages. Work will often be long and laborious, being an amputee makes work next to impossible to complete without a proper prosthetic. With the medical facilities being hours of walking from the village, and the expenses required for a prosthetic, these amputees have essentially been denied the access to prosthetics.

"The dynamic of low and unstable income combined with on-going health care and other disability-related costs gives rise to a range of coping mechanisms (borrowing, reducing and foregoing expenditures, drawing upon savings and substituting labor) that helps to maintain living standards in the short-run yet threatens the longer-term welfare of both the individual with disability and their household." (Palmer, 2015).

Citizens living in these rural villages, farming produce, tending to their crops and animals, face numerous of challenges so that they could have a decent income to live a good life. Their success relies on their ability to work, the ability to travel to markets, and access to proper healthcare.

3.1.1 Needs/Benefits not Met by Current Products

Current prosthetics used by amputees cover a very broad spectrum. Through research, two main prosthetic categories revealed themselves through analysis. Excluding technical equipment such as microprocessor and myoelectric systems, as these prosthetics are considered extremely high end even in first world countries. Most prosthetics used in developing countries for daily use fall into the categories of either rudimentary or complex.

Above-knee prosthetics currently lack humanistic aesthetic in their designs, manifesting to a more utilitarian aesthetic, which can be solved through design solutions. Current rudimentary prosthetic solutions lack the durability and flexibility required to be used daily, while also having a long lifespan. These prosthetics do not allow for the user to be able to fully function and complete their required tasks, forcing them to stop working or push themselves till they injure their body.

A complex prosthetic is an ideal option for an amputee as they will allow the user to be able to function better, but in developing countries like Vietnam, they are extremely difficult to obtain. Citizens living in rural Vietnam have an exponentially difficult time obtaining any type of prosthetic in general as they do not have the access or income available to them. Even with access to complex prosthetics, they often require constant maintenance, and they are unable to withstand activities involving water.

Comfort for amputees is paramount when designing, avoiding damage to the user's residual limb and body, as this will be a product used everyday for long hours, any discomfort may cause long-term damages. Proper stability is required in prosthetics, so that when in use chances of the user falling are avoided so that they do not injure themself or their residual limb.

3.1.2 Latent Needs

Latent Needs	*Benefit Statement*
Comfort	Offers user comforts, feeling natural and efficient when using the prosthetic. Comfortable to use for up to 8 hours a day.
Stability	Proper stability when used to help the user to avoid falling or slipping so there are no further injuries.
Efficiency	Efficient in terms of cost and performance, so that the user may use the prosthetic in any type of event.
Ease	Ease in terms of cleaning and maintenance, to provide the least amount of effort needed to use the prosthetic
Use	Ability to perform various tasks without damage to the prosthetic or user, withstanding heavy loads, athletic activities, and all terrain use.

Table 9 - Latent needs developed through analysis of benchmarked products and user observation.

3.1.3 Categorization of Needs

Through user interviews and product benchmarking analysis, the needs are divided into categories that are based off their importance to the design solutions design and function. This is to link the product benefits with the complementary fundamental human needs. Referencing the "Hierarchy of Human Needs" by Abraham Maslow, a table has been assembled to summarize these needs and their respective categories.

Need	*Benefit Statement*	*Relationship with Benefit*
Control	User can adjust their prosthetic (speed, precision, power) and has full authority of their prosthetic.	*STRONG*
Functionality	Enables the user to perform all required tasks with their prosthetic without any disturbances.	*STRONG*
Safety	Ensures that the user will not fall into harm further damaging their residual limb or injuring themselves.	*STRONG*
Latent Need	*Benefit Statement*	
Comfort	Offers user comforts, feeling natural and efficient when using the prosthetic. Comfortable to use for up to 8 hours a day.	*STRONG*
Stability	Proper stability when used to help the user to avoid falling or slipping so there are no further injuries.	*STRONG*
Efficiency	Efficient in terms of cost and performance, so that the user may use the prosthetic in any type of event.	*MODERATE*
Ease	Ease in terms of cleaning and maintenance, to provide the least amount of effort needed to use the prosthetic	*MODERATE*
Use	Ability to perform various tasks without damage to the prosthetic or user, withstanding heavy loads, athletic activities, and all terrain use.	*STRONG*
Wants	*Benefit Statement*	
Cost Effective	Easy to afford and maintain.	*STRONG*
Stylish Aesthetic	Humanistic aesthetic, stylish, modern appeal.	*MODERATE*

Table 10 - Benefits Relationship Table

3.1.4 Needs of Analysis Diagram

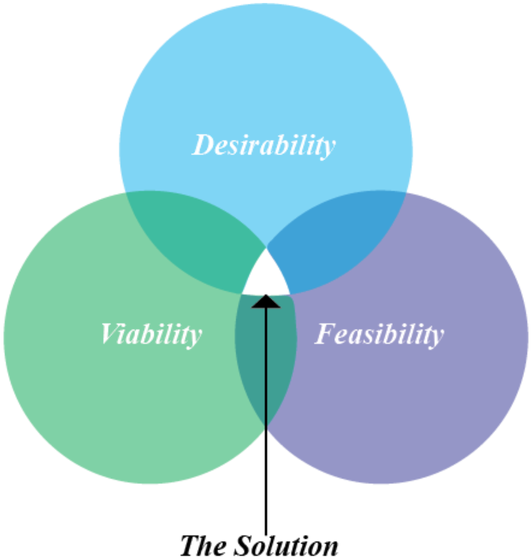


Figure 15 - Needs Analysis Diagram

Desirability

Amputees did not ask for their limb to be removed, if given the chance they would have kept their original limb and avoid any amputation. Since amputees are forced into a situation that leaves them without a limb, they require the next best option, a prosthetic. Many above-knee amputees depend on their prosthetic so that they may complete their daily routine. Prosthetics are often used daily for long periods of time and amputees may heavily rely on their prosthetic.

Viability

When the lifestyle of users living in developing countries are revealed, there are many who would decide to either donate or volunteer to improve the quality of life for these users. There are non-profit organizations whose mission is to provide users in developing countries with supplies that they are in dire need of.

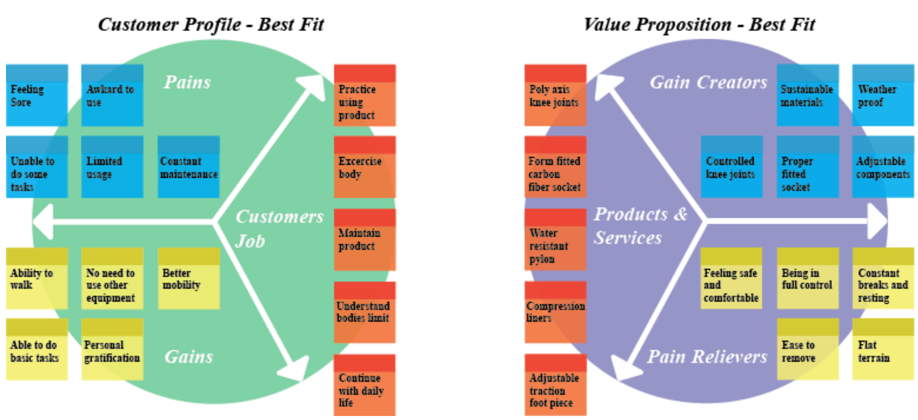


Figure 16 - Customer Profile/Value Proposition Best Fit Diagram

Feasibility

Existing technology for above-knee prosthetics are utilized and are constantly being researched to discover new effective ways to give these users the ability to walk. The challenge is making this technology available in developing countries and having it be accessible for any level of class. Product innovation occurs when the technology used in above-knee prosthetics and sustainable resources are combined with adjustable components.

3.2 Analysis – Usability

3.2.1 Activity – Workflow Mapping

User interview was used to develop an activity map and identifying stages of use in multiple contexts. The activities noted are the steps in which the user's residual limb is casted in plaster, walking with the test socket, and receiving the final socket.

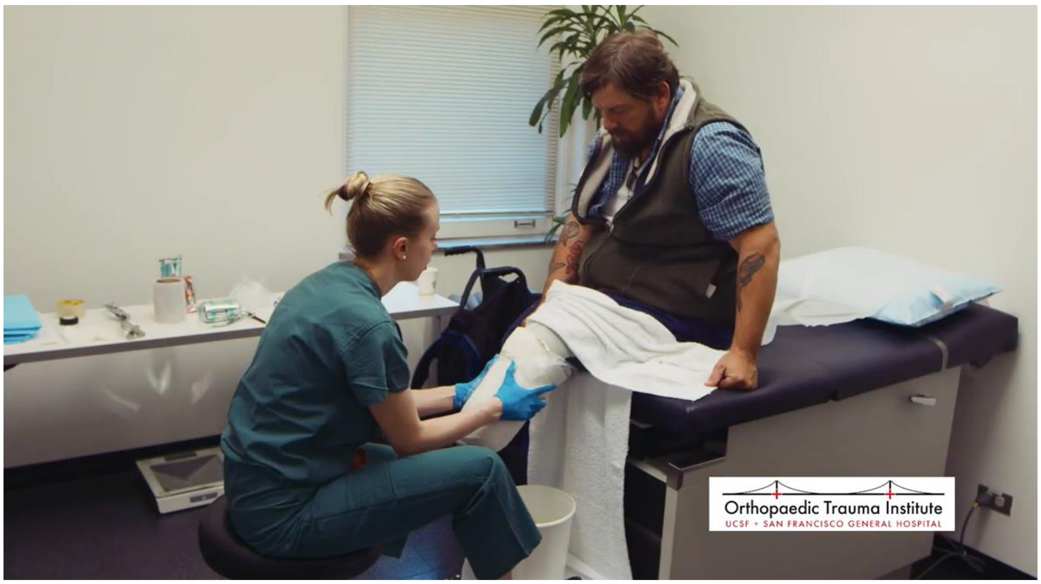


Figure 17 - Retrieved from https://www.youtube.com/watch?v=fIGX9yyPRiE&t=713s

Activity 1	*Steps/Process*	*Base User Experience*	*Potential for Improvement*
Casting the user's residual limb with plaster.	-User wears the gel liner while the prosthetist covers the user's residual limb with saran wrap. -Prosthetist layers plaster strips on the user's residual	-User listens to the prosthetist for any important information about the prosthetic. -Remain calm and relaxed as the plaster is being applied.	-Develop methods for the measuring process to be done remotely. -Simplify process so it can be done volunteers.

	limb and uses the cast to make a plastic test socket.		

Table 11 - Activity 1 Breakdown from Video Analysis.

The first activity conducted is the casting of the user's residual limb. This is done by a prosthetist, before casting measurements are taken of the user's residual limb. If the user will be using a gel liner with their prosthetic, the prosthetist will cast the user's residual limb with the liner, covering it with saran wrap as not to damage the liner when casting. During the casting process the user will feel the plaster begin to generate a slight amount of warmth. Once the plaster has dried, the prosthetist will remove it and use it as a mold of the user's residual limb, which will then be used to vacuum form plastic over, creating the test socket.

Figure 18 - Retrieved from https://www.youtube.com/watch?v=fIGX9yyPRiE&t=713s

Activity 2	*Steps/Process*	*Base User Experience*	*Potential for Improvement*
Walking with the test socket.	-The prosthetist attaches the test socket temporarily to the pylon.	-User may feel some discomfort when walking with the test socket.	-Adjustable socket that can form to the user's residual limb.

	-User walks with the test socket and informs the prosthetist of any discomfort they feel. -Prosthetist will take not of pressure points and adjust the socket as needed.	-Walking may feel difficult, user will need an aid.	-Socket may have an open bottom to alleviate pressure from the incision point

Table 12 - Activity 2 Breakdown from Video Analysis.

The second activity is having the user walk with the test socket. During this activity, the user must disclose any discomfort, pressure, or areas of pain to the prosthetist so that adjustments can be made to the test socket till it proper fits. This process of fitting and adjusting can take place multiple times, this is to ensure that the final socket will not cause the user any discomfort or have negative effects to the residual limb.

Figure 19 - Retrieved from https://www.youtube.com/watch?v=fIGX9yyPRiE&t=713s

Activity 3	*Steps/Process*	*Base User Experience*	*Potential for Improvement*
Receiving the final socket	-When the final socket is ready to be made, the user can pick a specific fabric used in making the socket, this is so the user can customize their socket. -User will receive the final socket and the prosthetist will inform the user of all the required maintenance for the prosthetic.	-User is excited to receive the final socket that has been customized to their aesthetics. -User must take it a large amount of information about the prosthetic.	-Develop a method for the user to receive their socket earlier so there is less wait time. -Allow the user to have more customizable options available

Table 13 - Activity 3 Breakdown from Video Analysis.

An analysis of the fourth activity identifies the user receiving their final socket and being able to use their prosthetic at their leisure. When receiving the socket, the prosthetist will inform the user about the actions needed to maintain their prosthetic, exercise their residual limb and the recommended amount of time for use.

3.2.2 Activity – Experience Mapping

Experiencing mapping proved to be a useful method when analyzing data, it offers a visual representation of the data that has been collected to identify the primary pain points as the user completes their task. The activity map is used to benchmark the average experience the user may have during this activity and their level of contentment that they experience when completing the activity. This can be used to analyze where there can be improvements made to the activity, which will inform the thesis design solution.

Shown in Table 14 is an experience map for a user having their residual limb casted to receive a final socket for their prosthetic. The collected data samples have been graphed in terms of the user's experiences, identifying areas for enhancing the experience.

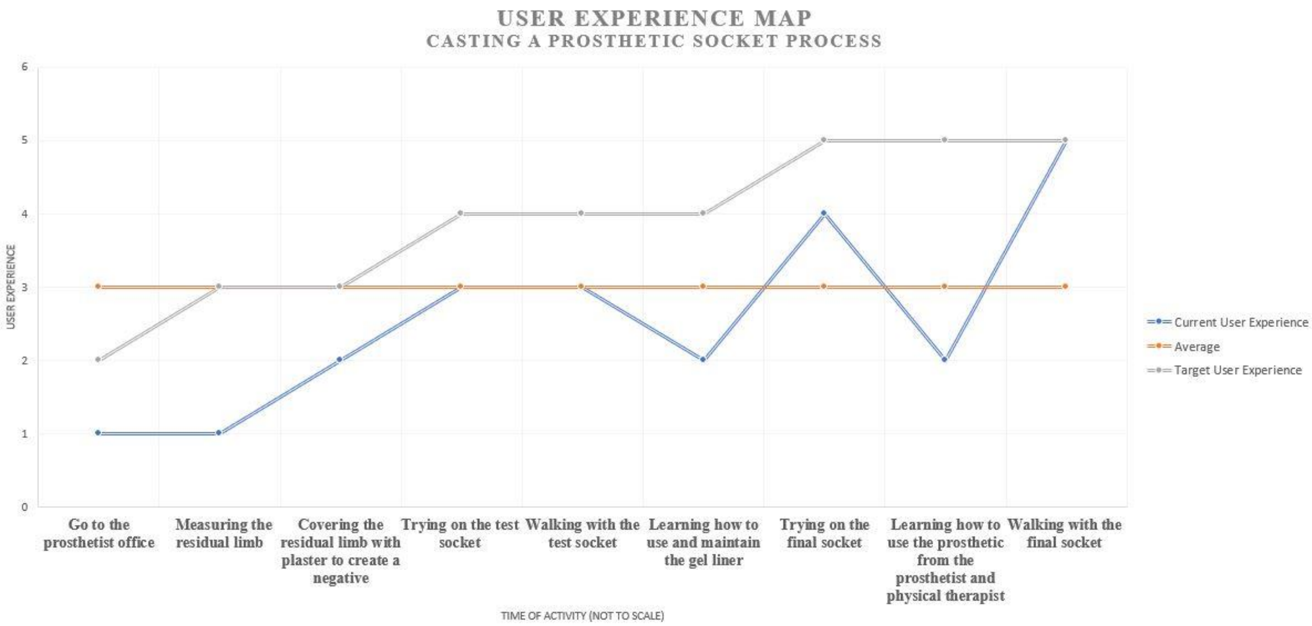


Table 14 - Projected User Experience Map

1 (Very Poor), 2 (Poor), 3 (Average), 4 (Good), 5 (Very Good)

As observed, the user begins the activity with a low satisfaction level, due to the length of time spent going to the prosthetist office and the anxiety the user may feel about getting casted. When it is a user's first time being casted for a prosthetic socket, the user may feel nervous about what they will experience. When the prosthetist is measuring the user's residual limb, this can be a very intimate process that may make the user feel uncomfortable. The casting process itself is very simple and does not cause the user to feel any discomfort or pain, the feeling itself may simply feel odd. During the meetings with the prosthetist, they will inform the user of what they must do to maintain their prosthetic, this can be an overwhelming amount of information for the user which can cause the user experience levels to drop below average. Once the prosthetist has made the test socket the user will feel more excited as they are closer to receiving their final prosthetic, though the test socket may cause the user some discomfort, but this will be adjusted by the prosthetist. After multiple fittings with the test socket, the final socket can be made using a fabric chosen by the user. When the final socket has been finished the user is able to try it on with their prosthetics, this is where the user experience peaks as the user is able to walk with their prosthetic. At first the prosthetic may feel odd for the user to walk with as their body must adjust to this new addition. Minimizing these pains, while enhancing the user's experience in these areas will add credibility and value to the final design solution.

3.3 Human Factors

For an amputee, there are two options for the user, obtain a prosthetic and adjust the way they function to use it, or use other equipment, such as crutches or a wheelchair. Regardless of the choice that the user makes, their body will have to adjust the way it had normally functioned, these adjustments if not done right may cause risk to the user's health. Ergonomics in above-knee prosthetics is extremely important, the slightest misalignment may rapidly wear down the user's joints, or if there are pressure points in the socket, it may cause the residual limb to swell. In developing countries such as Vietnam, these ergonomic factors may not be prioritized as there is limited accessibility to obtain a prosthetic in general. The ergonomic interactions this report will focus on the user's experience while using their prosthetic in their day-to-day life. Important factors to focus on within the context of ergonomic testing were:

- Innovating the socket for the residual limb
- Determining the level of movement of the user when conducting daily tasks

Literature Review

The anthropometric data that is referenced throughout this report is retrieved from "The Measure of Man and Woman" (Dreyfuss & Tilley, 1993). The overall dimension for a male 97.5^{th} percentile and female 2.5^{th} percentile is used in this report. The specific dimension considerations are seating variations, walking, or standing aids, and overall movements. These dimensions will be used to accommodate users ranging from the 97.5^{th} to 2.5^{th} percentile of users, ensuring comfort and safety for the users. A poorly designed product may cause harm and jeopardize the user's safety if the proper ergonomic standards are not met. The ergonomic design will take into consideration physical differences in international populations as well, without compromising "the needs of the statistically defined *average* person." (Dreyfuss & Tilley, 1993).

Methodology

The ergonomic evaluation and analysis of the ergonomic buck model of the above-knee prosthetic leg design was conducted with the following elements being constructed:

Above Knee Prosthetic Leg	This ergonomics will focus on the joinery for the prosthetic and how it will produce a natural gait for the user. The joint between the socket and the knee requires smooth movement that can easily be controlled by the user.
Adjustable Cane	Ergonomics for the adjustable cane will provide comfort and support for the user when used with their prosthetic.
Compression Shorts	The electro-stimulators and controls will be mapped in this ergonomic buck to obtain the most ideal placements for the user.

Table 15 - Ergonomic Buck Elements

Objective(s)

The aim of this process was to evaluate the full-bodied human interaction design and full-bodied ergonomic challenges for an above-knee prosthetic leg. While *full-bodied* as a term may have several meanings, pertinent to the thesis criteria, this report evaluates only three major body part areas relevant to full-bodied human interaction design (Chong, Zaccolo, Kappen, Thomson, Burke & White, 2020). This ergonomic evaluation report outlines the methods used to evaluate the three major body-part areas for assessment from human factors, ergonomics, and convenience of use challenges.

Decision(s) to be Made

The following user interactions were analyzed to identify any negative interactions an amputee may have with their above-knee prosthetic leg. Major body part areas (Chong et al., 2020) were investigated to minimize the negative experiences and maximize the positive experiences of:

1. Putting on and taking off the prosthetic (Hands, Leg, and Torso)
2. Wearing the prosthetic for long periods of time (Leg and Torso)
3. Removing and replacing modular parts (Hands and leg)

Description of Users Targeted by Product

The following traits were used during the consideration process of the various components of the ergonomic prosthetic:

- The target demographic are above-knee leg amputees living a laborious lifestyle in rural Vietnam.
- Ages range from 45-65 years old with a majority of the demographic being male.
- For the user observation report, individuals were observed interacting with a prosthetic leg.

Evaluation Process

The evaluation process consisted of designing, construction, and testing of a full scale (1:1) ergonomic model of the above-knee prosthetic leg which allowed for critical observation of the following:

1. Observing how the user puts on and takes off the prosthetic. (Hands, Leg, and Torso)
2. Observing how the user interacts with their prosthetic while wearing it. (Leg, and Torso)
3. Documenting the user when adjustments are made to the prosthetic. (Hands, and Leg)
4. Analyzing the user when they are removing and replacing modular parts. (Hands, Leg, and Torso)
5. Identifying critical human dimensions affecting product use

Description of User Observation Environment Used in this Study

The ergonomic model for the prosthetic was created in a home studio located in Markham, Ontario. Materials such as corrugated cardboard, MDF, metal wires, fabric, and blue foam were used to construct the model prosthetic.

Location and Timeframe

Date of Observation(s):	January 10, 2021
Location of Observation(s):	Markham, Ontario

Table 16 - Observation Location and Timeframe

Results

The results of the ergonomic testing's are illustrated below. Anthropometric data was combined with the visuals of the ergonomic buck in order to depict natural in use photographs. The ergonomic drawings were created using the dimensions of a 95th percentile male, 50th percentile male and 5th percentile female, as these are the primary demographics for the proposed design. The physical evaluation was conducted with a broad range of human percentiles.

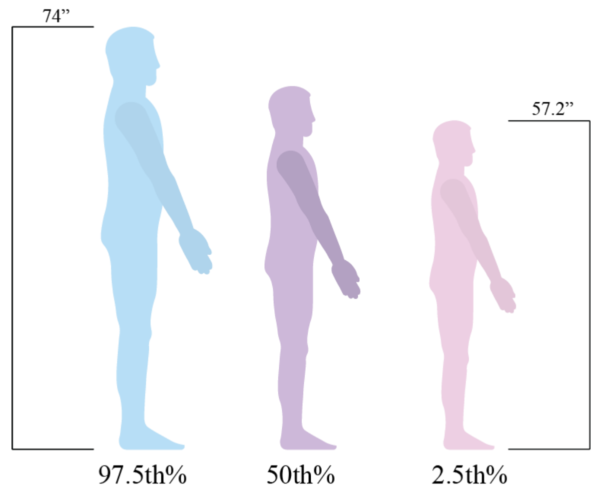
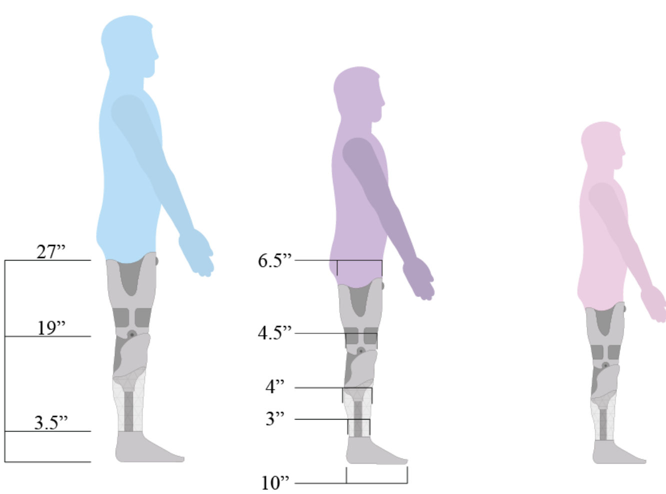


Figure 20 - Human Percentile Graphic

Analysis

The following graphic elements were used to depict the various human percentiles in the ergonomic drawings, color coordinated to differentiate these percentiles and are used throughout all the drawings.



In this image, the above knee prosthetic design is laid out over the human percentiles. The prosthetic will consist of an adjustable socket, poly-centric knee joint, prosthetic pylon, 3D printed pylon cover and a modular foot. The main areas of measurements are illustrated in the image, the height/diameter of the user's thigh, knee, and ankle.

Figure 21 - Prosthetic Ergonomic Measurements

An adjustable cane was designed as an accessory for the prosthetic, so that it may be attached to the knee joint to assist the user with navigating with their prosthetic. The cane is designed to be printed with a living hinge, allowing for the cane to fold in half for easy travel. This design is to provide the user a locking system to easily allow the user to fold and unfold the cane without jeopardizing the canes strength. The bottom of the cane is embedded with a high strength magnet to hold the canes shape when folded.

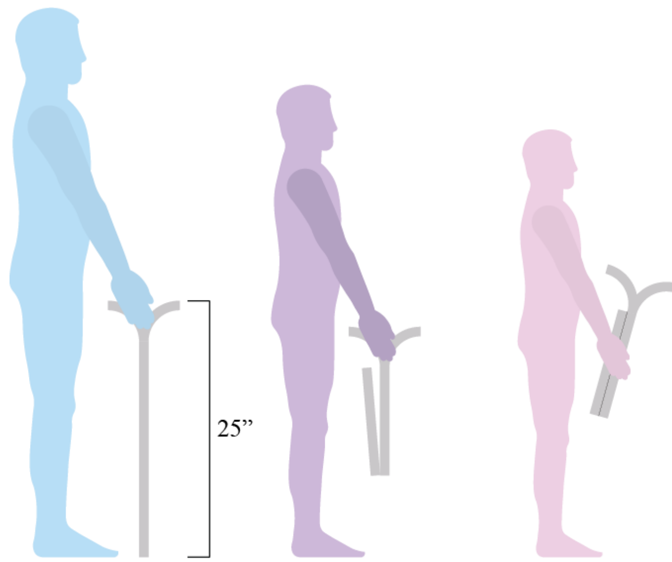
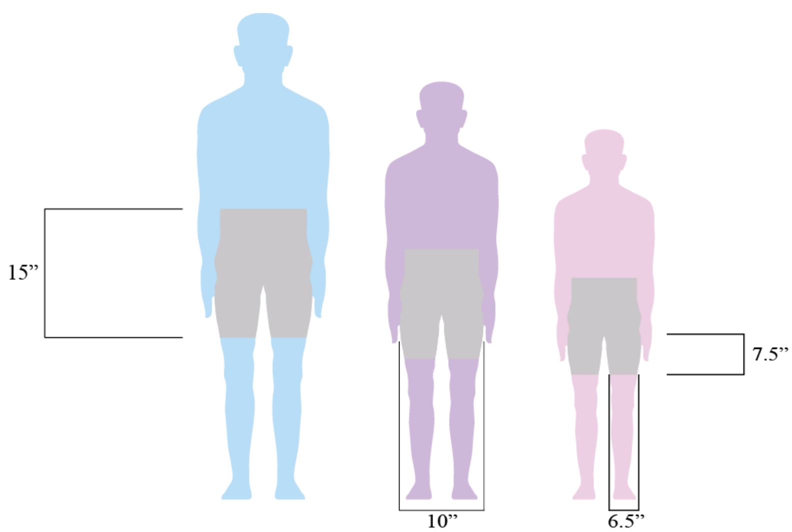


Figure 22 - Cane Ergonomic Measurements



This final accessory is a pair of compression shorts modified for above-knee amputees, providing the user with electro-stimulation on their residual limb to alleviate, pain, soreness, or phantom limb symptoms.

