AUTOCAST

Healing Made Easy, Anytime, Anywhere

Daniel Rowland

Industrial Design Thesis Report

Enhancing Orthopedic Casts In Rural Areas

by

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Abstract

According to the Journal of the American Academy of Orthopaedic Surgeons data, Half of the world's population lacks adequate primary health care, and two-thirds lack access to orthopedic care. This thesis seeks to increase access to orthopedic casts, emphasizing accessibility and proper application in rural areas. The rural population, constituting half of the global population, often travel long distances to access rudimentary orthopedic care, facing challenges from inadequate training, facilities, and technology. This thesis emerges from a critical examination of the drawbacks associated with traditional casts and the prohibitive costs of advanced solutions, aiming to alleviate the complications and economic burdens induced by improper cast application. By leveraging ergonomic and human-centered design principles, this thesis aims to develop an all-encompassing system that simplifies cast application, minimizes user error, and universalizes access to modern casting materials and technology. This not only aims to enhance individual quality of life by reducing healing times and mitigating adverse outcomes, but also endeavors to contribute to a broader societal advancement by fostering equitable healthcare solutions in underserved rural settings.

Keywords: Primary health care, Orthopedic care, Orthopedic casts, Accessibility, Training, Traditional casts, Complications, Human-centered design principles, Cast application, Quality of life, Societal advancement, Equitable healthcare solutions

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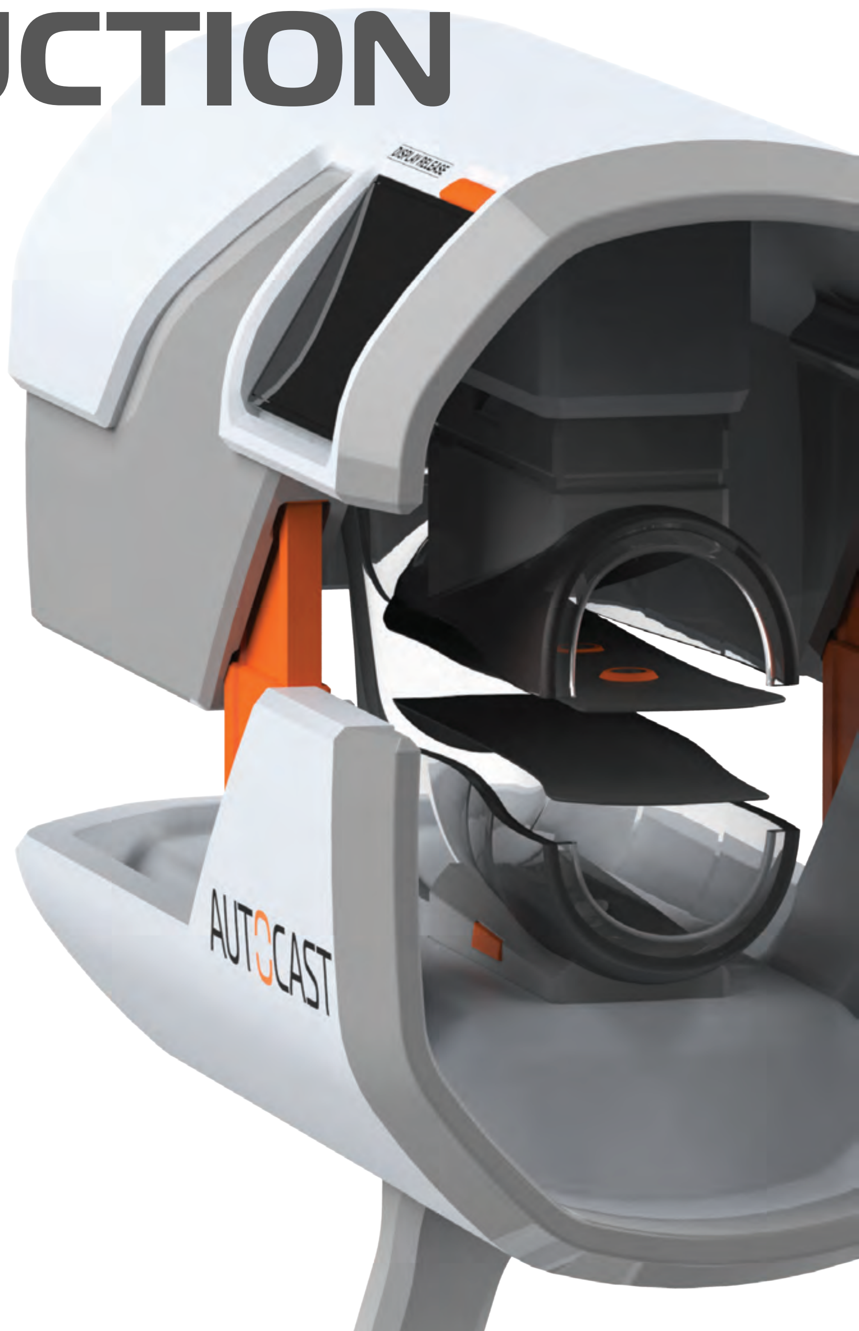
INTRODUCTION