Figure 23 - Compression Shorts Ergonomic Measurements

Ergonomic Buck Interaction & Analysis

<table>
<tr><th colspan="2">Above – Knee Prosthetic Leg (Field Data Analysis)</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>The 50th percentile female is simulating how the prosthetic would be worn by an amputee by standing with the prosthetic.</td><td>The 50th percentile female takes apart the prosthetic, to simulate how users would disassemble the prosthetic to provide maintenance or replace parts.</td></tr>
<tr><td colspan="2">This study focuses on the ergonomics surrounding the hands and leg, how they interact with the prosthetic, minimizing any strains when in use.</td></tr>
</table>

Table 17 - Prosthetic Ergonomic Buck

Electro-Stimulation Compression Shorts (*Field Data Analysis)*	
	
In this image the 50th percentile female is comparing the sizing of the compression shorts to themselves. The material for the shorts will be a flexible fabric to ensure other percentiles may comfortably wear them as well.	Here the 50th percentile female is simulating how a user would wear the compression shorts with the prosthetic, showing that the residual limb is fully covered while the sound limb is exposed.
This study focuses on the ergonomics surrounding the leg and torso of the user to ensure comfort for the user when in use	

Table 18 - Compression Shorts Ergonomic Buck

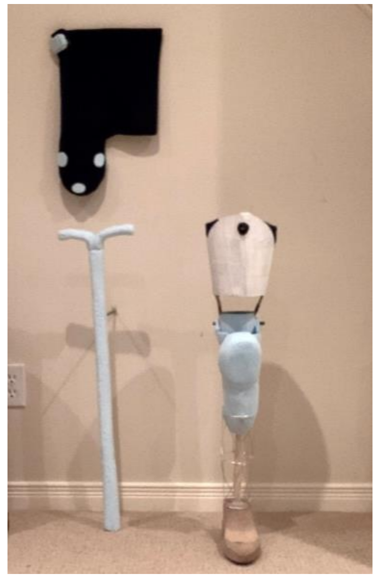
<table>
<tr><th colspan="2">Adjustable Cane (Field Data Analysis)</th></tr>
<tr><td></td><td></td></tr>
<tr><td>In this image the 50th percentile female had attached the adjustable cane to the knee joint of the prosthetic to demonstrate how the user would walk with the cane attached to the prosthetic.</td><td>This image is a comparison of the cane to the prosthetic leg. The handle is designed to be used by either a left or right above knee amputee.</td></tr>
<tr><td colspan="2">This study focuses on the ergonomics surround the hands and their interaction with the prosthetic.</td></tr>
</table>

Table 19 - Adjustable Cane Ergonomic Buck

Ergonomic Buck Analysis

This proposed thesis solution along with the human interaction study enforces the efficiency which an above-knee leg prosthetic can offer. The ergonomic study demonstrates the modularity and comfort that can be provided to amputee users in developing countries such as Vietnam. This design is based on the ease of manufacturing leg prosthetics so that users living in rural areas are not limited by cost, distance, and sizing as heavily.

The interactions that the 50th percentile female had with the ergonomic buck which were constructed, focuses on the primary attributes of this thesis, which is removing challenges with owning and maneuvering an above-knee prosthetic leg. Specifically focusing on amputees living in rural villages in Vietnam, suffering from a lack of income. Physical limitations such as weather, and body strength were not possible, leaving room for error and inference. Amputees living in rural Vietnam suffer a great deal to continue living their life, especially with the lack of a stable income. The design for this thesis is to not only design an accessible prosthetic but also design an organization that travels throughout rural villages in Vietnam to provide as many prosthetics as possible. The manufacturing of the prosthetic itself can be done by this company using various 3D printers. As many first world countries outsource their manufacturing to developing countries such as Vietnam, negative environmental impacts are essential to avoid as these impacts would be reflected upon Vietnam once more.

The ergonomic buck of the prosthetic demonstrates how the proposed design solution would allow the user to disassemble and maintain their prosthetic with ease. This is an important factor, as many of these users have limited access to medical facilities. This feature would also allow for worn parts of the prosthetic to be easily replaced. The design of the prosthetic accessories was designed with compatibility in mind to support the laborious lifestyle of the user. These accessories may be easily stored in a travel bag and brough along with the user, so that they may be used when in dire need of support.

Limitation and Conclusions

Identifying critical human dimensions affecting users and product use were as follows:

- Optimizing the sizing of the prosthetic socket and ensuring comfort when worn.
- Customizable height for the prosthetic pylon covers to support various heights and to produce a natural gait for the user.
- Overall dimensions of each part of the prosthetic are critical to provide comfortable use and feasibility of walking or running when worn.

3.4 Aesthetics & Semantic Profile

Considering the environment of use, Vietnam, in which this solution will ideally be used, the look and feel of the solution should match accordingly. Additionally, it will be heavily reliant on the humanistic and organic aesthetic of the design. The design for this solution will not include additional parts that do not benefit the user or their ability to function with the prosthetic. Function will be the primary driver of this design, while also providing the user with an option of customization.

The overall form of the prosthetic will be organically formed to mimic the muscular anatomy of a human leg. Care will be taken to address the durability of fluidness of the prosthetic form, ensuring that whilst it is high strength, it will also be lightweight and natural. The organic design of the solution is used to provide a connection between the user and their prosthetic, ensuring when in use there are minimal differences between their prosthetic and their sound limb.

Concept prosthetics offers an interesting insight into the exploration of form and function. Using the blue-sky technique to approach the design while keeping the overall organic form in consideration. The study of unique and abstract forms enables some level of creativity to be revealed in the final design.

The goal of this aesthetic exploration is used to encourage innovation and diverse styling solutions in this organic form. The following mood board was developed to ensure a consistent and sophisticated styling approach to the final design solution.

Figure 24 - Styling Mood Board

3.5 Sustainability – Safety, Health and Environment

3.5.1 Safety

Working in Vietnam, living in rural villages and being in middle-lower class, is a hardworking lifestyle. Safety concerns for amputees living this lifestyle and longevity must be addressed in order to satisfy the essential and basic needs of the user. The safety and comfort of amputees is very important, as improper use or inaccurate ergonomics may cause them further harm. Vietnam's environment is laborious, hands on work is the commonly worked industry, this environment will be taken into consideration to ensure it will cause no damages towards the prosthetic and user. Temperature in Vietnam ranges between 20°C – 35°C throughout the year and has an annual humidity of 85%, therefore the prosthetic must be able to withstand constant heat while not being affected by high humidity.

As it is common to come across water throughout the day whether it is showers or simply rain, the prosthetic must not be affected by this. Slips and falls are extremely dangerous for an above knee amputee, as impact on their residual limb may cause terribly painful and long-lasting injuries. This can be solved by using materials in the prosthetic that is not affected by water and providing a non-slip sole for the foot. The user must be able to adjust towards their prosthetic, whether it be maintenance or setting changes, with ease and in a manner that does not jeopardize the user's safety. This is a manual task that will require the user to be educated on these matters so they can be done in a proper fashion.

When worn daily, low quality prosthetics may cause irritation to the user's skin and residual limb. The constant friction between the user's residual limb and their prosthetic may cause the user to be unwilling of continuing to wear their prosthetic, leaving them to options such as crutches, wheelchairs or by

hopping on their sound limb. Crutches can cause irritations to the users' arms and puts additional pressure on the user's sound limb, causing it to deteriorate faster than it should. Wheelchairs are a sustainable option but are high cost and unsuitable for the terrain in rural areas of Vietnam. All prosthetists and physical therapists do not recommend sampling hopping around on their sound limb as it will cause their knee joint to rapidly age and deteriorate, the user will also be at high risk of injury from falling.

Figure 25 - Derek Hudson, Retrieved from https://www.derekhudson.com/work-/vietnam-legacy/#still502

3.5.2 Health

The health of citizens in Vietnam is not always prioritized compared the health of citizens in other countries. Being a developing country, Vietnam does have hospitals and medical facilities but citizens living in rural villages must travel a long distance either by walking or bicycle, maybe a bus if the citizen has enough money to spare. Medical insurance in Vietnam is also limited as many citizens are self employed or work for smaller companies, therefore they have difficulty covering these expenses, not giving them the access to proper healthcare. The physical labor these citizens work in order to make their income takes a toll on their bodies, the prosthetic is designed to not only keep up with this style but avoid the user from additional pains or injuries. It is crucial that the prosthetic does not cause any harm or irritation towards to avoid long term injuries and to encourage the user to wear their prosthetic continuously.

Figure 26 - Justin Mott, Retrieved from https://www.nytimes.com/slideshow/2013/06/04/world/asia/05vietnam.html

The mentality of these users is important, as adapting to this new lifestyle is extremely difficult and will cause stresses towards the user. It is common for recent amputees to go through depression, this feeling can last years for the user if they do not receive the help they need. To reduce the difficulty when using a prosthetic means it will reduce the frustrations users experience when learning how to normally function again. The physical stresses that these users experience can cause mental effects as well, users may experience somatization, the significant focus of physical symptoms. Depression, anxiety, and anger are common psychological effects post-amputation. To reduce the risks of these psychological effects by making the transition from a wheelchair to prosthetic as smooth as possible.

3.5.3 Environment

As many countries outsource their manufacturing to developing countries, Vietnam is being polluted and saturated from the remnants of these factories. The manufacturing for the prosthetic will be conducted in Vietnam, therefore it is crucial that there is no additional pollution from the manufacturing process.

The design for this prosthetic is to have a portable facility travel across Vietnam to provide prosthetic to as many citizens as possible. To refrain from adding additional pollution to Vietnam, this facility would be built from an upcycled cargo shipping container, driven on the back of a solar powered semi-truck. All components of the prosthetic will be manufactured using 3D printing powered by the same energy gathered by the semi-truck, this will also allow for failed prints to be upcycled and used again so nothing goes to waste.

The materials that the prosthetic will be made from are titanium, Dupont Delrin plastic and Roica sustainable yarn. These materials are durable to produce a long-life product, and they are sustainable. The designed prosthetic is composed of 5 main parts; the socket, knee joint, knee cover, pylon and foot, all parts can be easily fastened together. The user will be taught how to assemble and disassemble the prosthetic if needed so they may maintain their prosthetic if they are a great distance away from the prosthetic facility. The prosthetic is also designed to be disassembled so that certain parts may easily be replaced when they have been used to their full extent. It will be encouraged for users who own these prosthetics, return their worn parts for new ones so that the worn parts may be turned into filament to be used to 3D print more prosthetics.

The impact the prosthetic design and manufacturing has on the environment in Vietnam is crucial. The prosthetic is designed for citizens and Vietnam to benefit both as much as possible. The prosthetic is designed using the cradle-to-cradle method of manufacturing to ensure there is as little waste as possible produced.

3.6 Feasibility & Viability

As depicted in the cost estimate below, the costs for the above-knee prosthetic and accessories would add to a total of $581 per unit when manufacturing with the business model, as a rough cost.

Component	*Cost (CAD)*
Socket	$15
Knee Joint	$5
Pylon	$2
Foot	$5
Shin Cover	$370
Collapsible Cane	$130
Compression Shorts	$50
Shoe Cover	$2
Fasteners	$2

Table 20 - Component Cost

In the table below are the estimated costs for the business model to produce the prosthetic and accessories, coming to a total of $643,600.

Component	*Cost (CAD)*
Semi-truck	$190,000
Cargo Container	$5,600
Interior remodeling	$5,000
Furniture	$2,000
Plastic 3D Printers (4 units)	$5,000
Metal 3D Printers (4 units)	$200,000
Fabric 3D Printers (2 units)	$36,000

Table 21 - Business Model Cost

3.7 Design Brief

This design brief will act as an aid as the design progresses through the concept development stages. The goal of this thesis project is to a design an above-knee prosthetic that is easily accessible for users living in rural Vietnam. This prosthetic should be easily manufactured, affordable, allows users to maneuver through their daily activities with ease and assist them through the initial stages of becoming accustomed to walking with a prosthetic.

Safety	Creating a safe prosthetic that allows the user to continue with their daily functions without any additional pressures or pains. Developing strong structures to ensure that the user's safety will not be compromised.
Ergonomics	Curate a design that is able to secure various users, ensuring that the user is fully supported regardless of what human percentile they categorize as.
Aesthetics	The aesthetics must inspire confidence for the user, motivating them to continue with their daily tasks without feeling challenged by their disability.
Intuitive and Trustworthy	Technology and solutions implemented into the design must be intuitive for the user and easily maneuvered. This solution must inspire trust and confidence for the user, ensuring that minimal changes need to be made in their lives.
Integration of New Technology	Adopting current prosthetics technology and entertaining the ideas for new and adapting technologies will be crucial to this thesis. Integrating technology from other industries that are applicable can be useful when seen from various perspectives.
Versatile	This thesis solution will need to be versatile in its functions and its forms Being able to accommodate city or rural lifestyles, functioning in wet environments and having various aesthetics to match various users.

Sustainability / Less harmful to environment	Ensuring that the materials and manufacturing methods have minimal to no environmental impact is essential. Since many first world countries outsource their manufacturing to third world countries such as Vietnam, these manufacturing factories pollute Vietnam’s environment.
Comfort	Prosthetics are worn an average of 6-8 hours per day, which may cause pains and discomfort for the user. The thesis solution must be able to allow the user to feel comfortable when worn for 8+ hours to ensure the user is highly functional.

Table 22 - Thesis Design Brief

4

Design Development

Figure 27 - Falco Negenman, Retrieved from https://unsplash.com/photos/Il0GaJtfvj0

4
Design Development

Figure 28 - Falco Negenman, Retrieved from https://unsplash.com/photos/Il0GaJtfvj0

4.1 Idea Generation

To start the design process, three categories of prosthetics were developed; Training, Travel and Farming, to direct the design solution away from a traditional prosthetic leg. As the thesis warrants itself towards a highly technological focused product but ensuring that design was easily accessible was very important. From the beginning of the project, it was a challenge to stay away from a highly technological design that would be difficult for other users to obtain. Likewise, refraining from implementing styling decisions which twist the design towards a more utilitarian aesthetic were avoided. The ideation phase involved many visual and aesthetic directions, focusing on organic and refined forms with a great emphasis on styling.

4.1.1 Aesthetics Approach

Figure 29 - Inspiration Board

An inspiration board was created to better understand the design process and generate new ideas, while also developing a specific style direction.

Companies such as Penta, Ottobock and Limbox were used to help develop the form and style of the prosthetic. The ideal aesthetic for the design is an emphasis on complex organic forms with a sleek and modern design.

4.1.2 Mind Mapping

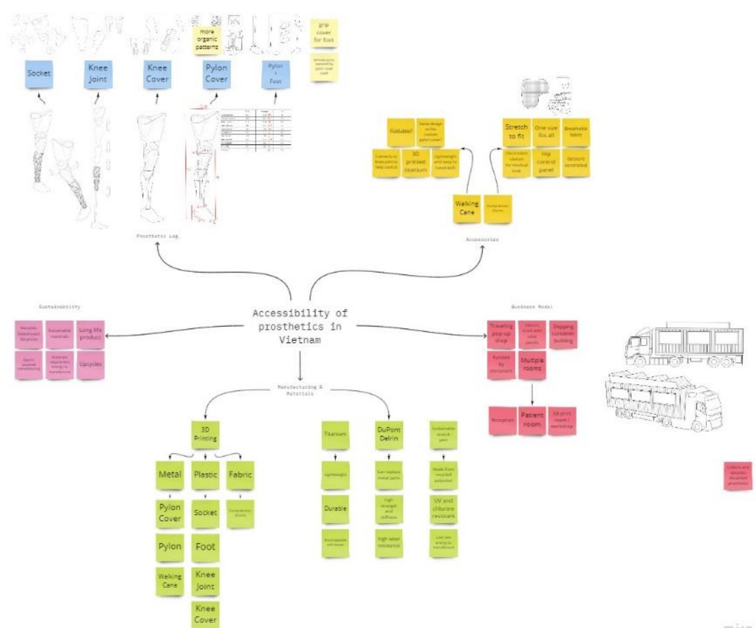


Figure 30 - Mind Mapping Experience

4.1.3 Ideation Sketches

At the beginning of the design process, initial ideation sketches were drawn to obtain and understanding of how the prosthetic would improve the user's quality of life. With a combination of research and form study, six initial ideation sketches were made. The aim of this process was to generate as many ideas as possible and generate a general design direction that could later be improved upon.