1.1 *Problem Definition*

The global landscape of medical care reveals a concerning inequality, with over half of the world's population lacking even basic primary health care, and two-thirds unable to access orthopedic care. This scarcity stems from a variety of challenges including the absence of adequately trained medical personnel, insufficient facilities, and the inaccessibility of these facilities, especially in rural settings. In many cases, individuals must travel distances ranging from 50 to 100 km just to reach rudimentary orthopedic care facilities. Such journeys are not just tedious but can have lasting consequences, as delays and improper cast applications can lead to complications like dermatologic issues, pressure-induced injuries, and subsequent infections. These complications not only prolong healing times but also impose economic burdens, as affected individuals are rendered incapacitated, and unable to work. The source of the issue lies in the lack of medical specialists and training involving medical procedures, a lack of funding, and the limited access to adequate facilities. The issue extends to the drawbacks of traditional orthopedic casts and the high costs of modern solutions forcing patients to settle for rudementary treatment options with a lower quality of living during recovery. The overall goal is the comprehensive design of a system that integrates modern technology and materials, ensuring proper orthopedic cast application, thereby reducing the negative drawbacks of traditional methods and enhancing the quality of life for patients.

1.2 Rationale & Significance

Addressing the inequalities in orthopedic care, especially in rural and remote areas, is crucial for reducing societal and economic burdens. The rationale behind choosing this issue stems from the understanding that medical care, is not just about treating injuries but is linked to the overall well-being and quality of life of individuals. The lack of access to proper orthopedic care can lead to prolonged healing times, complications, and even permanent disabilities. The economic implications cannot be overlooked, as individuals with untreated or improperly treated orthopedic issues may be rendered incapacitated, affecting their ability to work and contribute to their communities.

Newer existing solutions, while advanced, often overlook the unique challenges faced by those in rural settings. These include not just geographical and logistical constraints, but also cultural, economic, and educational barriers. Understanding why previous attempts to bridge this gap have been unsuccessful is crucial. It provides insights into the challenges of creating a solution that is not only medically sound, but also economically viable, and logistically feasible.

Several design constraints need careful consideration. These involve understanding the procedures of orthopedic casting, the equipment and facilities required, their operational prerequisites, and the challenges of making them accessible to remote areas. Furthermore, understanding the motivations, concerns, and limitations of the primary and secondary users is crucial. This involves delving into their pain points, apprehensions, and reasons for not accessing or utilizing existing orthopedic care services.

To comprehensively research the previously mentioned areas, a multi-faceted approach will be applied. Literary reviews will provide a foundation, drawing from existing quantitative and qualitative data. In addition, a broader perspective will be sought from online sources, including blogs, forums, and product reviews, offering insights into the average user's experiences and challenges. Engaging with both users and experts in the field will be invaluable. Through interviews, surveys, and observational studies, firsthand insights and feedback will berecorded and analyzed. Tools like activity mapping, empathy mapping, and comparison charts will then be employed to analyze the gathered information, laying the groundwork for an informed and viable solution.

1.3 Background / History / Social Context

Orthopedic casts, essential for treating bone fractures, have historically been a challenge in remote areas due to limited access to specialized care. Many individuals in these regions often travel between 50 to 100 km to access even basic orthopedic services (Jain, 2007). Traditional casts, primarily made from plaster of Paris, have their drawbacks. They take up to 48 hours to dry, are vulnerable to water, and lack breathability, leading to discomfort and potential medical complications like skin infections (Ansilotti, 2023). However, there's a shift towards modern solutions. 3D printing technology, for instance, offers casts that are customizable, breathable, and water-resistant. But its adoption is hindered by factors like cost and the need for specialized training.

Demographic data highlights the urgency for better orthopedic solutions. With a significant portion of the global population lacking primary and orthopedic care, the demand is substantial (Dormans et al., 2001). Furthermore, improper cast application can lead to extended healing times, impacting individual well-being and community economics (Bisignano, 2019). While challenges persist in delivering orthopedic care in remote areas, advancements in technology and materials offer hope for more accessible and effective solutions.

02
RESEARCH

2.1 User Research

Understanding the users and their specific needs is necessary when crafting a solution that addresses the challenges of orthopedic casts and treatment in remote areas. To gain insights into these users, a combination of interviews, observational studies, and surveys are utilized. These are used to inform the design direction for a product aiming to solve issues found with orthopedic casting in rural areas. The data collected is then analyzed using various techniques, such as user observation to understand the treatment procedure and identify areas of opportunity, coding to extract key insights from videos and interviews found online, and various mapping methods to analyze the process and record the pain points experienced by users involved in the orthopedic casting process. Interviews conducted with experienced personnel provided valuable insights into the challenges faced by professionals and patients alike.

2.1.1 User Profile - Personna

Primary User: Healthcare Providers in Rural Northern Canada

Personna

Name: Peter Scott

Age: 44

Occupation: General Practitioner

Income: $150,000Family: Wife, 1 Child

Location: Nunavut

Figure 1: Primary User, Personna, Peter Scott

Profile

Peter Scott is a General practitioner working in remote Northern Canada. He makes $105,000 working in a small, understaffed clinic. He is married, and the father to one child. Peter spends majority of the day in the towns clinic. The nature of living in remote Northern Canda means resources are limited, along with trained personnel to aid in patient care. Often having to fulfill multiple roles, Peter is burnt out and finds it difficult to perform at his best.

Pains

- Lack of training
- Lack of resources
- Lack of time
- Traditional Materials
- Access to new technology

Gains

- Easier to use tools
- More versatile materials
- Automated Processes
- Integration of new tech

Primary User: Medical Personnel

Healthcare providers in rural Northern Canada, such as nurses and general practitioners, are the primary users of the orthopedic casting machine. These professionals often work in isolated areas with extreme weather conditions and limited resources. They are typically in the 30-50 age range and are forced to adapt to resource constraints, often playing multiple roles due to lack of medical personnel. They also rely on telemedicine and occasional visits from specialists. Interviews with healthcare providers revealed a need for easy-to-use, fast-acting orthopedic casting materials to overcome remote healthcare challenges such as lack of training. Surveys indicated that these providers often face delays in receiving medical supplies, impacting patient care.

Secondary User: Patients

Patients in rural Northern Canada, requiring orthopedic care, are the secondary users. They often face challenges in accessing timely medical care due to geographic and infrastructural barriers. These patients, ranging from young adults to seniors, predominantly reside in remote and rural communities. They often delay seeking treatment due to ineaduqate medical facilities and are faced with long distance travel and transportation issues, leading to worsened conditions. A survey conducted among patients highlighted issues like long travel times to medical facilities equipped to treat a bone fracture, variability in the quality of care, and post-care challenges like skin irritation and discomfort with traditional casts, mainly plaster of paris.

Tertiary User: Medical Facilities

Medical facilities in these remote areas, including clinics and small hospitals, are the tertiary users. They play a crucial role in providing healthcare services to the local population. These facilities, scattered across vast rural areas often operate with minimal staff and resources, focusing on providing basic healthcare services. They face challenges like limited infrastructure, shortage of medical equipment and supplies, and lack of trained medical specialists. Interviews with healthcare professionals indicated a scarcity of resources and specialists in rural areas, emphasizing the need for training and better medical infrastructure.

2.1.2 Current User Practice

Orthopedic casting involves a series of steps, primarily conducted by healthcare providers such as Orthopedic surgeons or technicians, nurses, or general practitioners. This procedure outlines the bone immobilization process from the bone fracture occuring and the patient entering a facility, to the patient being fully treated and cast removed.

Initial Assessment and Preparation: The process begins with a thorough assessment of the injured limb. This includes examining the skin, and bone structures using diagnostic tools such as an x-ray machine to get images of the patients potential fracture. (AAFP, 2009).

Decision for Immobilization: Once the need for immobilization is determined, the medical specialist must decide whether to apply a splint or a cast (AAFP, 2009). Casts are generally used for most fractures as they provide more effective immobilization. If the fracture is displaced, the provider performs a reduction, aligning the bone fragments. This step is challenging in rural settings due to the delay in presentation, underestimation of urgency, and the need for specialty services (PubMed, 2019).

Application of Padding and Traditional Casting Material: Padding is applied to protect the skin, followed by the casting material, often pre-prepared fiberglass or plaster of paris. Multiple thin layers of plaster or fiberglass strips are applied over the padding. These materials quickly harden through a chemical reaction to form the cast. The material is molded to the body part by a trained medical specialist to immobilize the fracture. The process must consider potential complications such as thermal injury from the hardening reaction, pressure sores, compromised circulation, or nerve function (McCue, 2022).

Figure 2: Materials used in Plaster cast application

<u>Setting and Drying:</u> Fiberglass casts have a quicker drying time compared to plaster, which is beneficial in remote settings. Plaster can take up to 48 hrs to fully cure while fiberglass is harder to mold to the contours of the patients body.

<u>Post-Application Care:</u> The healthcare provider instructs the patient on cast care, emphasizing the importance of keeping it dry and avoiding inserting objects inside the cast. Follow-up appointments can often be conducted via telehealth due to geographical challenges (Rural Health Information Hub, 2021).

Cast Removal: Once the bone has healed, the cast is removed using a specialized cast saw, requiring specific training for safe use. Cast saws have the potential for inflicting harm onto the patient. Cast saw burns are a potential complication during the process of cast removal and splitting. These injuries can lead to significant medical, financial, and legal consequences (Larson, 2021).