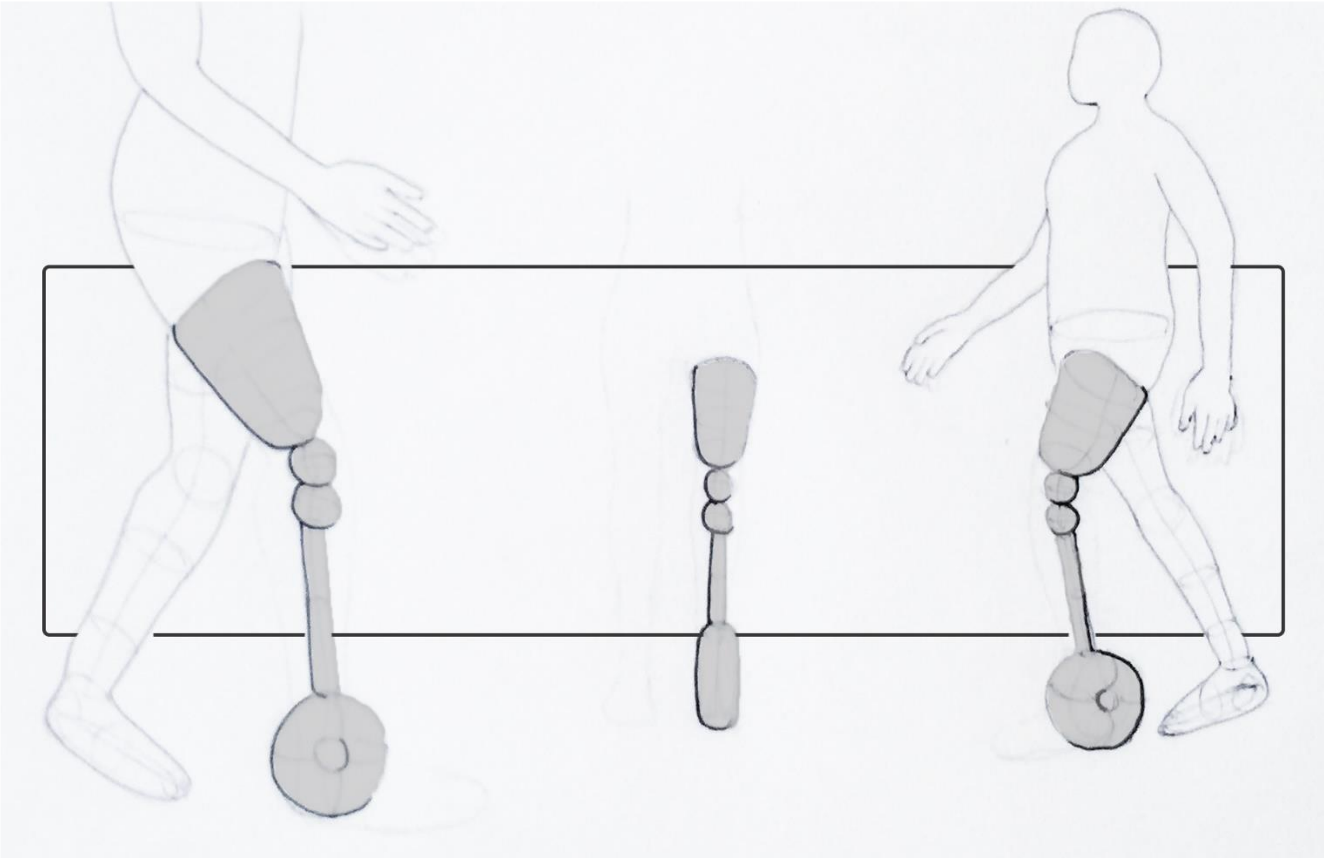


Figure 31 - Ideation Sketch 1

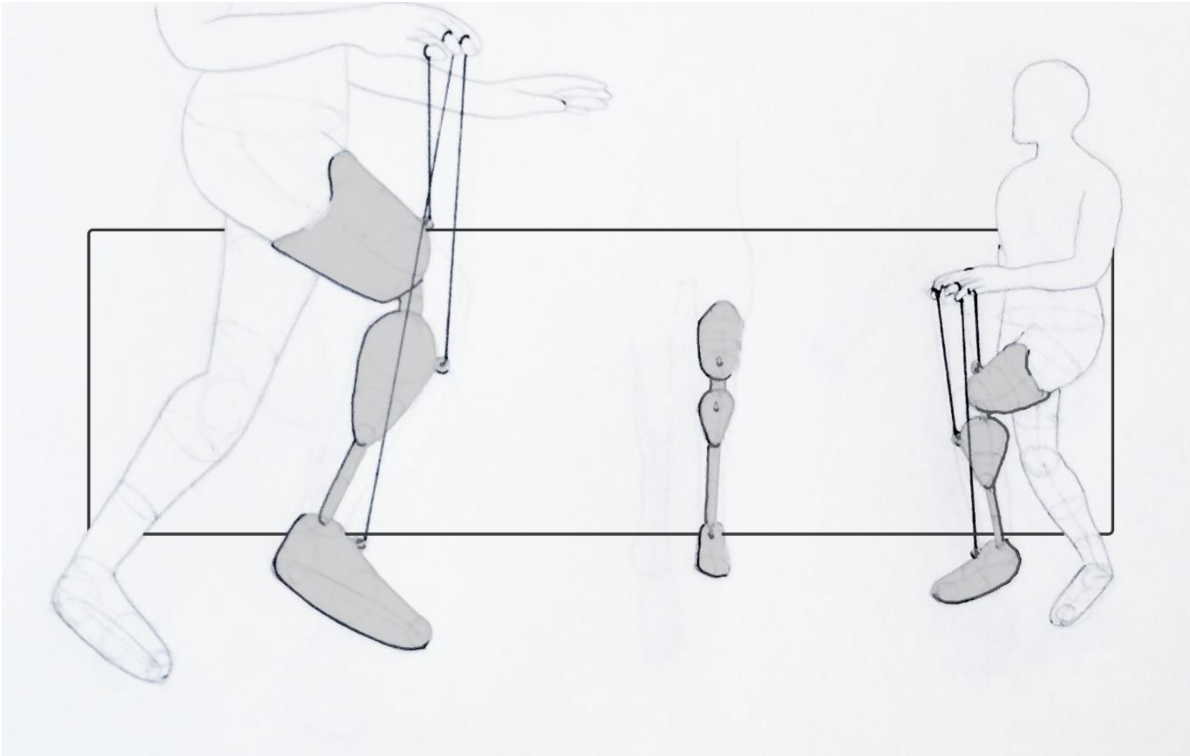


Figure 32 - Ideation Sketch 2

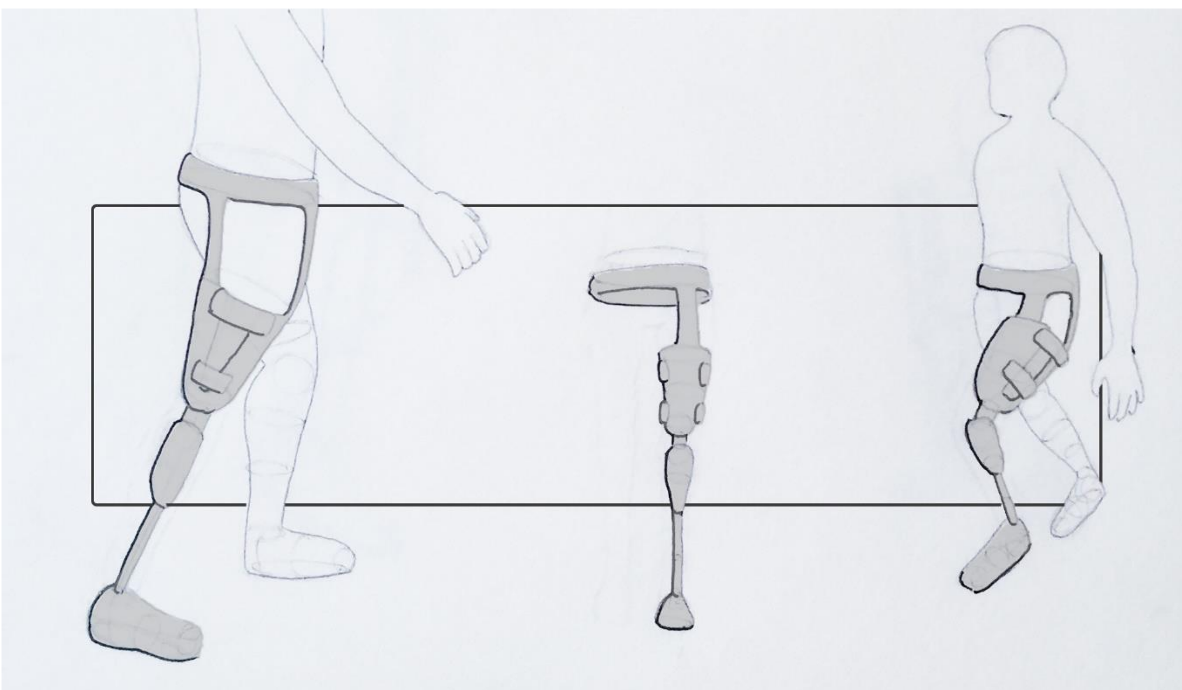


Figure 33 - Ideation Sketch 3

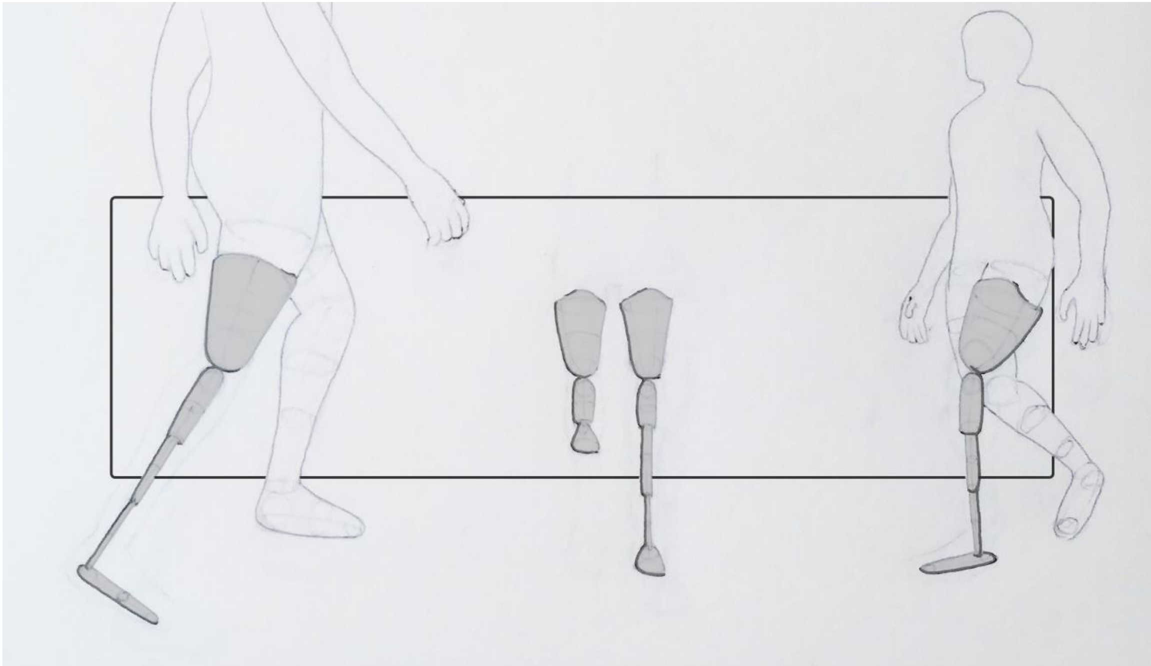


Figure 34 - Ideation Sketch 4

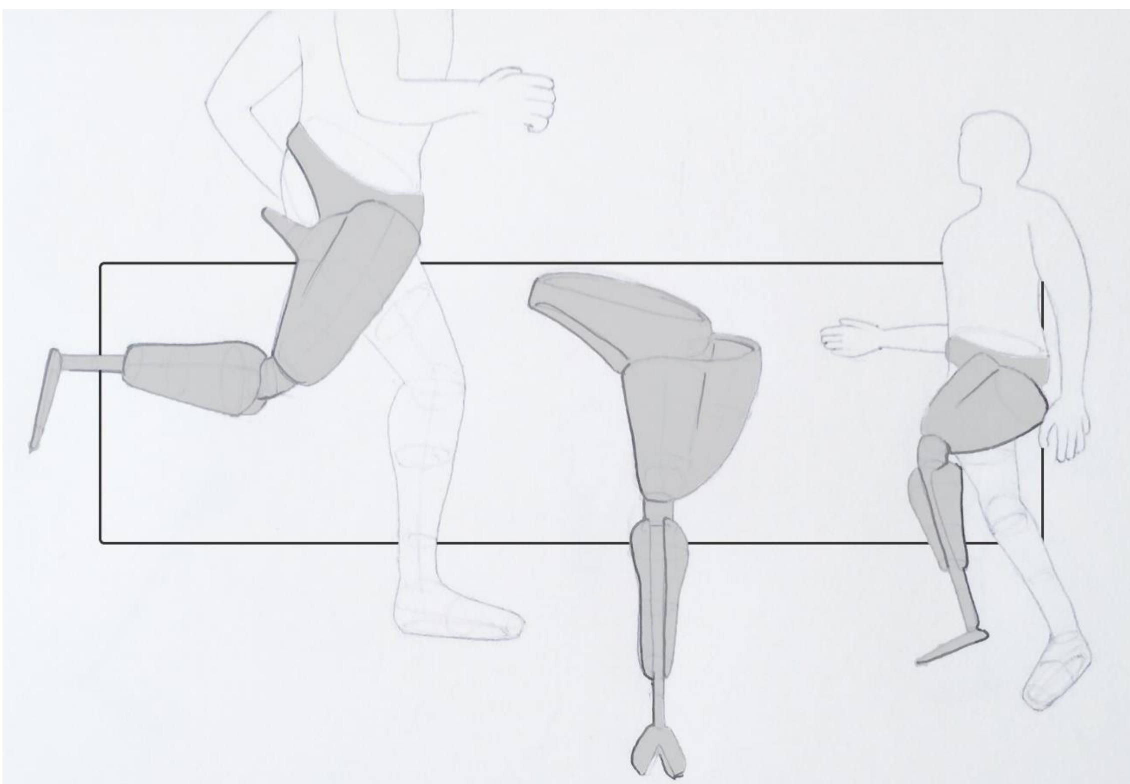


Figure 35 - Ideation Sketch 5

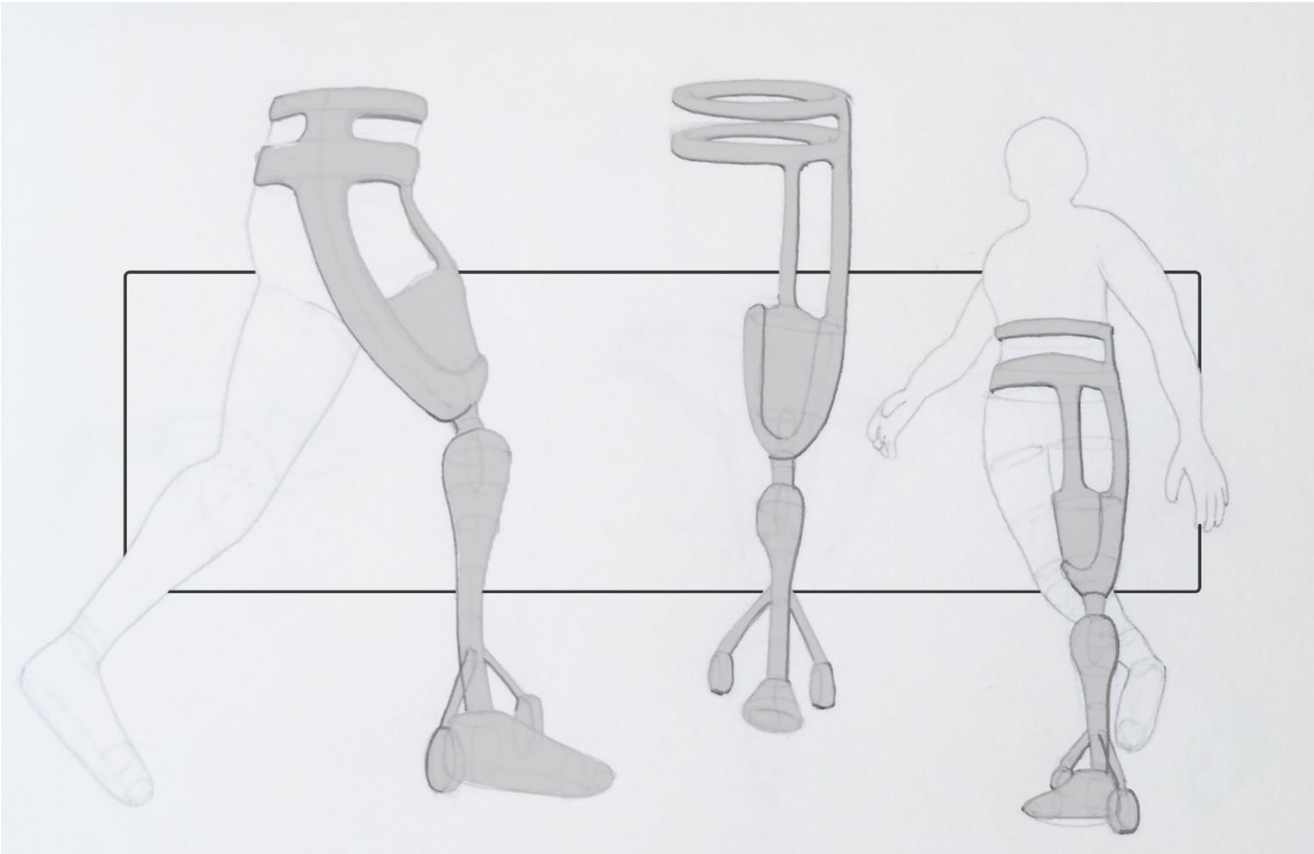


Figure 36 - Ideation Sketch 6

4.2 Preliminary Concept Explorations

Concept development for this thesis involved taking the six initial directions as derived from the ideation process and selecting three of the most practical and relevant ideas to further develop. These three ideas were then explored further, each concept focused on one of the three categories for prosthetics: Training, Travel and Farming.

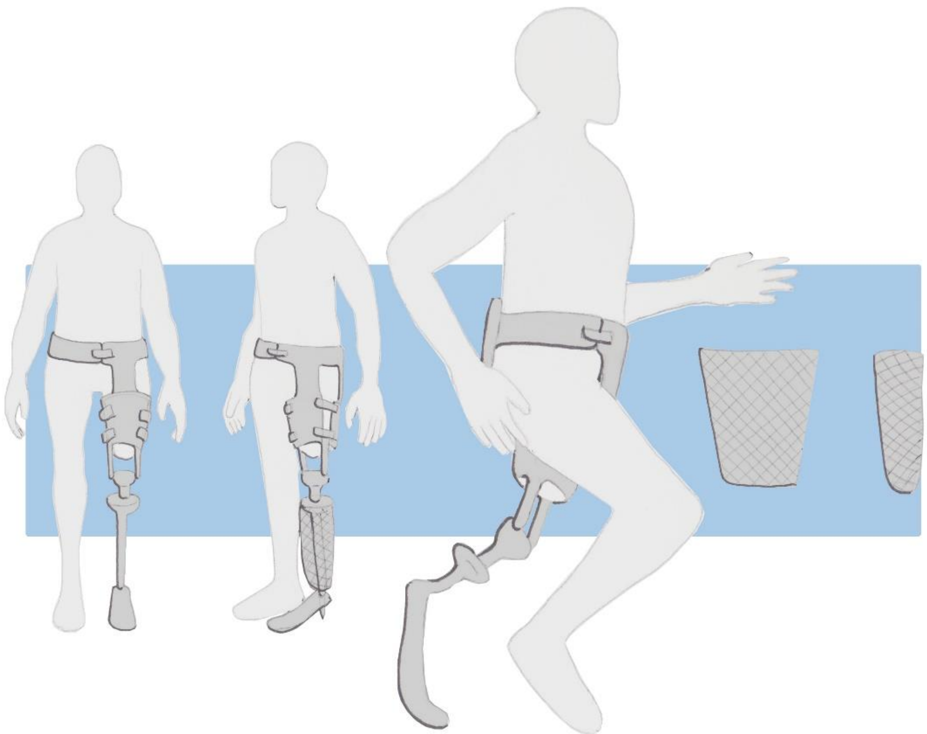


Figure 37 - Concept Sketch 1

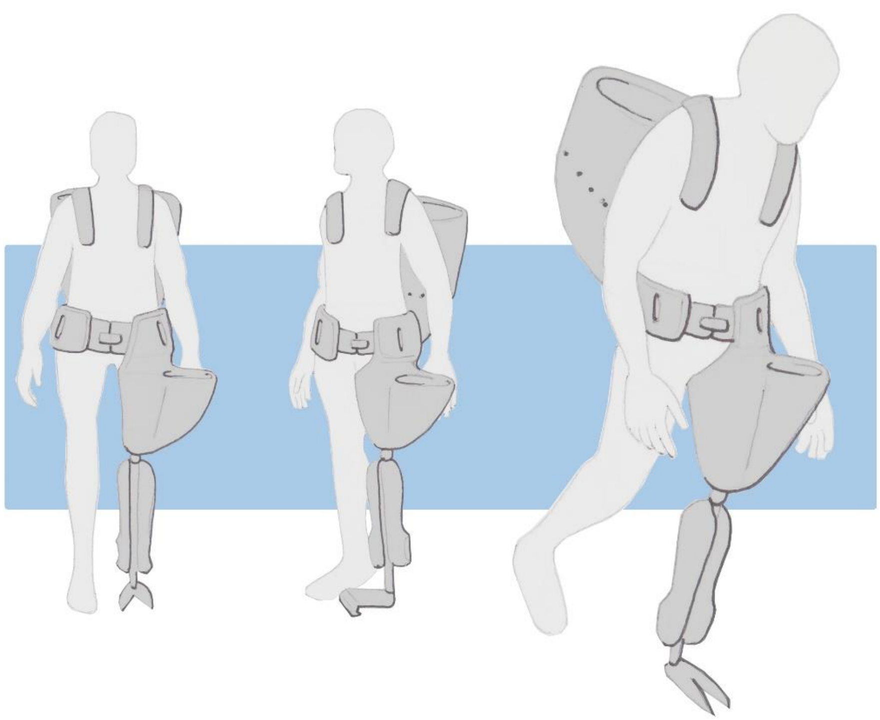


Figure 38 - Concept Sketch 2

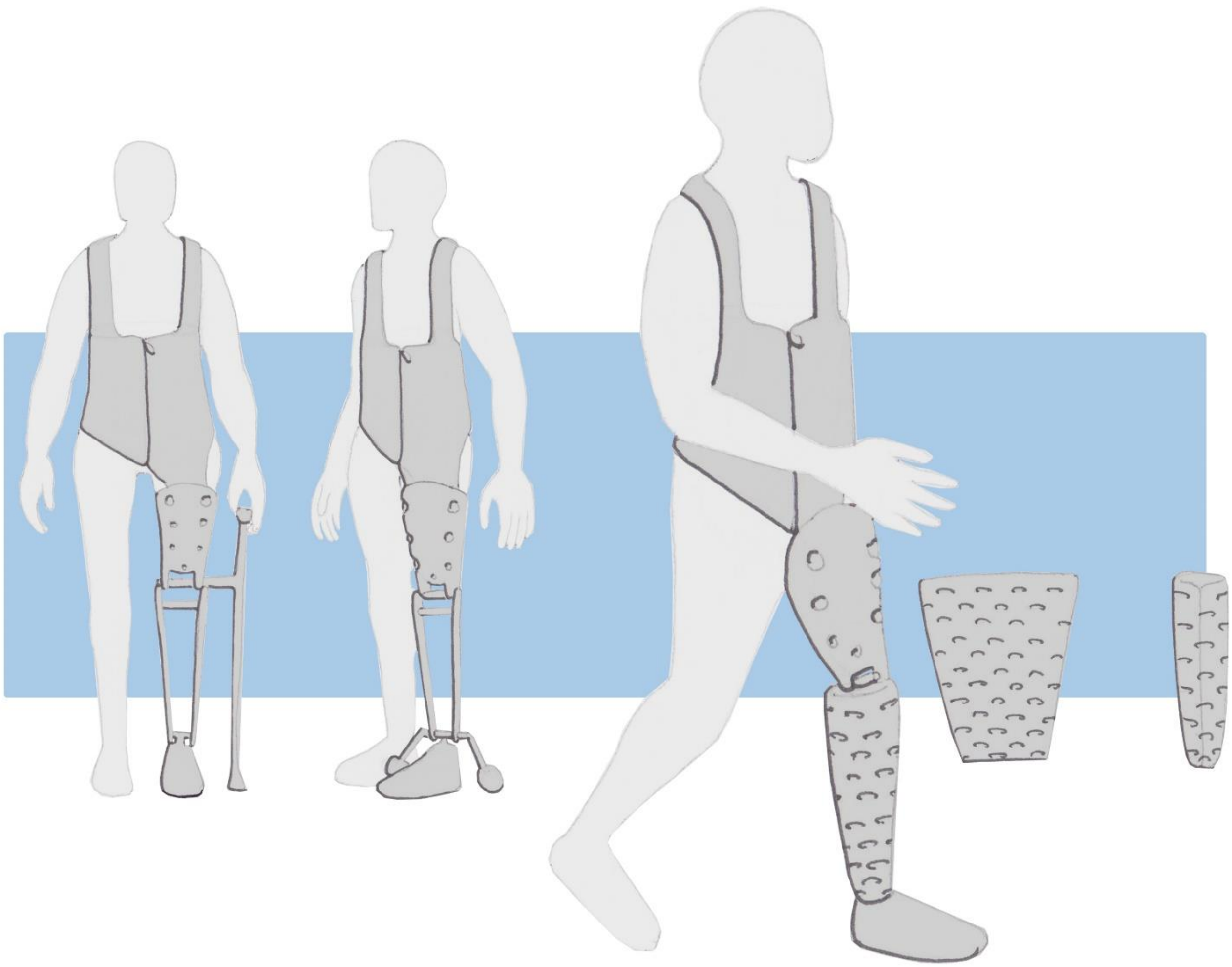


Figure 39 - Concept Sketch 3

4.3 Concept Strategy

The concept designs for the categories of training and travel were combined to optimize the prosthetics in terms of aesthetic and functions. The final design broke the prosthetic into five main pieces: the socket, knee joint, pylon, shin cover and foot. This design included modular pieces such as interchangeable foot pieces, a compact seat, training modules, and a compacting cane.

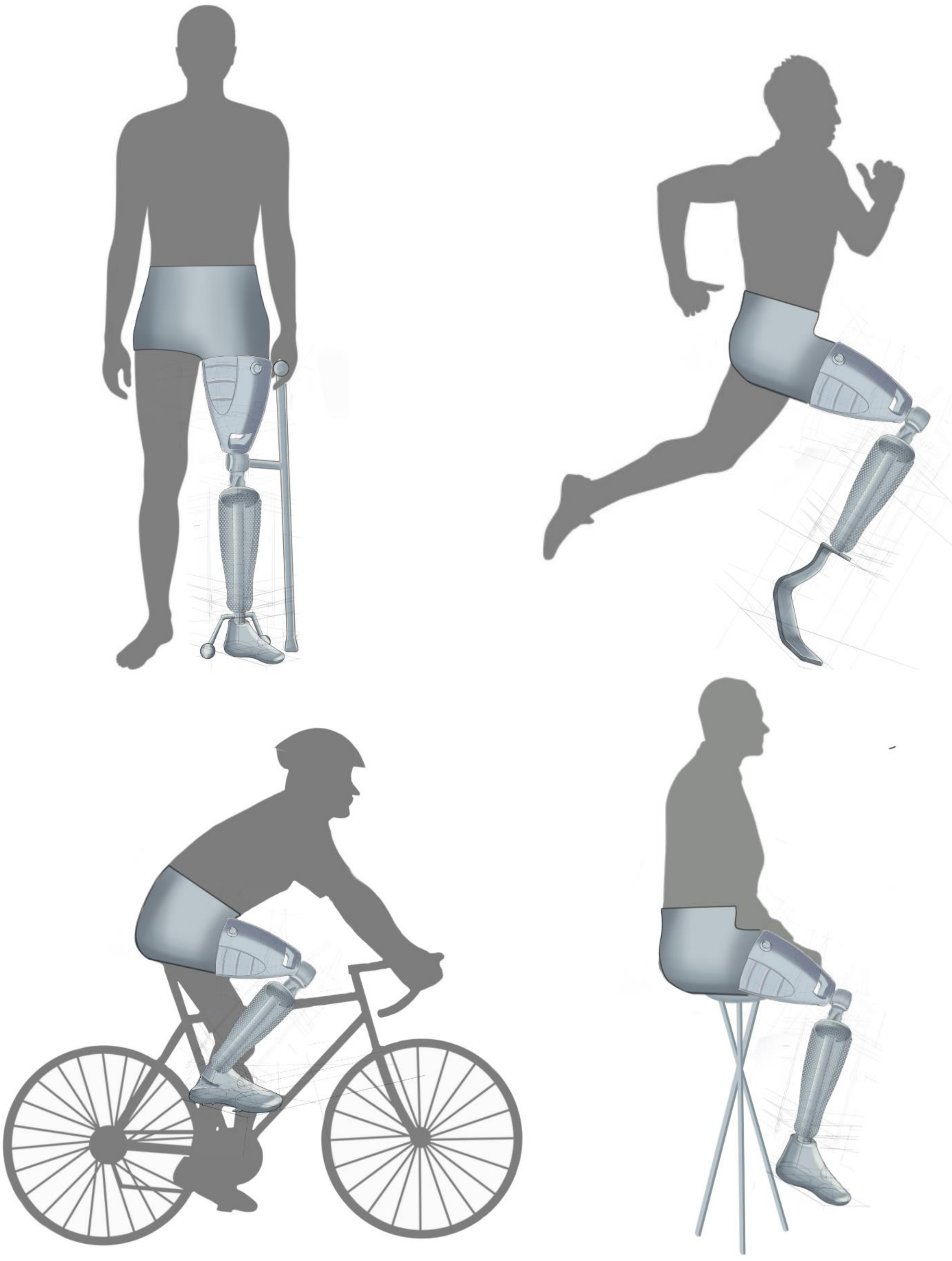


Figure 40 - Concept Strategy Sketch 1

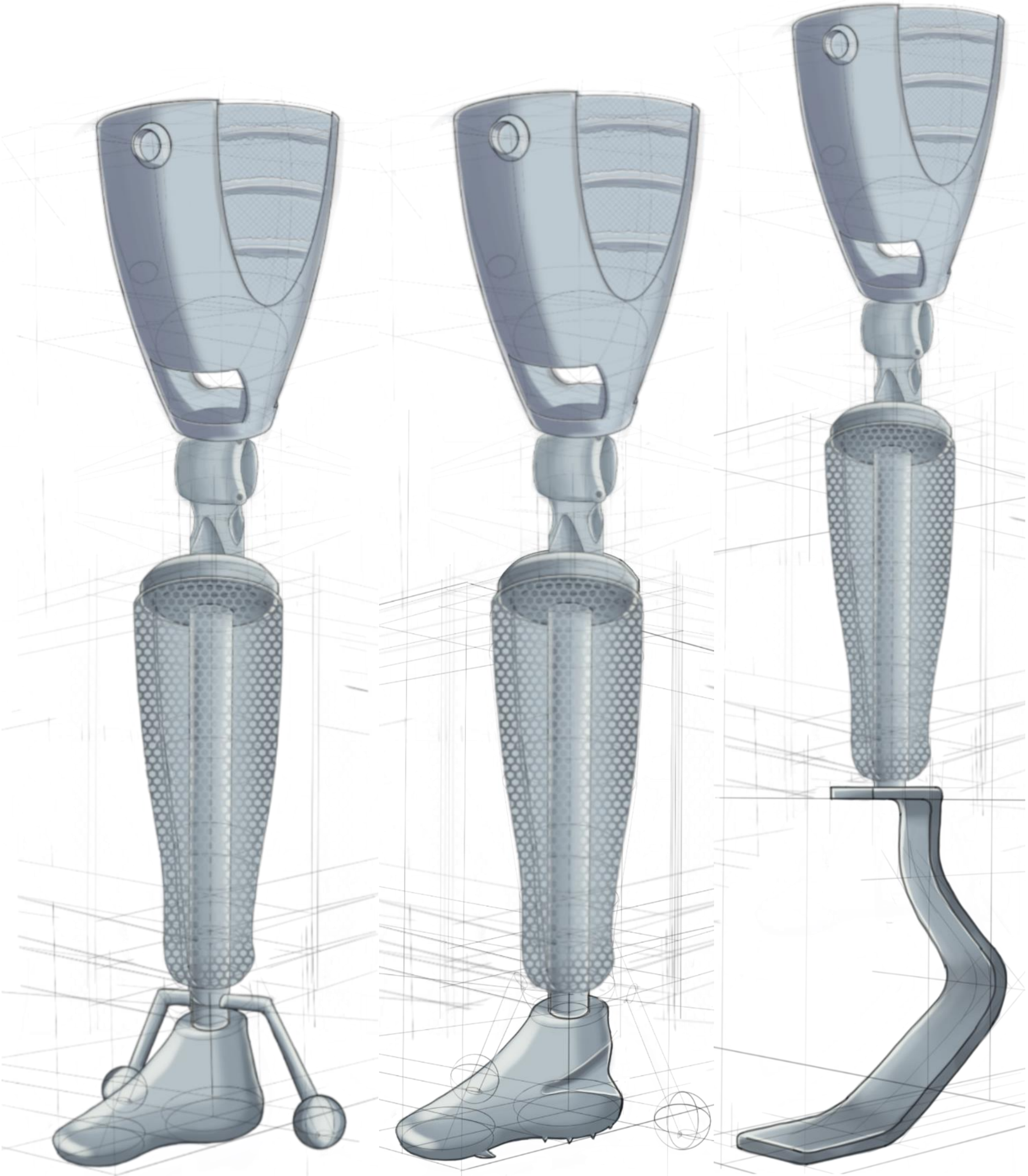


Figure 41 - Concept Strategy Sketch 2

4.4 Concept Refinement

After further development, the design evolved to a more organic form, including gel padding in the interior of the socket, creating a complex oriental pattern printed into the shin cover, and designing various accessories.