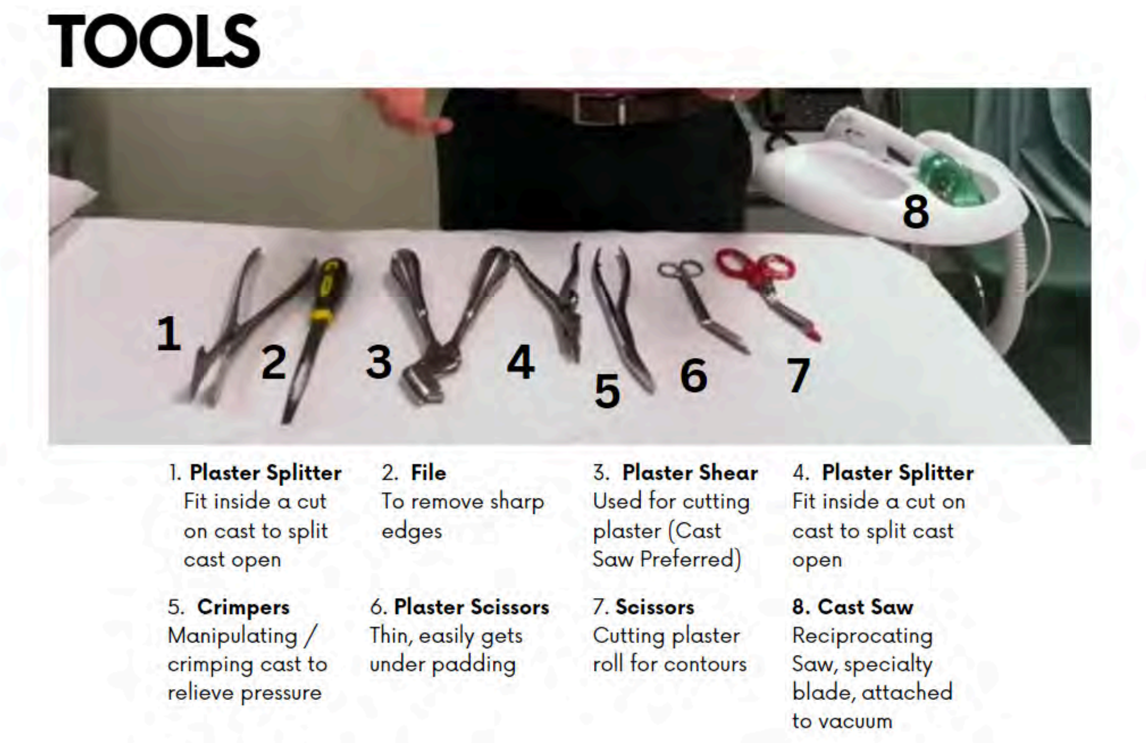


Figure 3:Tools used in plaster and fiberglass cast removal

Now in the case of a 3D printed cast, the process begins with a thorough assessment of the injured extremity. The physician then decides whether immobilization is necessary and chooses the appropriate casting option.

3D Printing Process: 3D imaging of the injured area is performed, typically using a 3D scanner, requiring training on the technology inorder to use it effectivly. This image is then used to design a custom-fit cast. The cast is then printed, often with a Stereolithography(SLS) format printer (Chen, 2020) as it allows the cast to be created from light weight materials, provide adequate ventilation, and personalized fit.

From the interview conducted with a orthopedic technician, several challenges were highlighted in the application and fitment of casts. These included patient compliance, especially with children who find it hard to sit still, and the need for more staff when treating children. The technician also pointed out the limited resources in remote areas, especially the lack of trained specialists. While materials like plaster and fiberglass are available, there's a shortage of skilled individuals to apply them correctly.

The technician emphasized the need for fast-acting materials, especially in places with limited resources. They suggested looking for materials that can be applied and set immediately. Another crucial recommendation was to develop a system or product that's easy to follow and simple to use, given the lack of training among many who apply casts in these areas.

2.1.3 User Observation - Activity Mapping

Understanding the steps and activities performed by the user while going through the orthopedic casting process is necessary to better understand the needs and desires of the primary users. This process or workflow was then analyzed using various mapping techniques. First off, the users workflow was recorded. Key tasks in the process were recorded and placed into and activity map **(Figure 4 & 5).** For this study a video of a orthopedic clinic was used. This walked through the process of application and removal of a plaster cast. The location is at Gloucestershire Hospitals NHS foundation. Small clinic room where patient is treated in a orthopedic casting chair with a padded surface for patients limb positioning. This aided in narrowing down the scope of research and identifying the key steps, ultimately defining various pain points in the process.