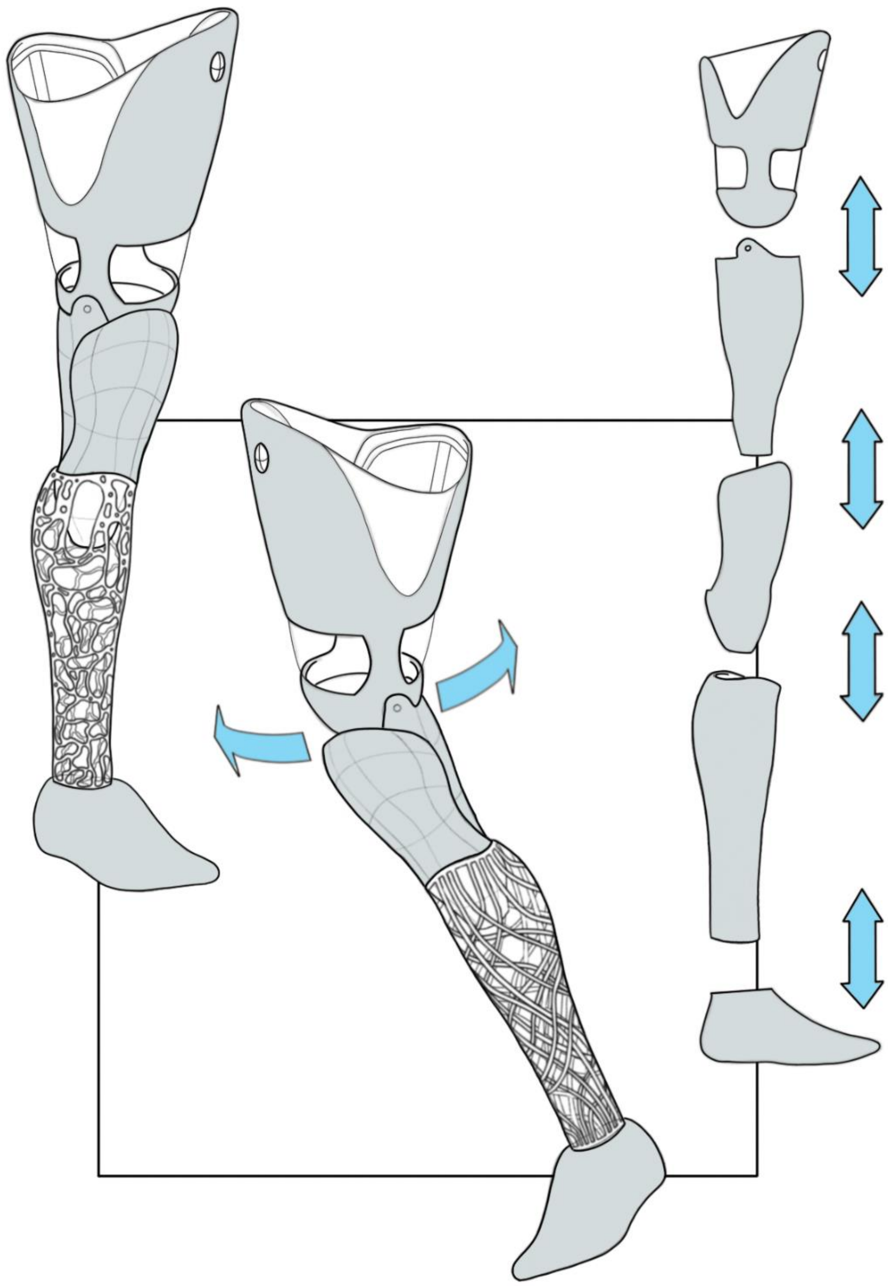


Figure 42 - Concept Refinement Sketch 1

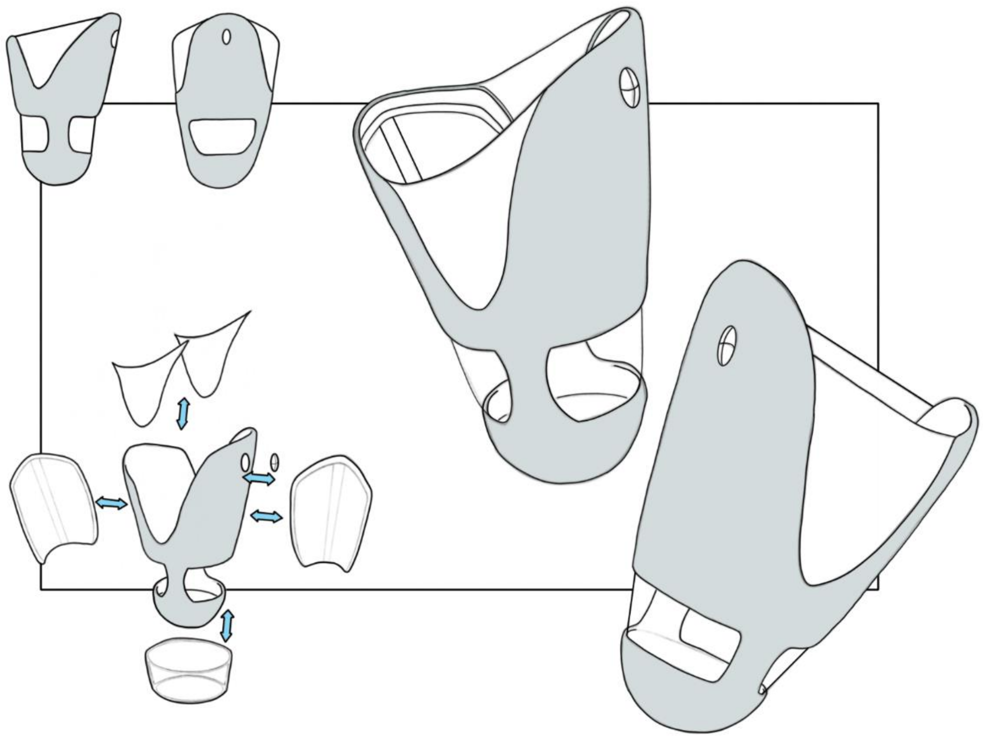


Figure 43 - Concept Refinement Sketch 2

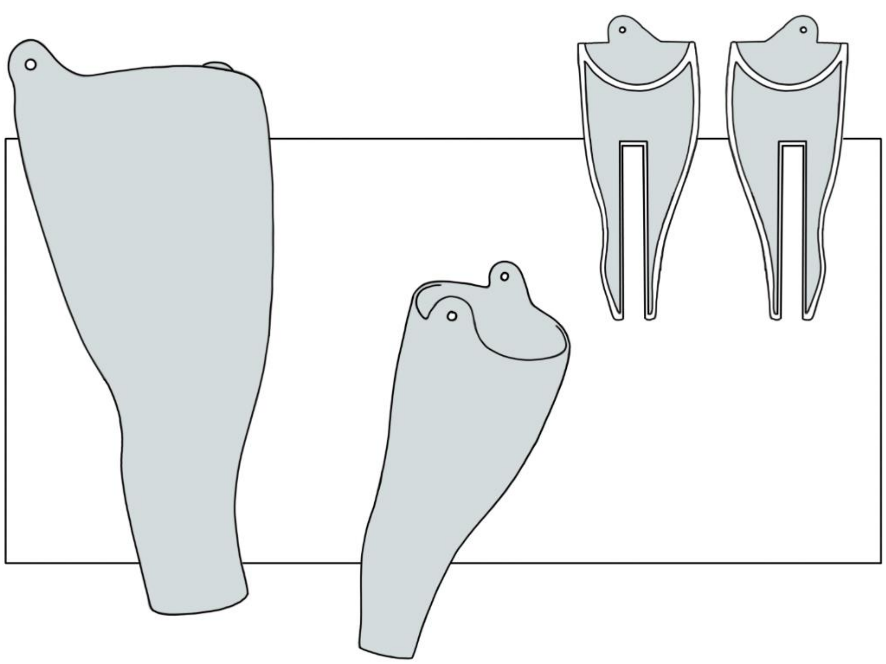


Figure 44 - Concept Refinement Sketch 3

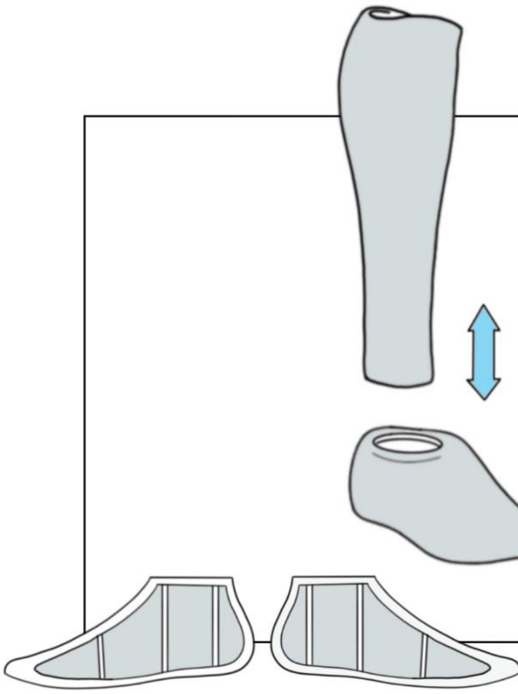


Figure 45 - Concept Refinement Sketch 4

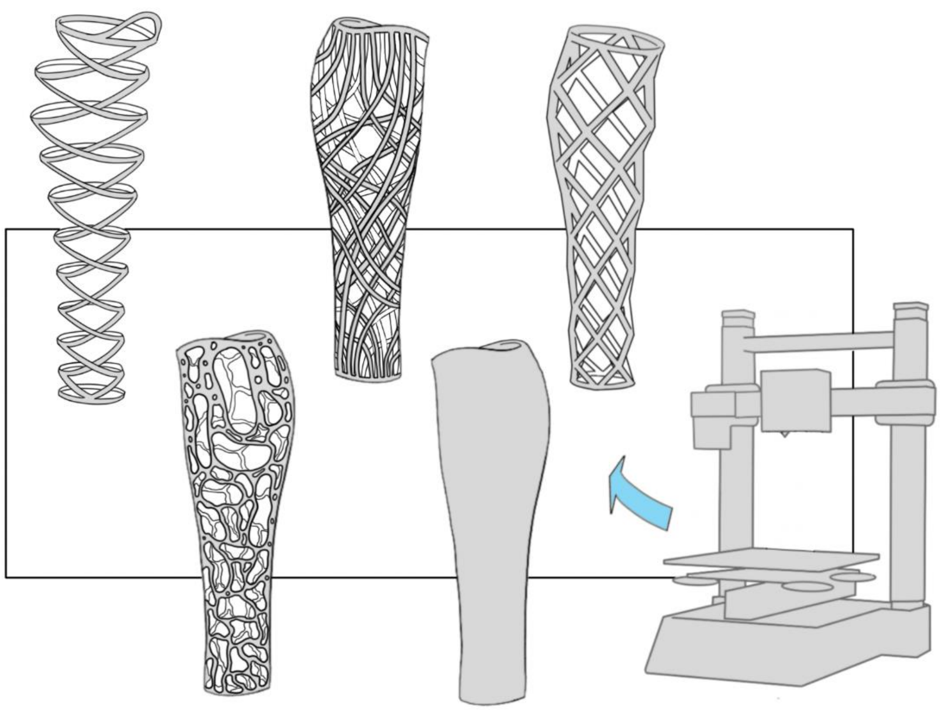


Figure 46 - Concept Refinement Sketch 5

The accessories designed are the electro stimulating compression shorts, folding cane, and a shoe cover to allow the user to have better gripping. This design would allow for the user to have adjustability, mobility, and additional support with the use of the cane when connected to the knee joint.

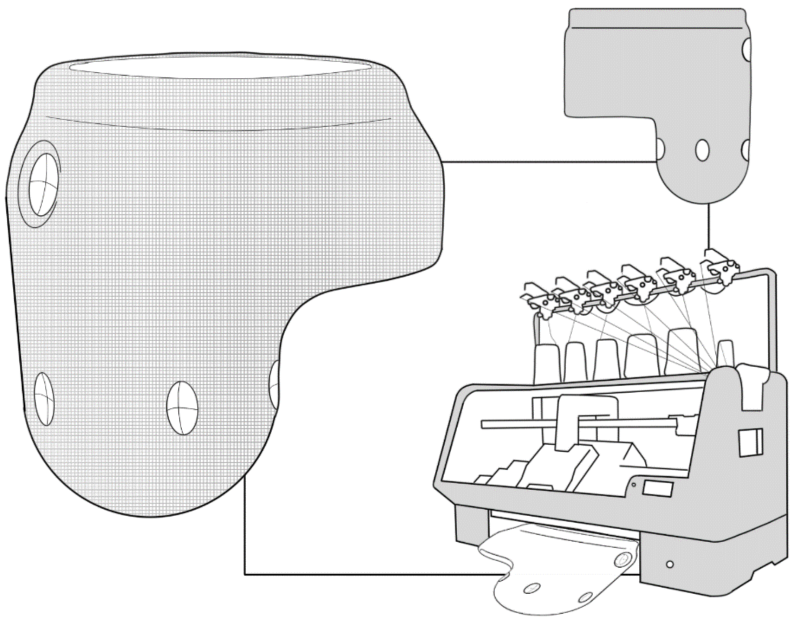


Figure 47 - Concept Refinement Sketch 6

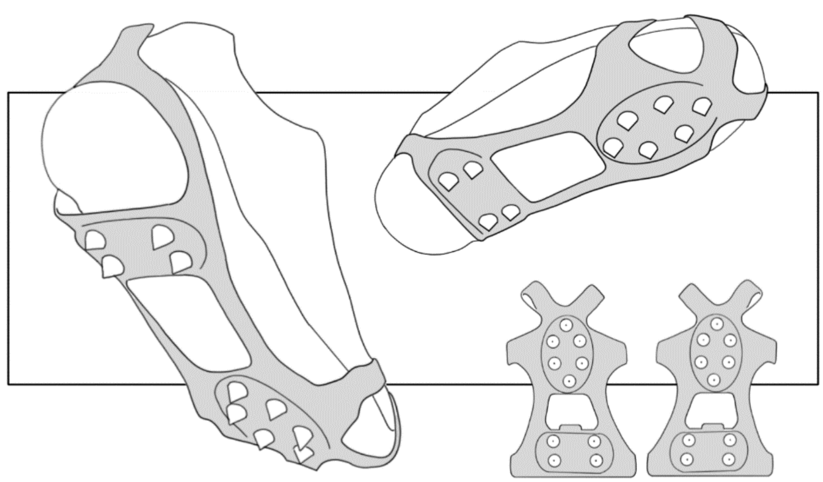


Figure 48 - Concept Refinement Sketch 6

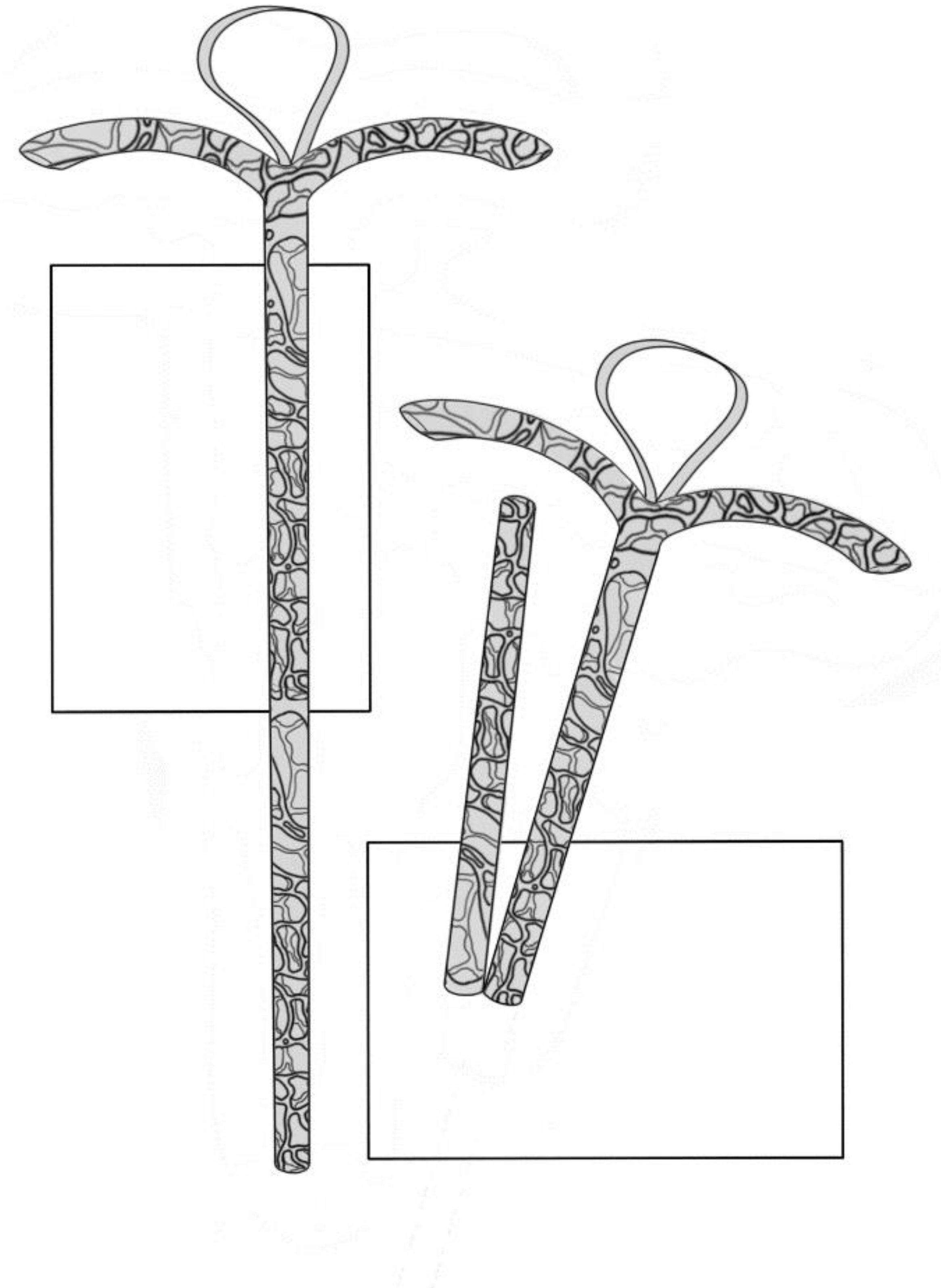


Figure 49 - - Concept Refinement Sketch 7

A business model was also designed to fit this concept, this would include an electric flat bed semi truck with additional solar panels on the roof, carrying a recycled cargo ship container that would be refurbished workspace. This workspace would be broken down into three rooms: patient area, assembling area, and printing area. Since every component of the prosthetic can be 3D printed there would be eight 3D printers included in this model.

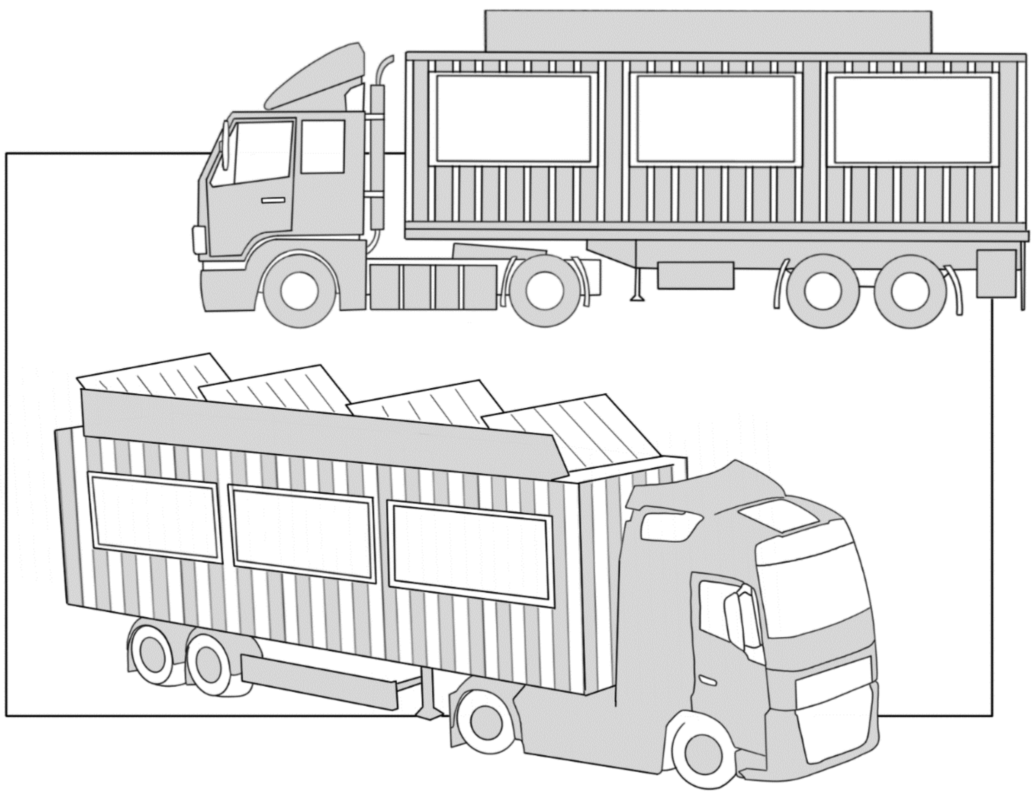


Figure 50 - Concept Refinement Sketch 8

4.5 Design Realization

Design realization focuses strongly on taking the final concept and sculpting the characteristics which makes it unique, ensuring a consistent and collective design. The detailing in this phase can be seen in the cut-out pattern wrapped around the shin cover, the joining between multiple parts and the organic form of the parts as well. Staying away from the conventional detailing of traditional prosthetic legs was an important step to take to create a visual paradigm shift. The design realization phase had also aided in figuring out more final styling features, ensuring the CAD process to be more efficient and organized.

4.5.1 Physical Study Model

A sketch model was constructed in 1:4 scale to get a better understanding of the ergonomics and the layout of the parts. This model was constructed using foam core and Bristol vellum, using various paints to express the detailing's. Building a scaled sketch model also helped to define areas which needed improvement and helped to make the realization that1:3rd scale was more ideal for the final model. Two important points of the prosthetic are the knee and foot joint, ensuring the model would have the ability to rotate on the axis smoothly.

Figure 51 - Physical Study Model 1

Figure 52 - Physical Study Model 2

Figure 53 - Physical Study Model 3

4.5.2 Product Schematic

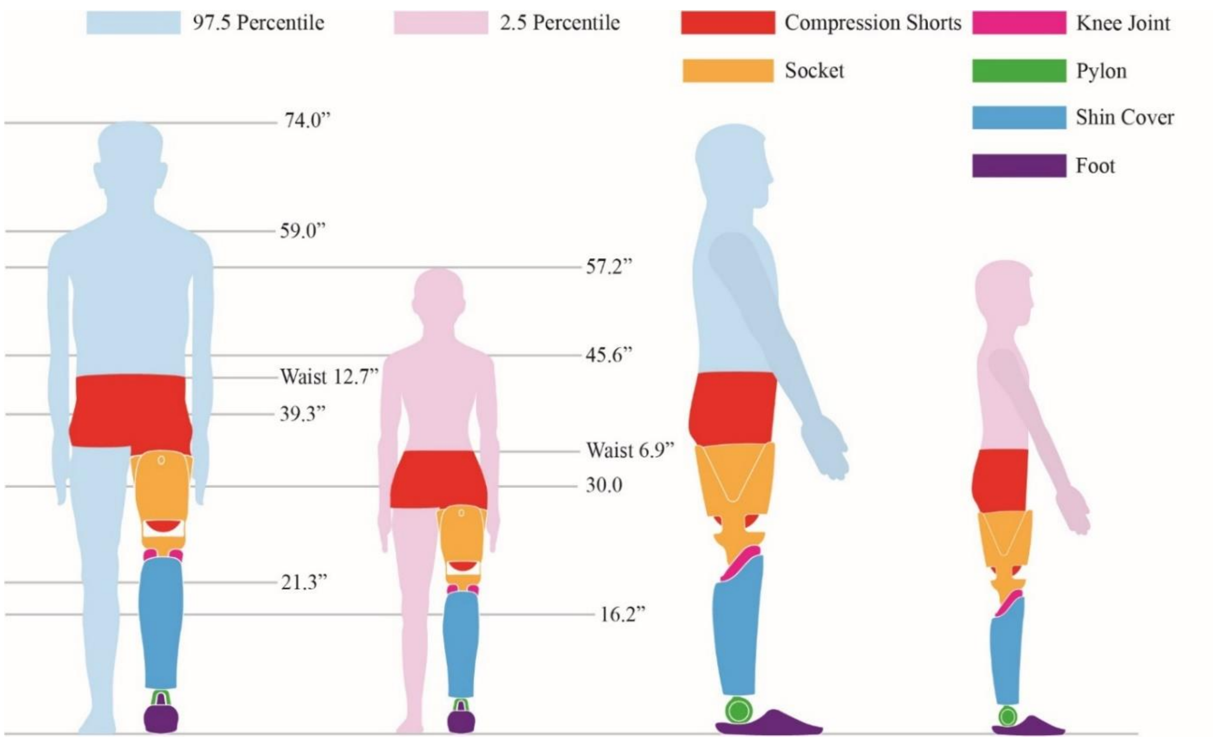


Figure 54 - Revised Product Schematic

The sketch model covers the main ergonomic features of the various prosthetic parts, socket, knee, shin cover and foot. The ergonomics of these parts are key for the prosthetic to look proportionate towards the user. These revisions were important to note for the CAD process to ensure the final design is fully ergonomic.

4.6 Design Resolution

Design resolutions made to the prosthetic are the proportioning of the knee joint and shin cover, having them replicate the form of a leg more accurately, while also adjusting how they form together. Resolutions were also made to the joining method, to ensure that the knee and foot joint can efficiently rotate on a single axis. Small details were also refined to smooth out the overall design, so the final model is clean and modern. The final design for the detailing on the shin cover was fully resolved during this process, to reflect traditional orient designs, inspiration for the design was taken from the figures below.

Figure 55 - Pattern Inspiration 1

Figure 56 - Pattern Inspiration 2

4.7 CAD Development

The CAD modeling process too place over several weeks, using Solidworks 2019-2020 to create the model. The initial CAD was started and re-started approximately three times before the preliminary modeling issues were resolved. The entire design was constructed in a single part file, without using the "Merge Results" options, enabling the construction of various parts to fit seamlessly together. To ensure the files were efficient, accessories were made in an older version of the model where the pattern on the shin cover had not yet been implemented. In order to transfer these files into an assembly file, various parts were saved from the main file, toggling which parts were shown to efficiently represent the model and the assigned appearances.

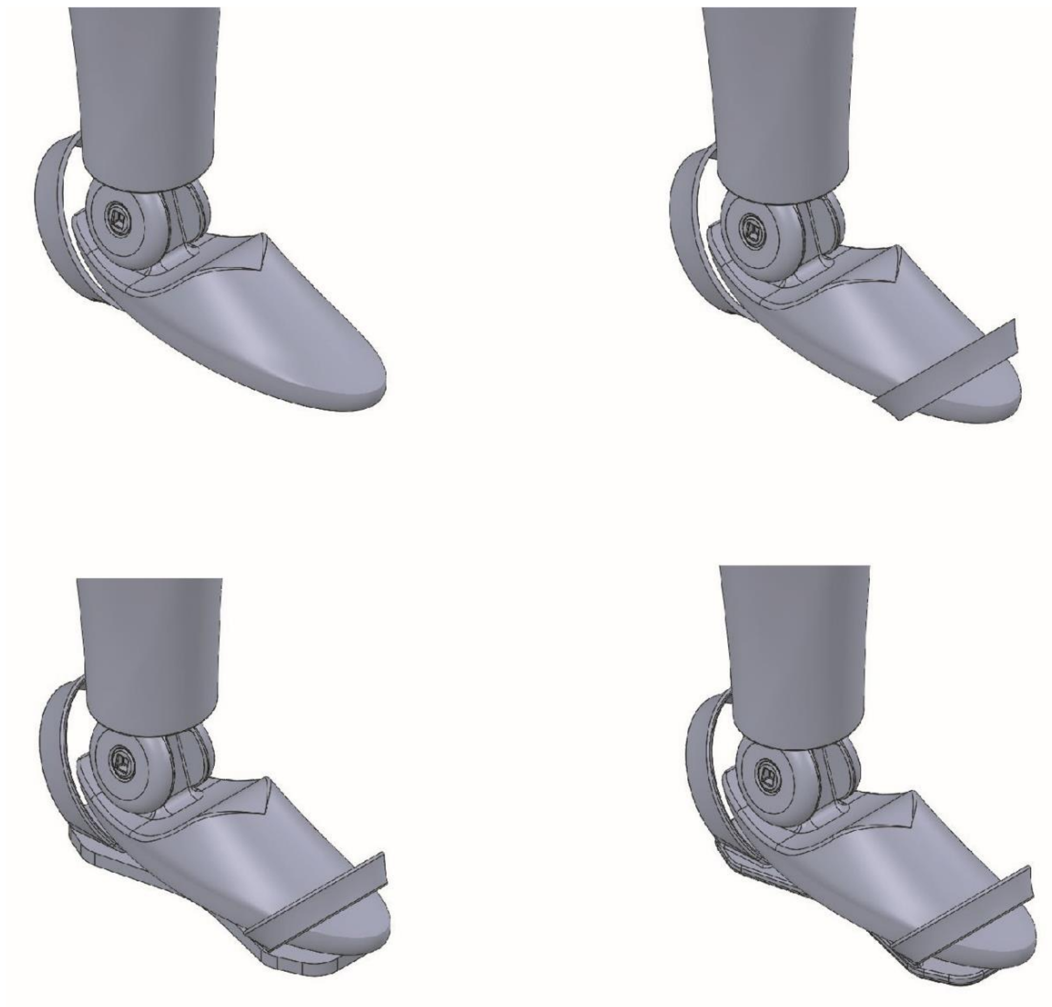


Figure 57 - CAD Development 11

Figure 58 - CAD Development 2

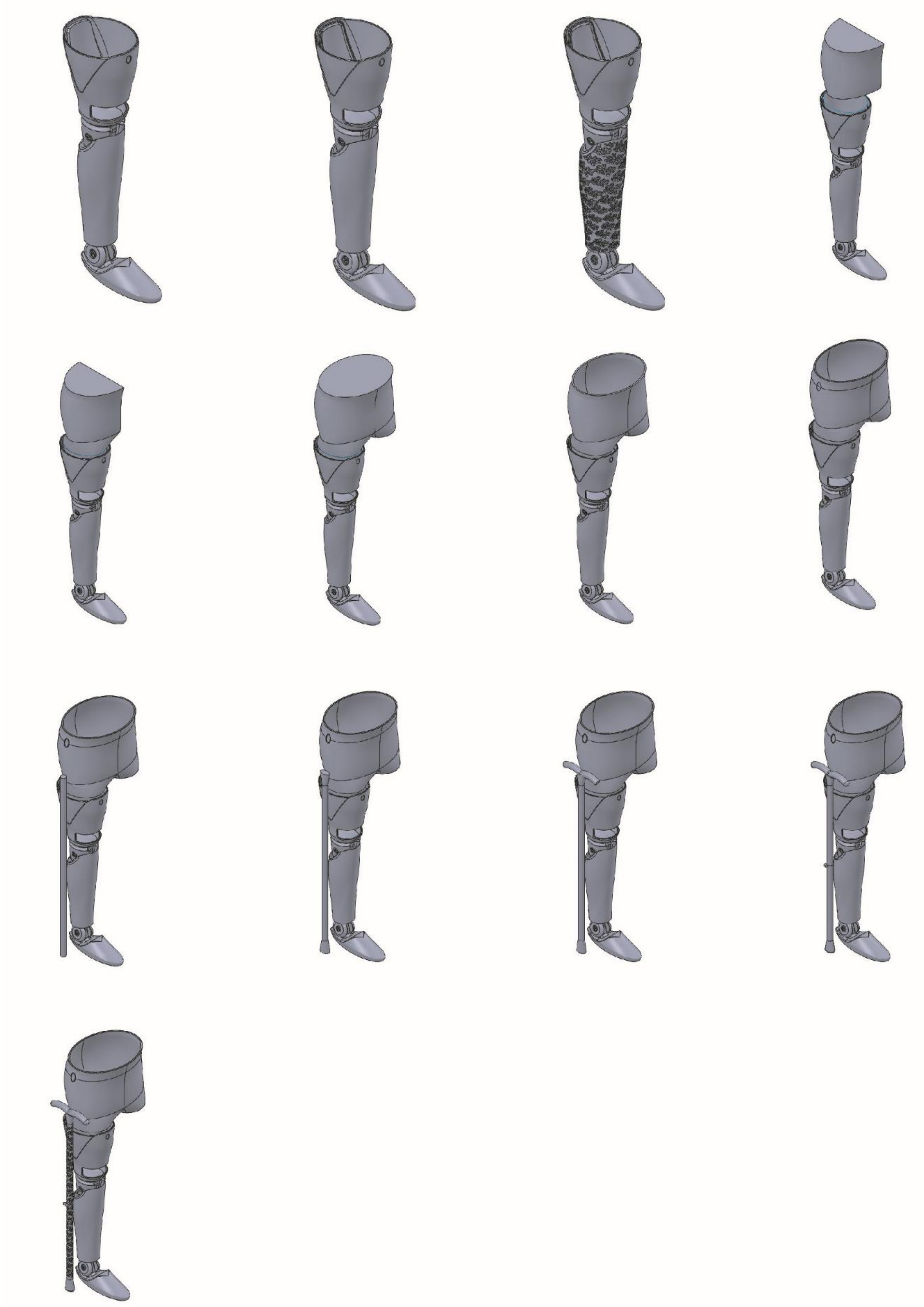


Figure 59 - CAD Development 3

4.8 Physical Model Fabrication

The final model of this thesis was constructed using 3D printed parts, Bondo body filler, and Gorilla superglue. In an effort to save cost, a Creality Ender 3 printer and PETG filament was purchased to create the model. With the physical model being 1:3rd scale, every component was able to be printed without having to split the model. There was a major learning curve with understanding how to efficiently use the printer in order to create high quality prints. Once the model was printed, Bondo body filler was used to level imperfect areas and high spots to create a smooth surface after sanding. The sanding process used grits ranging from 80 grit to 2000 grit.

Rust-Oleum filler primer was used on the models, approximately 4 coats, and were sanded between every coat, aiming for a high-quality finish. The final model was finished with Rust-Oleum flat soft iron, satin canyon black, and gloss winter grey were used. After the main colors were applied to the model, the parts were applied with a light coat of Rust-Oleum clear gloss. The paints and finishes were initially tested on failed initial prints of the model to ensure there would be no chemical reactions that would affect the model and to see if the filler primer would result in a loss of detail in the shin cover.

The final model of Asa is comprised of 12 parts.

Figure 57 - Model Process Photos 1

Figure 58 - Model Process Photos 2

Figure 59 - Model Process Photos 3

5

Final Design

Figure 60 – Kiril Dobrev, Retrieved from https://unsplash.com/photos/UB0QiVPsXgc

5 Final Design

Figure 61 - Abbas Jamie, Retrieved from https://unsplash.com/photos/QmgySmrWEFs

5.1 Summary

5.1.1 Description

Asa is a fully 3D printed above-knee prosthetic leg, optimized with an adjustable socket, electro-stimulating compression shorts to reduce phantom limb symptoms, and accessories to assist with the training process involved with initial use of the prosthetic.