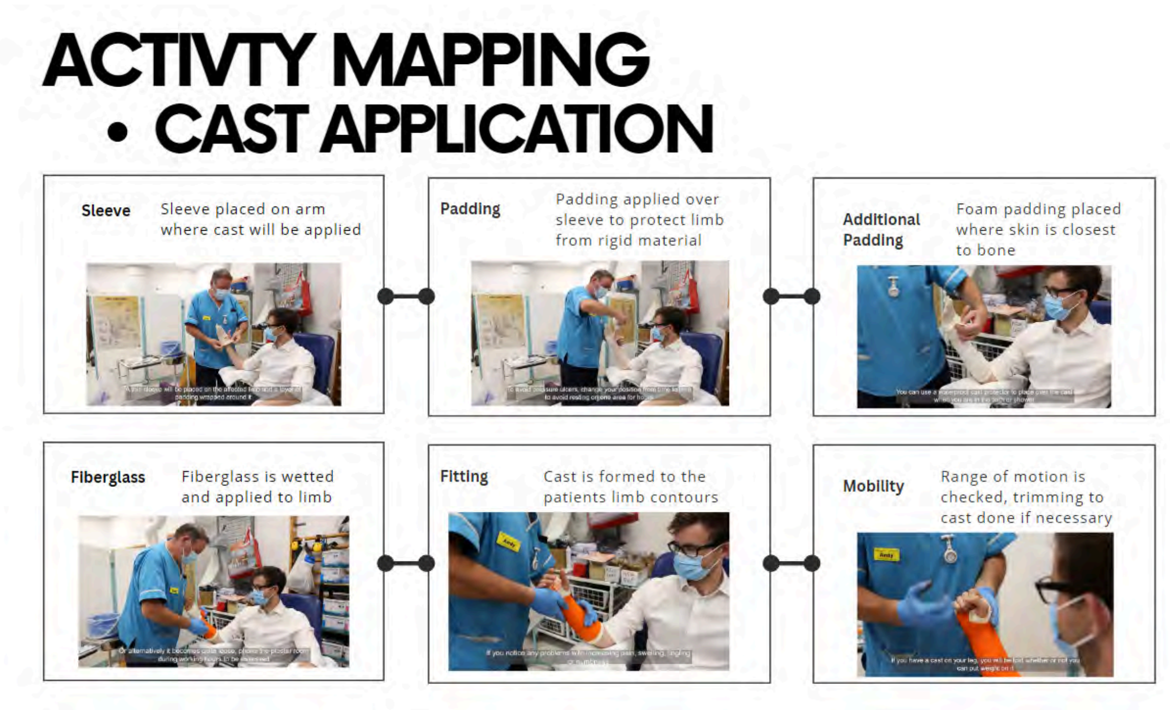


Figure 4: Cast application activity map

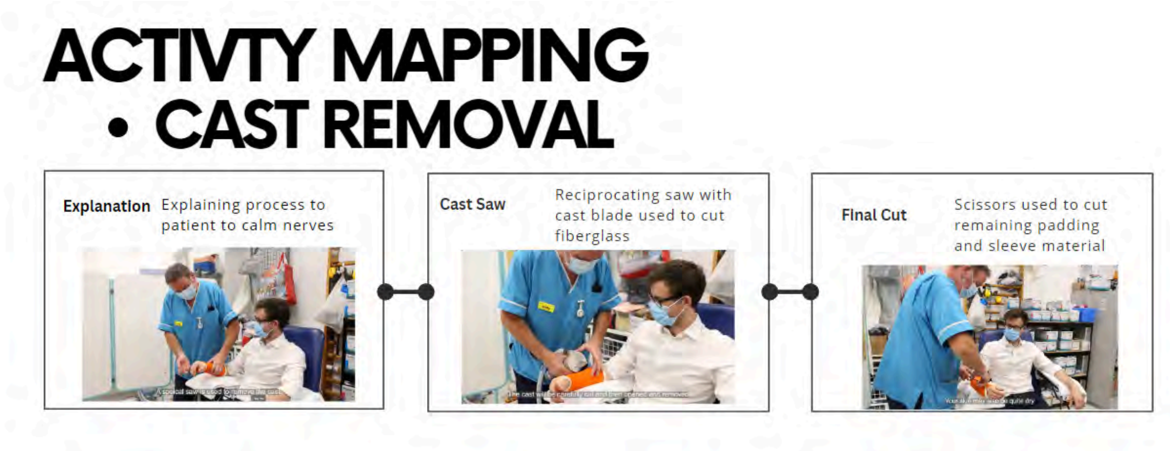


Figure 5: Cast removal activity map

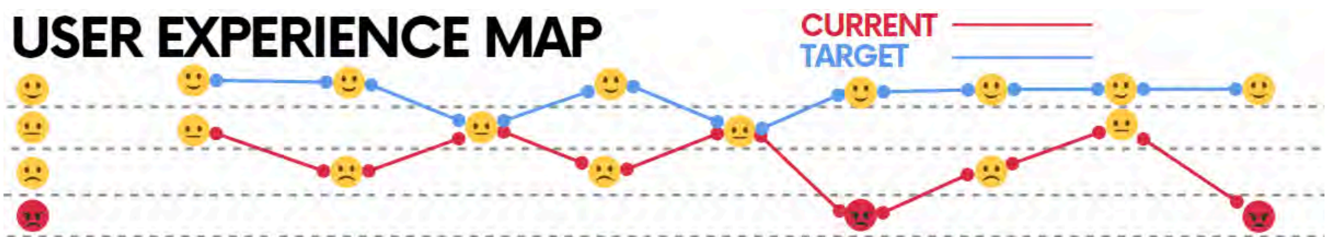
The information recorded in the activity mapping **(Figure 4 & 5)** was then analyzed and placed into a user journey map. The journey map and experience map**(Figure 6 & 7)** helps record the users emotions and thoughts while going through the work flow process. This helps in targeting specific points for improvement in the current products.

JOURNEY MAP

	PHASE 1 Injury Assesment	PHASE 2 Positioning Patient	PHASE 3 Sleeve & Padding Application	PHASE 4 Casting Material	PHASE 4 Fitting	PHASE 4 Mobility Check
DOING	Assessing patients injury	Elevating patients limb to begin treatment	Applying sleeve to separate skin from cast and padding to protect boney area	Gathering material and getting it ready for application	Molding material to patients limb, molding to limbs contours	Checking the patients mobility with cast to make sure there is no constraints
THINKING	This patient has a bone fracture	I need to position my patient for successful casting	Where is the skin closest to the bone	How long do I need to wet my material for this application, How much material will I need	Where do I need to use more pressure, will this cause pressure for the patient	Where do I need to remove material to improve range of mobility
SAYING	We will need to cast your limb	Can you place you elbow on the rest and hold your arm up	I'm adding this for comfort, do you have any sensitive areas	The POP will heat up during application let me know if it becomes too uncomfortable	Is there any constriction or uncomfortable pressure?	Are you able to move your fingers and elbow with a full range f motion?

Figure 6: Cast application journey mapping

USER EXPERIENCE MAP



	Planning	Prep	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Post
User Goals	Assess injury and apply treatment	Prepare workspace and materials	Asses Injury	Position patient	Apply Sleeve and Padding	Gather and prep Material	Fit Casting Material	Check Mobility and trim material	Post care check up
Problems / Challenges	Managing swelling, assessing severity of injury	Sanitization, large assortment of materials and tools	Managing swelling, assessing severity of injury	Ergonomically positioning patient/medic al personnel, elevating limb,	Protecting boney areas successfuly, identifying areas that need padding	Gathering sufficient materials, activating material	Properly fitting cast to limbs contours, applying material succesfully	Making sure cast doesn't rub limb, assuring patient comfort	Viewing limb under cast, checking for complications
Ideas / Take-aways	Pairing x-ray with limb scanner for accurate data	Ergonomic workstation, easier access to materials and tools on demand	Pairing x-ray with limb scanner for accurate data	Adjustable bed for positioning, extra surfaces for limb placement	Limb Scan/X-ray, custom padding, 3D print sleeve	3D printed custom cast material, automated dispensing and activation	Automatic fitment machine, computer aided fitment	Computer aided fitment, adjustable cast	Removable cast, injury assessment tech in cast

Figure 7: Cast application experience mapping

This in-depth observational study conducted with an orthopedic technician performing the cast application and removal process resulted in a thorough analysis of the standard procedures and patient interactions. It became evident that technicians play a pivotal role in patient care, from ensuring succesfull cast application to addressing patient concerns. Reducing the training and complexity of the application process will be necessary in improving the overall patient experience.