5.1.2 Explanation

The current process to obtain a prosthetic leg, specifically the socket, is time consuming, requires multiple visits by the user to the medical facility and is costly in relation to users living in rural Vietnam's income. Traditionally prosthetic sockets are custom made for the user's residual limb, this method is difficult for many users as they have limited means of transport and income. Prosthetics in developing countries such as Vietnam are highly priced, resulting in many users making rudimentary prosthetics of their own, deciding to not use a prosthetic at all or spending their life savings on a basic prosthetic. Regardless of the choice these users make, their lives are forever changed by the amputation and their lifestyle must adjust. In order to make income in Vietnam work is often laborious, either farming, fishing, construction or etcetera. Users who must go through the experience of amputation have an extremely difficult time physically adjusting so that they may continue their work, sometimes users result to begging for money because they have no other means of income. The goal of this thesis was to create above-knee prosthetic legs easily accessible for users living in rural Vietnam, ensuring when used the users are comfortable and can easily adjust to their new lifestyle.

Asa is a solution which addresses these issues, providing users with the necessary amenities and facilities to obtain an above-knee prosthetic leg, thus mitigating these challenges. The concept prosthetic incorporates unique technologies and functioning features which enables a smooth transition to the change in lifestyle with minimal challenges. Various accessories have been designed to ease the user through challenges they may face such as phantom limb symptoms and producing a natural gait.

5.1.3 Benefit Statement

Asa is a fully 3D printed above-knee prosthetic solution which incorporates an adjustable sized socket, gait training with the connection of the walking cane and electro-stimulation therapy at the user's discretion. This enables Asa to guide the user at their own pace so they may quickly become adjusted to their new lifestyle without having to sacrifice their income, dignity, or additional pains. Asa eliminates the need for users to travel far distances to obtain prosthetic, instead Asa travels to these users to provide them with necessities they are entitled to.

Figure 62 - Final Design 1

5.2 Design Criteria Met

5.2.1 Full Bodied Interaction Design

Asa is a 3D printed prosthetic which is entirely based on a human-centred design approach to be as ergonomic and considerate for users as possible. The socket of the prosthetic is designed to be able to fit a wide range of users, providing a comfortable solution for the users. The socket would be available in two sizes to accommodate extreme size differences such as a fifth percentile female versus a ninety-fifth percentile make. The height of the prosthetic can easily be altered to better fit the user by extending the pylon and shin cover. Asa's accessories provide an additional user body interaction as well.

Figure 63 - Final Design 2

Socket

The socket of the prosthetic compresses against the user's residual limb to create enough pressure to secure the prosthetic. The user would be able to make any required adjustments to the pressure of the socket to ensure the pressure is to their desires. This pressure can easily be released when the user presses on the highlighted button on the front of the socket.

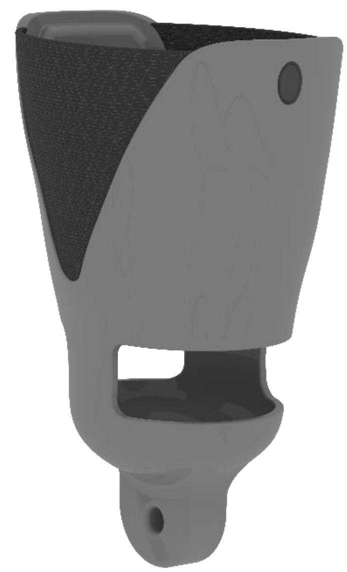


Figure 64 - Final Design Socket

Figure 65 - Final Design Knee Joint

Knee joint

Asa's knee joint connects to the socket with a specialized fastener, this smooth organic surface allows for natural movement to mimic human knee agility. The knee joint may be disassembled from the prosthetic by the user to be replaced, adjusted, or customized according to the user's needs. The organic form and smooth surface also allow the user to comfortably handle the knee joint when needed.

Shin Cover

The shin cover for Asa is a 3D printed titanium part that allows for connection between the knee joint and the pylon. This part is finished with a smooth surface to ensure the users may easily handle and maneuver through their day with comfort. The shin cover is specifically shaped to fit the exact measurements of the knee joint to ensure a tight fit connection between the two parts.

Figure 66 - Final Design Shin Cover

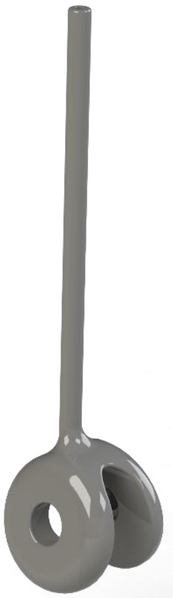


Figure 67 - Final Design Pylon

Pylon

Asa's pylon also serves as the ankle joint as well, assisting to produce a natural gait for the user. The fastener between the pylon and foot allows for the user to adjust the tension between the two parts at their own discretion. The pylon also serves as internal structural support inside the shin cover to support the pressure of the user's weight.

Foot

Asa has various sized foot pieces developed in CAD so various sizes may be printed for users who require that sizing. The sizing of the foot is an important factor for the user to produce a natural gait. The foot is designed as an organic form with a smooth surface so the user can easily apply clothing such as socks or shoes.

Figure 68 - Final Design Foot

Accessories

Asa has three accessories design alongside of the prosthetic, electro-stimulating compression shorts, a foldable walking cane, and a gripping shoe cover. These accessories provide additional supports and features to ease the new prosthetic users through the process and trains their gait.

Figure 69 - Final Design Accessories

5.2.2 Materials, Processes and Technology

Various materials were explored for the final design of the prosthetic for the scenario of if it was produced in a hypothetical fashion. In section 2.2.4 of this report, a full breakdown of the potential materials and finishes were detailed. A table was included in section 2.2.4, various metals, alloys, and polymers were considered for the primary materials used in the final design. The chosen final materials include, titanium, Dupont Delrin plastic and recycled polyester yarn. With the implementation of current technology and the assumption of innovation of this technology in five to ten years, the entire solution would be manufactured using 3D printers. This process of manufacturing will allow for easy travelling of the manufacturing facility in order to accommodate for the business model.

The prosthetic industry is constantly being innovated and improved upon to better enhance the users' experiences. As a result, new technology and evolving methods are being explored, tested, and implemented into current solutions. The technologies which are implemented into the final design includes:

- Electro-stimulation pads
- BOA fit system
- 3D printing

5.2.3 Implementation – Feasibility & Viability

Manufacturing costs have proven to require a more detail-oriented approach throughout this project. This solution is unlike current prosthetic solutions seen on the market; cost reports have been difficult to create without making assumptions. With conceptual thinking, the final design was inspired by similar products that are currently on the market and those associated costs of manufacturing were considered to determine an estimate cost for manufacturing.

The table below indicates an estimate amount of the various components seen within the final model, inspired by similar products in the existing market.

High-Cost Items

Concept Item	*Description*	*Estimated Cost/ Each*	*Similarly Produced Item*	*Quantity*	*Material*
Tesla Semi	Semi-truck	$190,000	Peterblit 389	1	Various
Markforged Metal X	Metal 3D Printer	$100,000	Xometry Metal 3D Printer	4	Various
Steiger Vega 3.130	Fabric 3D Printer	$18,000	Kniterate	2	Various

Medium Cost Items

Concept Item	*Description*	*Estimated Cost/ Each*	*Similarly Produced Item*	*Quantity*	*Material*
Cargo Container	40 ft container	$5,600	-	1	Steel
Furniture	-	$5,000	-	-	Various

Prusa i3 MK3S	FDM 3D Printer	$1,250	3DPrintMill	4	Various
Low-Cost Items					
Concept Item	***Description***	***Estimated Cost/ Each***	***Similarly Produced Item***	***Quantity***	***Material***
Shin Cover	Prosthetic Component	$370	-	Numerous	Titanium
Collapsible Cane	Prosthetic Component	$130	-	Numerous	Titanium
Compression Shorts	Prosthetic Component	$50	-	Numerous	Polyester
Socket	Prosthetic Component	$15	-	Numerous	Delrin
Knee Joint	Prosthetic Component	$5	-	Numerous	Delrin
Foot	Prosthetic Component	$5	-	Numerous	Delrin
Pylon	Prosthetic Component	$2	-	Numerous	Delrin
Shoe Cover	Prosthetic Component	$2	-	Numerous	Delrin
Fastener	Prosthetic Component	$2	-	Numerous	Delrin

Figure 70 - Cost Breakdown

5.3 Final CAD Rendering

Figure 71 - Final CAD Rendering 1

Figure 72 - Final CAD Rendering 2

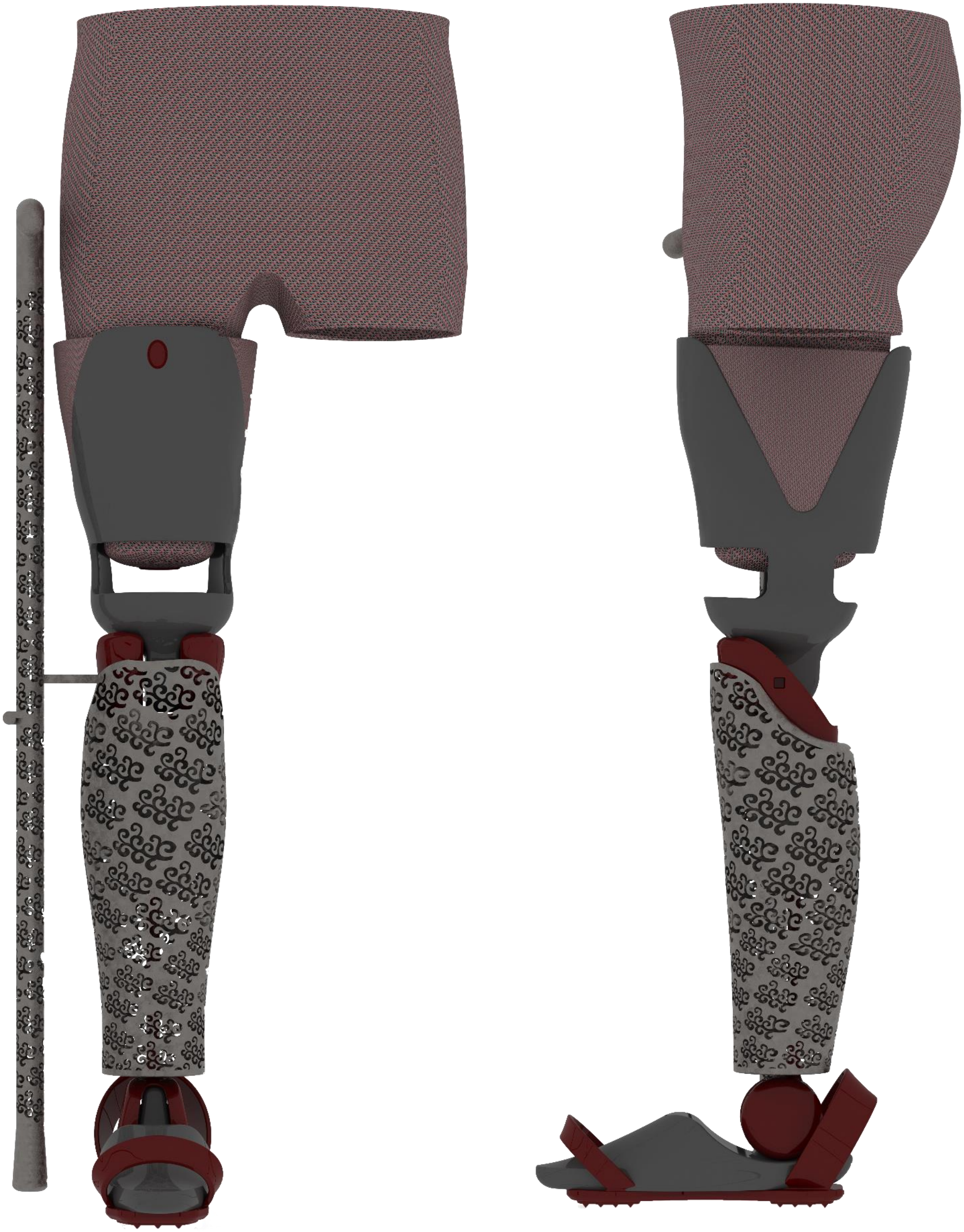


Figure 73 - Final CAD Rendering 3

Figure 74 - Final CAD Rendering 4

Figure 75 - In Situ Rendering 1

Figure 76 - In Situ Rendering 2

Figure 77 - In Situ Rendering 3

Figure 78 - In Situ Rendering 4

5.4 Physical Model

The physical model for this thesis was produced using a Creality Ender 3 printer.

Figure 79 - Physical Model 1

Figure 80 - Physical Model 2

Figure 81 - Physical Model 3

Figure 82 - Physical Model 4

5.5 Technical Drawings

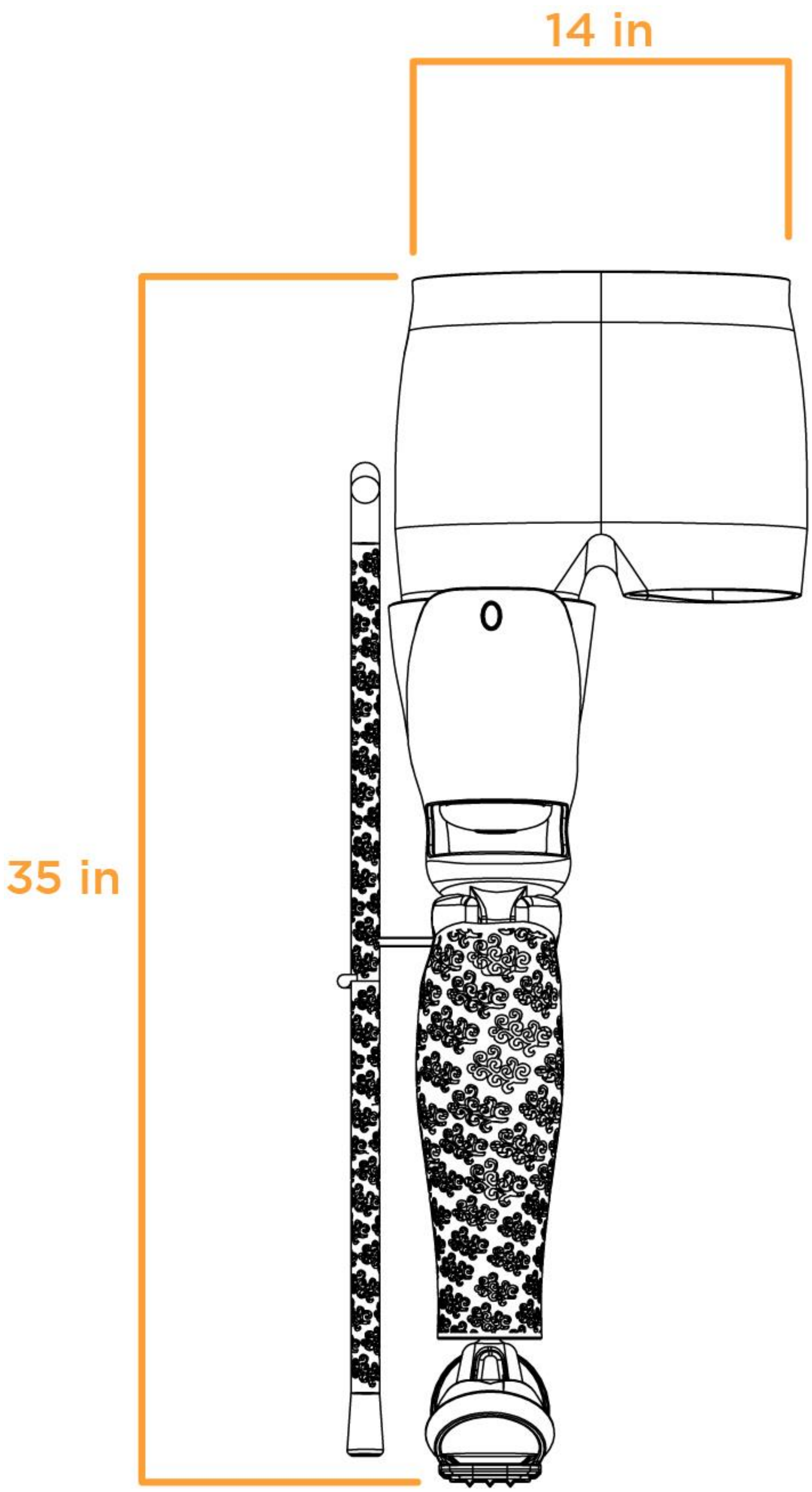


Figure 83 - Technical Drawing 1

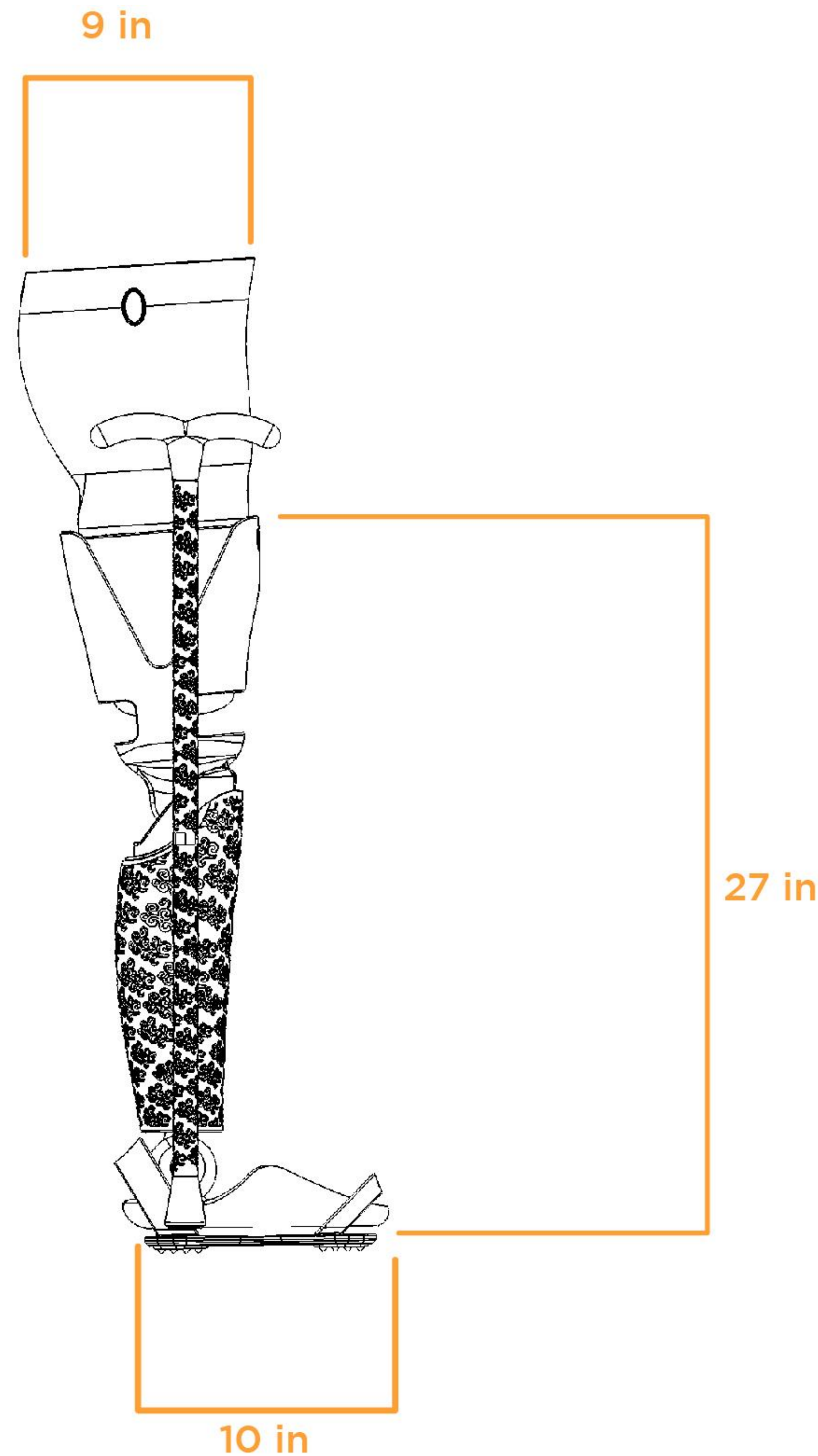


Figure 84 - Technical Drawing 2

5.6 Sustainability

Sustainability for the environment, materials and humanity is crucial to the success of this thesis and the industrial design industry as it evolves. Without the consideration of sustainable design, the planets ecosystem will deteriorate to the point where it cannot sustain life. Within the context of this thesis, sustainability is a design element that reduces the negative impact and repays the environments ecosystem. The design ensures that sustainable and recycled materials are used throughout the manufacturing process. This thesis also contributes to the improvement of the quality of life for the end users, so they may continue with their current lifestyle.

The materials used in the production of Asa are specifically chosen because of their durability and useability. These materials will ensure the components can be used for a long period of time before having to be replaced, this will reduce the need to constantly replace worn components. Components that reach the end of their life will be collected to be processed into new filament to produce new components. This process recycles material to reduce the amount of waste produced.

The business model designed for Asa focuses on the use of sustainable energy to power the vehicle and manufacturing. The combined use of solar and electric energy allows for the vehicle to charge at electric charging stations and continues to charge when driving with the use of the solar panels. The manufacturing process and business model is aimed to produce as minimal amount of waste as possible. Third world countries are often used to outsource manufacturing for companies because their labor prices are considerably lower. The business model aims to avoid this to give back to the local community and ensure there is no additional damages to the environment.

Asa requires minimal finishing to the final product, mainly light sanding and polishing to produce a smooth surface. The components of Asa are printed either naturally or with a pigmentation to remove the process of aerosol painting. Though this is a small aspect that is removed from the manufacturing process it also benefits the environment by removing the additional chemicals being added to the ecosystem. Aerosol products are affecting the environment negatively by changing the amount of heat that can enter or exit the atmosphere and can influence the formation of clouds. Asa aims to avoid using additional products that have a negative impact on the environment and community.

6

Conclusion

Figure 85 - In Situ 1

6 Conclusion

Figure 86 - In Situ 2

Current designs for above-knee prosthetics are a long process that is only accessible for users who have the available income and means of transportation. The design of prosthetic often jumps from a rudimentary to highly technical design with minimal prosthetics that is between the two stylings. The manufacturing process for current prosthetics is a long process that produces a large amount of waste and toxins which enters the ecosystems. In rural Vietnam, the lifestyle is very laborious and isolated from major cities and landmarks. Living in the country sides requires users to be able to highly functional in terms of physicality. Vietnam has the highest percent of amputees, which can be caused by accidents or disease.

Asa a completely 3D printed above-knee prosthetic leg designed for amputees living in rural Vietnam who have limited access to medical facilities. Asa is designed to support a laborious lifestyle, while keeping in mind the sustainability aspect. This solution removes the additional time involved in manufacturing and eases the ability to produce prosthetics. Asa can be easily accessed via a traveling business model, bring the prosthetics to the user.

Asa is a solution which addresses the lack of accessibility of prosthetics to users of lower income living in rural Vietnam. The concept prosthetic incorporates unique technologies and functional features which enables safety, comfort, and ease of use for the user. The ergonomic design allows the user to easily maneuver with Asa and allows for the user to ease the use of walking with the specially designed walking cane. This allows for users to practice improving their ability to produce a natural gait Asa is designed to improve the overall quality of life for users who have been affected by amputation living in rural Vietnam who have minimal access and income available to them. Asa provides users with everything required to improve their lifestyle and ensure they are fully functional no matter their situation.

7

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8 Appendix
8.1 Appendix A – Discovery

A key article for this topic was sourced and selected. Required article contect (Abstract, Introduction and Conclusion sections) were copied and highlighted.

Search Engine: Google Scholar

Keywords used in search: Vietnam, Prosthetics, Amputees

Findings:

Matsen, S. (1999). A closer look at amputees in Vietnam: A field survey of Vietnamese using prosthese: O&P Virtual Library. Retrieved November 10, 2020, from http://www.oandplibrary.org/poi/1999_02_093.asp

Key Contact: is reproduced below.

Summary Statements:

- Quality prosthetics can cost up to $50,000 CAD depending on the type of prosthetics. In developing countries people who require these prosthetics do not have access to quality products because of general price, availability in their country and/or distance to the nearest medical center.
- Quality prosthetics are steeply priced and difficult to access for people living in developing countries.
- The manufacturing process for prosthetics begins with measuring the patient to ensure that the prosthetic is the right fit for them. Though if these patients in developing countries have less access to these medical facilities, there is already a problem before the prosthetic is manufactured. The top 5 companies for prosthetics are located in North America and Europe, therefore if a patient in a developing country required one of their $50,000 prosthetic, the medical facility will add an addition fee for shipping and handling, or if the patient wants it sooner an express shipping fee.
- In developing countries, their people are often suffering from war, poor economy, corruption, poverty, healthcare, and education, to list a few. On top of all these issues there are thousands of amputees as a result from war and violence, with better accessibility to quality prosthetics,

they have less to suffer from in life. The problem is not only requiring the prosthetic but the availability to proper physical therapy afterwards. If the patient has limited accessibility to a medical facility and if they are able to get a quality prosthetic, it will take them years longer than patients in North America, to regain proper function with their prosthetic.

Professional Interview – James Jordan

The interview for this thesis, in understanding and mitigating challenges faced by above-knee leg amputees living in rural Vietnam, James Jordan was Contacted. James is experienced in the prosthetic industry and is an amputee himself as well.

Name	*Email*	*Basis of Expertise*
James Jordan	James.Jordan@waramps.ca	Working with War Amps Canada for 10+ years. Congenital upper limb amputee.

Method

Questions were prepared in advance to the interview. These questions were aimed towards gaining insight from personal experiences of the lifestyle of an amputee. In the context of this interview, questions were specified towards the interviewee and his own unique work and background.

The questions that were asked were in a simple conversation style between the interviewer and the interviewee, James Jordan. In some instances, the exact phrasing of these interview questions was changed within the context of the situation and additional questions were asked.

What is your name and work title?

James Jordan, Public awareness (Champ program)

How long have you been working in this industry?

10-12 years

Would you be able to explain to me the process in getting a prosthetic?