2.1.4 User Observation - Human Factors of Existing Products

Recognizing the important link between human factors and the interaction with current products is paramount in understanding the potential benefits for users. As uncovered through user observation research **(Figure 8)** the current user experience was recorded to uncover potential improvements during the key steps.

Figure 8: Cast application process, key steps

This observation **(Figure 8)** revealed issues in the users workflow and areas for improvement. During the cast application, medical personnel is forced to spend significant preparing materials, measuring out the appropriate amount for casting, and manually applying standardized roles inorder to fit the various percentiles of patient sizes. All this preperation prolopngs the patients treatment, furthering their negative feelings surrounding their injury.

During the application and removal, the patients limb positioning is set up using adjustable tables and surfaces, while this allows the injured limb to be elevated for proper casting, this often results in uncomfortable positions for the medical personnel administering the cast.

As revealed in **Section 2.1.2,** there is a large variety of materials and tools involved in both the application and removal process. This results in specific training inorder for successful use in the workflow. This can cause further medical issues such as pressure sores and skin laceration if improper application is to occur. Improvements to the cast fitment process and the ease of use of materials offer potential.

Human factors and ergonomics play a pivotal role in shaping the users experience and products functionality. Research into orthopedic casting tables shows an emphasis on ergonomic design to ensure both patient comfort and technician efficiency. Key human factors identified include adjustable height settings, which cater to various patient sizes and technician working conditions, and cushioned surfaces for enhanced patient comfort during procedures. Features like easy-to-clean surfaces and portable designs offer up ease of use, accommodating the practical needs in a medical setting, where hygiene and flexibility are paramount.

2.1.5 User Observation - Safety and Health of Existing Products

While orthopedic casting materials like fiberglass offer benefits like lightweight and radiolucency, they also pose risks. Fiberglass casts can cause skin irritation and are challenging to mold precisely. While plaster casts are heavy and non-breathable, with the addition of not being able to get the plaster wet, it can negatively impact the patients life. Tools like the Cast Cutter, though designed for safety, still present risks of burns and cuts if not used with caution. Cast saw injuries can be thermal or abrasive, with risk factors including cast saw specifications, use of a dull blade, thin padding, and overly thick casting materials (Halanski, 2016) They can also be noisy and intimidating, potentially causing distress to patients, especially children.

Orthopedic casting tables and chairs, despite ergonomic designs, often lack sufficient padding, causing discomfort for patients during long procedures. Many casting tables, while versatile, can be difficult to adjust, posing a risk of injury to technicians. Moreover, workstations in many facilities are not always optimized for efficiency, leading to clutter and potential hazards. Despite advancements, the orthopedic casting process can benefit from health and ergonomic challenges getting addressed to increase both patient and medical personnel well-being.

2.2 Product Research

Product research was conducted to get a better understanding of the current products offered on the market to aid in the application of orthopedic casts. This research was taken from promotional advertisements, and product reviews inorder to analys each products perceived benefits and features, materials, size and portability, and aestheitics. This will help inform the direction of the design and identify market gaps with potential for innovation. This research is necessary as medical personnel in rural and remote areas need a streamlined and efficient casting application system. Which will significantly reduce the complexity and time involved in traditional casting processes, thereby enhancing the quality of patient care in environments with limited resources and access to advanced medical facilities.

2.2.1 Benchmarking - Benefits and Features of Existing Products

Inorder to determine the benefits and features for orthopedic casting tables was done by benchmarking related products and formatting them into a table (**Figure 9**). These products were then compared and analysed using promotional media to gather information. These tables then got placed into a chart to gain a visual representation of the current market based on benefits and features (**Figure 10**), Functionality (**Figure 11),** Interaction (**Figure 12**), and aesthetics (**Figure 13)** inorder to identify gaps where an opportunity can arise.

Benefits

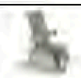
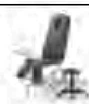
TABLE: Benchmarked Product Benefits					
					
1	2	3	4	5	6
HA90CT Orthopedic Casting Medical Chair by Hill Laboratories	Orthopedic Hi-Lo Casting Tables by Oakworks Inc	Adjustable Cast Stand by AliMed	Orthopaedic Table for Plaster Casting Technicians	Turnstile Casting Stand® by Innovative Medical Products, Inc	Orthopedic Treatment Casting Table by Jameson Medical
Benefits					
Versatile use as chair and table, multiple color options, ADA tax credit eligibility, high comfort with padding, customizable settings.	Easy cleanup with thermoplastic leg, adjustable height for comfort, foot control for easy operation, durable construction, safety side rail.	Ideal for lower leg casting, height adjustability, durable stainless steel, includes drip bucket, lightweight for easy movement.	Customizable for various procedures, adjustable leg sections, optional accessories, specifically designed for technicians, robust construction.	Comfortable arch molding, prevents over-tightening, non-stick coating for easy cleanup, patented keel feature, enhanced patient comfort.	Ample storage with pull-out drawers, customizable fabric colors, large surface area, popular among orthopedic professionals, sturdy design.