We are all going over the process I yeah if you don't mind starting now yeah so first of all it's a little bit different in each province so something to note is that depending on the province you're in there maybe provincial coverage for standard prosthetic devices or there might not be so in Ontario there's a program called assistive devices program 480P and they will provide up to an amusing airport stations when I do that up to 75% of the cost of a standard blip standard lame is a leg to walk on and on the graph does not have anything to do with sports recreation or anything like that so that's Ontario and for each province like I said it's different so in most provinces there's coverage but just to mention a few like New Brunswick and you can land there are absolutely no coverage for prosthetic devices not even for standard loans wow no so after so when you want to if your auntie wants to get a prosthetic device made you have to visit a prosthetic centre and a certified prosthetist so assert there are many certified prosthetists prosthetic centres throughout Canada there's always a few in each town hang on when you get to really rural areas that if you might have to travel to a larger city so once you get into the prairies and through the prairies in Canada if your way if you're at way out the country you're going to have to visit a main or main centre city to reach across item shop because there's you know there scattered throughout Canada but they're not there in in most of the major cities but the smaller towns don't always have a prosthetist available and just a note a prosthetist yeah an orthotist is sort of the same thing so a lot of the shops are growing process prosthetics and orthotics so when you want to acquire a prosthetic limb you would just visit your centre the prosthetic centre that and visit a prosthetist and I mean if you want to talk about funding you don't have coverage so in Canada obviously it's a lot different because out the walls because of the organization I work for in the child and the program we provide financial assistance for artificial limbs so anyone under the age of 18 there is a child who is enrolled in our child amputee program will receive 100% coverage so if they go into have eliminate list say they are in Ontario and part of that part of their standard land is covered by ADP like I mentioned in assistive devices program say assistive devices program Ontario covers 50% of their artificial limbs artificial limb pick quite expensive they usually about 10,000 or more depending on limb if you're talking a leg it could be 20 to $30,000 there very expensive my arm that I use is a myoelectric arm that's worth $25,000 so assistive devices program cover $12,000 of that so if I wasn't part of the champ program the rest of that bill would have to come out of my pocket which would have been about another $12,000 so I would never be able to have an artificial limb if it wasn't for the war Maps so why don't they step in they do that for all of their child so like I said stay in Ontario to cover half the warrant another family had the word sort of about providing coming up with that money so it's a little bit a lot different than a lot of other countries out there that's so you only have your prosthetic you have your prosthesis made So what they do is that sort of taken cast of your residual limb and you're in residual limb is the technical term for someone's amputated her more like so yeah residual images acted and the terminology for your put up for another limb on your body that is not affected is called your sound so for instance I'm missing my left arm so my left arm and I had like a stump it's called my residual limb and my right arm is fine but my right arm is normal and that's called my soundly just in case you're wondering what the technical terminology is for amputated limb and your saddle so they what they do is they can ask of your sound when I'm sorry of your residual in of your amputated leg and they basically get a negative so they will fill it with plaster and then they get the exact replica of the shape of your residual limb or your stuff and then basically they created the prosthesis by I mean I'm getting pretty in-depth here and like I actually worked a prosthetic shop so I could go into detail really but i mean you probably don't even know the full details on how across the trustees is made. Basically what happens is your first visit to take a pass and then like I said they'll fill that pastor to get exact replica shape of your residual limb and then they use that on file so they had a room full of class of everyone’s stumps it's it sounds weird but they really have a room full of everyone’s residual limbs all their patients residual lives So what they'll do is they'll melt liquid plastic over top of that limb and use our vacuum to sort of suck it suck the classic to the exact shape of that pass so then when you come back in it would be spent with what's called a test soccer and a test socket is just to make sure that it's fitting right if there's any pressure points because a lot of adjustments have to be made especially if you're creating a leg so especially if it's like a leg pure legatee because alignment of your prosthesis has to be perfect or else it will affect it will greatly affect you it could affect your back your back issues that issues with walking and whatnot so the physics that go behind fitting someone with a leg amputee is a lot more sort of in depth let's say than hitting someone with a like a prosthesis for an arm like myself now having said that replicating hand is probably a lot harder than replicating a foot life because there's so many little bones in your home that it's just it's almost impossible to replicate a hand like a natural home that's like the hardest thing to do so so legs are a little bit easier to replicate but there's a lot that goes into the lot to go into the prosthesis when you're being fed with it and making sure that if aligned properly even walk properly on it or else that it can have negative effects on your body that and then with arms it's not so much the case and again for leg amputees you need to have a laugh it's how your it's how you have mobility how you get around how you walk around so Leggett and you don't really have a choice to not wear a prosthesis or else they'll be in a wheelchair or they have to hop around and it will literally destroy your need by the time the 20 whole life so you know being a leg in Turkey absolutely sort of have to have a leg to stand on our massicus is not necessarily the same case like a lot of our massicus choose not to wear an arm and just use their residual limb for you know their daily routines and activities so that's just a small difference between leg and arm but of course I know a lot of iron if you give him a lot of leg but I know a lot of maybes and most Americans do wear an artificial limb and there are different hands out there some are just static that don't move at all better just more cosmetic so they look more realistic silicone hands and things in males and some of them have heirs and some of them are even designed to look at exactly what your sound deliver we left or right out of it you still have and then what I wear is called a mile left and that is a hand that opens and closes and how it worked as muscle impulses so there's a sensor on my top muscle sensor on my bottom muscle and I flex my muscle up in the hand opens I'm going to collect my muscle close flex my muscles down and it closes the hand so you just let your muscle up and down and the centres are within the process if so where you would put the residual level where I would put my stumps into the prosthesis I still had muscles left on my on my stuff and so the centre would be up for those muscles I've just flex up and down and open the closes for me this is this is what works something like functional like I care less about the looks of it but it's sort of it looking like perfectly cosmetic and a real hand I'm more about the functionality being able to grab things hold things is is more important to me than how it looks.

For your second appointment is your test socket when they try to you know figure out fits well how it works they make all their adjustments and then from there your third appointment after they do the test socket they'll go and they'll take their notes and other adjustments and they'll create their real software and how that's made really is the same as the same deal it's just that they'll use instead of use for their test socket stage they just uses a clear classic but the very simple cheap clear plastic that like I said inexpensive to me and then what they do when they make other adjustments and they go to make the real socket it's a lot more reinforced a lot more durable and how it works as it's just layers of fabric they pull layers of fabric over top of the casting the residual limb casting that they've taken they pull layers and layers of fabric and then they'll dump liquid plastic and have a backing account stuck the liquid plastic into the fibers and then a liquid plastic hardens into the fibers in the exact shape of the residual in passing that they took and because this is this liquid plastic is being sucked into the fibers of fabric it becomes incredibly strong like you couldn't you would have to take a hammer and smash it hardcore to be able to finally get through someone process there like it's the it's very durable and that it needs to be because that's you know you're using this arm everyday like they need to be so then you're going for your last appointment you'll get fit with your at the final casting of your prosthetic limb and again they might have to make a few adjustments Delafield now there are different ways that you can fit into a limb sometimes you can just sometimes you use what's called a pinlock liner so you'll roll silicone sleeve over your stuff and then the silicone leave has a little pin lock on the end of it and it just locks put it into the device and it's our launch into device sometimes it's just soft plastic on the inside and you don't wear any sleep and we just put your stuff right into the arm like there's a few different there's a few different methods on exactly how you know the arm connects to your arm there's a lot of silicone sleeves that connect to it or you just put but like empty same thing where they might use a silicone sleeve like a pin lock liner lock their legs into their stumping for the leg or they might just use it just might be like a stop sort of sponge on the inside of the inside the prosthesis and they put their stump rate in and it sits on sort of a soft sponge and it's held on by how much suction in some number just held on by low bone or unibo and if you're above the knee we are closer to the head sometimes or if you're closer to the shoulder like I'm below the elbow to say I was above the elbow close to my shoulder then some prosthetics have to be held on by Velcro straps or strapping around your back and the same for people that are up near there leg amputee above the knee up here to help you might have to have a strap almost of themselves going around your waist that holds the crust on yeah so you have the final step there you sort of go home with your prosthesis start using it and see how it feels within the first couple weeks you sort of tested make sure it feels right sometimes you might get sore sometimes you might have abrasions there might be you know it might be like pain in some areas so there's always adjustments have been made so you have to go back likely you know I would say more times you know more than 50% of the time you're going back to your process they have adjustments made to make sure everything is functioning perfectly and not experiencing any pain and then it's fitting properly so it's quite a process of getting with a prosthetic device because it's there's a lot there's a lot of variables that come into play like you know it's causing maintain again if it's causing the rest of your body and physical stress like for leggings before the fact you might have alignment issues though there's always adjustments that have been made afterwards tables Cortana play now having said all that we have the war amps I've been studying prosthetics and recording issues at over 100 years and sister First World War special World War hickeys that actually started the program so even recording issues in over 100 years centre of excellence would like to say for everything application related and um I don't know where it is where was I going with that one year when you do get sick with like a an artificial lens

What are some common problems you have seen your patients' experience?

- Huge mental change
- Depends on age when the accident happens
- Can be mentally devastating
- Depends on how you lost the limb
- Huge mental aspect to accept your amputation
- Needs to wait for the surgery to completely heal same with the scars up to 6 months
- Most difficult for adults kids are more accepting
- Users can teach themselves how to use the prosthetic
- There are users who completely give up
- Based on the individual person

Would you be able to describe to me your daily activities as an amputee and the challenges you face?

- Get up
- Bathroom brush teeth
- Challenge to squeeze tooth paste without spilling
- Users with more extreme amputation need special equipment for bathroom use
- Showers clean the residual limb bit of a challenge soap dispenser to help get soaps or pump bottles
- Leg amputee is very important to have a waterproof leg (showering) water leg
- If no water leg has a seat not recommended to stand with the one leg
- Need to have nonslip surfaces in the shower for leg amputee
- Do dishes in the morning, body gets soaked bc holding against body and breaks things more often, back pains bc leaning into the sink to wash, cannot submerge myoelectric armor will ruin it
- Same with cooking, difficulty carrying food, carries food against body and will soil clothes, need to do laundry more often

- Leg amputee in the kitchen is not as affected, most concern is slippery floors, non-secured area rugs and can slip,
- Does not wear arm around the house mainly for outdoor use
- Any amputees need to have railing at all stairwells for extra stability
- Grab bars on the side of the bathtub to help user get out of the tub safely needs to be able to hold users' entire weight
- Door handle knobs should not be round for arm amputees impossible to open if round flat handles are best to use with residual limb
- If leg amputees spill liquids can make the floor slipper
- Straining pasta and holding pots is very difficult for arm amputees
- Arm amputees can burn themselves when cooking
- Special pots and kitchen tools that make it easier to use for arm amputees
- Challenge to cut vegetables on the cutting board for arm amputees
- Handheld food processors to help cut up vegetable's tomatoes and onions
- Tools are a huge help for arm amputees in the kitchen
- Use cream or lotion before putting on the residual limb before putting on the prosthetic arm for conductivity to help control the arm very easy to put on biggest concern on where the users leave the arm
- Leg amputation – put the leg on and not want to take it off for the day, hurts after standing on it for a long time so they need to take it off to take breaks, annoying to take it off, sleeve with a silicone liner stump sock first before prosthetic, need to rest after continuous use cannot always take it off in public so they have to push through , difficult to put on a prosthetic when wet like after a shower or swimming, doesn't like showering as much
- Can easily get tendonitis in the sound limb, sound limb is double the users age bc they use it more than they must, important to have a prosthetic to balance the work
- Forearm crutches are best for leg amputees, armpit is not as good, keep crutches around the house or close by if not using the prosthetic (stop the hop)

8.2 Appendix B – User Research

User Profile

Primary User	Prosthetic User
Secondary User	Prosthetists
Tertiary User	Physical Therapists

Findings

Demographic		*User Behavior*	
Age	55 - 65	*Psychological Effects*	High
Gender	Male	*Lifestyle*	Laborious
Income	Low	*Body Image*	Low
Location	Rural	*Self-Esteem*	Low
Ethnicity	Vietnamese	*Physical Activities*	Low

Demographic

The primary user would most likely be a male between the ages of 50 – 80 years old living in rural Vietnam. This user would be working a labor-intensive job that would provide a low/irregular income. When adapting to a lifestyle of having a prosthetic, it can take a toll on the user's psyche, how active the user is and their views on themselves.

User Behavior

Findings have been summarized below according to the relevant categories: Psychological Effects; Physical Activity; Lifestyle and Personality; Body Image and Self-Esteem.

When having to amputate a limb, it can be expected for the user to experience psychological effects afterwards. Their mind can also trick them into thinking their original limb is still there, this is called *Phantom Limb.* Due to amputation of limb and the psychological effects, users do not usually take part in physical or recreational activities such as sports.

Living with a prosthetic can be very difficult in the beginning but if the user is surrounded with support, they are able to overcome it. Still after 12 years users can feel some sort of sensation from their amputated limb. Users with lower-limb amputations have a low view of their body image, and low self-esteem.

The loss of a body part disrupts the integrity of the body and affects the physical and psychological condition of the user. The variable found in this aspect of understanding what the user goes through when having to amputate a limb. The prosthetic lifestyle is very dependent on the user’s environment and their support system.

The user will go through a vast amount of psychological stress and will cause damage to their self-image. When living with a prosthetic it is not a process that is overcome in a couple years, a decade could pass and there will still be some phantom limb sensation.

Persona

An above-knee amputee persona is developed, a fictitious person, who fits the demographic, motivation and background based off the demographic research. The use of the persona aims to refocus the design intent from the product to the user.

Age & Gender

Gender. As inferred from the image search above most of the prosthetic users are male. While there are a minimal number of women requiring lower limb amputation.

Lower limb amputees in Croatia 95

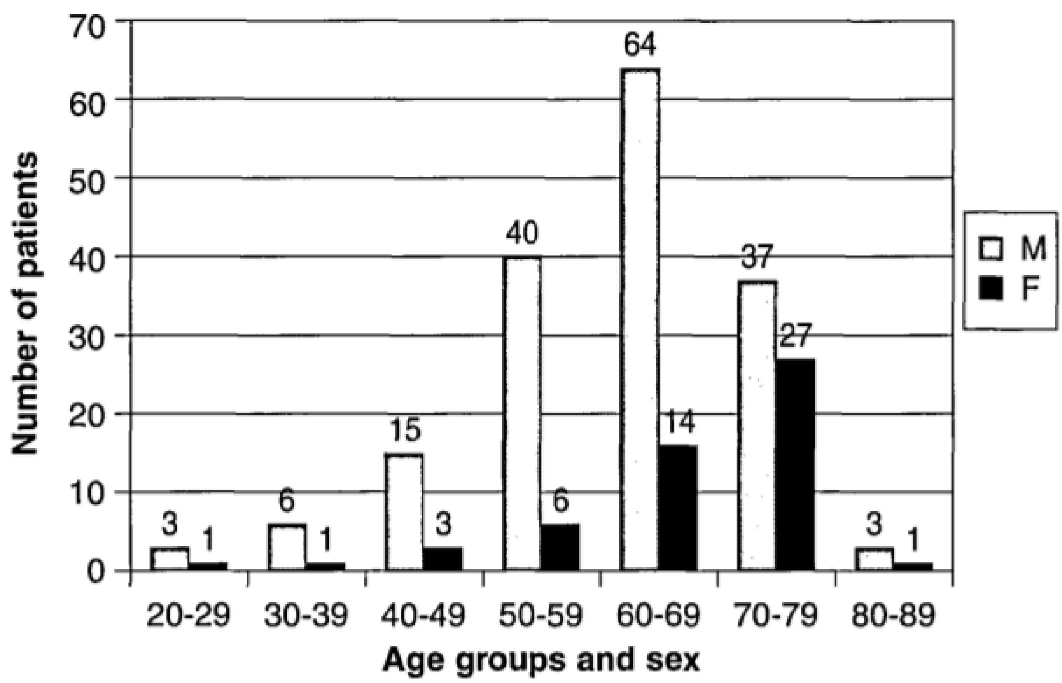


Fig. 1. Age groups, sex and frequency of amputation.

Kauzlarić, N., Sekelj-Kauzlarić, K., & Jelić, M. (2002). Experience in prosthetic supply of patients with lower limb amputations in Croatia. Prosthetics and Orthotics International, 26(2), 93–100. https://doi.org/10.1080/03093640208726631

Age. Age as seen in the image search was somewhat diverse, from Figure 4, it shows that the age range most at risk of lower limb amputation are users in their 60's. In the image above it shows that the average age of users with lower limb amputation that participated in the survey was 55 years old.

Table 1. Participant characteristics (n = 422).

Characteristic (valid observations)	Mean
Age (years) (399)	54.7
Body weight (kg) (400)	65.5
Height (cm) (399)	165.8
Body Mass Index (kg/m^2) (399)	23.8
Months since amputation (127)	258.6

Poonsiri, J., Dekker, R., Dijkstra, P. U., Nutchamlong, Y., Dismanopnarong, C., Puttipaisan, C., . . . Geertzen, J. H. B. (2019). Cycling of people with a lower limb amputation in thailand. PLoS One, 14(8) doi:http://dx.doi.org.ezproxy.humber.ca/10.1371/journal.pone.0220649

Income. In this image it shows that almost half of the participants live in rural villages wit irregular income or no income at all. Most of the participants also did not have the ability to pay for the cost associated with the prosthetic.

Table 1 Demographics and characteristics in the study groups (*n* = 222)

	Entire study group *n* (%)
Country of residence	222 (100)
Age, *n* = 220	
Mean years, range	35 (15–81)
Sex, *n* = 222	
Female	75 (34)
Male	147 (66)
Rural/urban areas *n* = 222	
Living in cities	127 (57)
Living in villages	95 (43)
Level of income *n* = 222	
No income at all	85 (39)
Irregular income	93 (42)
Regular income from employment	42 (19)
Ability to pay for costs associated with receiving the service appliances, accommodation, travel *n* = 222	
Yes	91 (41)
No	131 (59)

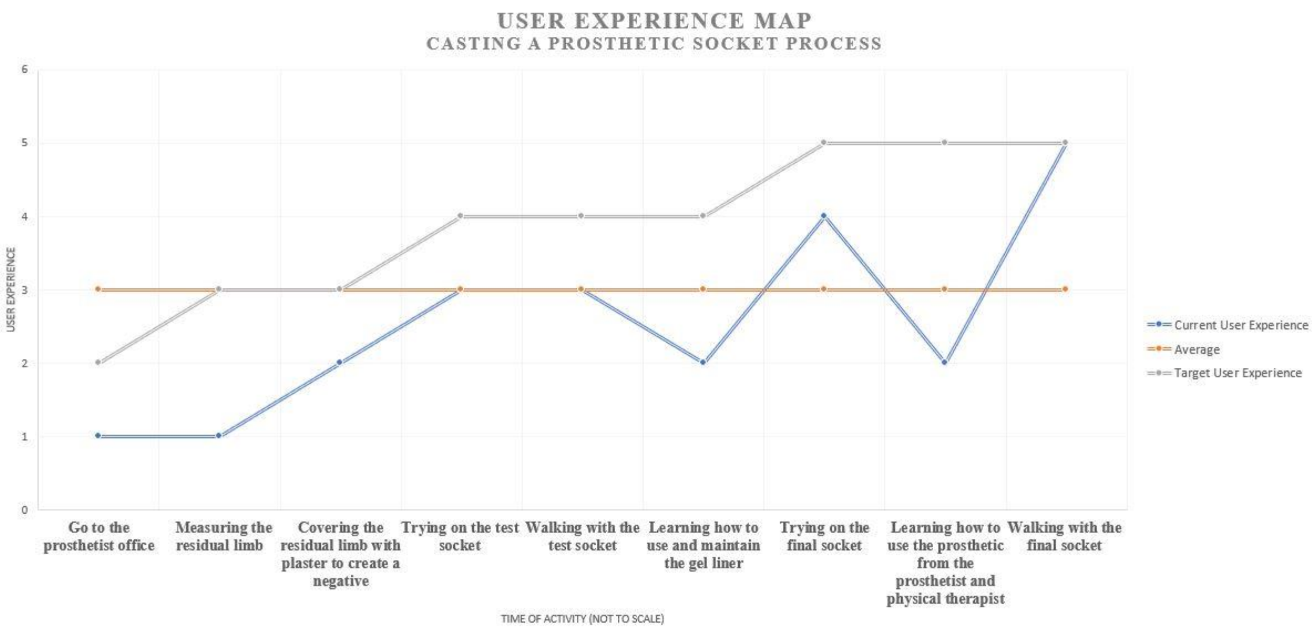
Magnusson, L., & Ahlstrom, G. (2017). Patients satisfaction with lower-limb prosthetic and orthotic devices and service delivery in sierra leone and malawi. BMC Health Services Research, 17 doi:http://dx.doi.org.ezproxy.humber.ca/10.1186/s12913-017-2044-3

User Observation: Video Analysis

- **1 min** – very intimate relationship between prosthetist and patient lot of people can be uncomfortable with this, need to be comfortable with them and have a good relationship people can be very uncomfortable with people touching their stump
- **2 min** – more comfortable to cast with the liner on, without the plaster feels warm and nice, some use a small saw when getting the plaster off and it can be extremely scary (vibrating disk saw) cuts the cast off without cutting the user can be uncomfortable because it can be very hot and can burn the user a bit, uncomfortable process
- **4:30 min** – where it hurts where its comfortable, tightness or pain, pointing out how the test socket is fitting and how it feels, pressure, where they feel it, pointing it all out, asking anything on their mind
- **5 min** – same as before, how it feels, point out anything that needs to be changed
- **6 min** – the final prosthetic is made using the user's choice of fabric so that it is personalized by whatever graphic is chosen
- **7 min** – the gel liner when casting makes it, so the user doesn't feel as much of what's happening during the process and makes the cast more accurate if the user is wearing the liner when using the prosthetic
- **8 min** – When measuring the residual limb there shouldn't be any pain or discomfort, at most it would feel a bit awkward
- **9 min** – the casting process is quite comfortable, the user needs to let the prosthetist know if they feel any discomfort, the user is holding the air hose that is used later to take the cast off.
- **10 min** – When using the test socket there can be some discomfort or pain and any of that needs to be told to the prosthetist so they can make adjustments, there's no guarantee of taking it home that same day.
- **11 min** – The many layers of socks and liners that need to be worn with the socket can feel quite warm, they need to make sure that it doesn't feel too tight or loose
- **12 min** – Learning everything the user needs to do when using the prosthetic can be overwhelming as there is a lot of cleaning and exercising that needs to be done
- **13 min** – User needs to think about what is most comfortable to them so that the final prosthetic doesn't irritate the residual limb, both the prosthetist and physical therapist are together to help inform the user

- **14 min** – Learning to clean and maintain the gel liner for the socket, remembering the steps that needs to be taken to maintain it
- **15 min** – Ask any and all questions that may be on their mind

User Experience Map



1 (Very Poor), 2 (Poor), 3 (Average), 4 (Good), 5 (Very Good)

Activity 1	*Steps/Process*	*Base User Experience*	*Potential for Improvement*
Casting the user's residual limb with plaster.	-User wears the gel liner while the prosthetist covers the user's residual limb with saran wrap. -Prosthetist layers plaster strips on the user's residual limb and uses the cast to make a plastic test socket.	-User listens to the prosthetist for any important information about the prosthetic. -Remain calm and relaxed as the plaster is being applied.	-Develop methods for the measuring process to be done remotely. -Simplify process so it can be done volunteers.

Activity 2	*Steps/Process*	*Base User Experience*	*Potential for Improvement*
Walking with the test socket.	-The prosthetist attaches the test socket temporarily to the pylon. -User walks with the test socket and informs the prosthetist of any discomfort they feel. -Prosthetist will take not of pressure points and adjust the socket as needed.	-User may feel some discomfort when walking with the test socket. -Walking may feel difficult, user will need an aid.	-Adjustable socket that can form to the user's residual limb. -Socket may have an open bottom to alleviate pressure from the incision point

Activity 3	*Steps/Process*	*Base User Experience*	*Potential for Improvement*
Receiving the final socket	-When the final socket is ready to be made, the user can pick a specific fabric used in making the socket, this is so the user can customize their socket. -User will receive the final socket and the prosthetist will inform the user of all the required maintenance for the prosthetic.	-User is excited to receive the final socket that has been customized to their aesthetics. -User must take it a large amount of information about the prosthetic.	-Develop a method for the user to receive their socket earlier so there is less wait time. -Allow the user to have more customizable options available

Overall Analysis

The process of having a lower limb socket made can be very daunting for the user initially if it is their first time. In general, it is a long but simple process that the prosthetist tries to make comfortable for the user. The relationship between the prosthetist and the user is very intimate because the prosthetist needs to properly feel/measure the residual limb so that the socket will sit comfortably. It will take multiple sessions to get the final socket made, as test sockets are needed to ensure the user can walk comfortably with the prosthetic. When having to learn about the process in using and maintaining a prosthetic, it can be intimidating at first because there is a lot of information for the user to process. Getting a prosthetic can be a long process and depending on how the user lost their limb, it changes how the user feels about the prosthetic.

Key Observation	Potential Improvements
Intimacy with the prosthetist and awkward	The user's residual limb can be scanned to get an extremely accurate measurement
Removing with the hand tool can be very scary	A print for the residual limb can be used to eliminate this process
A lot for the user to learn and remember	Liner can teach the user how to use it and can always be looked back at
Odd feeling when using a new prosthetic	Additional padding can be used on the inside of the socket or can be made using a more malleable material
Adjusting to using the prosthetic	Prosthetic teaches the user proper exercise
Discomfort after using for multiple hours	Prosthetic has a timer to remind the user to take a break from using the prosthetic

8.3 Appendix C – Product Research

The following section of this thesis report is to examine various prosthetics and accessories used by amputees, to identify key benefits and features, while highlighting areas for innovation. When researching various prosthetics, companies broke down the prosthetic to 3 main pieces that are featured on their site; the knee joint, pylon, and prosthetic foot. A pool of 10 products were initially selected, with the following 4 being critically analyzed for this report. Below is a table identifying the 4 selected products.

Product Name	*Product Image*	*Features*	*Product Reference*
Aqualine Water Leg		1. 3WR95 Aqua knee has a manual lock that stops the knee from moving, allowing stability when walking in wet areas 2. 1WR95 Aqua foot has textured soles to provide additional traction so it is anti-slip, the foot is sealed from any water at the top and has a plug on the sole 3. The Aqua foot is designed to replicate a natural foot with defined toes so sandals can be easily slipped on with confidence 4. The pylon is protectively coated to resist wear and corrosion. The simple shape allows for the pylon to be easily cleaned	https://www.ottobock.ca/en/prosthetics/lower-limb-prosthetics/solution-overview/aqualine-waterproof-above-knee-system/

C-Leg		1. Stumble recovery reduces the frequency of falls for people with transfemoral amputations, making it a reliable prosthetic that increases precision while also offering better stability 2. The microprocessor knee can be controlled by the Cockpit app that can be downloaded on the user's phone for information about the joint, and battery level, connected by Bluetooth 3. The C-Leg uses sensors to figure out where it is in the space to make precise adjustments to making walking on various terrain easier 4. The prosthetic can support up to 300 lbs. to support users who weigh more or those who are required to carry heavy loads	https://www.ottobock.ca/en/prosthetics/lower-limb-prosthetics/solution-overview/c-leg-above-knee-system/
Ottobock's Fitness Prosthetic		1. The 3S80 sport knee joint has powerful rotation hydraulics designed for running sports and high stride rates 2. The runner foot is a lightweight carbon spring to provide runners with a higher level of propulsion while also improving stability when going around corners	https://www.ottobock.ca/en/prosthetics/lower-limb-prosthetics/solution-overview/above-knee-fitness-prosthesis/

		3. Runner soles are compatible with the runner's foot to provide the user with the ability to traverse over various terrain such as asphalt, gym floors, and natural trails 4. This prosthetic can support a maximum weight of 220 lbs. to support users who weigh more or those who exercise with heavy weights	
LIMBox		1. LIMBS Knee is a simple joint that can withstand extreme loading conditions and flexions, it has easier swing-through without any loss of stability and provides the user with a normal gait 2. Niagara/LIMBS Foot is an affordable and high-quality foot that can withstand rugged conditions. This foot is made from impact resistant DuPoint Delrin, and can be easily trimmed to make it smaller or use a foot cover to make it larger	https://www.limbsinternational.org/technology-development.html

Below, the key benefits have been grouped into three columns. All benefits from promotional literature have been gathered in the column titled BENEFITS. In the middle column, 'Sort #1' the Data is color coordinated into various categories. In the third column on the right, 'Sort #2' these benefits are sorted into their appropriate categories and given a category name to make identifying the general scope of these benefits easier for future reference.

BENEFITS	Sort #1	Sort #2	
From Promotional Material	**DATA [On Menu Bar] →**	**Groups like categories**	
Comfortably	Affordable	***Comfort:***	***Ease:***
Style	Battery level	Comfortably	Battery level
Easy to clean	Better stability	Confidence	Easier swing-through
Enjoy their time	Carry heavy loads	Confident	Easily cleaned
Used in the shower	Comfortably	Enjoy their time	Easily trimmed
Stability	Complete various atheletic activities	Style	Easy to clean
Traction	Confidence	Support users who weight more	Information about the joint
Sealed from any water	Confident	Support users who weight more	Make it larger
Natural foot	Control		Natural foot
Confidence	Cost-efficient	***Stability:***	Necessary components
Easily cleaned	Durability	Better stability	Normal gait
Stability	Easier swing-through	Control	
Control	Easily cleaned	Extreme loading conditions	***Use:***
Energy and cost efficient	Easily trimmed	Flexions	Carry heavy loads
Reduce risk of falling	Easy to clean	Improving stability	Complete various atheletic activities
Confident	Energy and cost efficient	Increases precision	Mobility
Natural gait	Enjoy their time	Stability	Running sports
Used in any type of weather	Extreme loading conditions	Stability	Training process
Increases precision	Flexions	Stability	Used along the beach, over a trail, on a track
Better stability	High stride rates	Strength	Used in any type of weather
Information about the joint	Higher level of propulsion	Superior functionality	Used in the shower
Battery level	High-quality	Traction	
Walking on various terrain easier	Improving stability		
Support users who weight more	Increases precision	***Efficiency:***	
Carry heavy loads	Information about the joint	Affordable	
Used along the beach, over a trail, on a track	Lightweight	Cost-efficient	
Strength	Make it larger	Durability	
Mobility	Mobility	Energy and cost efficient	
Complete various atheletic activities	Natural foot	High stride rates	
Training process	Natural gait	Higher level of propulsion	
Running sports	Necessary components	High-quality	
High stride rates	Normal gait	Lightweight	
Lightweight	Reduce risk of falling	Natural gait	
Higher level of propulsion	Rugget conditions	Reduce risk of falling	
Improving stability	Running sports	Rugget conditions	
Traverse over various terrain	Sealed from any water	Sealed from any water	
Support users who weight more	Stability	Traverse over various terrain	
Necessary components	Stability	Walking on various terrain easier	
Cost-efficient	Stability		
Superior functionality	Strength		
Stability	Style		
Durability	Superior functionality		
Extreme loading conditions	Support users who weight more		
Flexions	Support users who weight more		
Easier swing-through	Traction		
Normal gait	Training process		
Affordable	Traverse over various terrain		
High-quality	Used along the beach, over a trail, on a track		
Rugget conditions	Used in any type of weather		
Easily trimmed	Used in the shower		
Make it larger	Walking on various terrain easier		

Below, the key benefits have been grouped into three columns. All benefits from promotional literature have been gathered in the column titled BENEFITS. In the middle column, 'Sort #1' the Data is color coordinated into various categories. In the third column on the right, 'Sort #2' these benefits are sorted into their appropriate categories and given a category name to make identifying the general scope of these benefits easier for future reference.