TABLE 2.2.1 Top Benefits of Benchmarked Products	
1	Ergonomic
2	Durable
3	Portable
4	Ease of Cleaning
5	Adjustable

Figure 9: Benchmarked current product benefits

Features

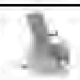
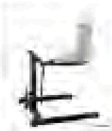
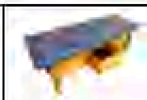
TABLE: Benchmarked Product Features/Functionality						
						
	1	2	3	4	5	6
	HA90CT Orthopedic Casting Medical Chair by Hill Laboratories	Orthopedic Hi-Lo Casting Tables by Oakworks Inc	Adjustable Cast Stand by AliMed	Orthopaedic Table for Plaster Casting Technicians	Turnstile Casting Stand® by Innovative Medical Products, Inc	Orthopedic Treatment Casting Table by Jameson Medical
Features						
Adjustability	Height adjustable, versatile chair/table design.	Height adjustable with foot controls. 17"-35"	Height adjustable. 12" - 22"	Height adjustable 19 - 39"	Adjustable arch support, and height	No Adjustability
Material	High-quality materials, robust construction.	Sturdy construction.	Stainless steel construction.	Stainless Steel and PP	Stinless steel with non stick coating	Wood, Vinyl, Foam
Ease of Cleaning	Easy to clean surfaces.	Thermoplastic leg section for easy cleanup.	Easy to clean, includes drip bucket.	Many Surfaces to clean	Non-Stick coating for ease of cleaning	Simple design easy to clean
Patient Comfort	Cushioned for comfort, ergonomic design.	Padded with 2.5" Foam	Designed for comfort during casting.	Foam Padding on chair	Molds a comfortable arch	Low, Flat, non ergonomic
Mobility	Not specified as portable.	Not portable.	Lightweight, easy to move 15lbs	In clinic use, not mobile	Small and portable weight 5lbs	Not portable, fo in-clinic use
Size	Standard medical chair size	31" W x 73" L	Compact size.	19-39" H 25" H	12 - 20" H 17.5" W	27" W x 72" L x 30" H
Weight Capacity	Not explicitly stated.	530lbs	N/A	350lbs	N/A	550lbs
Safety Features	Designed with patient safety in mind.	Includes safety side rail.	Stable design.	Designed for technician and patient safety	Prevents over-tightenin g at metatarsal heads.	N/A
Price and Value	$4,195.00	$3000.00	$243.60	N/A	N/A	$3,240.00
Additional Accesories	33 color options.	N/A	Drip Bucket / Foam Roller	Electric height adjustment, backrest operation, tilt operation, shrouded base frame	N/A	N/A

Figure 10: Benchmarked products features / functionality

From this table the top features of the benchmarked products are listed as below:

- Adjustibility - Essential for accommodating different patient sizes and positions, and for ergonomic working conditions for the technician.
- Material Quality and Durability - To ensure longevity and reliability of the product, especially given the frequent use and potential for heavy loads.
- Ease of cleaning and Maintenance - Important in a medical setting for hygiene and infection control.
- Comfort for patient - Ergonomic design and padding are crucial to ensure patient comfort during the casting process
- Safety Features - Such as side rails and stable construction, to prevent accidents and injuries.

<u>Results - Comparitive Analysis</u>

The benchmarked products included a range of orthopedic casting tables and chairs, each offering unique benefits. For instance, the HA90CT had versatility and comfort, offering multiple color options and customizable settings. Similarly, the Orthopedic Hi-Lo Casting Tables offered an increased ease of cleanup and adjustable height, enhancing operation convenience. The Adjustable Cast Stand, with its design for lower leg casting and height adjustability, represented another key product in the analysis, being portable solutions. Each product has its own specific advantages, from the Turnstile Casting Stand adjustable arch molding to the Orthopedic Treatment Casting Table by allowance of storage space and sturdy design.

Key attributes like adjustability, material quality, ease of cleaning, patient comfort, and safety features were evaluated. Adjustability was found to be essential in accommodating various patient sizes and ensuring ergonomic conditions for technicians. The quality and durability of materials emerged as critical factors for the longevity and reliability of these products, particularly considering their frequent use. Ease of cleaning and maintenance were highlighted as important aspects, given the need for hygiene and infection control in medical settings. Comfort for patients, achieved through ergonomic design and padding, was also deemed crucial for patient satisfaction during the casting process.This analysis provides valuable insights into the current market. It offers a foundation in identifying key features that enhance the functionality and user experience of orthopedic casting tables.

2.2.2 Benchmarking - Functionality of Existing Products

Functionality benchmarking was carried out to determine the common functionality among the current orthopedic casting tables offered on the market, this helps gain insights on differentiating a product amongst the competitors. Characterizing the functionality was performed usign the data collected int the features and functionality table (**FIGURE)**, the data was then formatted on a x-y graph comparing the two most important features to identify a gap in the market.