FEATURES		Sort #1	Sort #2
From Promotional Material	Re-order: NOUN first	DATA [On Menu Bar] →	Group like categories
Used in water	Leg-Used in water	Foot-Carbon fiber	**Foot:**
Moisture will not affect	Leg-Moisture will not affect	Foot-Carbon spring	Foot-Carbon fiber
Non-corrosive	Pylon-Non-corrosive	Foot-Defined toes	Foot-Carbon spring
Manual lock	Knee-Manual lock	Foot-DuPoint Derlin	Foot-Defined toes
Textured soles	Foot-Textured soles	Foot-Foot cover	Foot-DuPoint Derlin
Plug on the sole	Foot-Plug on the sole	Foot-Niagara/LIMBS foot	Foot-Foot cover
Defined toes	Foot-Defined toes	Foot-Plug on the sole	Foot-Niagara/LIMBS foot
Protectively coated	Pylon-Protectively coated	Foot-Runner soles	Foot-Plug on the sole
Simple shape	Pylon-Simple shape	Foot-Textured soles	Foot-Runner soles
Microprocessor	Knee-Microprocessor	Knee-3S80 sport knee joint	Foot-Textured soles
Stumble recovery	Knee-Stumble recovery	Knee-App	
App	Knee-App	Knee-Bluetooth	**Knee:**
Stumble recovery	Knee-Stumble recovery	Knee-Cockpit app	Knee-3S80 sport knee joint
Microprocessor knee	Knee-Microprocessor knee	Knee-LIMBS knee	Knee-App
Cockpit app	Knee-Cockpit app	Knee-Manual lock	Knee-Bluetooth
Bluetooth	Knee-Bluetooth	Knee-Microprocessor	Knee-Cockpit app
Sensors	Knee-Sensors	Knee-Microprocessor knee	Knee-LIMBS knee
Precision adjustments	Knee-Precision adjustments	Knee-Precision adjustments	Knee-Manual lock
Support up to 300 lbs.	Knee-Support up to 300 lbs.	Knee-Rotation hydraulics	Knee-Microprocessor
Carbon fiber	Foot-Carbon fiber	Knee-Sensors	Knee-Microprocessor knee
Sport knee joint	Knee-Sport knee joint	Knee-Sport knee joint	Knee-Precision adjustments
3S80 sport knee joint	Knee-3S80 sport knee joint	Knee-Stumble recovery	Knee-Rotation hydraulics
Rotation hydraulics	Knee-Rotation hydraulics	Knee-Stumble recovery	Knee-Sensors
Carbon spring	Foot-Carbon spring	Knee-Support up to 300 lbs.	Knee-Sport knee joint
Runner soles	Foot-Runner soles	Leg-Dontated	Knee-Stumble recovery
Support up to 220 lbs.	Leg-Support up to 220 lbs.	Leg-Educate use and repair	Knee-Stumble recovery
Dontated	Leg-Dontated	Leg-Moisture will not affect	Knee-Support up to 300 lbs.
Educate use and repair	Leg-Educate use and repair	Leg-Support up to 220 lbs.	
LIMBS knee	Knee-LIMBS knee	Leg-Used in water	**Leg:**
Niagara/LIMBS foot	Foot-Niagara/LIMBS foot	Pylon-Non-corrosive	Leg-Dontated
DuPoint Derlin	Foot-DuPoint Derlin	Pylon-Protectively coated	Leg-Educate use and repair
Foot cover	Foot-Foot cover	Pylon-Simple shape	Leg-Moisture will not affect
			Leg-Support up to 220 lbs.
			Leg-Used in water
			Pylon:
			Pylon-Non-corrosive
			Pylon-Protectively coated
			Pylon-Simple shape

8.4 Appendix D – Needs Analysis

Statement of Need

An above-knee prosthetic that allows amputees flexibility to continue with their daily tasks. Further needs include ease of use, comfort, and stability.

Product – Above-Knee Prosthetic				
Needs	**Benefits and Underlying Needs**	**Level of importance**		
Basic Needs				
Food, water, shelter				
Pleasure, gratification *(sensory, compulsive responses)*	• Smooth interior of the socket		*Moderate*	
Security				
Safety (Protection of user)				
State, Group, Individual				
Securing resources *Optimization of limited resources (cost effectiveness)* • *Value* • *Accumulation of resources (wealth)*	• Price is important to users (lack or insurance, poor income, living in a developing country, etc.)			*High*
	• Reliability			*High*
Control over environment (tasks) Convenience *Ease of Use* *Speed (fast, less time)*	• Easy to walk or run in • Ability to go up and down stairs • Complete vigorous activities			*High*
	• Efficient speed		*Moderate*	
	• Precise movements when in use			*High*

Control (precision, responsiveness, power)				
Long Term Security/Stability of Group	• Ensuring no long-term effects on residual limb			*High*
	• Prosthetic has a long-life span		Moderate	
Social Belonging				
Fear of Abandonment	• User feels welcomed in community		Moderate	
Fear of the enemy	• May likely be attacked because they are seen as an easy target		Moderate	
Tribal Identity	• Continue to work with the community		Moderate	
Behavior cues for survival	• Trying not to stand out with the disability • Act like those around the user	Slight		
Behavior cues for social interaction of group	• Do not remove prosthetic when in a social environment		Moderate	
Peer Pressure	• Wearing the prosthetic when going out	Slight		
Social Expectation	• Function normally		Moderate	
Esteem				
Social Status	• Need for high end products with complex technology	Slight		
Social Recognition	• Seen as more than a disability			*High*
Sexual attractiveness	• Not having the prosthetic be the defining trait of the user			*High*
‘Hight order’ Functions/Needs. Needs that are pre-dominantly ‘outer cortex’				
Intrinsic pleasure	• Technology	Slight		
Creative endeavors	• Complete recreational activities		Moderate	
Experiential (extrinsic)	• Various weather • Other people’s actions	Slight		
Experiential (intrinsic)	• How the user sees themselves • How the user feels wearing the prosthetic		Moderate	

Emotional	• Positive emotional connection to prosthetic			*High*

Comfort in this context is decreasing the harshness of the walking with a prosthetic (harshness would contribute to feeling a loss of control when in use, damaging the user's residual limb, decreasing the sense of protection. **Security** is the major fundamental human need met.

Stability in this context is decreasing the possibility of the user falling when using the prosthetic (falling would contribute to feeling a loss of control when in use and can seriously injure the user depending on the circumstance).

Efficiency is defined as the effort required to perform at a particular level. This is related to **control** the user has during the activity (**autonomy**).

Ease is in many ways related to efficiency in terms for fundamental human needs (i.e. **control, autonomy**).

Use related to the **social expectations** the user is expected to follow and be able to complete their personal **accomplishments.** related to efficiency in terms for fundamental human needs (i.e. **control, autonomy**).

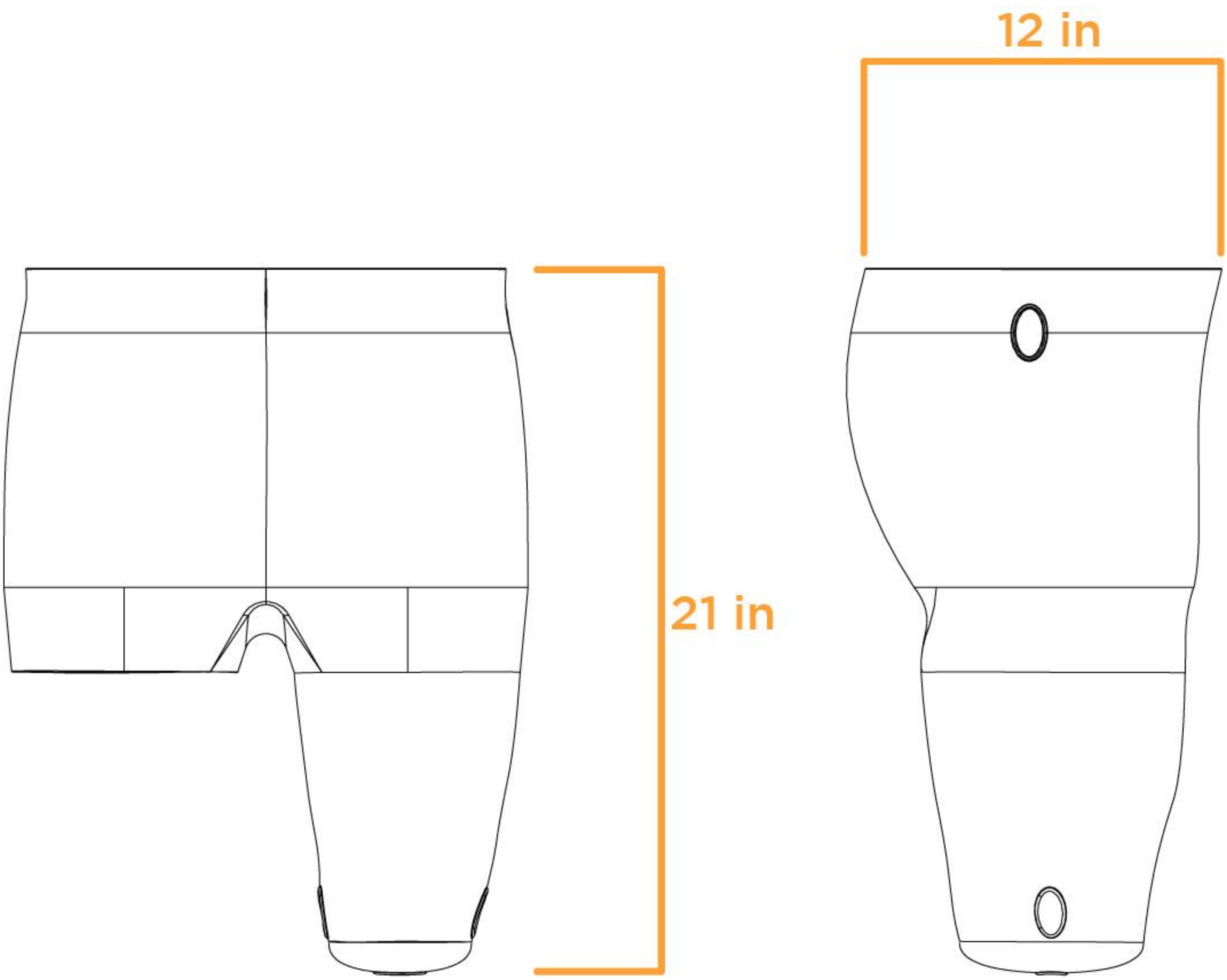
	Benefit	***Possible Corresponding Fundamental Human Needs (FHN)***	***Relationship between Benefits and FHN***
1	Comfort	Control, security, self-esteem	Strong
2	Stability	Control, security,	Strong
3	Efficiency	Accomplishment, autonomy, self-esteem	Strong
4	Ease	Accomplishment, autonomy, protection, security, self-esteem	Strong
5	Use	Social expectation, accomplishment	Strong

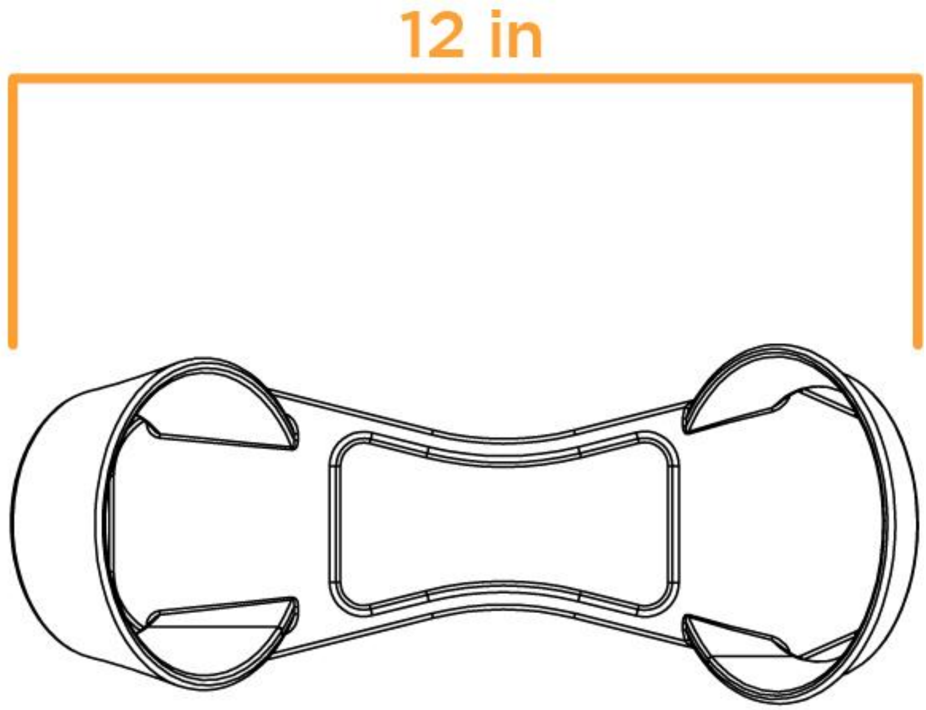
Statement Need

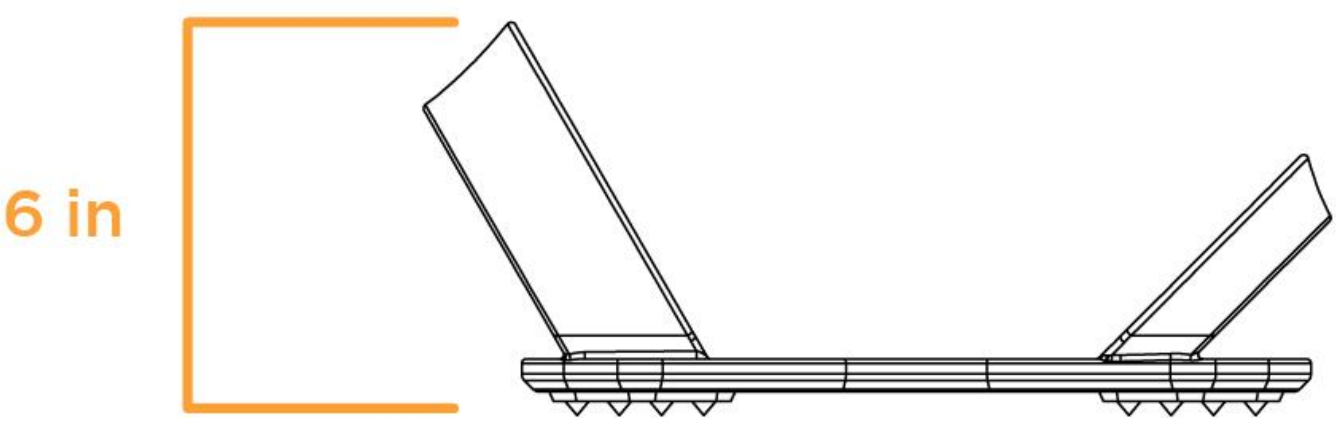
Walking with an above-knee prosthetic is a purposeful activity (user mobility) based on the ease of functioning and comfort afforded to the user (transport, control, security). User mobility is also a social activity since most transport involves interaction at each end of the journey. Esteem can be afforded by good styling/quality cues of the device. Control and mastery of the prosthetic is related to the performance of the prosthetic (effectiveness, ease, and comfort).

8.5 Appendix E - Physical Model Photographs

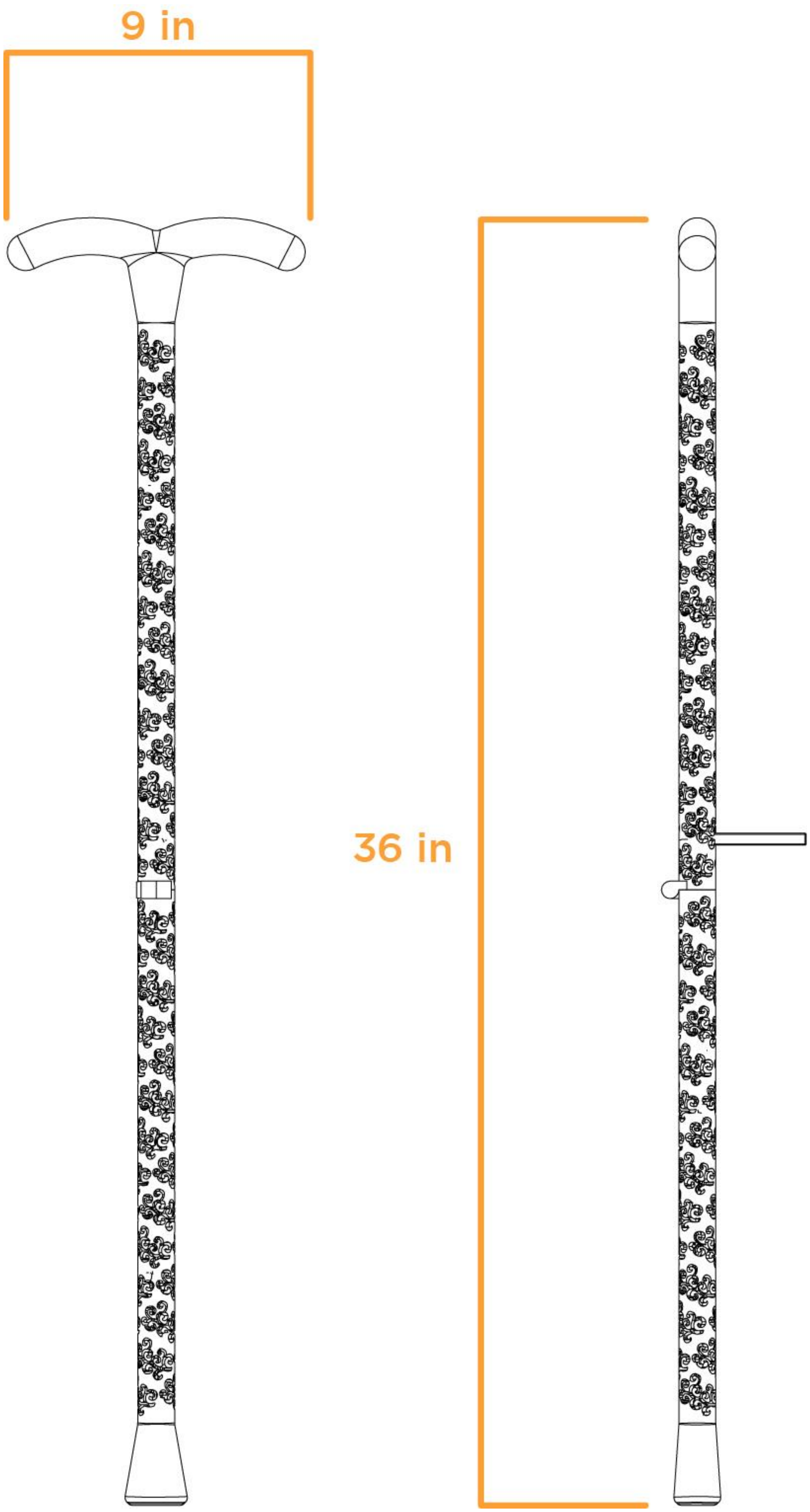
8.6 Appendix F – Technical Drawings







Asa



Asa

8.7 Appendix G – Manufacturing Cost Info/Data

High-Cost Items					
Concept Item	*Description*	*Estimated Cost/ Each*	*Similarly Produced Item*	*Quantity*	*Material*
Tesla Semi	Semi-truck	$190,000	Peterblit 389	1	Various
Markforged Metal X	Metal 3D Printer	$100,000	Xometry Metal 3D Printer	4	Various
Steiger Vega 3.130	Fabric 3D Printer	$18,000	Kniterate	2	Various
Medium Cost Items					
Concept Item	*Description*	*Estimated Cost/ Each*	*Similarly Produced Item*	*Quantity*	*Material*
Cargo Container	40 ft container	$5,600	-	1	Steel
Furniture	-	$5,000	-	-	Various
Prusa i3 MK3S	FDM 3D Printer	$1,250	3DPrintMill	4	Various
Low-Cost Items					
Concept Item	*Description*	*Estimated Cost/ Each*	*Similarly Produced Item*	*Quantity*	*Material*
Shin Cover	Prosthetic Component	$370	-	Numerous	Titanium

Collapsible Cane	Prosthetic Component	$130	-	Numerous	Titanium
Compression Shorts	Prosthetic Component	$50	-	Numerous	Polyester
Socket	Prosthetic Component	$15	-	Numerous	Delrin
Knee Joint	Prosthetic Component	$5	-	Numerous	Delrin
Foot	Prosthetic Component	$5	-	Numerous	Delrin
Pylon	Prosthetic Component	$2	-	Numerous	Delrin
Shoe Cover	Prosthetic Component	$2	-	Numerous	Delrin
Fastener	Prosthetic Component	$2	-	Numerous	Delrin

8.8 Appendix H – Sustainability Info/Data

INTRODUCTION

The sustainability aspect for this thesis has taken into consideration the Cradle-to-Cradle method of product design. It is crucial for the above-knee prosthetic design to have negligible effect towards Vietnam's environment and their citizens. The above-knee prosthetic will be made from mainly 3 materials: titanium, Dupont Delrin, and Roica sustainable yarn, all available for 3D printing. The purpose of these sustainability goals is so that there are no negative effects towards Vietnam as they are currently a targeted country for outsourced labor, and product manufacturing factories that pollute their country.

LITERATURE REVIEW

The sustainability data that is referenced throughout this report is retrieved from the "Circular Design Guide" from Cradle-to-Cradle (Cradle-to-Cradle, 2021). Referencing the list of sustainable materials and manufacturing processes that are available.

Safety

Working in Vietnam, living in rural villages and being in middle-lower class, is a hardworking lifestyle. Safety concerns for amputees living this lifestyle and longevity must be addressed in order to satisfy the essential and basic needs of the user. The safety and comfort of amputees is very important, as improper use or inaccurate ergonomics may cause them further harm. Vietnam's environment is laborious, hands on work is the commonly worked industry, this environment will be taken into consideration to ensure it will cause no damages towards the prosthetic and user. Temperature in Vietnam ranges between 20°C – 35°C throughout the year and has an annual humidity of 85%, therefore the prosthetic must be able to withstand constant heat while not being affected by high humidity.

As it is common to come across water throughout the day whether it is showers or simply rain, the prosthetic must not be affected by this. Slips and falls are extremely dangerous for an above knee amputee, as impact on their residual limb may cause terribly painful and long-lasting injuries. This can be solved by using materials in the prosthetic that is not affected by water and providing a non-slip sole for the foot. The user must be able to adjust towards their prosthetic, whether it be maintenance or setting changes, with ease and in a manner that does not jeopardize the user's safety. This is a manual task that will require the user to be educated on these matters so they can be done in a proper fashion.

When worn daily, low quality prosthetics may cause irritation to the user's skin and residual limb. The constant friction between the user's residual limb and their prosthetic may cause the user to be unwilling of continuing to wear their prosthetic, leaving them to options such as crutches, wheelchairs or by hopping on their sound limb. Crutches can cause irritations to the users' arms and puts additional pressure on the user's sound limb, causing it to deteriorate faster than it should. Wheelchairs are a sustainable option but are high cost and unsuitable for the terrain in rural areas of Vietnam. All prosthetists and physical therapists do not recommend sampling hopping around on their sound limb as it will cause their knee joint to rapidly age and deteriorate, the user will also be at high risk of injury from falling.

Health

The health of citizens in Vietnam is not always prioritized compared the health of citizens in other countries. Being a developing country, Vietnam does have hospitals and medical facilities but citizens living in rural villages must travel a long distance either by walking or bicycle, maybe a bus if the citizen has enough money to spare. Medical insurance in Vietnam is also limited as many citizens are self employed or work for smaller companies, therefore they have difficulty covering these expenses, not giving them the access to proper healthcare. The physical labor these citizens work in order to make their income takes a toll on their bodies, the prosthetic is designed to not only keep up with this style but avoid the user from additional pains or injuries. It is crucial that the prosthetic does not cause any harm or irritation towards to avoid long term injuries and to encourage the user to wear their prosthetic continuously.

The mentality of these users is important, as adapting to this new lifestyle is extremely difficult and will cause stresses towards the user. It is common for recent amputees to go through depression, this feeling can last years for the user if they do not receive the help they need. To reduce the difficulty when using a prosthetic means it will reduce the frustrations users experience when learning how to normally function again. The physical stresses that these users experience can cause mental effects as well, users may experience somatization, the significant focus of physical symptoms. Depression, anxiety, and anger are common psychological effects post-amputation. To reduce the risks of these psychological effects by making the transition from a wheelchair to prosthetic as smooth as possible.

Environment

As many countries outsource their manufacturing to developing countries, Vietnam is being polluted and saturated from the remnants of these factories. The manufacturing for the prosthetic will be conducted in Vietnam, therefore it is crucial that there is no additional pollution from the manufacturing process.

The design for this prosthetic is to have a portable facility travel across Vietnam to provide prosthetic to as many citizens as possible. To refrain from adding additional pollution to Vietnam, this facility would be built from an upcycled cargo shipping container, driven on the back of a solar powered semi-truck. All components of the prosthetic will be manufactured using 3D printing powered by the same energy gathered by the semi-truck, this will also allow for failed prints to be upcycled and used again so nothing goes to waste.

The materials that the prosthetic will be made from are titanium, Dupont Delrin plastic and Roica sustainable yarn. These materials are durable to produce a long-life product, and they are sustainable. The designed prosthetic is composed of 5 main parts; the socket, knee joint, knee cover, pylon and foot, all parts can be easily fastened together. The user will be taught how to assemble and disassemble the prosthetic if needed so they may maintain their prosthetic if they are a great distance away from the prosthetic facility. The prosthetic is also designed to be disassembled so that certain parts may easily be replaced when they have been used to their full extent. It will be encouraged for users who own these prosthetics, return their worn parts for new ones so that the worn parts may be turned into filament to be used to 3D print more prosthetics.

The impact the prosthetic design and manufacturing has on the environment in Vietnam is crucial. The prosthetic is designed for citizens and Vietnam to benefit both as much as possible. The prosthetic is designed using the cradle-to-cradle method of manufacturing to ensure there is as little waste as possible produced.

8.9 Appendix I – Approval Forms

IDSN 4002
SENIOR LEVEL THESIS ONE

Humber ITAL / Faculty of Applied Sciences & Applied Technology
Bachelor of Industrial Design / FALL 2020
Catherine Chong / Sandro Zaccolo

FTA-4 THESIS TOPIC APPROVAL (TEMPLATE)
This project/assignment constitutes 5% of total mark for the course

Start: Week #4 / Sep-28
Due: **Week #5 / Oct-05**

THESIS TOPIC APPROVAL:

Student Name:	Casey Ho
Topic Title:	How may we make prosthetics more accessible to those in developing countries?

Abstract

The amount of violence and suffering that occurs in developing countries is astonishing, but the main problem is their access to proper healthcare. It is a basic human right to have access to medical facilities, without it, citizens of these countries will continue to suffer. One of the largest problems in Vietnam is amputation, it completely changes the life of the patient. The effects of life after amputation is dependent on the quality and access of prosthetics, majority of events resulting in amputation are road accidents and war. Life in Vietnam can be difficult as living in rural villages is common, and the main sources of travel are biking, or walking, if they have money bus or taxi. These citizens lively hoods are dependent on being physically capable so that they can work on their farms to sell produce or efficiently work in manufacturing factories. The process when getting a prosthetic requires time and money, the socket must be measured and custom made, while the parts are imported, not to mention the physical therapy needed later. These crude scraps can damage the amputated limb and requires constant maintenance, while giving no guarantee for functionality for their jobs. This thesis proposes a thorough research of the daily lives of citizens in Vietnam and the challenges they face. Research methods such as data collection, surveys and interviews, this data will be analyzed to focus on improving the quality of life. Additionally, with reference to existing prosthetics and methods, a one-to-one model will be developed to understand the required ergonomics. Results from this analysis will secure a design solution that makes prosthetics accessible, improving the life of the user, and reducing strain on daily activities.

Student Signature(s):	Casey Ho
Date:	11/10/2020

Instructor Signature(s):	Catherine Chong
Date:	18/10/2020

Chong, Kappen, Thomson, Zaccolo

IDSN 4502

SENIOR LEVEL THESIS TWO

Humber ITAL / Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / WINTER 2021
Catherine Chong / Sandro Zaccolo

CRITICAL MILESTONES: APPROVAL FOR CAD DEVELOPMENT & MODEL FABRICATION

Student Name:	**Casey Ho**
Topic / Thesis Title:	**Prosthetic Accessibility for Vietnam**

THESIS DESIGN APPROVAL FORM

Thesis design is approved to proceed for the following: [X]	**CAD Design and Development Phase**
Comment: Initial CAD progress well as of week #7/March 1st, continue with detailing and refinement.	

Thesis design is approved to proceed for the following: [X]	**Model Fabrication Including Rapid Prototyping and Model Building Phase**
Comment: Design development progress well as of week #7/March 1st, once CAD is completed, can move forward to model fabrication from week #9 onward.	

Instructor Signature(s):

Date:	10th March 2021

1

Chong, Kappen, Thomson, Zaccolo

PANEL ON
RESEARCH ETHICS
Navigating the ethics of human research

TCPS 2: CORE

Certificate of Completion

This document certifies that

Casey Ho

has completed the Tri-Council Policy Statement:
Ethical Conduct for Research Involving Humans
Course on Research Ethics (TCPS 2: CORE)

Date of Issue: **10 September, 2020**

8.10 Appendix J – Advisor Meetings & Agreement Forms

Conditions of Participation

- ✓ I understand that I am free to withdraw from the study at any time without any consequences.
- ✓ I understand that my participation in this study is confidential. (i.e. the researcher will know but will not disclose my identity)
- ✓ My identity will be masked.
- ✓ I understand that the data from this study may be published.

☒ **I have read the information presented above and I understand this agreement. I voluntarily agree to take part in this study.**

James Jordan	*James Jordan*	11/09/2020
Participant's Name	Participant's Signature	Date

Project Information

Thank you very much for your time and help in making this study possible. If you have any queries or wish to know more about this Senior Level Thesis project, please contact me at the followings:

Phone: (647) 625-5233
Email: caseyho@live.ca

My supervisors are:

Prof. Catherine Chong, **catherine.chong@humber.ca**
Prof. Sandro Zaccolo, **sandro.zaccolo@humber.ca**

Research Study Topic:	How may we make prosthetics more accessible for those in developing countries?
Investigator:	Casey Ho, (647) 625-5233, caseyho@live.ca
Courses:	IDSN 4002 & IDSN 4502

I, James Jordan have carefully read the Information Letter for the project Prosthetic Accessibility for Vietnam, led by Casey Ho A member of the research team has explained the project to me and has answered all of my questions about it. I understand that if I have additional questions about the project, I can contact Casey Ho at any time during the project.

I understand that my participation is voluntary and give my consent freely in voice recording, photography and/or videotaping; with the proviso that my identity will be blurred in reports and publications.

Consent for Publication: Add a (X) mark in one of the columns for each activity

ACTIVITY		YES	NO
Publication	I give consent for publication in the Humber Library Digital Repository which is an open access portal available to the public	☒	☐
Review	I give consent for review by the Professor	☒	☐

Privacy

All data gathered is stored anonymously and kept confidential. Only the principle investigator /researcher Casey Ho and Prof. Catherine Chong or Prof. Sandro Zaccolo may access and analyze the data. All published data will be coded, so that visual data is not identifiable. Pseudonyms will be used to quote a participant (subject) and data would be aggregated.

I also understand that I may decline or withdraw from participation at any time, without negative consequences.

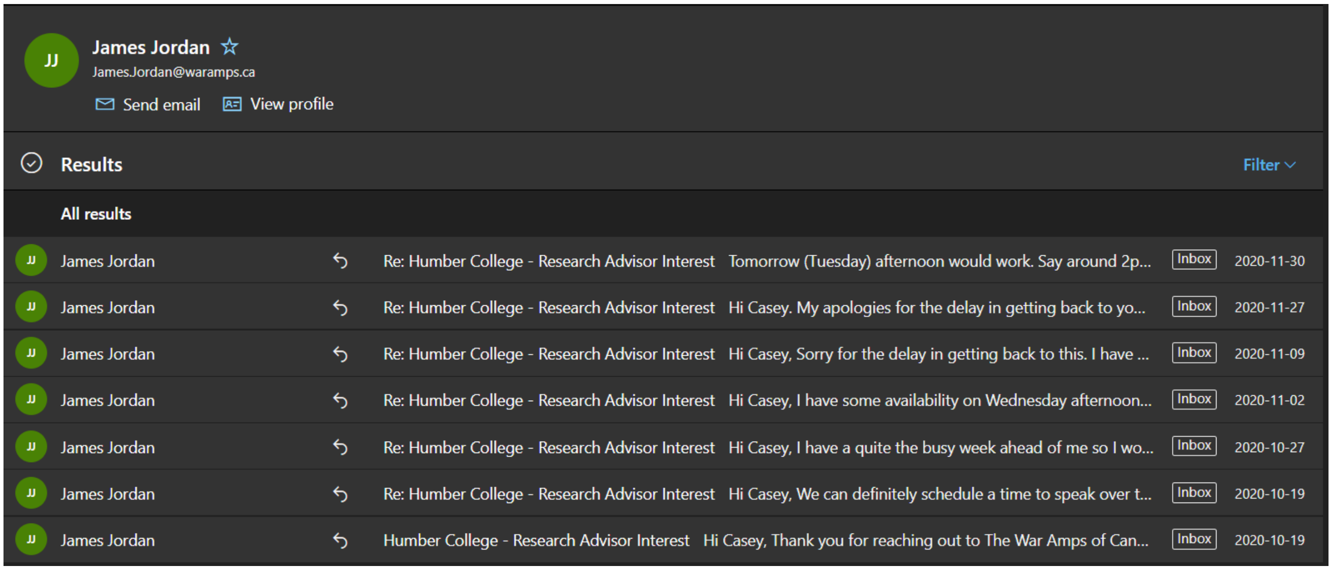
I understand that I can verify the ethical approval of this study, or raise any concerns I may have by contacting the Humber Research Ethics Board, Dr. Lydia Boyko, REB Chair, 416-675-6622 ext. 79322, **Lydia.Boyko@humber.ca** or Casey Ho, (647) 625-5233, caseyho@live.ca

Verification of having read the Informed Consent Form:

☒ I have read the Informed Consent Form.

My signature below verifies that I have read this document and give consent to the use of the data from questionnaires and interviews in research report, publications (if any) and presentations with the proviso that my identity will not be disclosed. I have received a copy of the Information Letter, and that I agree to participate in the research project as it has been described in the Information Letter.

James Jordan	*James Jordan*	**11/09/2020**
Participant's Name	Participant's Signature	Date


JJ
James Jordan
James.Jordan@waramps.ca
Send email
View profile
Results
Filter
All results
James Jordan Re: Humber College - Research Advisor Interest Tomorrow (Tuesday) afternoon would work. Say around 2p... Inbox 2020-11-30
James Jordan Re: Humber College - Research Advisor Interest Hi Casey. My apologies for the delay in getting back to yo... Inbox 2020-11-27
James Jordan Re: Humber College - Research Advisor Interest Hi Casey, Sorry for the delay in getting back to this. I have ... Inbox 2020-11-09
James Jordan Re: Humber College - Research Advisor Interest Hi Casey, I have some availability on Wednesday afternoon... Inbox 2020-11-02
James Jordan Re: Humber College - Research Advisor Interest Hi Casey, I have a quite the busy week ahead of me so I wo... Inbox 2020-10-27
James Jordan Re: Humber College - Research Advisor Interest Hi Casey, We can definitely schedule a time to speak over t... Inbox 2020-10-19
James Jordan Humber College - Research Advisor Interest Hi Casey, Thank you for reaching out to The War Amps of Can... Inbox 2020-10-19

8.11 Appendix K – Topic Specific Data, Papers, Publications

Durmus, D., Safaz, I., Adiguzel, E., Uran, A., Sarisoy, G., Goktepe, A., & Tan, A. (2015). The relationship between prosthesis use, phantom pain, and psychiatric symptoms in male traumatic limb amputees. Retrieved November 19, 2020, from https://www-sciencedirect-com.ezproxy.humber.ca/science/article/pii/S0010440X14003101?via%3Dihub

Abstract Objectives: The purpose of this study was to identify psychiatric symptoms by comparing male patients with traumatic leg amputations (LAs) with healthy controls and to determine the association between these psychiatric symptoms and phantom pain and prosthesis use characteristics. Methods: One hundred four volunteers, 51 LA patients (group 1) and 53 healthy controls (group 2) were included. Demographic data including age, height, weight, time since amputation, duration of prosthesis use, and Satisfaction with Prosthesis Questionnaire scores were recorded. Phantom pain was measured a visual analog scale (VAS). Psychiatric symptoms were measured using the Symptom Checklist-90-R, Beck Depression Inventory, Pittsburgh Sleep Quality Index, Rosenberg Self-Esteem Scale, and State-Trait Anxiety Inventory. Correlations were determined between time since amputation, duration of prosthesis use and satisfaction with prosthesis questionnaire scores and psychiatric scale scores. Results: Amputee patients had higher phobic anxiety, state anxiety, trait anxiety and sleep disturbance scores (p b 0.05) than the controls. No difference was determined in terms of psychiatric symptoms between the phantom pain and no phantom pain groups (p N 0.05). There were significant negative correlations between time since amputation, duration of prosthesis use, duration of daily prosthesis use, and satisfaction with prosthesis questionnaire scores and psychiatric symptoms. Conclusions: Apart from anxiety (state, trait or phobic) and disturbed sleep, other psychiatric symptoms in amputee patients undergoing lengthy prosthetic rehabilitation may not differ from those of healthy controls. The presence and severity of phantom pain appear to be unrelated to general psychiatric symptomatology. Length of time since amputation, length of prosthesis use, daily length of prosthesis use and prosthesis satisfaction are negatively correlated with general psychiatric symptoms. These characteristics must be borne in mind in psychiatric and prosthetic rehabilitation. © 2014 Elsevier Inc. All rights reserved. 1. Introduction Studies concerning amputee patients have largely concentrated on quality of life [1–6] and depression and anxiety symptoms [7–35]. The most important predictors of quality of life in amputee patients are depression, perceived prosthetic mobility and social support [36]. High depression levels are correlated with low quality of life [6]. More problems have been identified in such areas of quality of life as mobility, social isolation, pain, sleep and emotional disturbance compared to healthy controls [2]. Prosthesis use has been shown to be correlated with increased quality of life [5,37]. High anxiety and depression levels have been determined in the acute period in amputees [7–24]. In addition to studies suggesting that long-term depression and anxiety decrease in patients undergoing rehabilitation [25–29], others have proposed that these remain elevated even after many years [30–35]. We encountered limited studies in the literature investigating psychiatric symptoms other than depression and anxiety in amputee patients undergoing rehabilitation. Phantom pain is a widespread phenomenon in amputees. It emerges immediately after amputation and can even be seen many years later [38]. Studies in the literature regarding the association between phantom pain and depression and anxiety are inconsistent. Some of these studies have determined greater anxiety and depression symptoms in subjects with phantom pain [22,39–42], while others suggest there is no correlation [14,21,31,43–46]. We encountered no studies in the literature investigating psychiatric symptoms other than anxiety and depression in amputee patients with phantom pain. Sleep complaints are one of the most important symptoms in individuals with chronic pain. Such complaints in individuals with phantom pain include difficulty in falling asleep and poor-quality sleep. The impacts of sleep disorders and sleep disruption in worsening phantom pain processes are still poorly understood, although pain, depression and anxiety are inter-related with sleep complaints [38,47]. There have been few studies investigating sleep problems in amputee patients. Pell et al. [2] showed that overall quality of life and sleep quality following lower limb amputation for peripheral arterial disease are poor, although much of this is secondary to restricted mobility. Another study assessed sleep in amputee patients with restless leg syndrome [48]. These studies did not employ a structured sleep disorder scale and analyze the results in comparison with controls. The Pittsburgh Sleep Quality Index used in our study is capable of providing a multi-faceted sleep evaluation. Our study is the first to compare sleep disorders in traumatic amputee patients with phantom pain with a control group using a multidimensional structured scale. Prosthetic rehabilitation programs exhibit depression-reducing effects [7,25,30,49]. Nicholas et al. determined a negative correlation between daily length of prosthesis use and depression [50]. A positive correlation was determined between prosthesis use and quality of life and positive adaptation to extremity loss [29,37]. We encountered no studies in the literature investigating correlation between prosthesis use, daily length of prosthesis use and prosthesis satisfaction in amputee patients and psychiatric symptoms other than depression. The purpose of this study was to identify psychiatric symptoms by comparing male patients with traumatic leg amputations with healthy controls and to determine the association between these psychiatric symptoms and phantom pain and prosthesis use characteristics.

Jamieson, N., & Osborne, M. (2020, March 17). Agriculture, forestry, and fishing. Retrieved September 26, 2020, from https://www.britannica.com/place/Vietnam/Agriculture-forestry-and-fishing

Vietnam's greatest economic resource is its literate and energetic population. Its long coastline provides excellent harbours, access to marine resources, and many attractive beaches and areas of scenic beauty that are well suited to the development of tourism. Since the late 1990s, the country's economy has been on a vigorous upswing. Tourism has expanded, manufacturing and export earnings have increased, and the per capita gross domestic product (GDP) has grown rapidly. Early in the 21st century, state markets were opened to foreign competition, and Vietnam became a member of the World Trade Organization (WTO). This surge followed two decades of post-reunification economic instability, during which a slowly developing infrastructure, excessive population growth, environmental degradation, and a rising domestic demand (that was increasingly difficult to meet) impeded economic development.

During the period 1954–75, when the country was divided, there were three layers to the economies in both the north and the south: a bottom layer based on the cultivation of rice, a middle layer dominated by mining in the north and rubber plantations in the south, and a third wartime layer that relied on Soviet and Chinese aid in the north and American aid in the south. In the north, land reform in 1955–56 was followed by rapid collectivization of agriculture and handicrafts. Government investment favoured heavy industry at the expense of agriculture, handicrafts, and light industry, the traditional mainstays of the economy. Heavy industry grew, but efficiency was low, quality was poor, and further progress was hampered by deficiencies in agriculture and light industry. Economic aid from socialist countries masked many economic weaknesses. In the south, although a substantial proportion of manufacturing was conducted by state-owned enterprises, other sectors of the economy, such as agriculture, trade, and transport, were characterized by private ownership and private enterprise. Agriculture flourished in the Mekong delta, and the standard of living was significantly higher in the south than it was in the north.

After reunification, the northern model of development was imposed on the entire country. Efforts to socialize the commercial sector and to collectivize agriculture met with resistance, especially in urban centres and in the rich Mekong delta, where the majority of farmers in the 1970s were self-sufficient, middle-income peasants. The south also underwent a severe drain of human resources. Many well-educated people fled Vietnam after 1975. Hundreds of thousands more, mainly those who had been associated with the former government or the Americans and had not been able to leave the country, were placed in jails or reeducation centres, while other skilled but politically suspect people were forced to resettle in remote areas. The government's efforts to abolish private enterprise and private property in the south and its deteriorating political relations with China affected Vietnam's ethnic Chinese more than any other group and precipitated their flight from the country. The Chinese exodus was most intense in 1978–79, but it continued at a slower pace with sponsorship from the United Nations High Commissioner for Refugees into the early 1990s. Large police and military expenditures further strained the budget and diverted resources from productive enterprises.

These factors, combined with poor management of state-run economic programs, led to a severe economic crisis. Food production and per capita income dropped, and consumer goods were shoddy, expensive, and in short supply. The government responded with minor changes in 1979 and initiated a program of more basic reforms known as *doi moi* ("renovation") beginning in 1986. While maintaining state ownership in many sectors and overall government control of the economy, Vietnam moved away from a centrally planned, subsidized economy toward one that utilizes market forces and incentives and tolerates private enterprise in some areas. The quality and variety of food, consumer goods, and exports subsequently improved.

The pace of reform slowed during the 1990s, and the economy continued to be more cumbersome and bureaucratic than the dynamic market economies of Vietnam's more successful Southeast Asian neighbours. Although manufacturing and especially services grew in importance after the reforms were introduced, agriculture remained a major component of the economy. After 1998, however, the economy began to rebound. Exports diversified, and per capita income started to climb, nearly doubling in less than a decade.

Matsen, S. (1999). A closer look at amputees in Vietnam: A field survey of Vietnamese using prosthese: O&P Virtual Library. Retrieved November 10, 2020, from http://www.oandplibrary.org/poi/1999_02_093.asp

This study aims to improve the quality and effectiveness of follow-up data on prosthetics in developing countries. In order to bridge the gap between members of non-governmental organizations and their international patients, a field survey was conducted via direct interviews in Vietnam. Eighty-three (83) patients in 5 different geographic regions were interviewed using a standardized assessment tool designed by the author. Demographic information, questions of prosthetic history, inquiries into function, lifestyle and occupation, and queries of social and family integration were asked of each patient.

While the overall results prove salutary for those who serve the amputees of developing countries, it is clear that amputation presents a substantial challenge to the Vietnamese patient. On one hand, respondents wore their prostheses over 12 hours each day on average, rated their prostheses as quite comfortable, and were altogether satisfied with their prosthetic treatment. In addition, the provision of care for Vietnamese with amputations has improved markedly over the past few decades. On the other hand, many patients related the barriers they encountered due to their amputation, including their departure from previous careers, inability to perform rigorous physical activities, and difficulties with social interactions. Furthermore, discrepancies in care were noted between demographic groups and amongst different regions.

The questionnaire developed for this study may provide a useful evaluative tool for agencies working throughout the developing world. The use of such a standardized questionnarie could greatly improve the evaluation and comparison of prosthetic programmes and help guide the efforts of such organizations in developing countries.

As Western agencies look to assist the prosthetic efforts of developing nations, a number of impediments persist. The prolonged international debate on "appropriate technology", sustainability and durability continues as various organisations attempt to serve the underserved. While numerous theories are championed, an undeniable fact prevails: most organisations do not have quality data on the services they provide for their most remote and alienated patients (Cummings, 1996). Hughes (1996) writes that while "all the agencies are well intentioned.....there is an almost complete failure to evaluate the outcome of their efforts. No matter what technology is used, all countries and agencies involved have to answer the same questions: how to best utilise the resources which can be made available and how to measure the outcome and effectiveness of their programmes?"

More specifically, many authors have called for field studies in the actual living environment of the patients, Staats (1996) writes, "What is often overlooked is the evaluation of results for the amputee in the village, far from the workshops where the limbs are manufactured... This is rarely understood by modern or third world prosthetists until they visit amputees in their living and working situations". Cummings (1996) refers to the work of P. K. Sethi when he notes that the scientific approach in designing prostheses is "subject to failure if it ignores the lifestyles and cultures of the patients being served". This study evaluates patients served by the Prosthetic Outreach Foundation (POF) by interviewing the subjects directly in their living and working environments.

Vietnam was selected as the research site because of the persisting acute condition of Vietnamese amputees. The number of amputees in Vietnam in 1996 was estimated at 200,000 and increasing by 3-4% per year (Day, 1996). Like many developing countries savaged by wars in the twentieth century, Vietnam continues to suffer the human costs of undetonated landmines. However, mines are not solely responsible for losses of limbs. Road traffic accidents claim an increasing number of victims as the country shifts towards motorized transport. In Hanoi, the number of compound fractures of the lower limb increased 400% between 1990 and 1991. Train accidents, tumors and work-related accidents take their tolls as well. Citizens of Vietnam continue to lose their limbs at an alarming rate. Immediately after the Vietnam War, war victims accounted for 75% of amputees; by 1996, war victims comprised only 46% of the total Vietnamese amputee population (Day, 1996). Through personal interviews, this study helps define the prosthetic needs and the working and social environments of Vietnamese amputees.

In the weeks between June 1 and July 14, 1997, the author conducted personal interviews with 83 Vietnamese amputees in 5 different locations. Each interview followed a standard questionnaire designed by the author and the members of the POF in Seattle, USA (Appendix 1). Follow-up questions and questions of clarification were added as needed. A member of the Orthopaedic Institute of Rehabilitation Sciences and the Prosthetics Outreach Center served as interpreter in all the interviews. At least two photographs were taken of each patient: one focusing on the prosthetic leg of the patient and one of the entire person (**Fig. 1**).

Interviewees were identified by a variety of methods. In Hanoi, members of the POF clinic called patients at their homes to ask if an interview could be conducted. The author then travelled to the home or business of the patient. Six (6) interviews were conducted at the Hanoi Disabled Sports Association, where numerous amputee athletes congregate. In addition, a number of impromptu interviews were arranged when a patient visited the clinic for prosthetic care.

Patients in outlying areas were identified in a different manner. Interviews were conducted in conjunction with POF outreach trips during which the team delivered new legs or adjusted and repaired legs delivered previously. Members of the Hanoi POF clinic called the local government office when planning a trip. These district or sub-district offices of the Ministry of Labor, Invalids and Social Affairs then notified patients by letter that the POF team would be visiting the area. The 4 regions visited outside of Hanoi include: the Quang Tri Province south of the former Demilitarized Zone, the Vinh Phu Province in northwest Vietnam, and the towns of Phu Ly and Bac Giang. Approximate distances from interview sites to major prosthetic centers are provided in **Table 1**. In interpreting the results of this study, one should bear in mind the differing methods of patient selection on the levels of both prosthetic care and interview arrangement. Notably, a random sampling of patients proved impossible to achieve, given the government preference of care for veterans and other non-identifiable factors.

Mota, A. (2017). Materials of Prosthetic Limbs. Retrieved November 19, 2020, from https://broncoscholar.library.cpp.edu/bitstream/handle/10211.3/193171/MotaAnissa_LibraryResearchPaper2017.pdf?sequence=1#:~:text=It%20is%20commonly%20alloyed%20with,most%20commonly%20aluminum%20and%20vanadium.&text=Being%20lightweight%2C%20strong%2C%20resistant%20to,similar%20to%20that%20of%20bone.

ABSTRACT This paper will take a deeper look into prosthetic devices for limbs. A clear definition will be provided along with a brief history and evolution of prosthetic technology. Then, current materials and their properties will be examined. To conclude, this paper will discuss the future possibilities and areas of research in terms of their significance in the field of bioengineering and to the world. INTRODUCTION Prosthetics devices are becoming more and more common in both the medical and engineering fields, and now almost every body part can be replaced by a prosthetic. Prosthetics are part of the field of bio-mechatronics which is the science of using mechanical devices with human muscle, skeleton, and nervous systems to assist or enhance motor control lost by trauma, disease, or defect. (1) The creation of a prosthetic is tricky business as each piece is custom made for its user to fit their particular needs. These devices can help the individual accomplish tasks that they previously could not due to their disability, significantly improving their quality of life. No two prosthetics are the same as the users vary in size, weight, lifestyle, and amputation. Thus there is not one material or design that will fit all needs. When beginning to create a new prosthetic, the designer should strongly consider the material and the main load bearing structure. The prosthetic should be lightweight yet strong enough for an active and heavyweight amputee (9). It should definitely be aesthetically pleasing and waterproof to some degree (10). There have been many developments over the years as prosthetics are becoming more and more common. Major material properties to compare and analyze include but are not limited to the following; compressive, torsional, tensile, and shear strength, specific density, energy storage characteristics, stiffness, shock absorption (damping), fatigue resistance, fracture toughness, creep, yield stress, and biocompatibility. All these properties and characteristics are being continually improved, and designs are increasingly beginning to reflect the real functions of human limbs (2).

Palmer, M., Groce, N., Mont, D., Oanh, H. N., & Mitra, S. (2015). The economic lives of people with disabilities in vietnam. *PLoS One, 10*(7) doi: http://dx.doi.org.ezproxy.humber.ca/10.1371/journal.pone.0133623

Through a series of focus group discussions conducted in northern and central Vietnam, this study gives voice to the lived economic experience of families with disabilities and how they manage the economic challenges associated with disability. The dynamic of low and unstable income combined with on-going health care and other disability-related costs gives rise to a range of coping mechanisms (borrowing, reducing and foregoing expenditures, drawing upon savings and substituting labour) that helps to maintain living standards in the short-run yet threatens the longer-term welfare of both the individual with disability and their household. Current social protection programs were reported as not accessible to all and while addressing some immediate economic costs of disability, do not successfully meet current needs nor accommodate wider barriers to availing benefits.
The conceptual pathways between disability and poverty are often noted. Poverty may increase the risk of disability through malnutrition, lack of access to safe drinking water, unsafe living and working conditions, or limited access to essential health services such as maternal health care or immunization [1]. In the other direction which forms the bulk of currently available empirical evidence, disability may lead to lower living standards and poverty for the household due to any range of physical, attitudinal or environmental barriers [2–5]. Understanding the specific cost factors that contribute to poverty and their dynamics remains poorly documented. Even less well understood is how families are coping with these costs and their implications for members of the household over time. This issue is particularly timely as governments grapple with the task of including persons with disabilities in national social protection programs in accordance with their obligations under the United Nations Convention on the Rights of Persons with Disabilities (CRPD), and other human rights initiatives.This study was undertaken in Vietnam, a country with a large disabled population. According to census data, 7.8% of the Vietnamese population or 6.7 million people were living with a disability in 2009 [6]. This estimate likely underestimates the true extent of disability in the country. Vietnam is a signature member of the CRPD (22 October, 2007) and regional Incheon Strategy (2013–2022), both of which call for a range of social protection supports for people with disabilities [7, 8]. The government also recently passed a national disability law (July 2010) which outlines the right to state support across a range of sectors including welfare, health care and rehabilitation, education, vocational training, employment, transport, sports and entertainment [9]. Additionally, persons with disabilities are recognized as one of several social beneficiary groups eligible for state social protections, including a monthly cash transfer, non-contributory health insurance and education assistance [10–13].Vietnamese people with disabilities experience higher rates of poverty relative to the wider Vietnamese population when accounting for the additional costs of disability [5, 14]. To gain a deeper understanding of the relationship between disability and poverty, this study adopts a qualitative approach to the questions of disability costs. The research aim is broadly to aid understanding about the lived economic experience of disability for the household and their expressed needs in light of recent efforts to extend formal social protections to persons with disabilities. Over the period November 2012 to September 2013, seven focus group discussions were held across northern and central Vietnam that addressed the following three key themes and questions: (i) What are the costs associated with disability for the household? (ii) What mechanisms do households use to cope with the costs of disability? (iii) How do available formal social protection supports perform against needs?

Strait, E. (2006, January). Prosthetics in Developing Countries. Retrieved September 26, 2020, from http://www.doc-developpement-durable.org/file/sante-hygiene-medecine/handicaps/Protheses-Propylene/DevelopingCountries.pdf

ABSTRACT Throughout the world, the major objective of prosthetics is to restore, as close as possible, the functional capacity formerly held by a limb deficient person, while attaining the best cosmetic result afforded to, and deemed necessary by the patient. On the surface, it would appear that there would be very little difference in the design and manufacture of prosthetic solutions with respect to the approaches taken by Western and third world countries. However, availability of materials, resources and skilled personnel, together with a variety of cultural differences make third world prosthetics a subject in itself. This paper reviews the literature available on the subject, examines some different approaches to prosthetics in the third world, gives an overview of some materials and designs used for both upper and lower prosthetics, and considers adaptation for cultural differences. It concludes that, while direct transfer of Western prosthetics technology is useful in the short term, for long term benefit to the poorer amputees in the third world, culture-specific designs and materials are more appropriate.