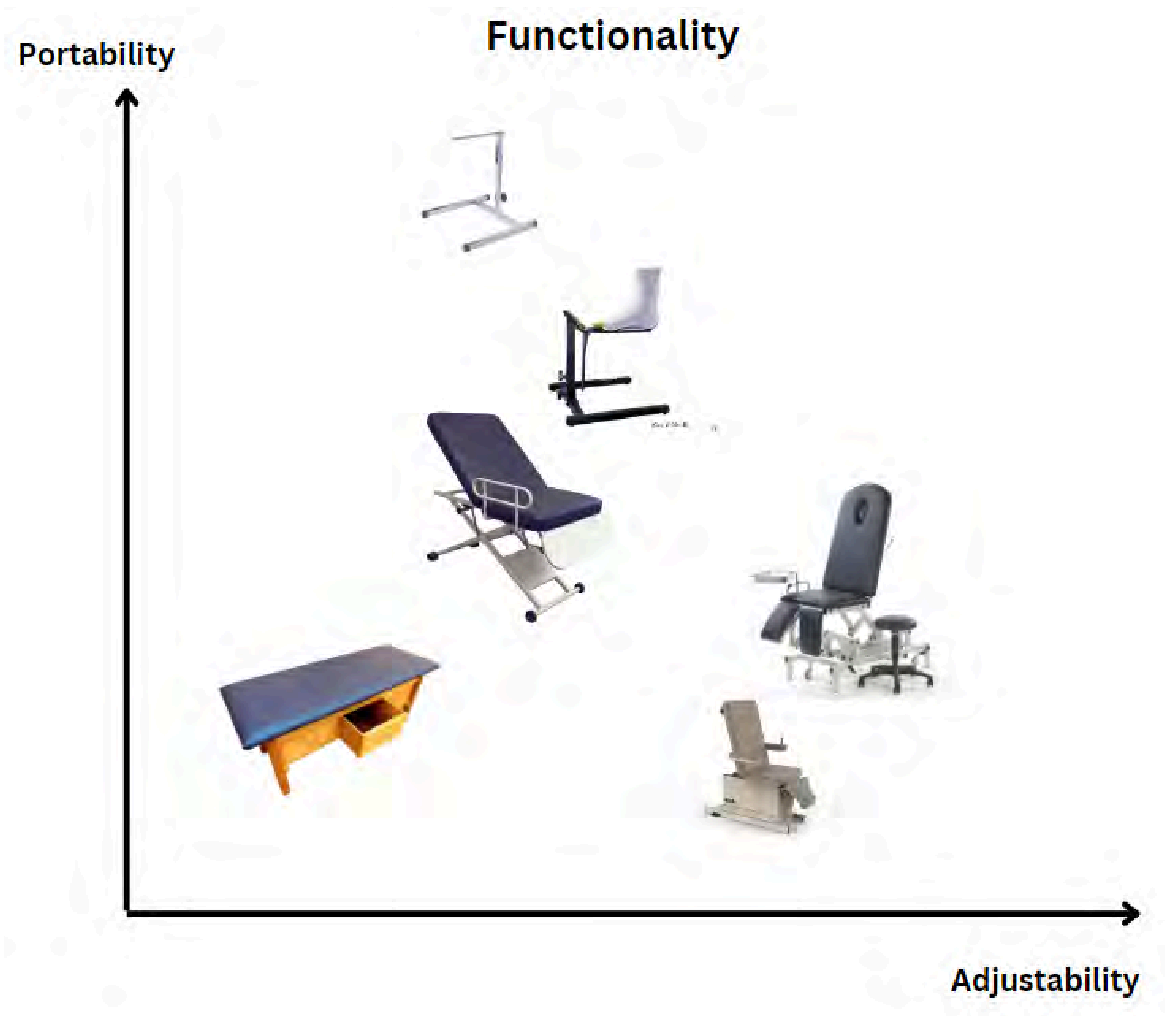


Figure 11 :Functinality mapping benchmarked products

<u>Results - Comparative Analysis</u>

As seen in the tables above **(Figure 11)** the top benefits of the analyzed products are portability and adjustability involving the ergonomics of the chair and how it interacts with the patient. The main feature the product needs is area for medical personnel to work inorder to apply a orthopedic cast to a patient. Therefore any product designed should have ample adjustability to ergonomically support patients from the 5% Female to the 99% Male, products that can accommodate a wide range of patients stood out amoung the competition. Another important feature is the portability of the product, this feature directly affects the products possible usecases and limits the flexibility of in various situations, this is increaingly important for medical personnel working in remote areas with limited resources.

2.2.3 Benchmarking -Aesthetics and Semantic Profile of Existing Products

An assessment of the aethetic and semantic profiles of the existing products on the market was conducted to gain an understanding of the design trends in current orthopedic casting tables. Aesthetic and form features were identified in the following table **(Figure 12)** then compared using a affinity graph.

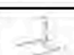
Styling and Aesthetics						
Overall Form (categories below reflect type of product selected)						
						
Shape *Geometric* Rectilinear, Ellipsoid, Cylindrical etc)	Rectilinear - soft	Rectilinear	Rectilinear	Rectilinear	Cylindrical Tube	Rectilinear
Material	Steel, vinyl, PP	Stainless Steel, Vinyl	Stainless Steel	Stainless Steel, Vinyl	Powdercoated Steel, Rubber	Wood, Vinyl
Mechanical Covering	Enclosed	Open - Tubular	Open - Tubular	Open - Tubular	Open - Tubular	Enclosed
Balance (symmetry etc))	Symmetric R & L	Asymmetric R & L	Symmetric R & L	Aymmetric R & L	Symmetric R & L	SSymmetric R & L

Figure 12: Benchmarked products - styling and aesthetics

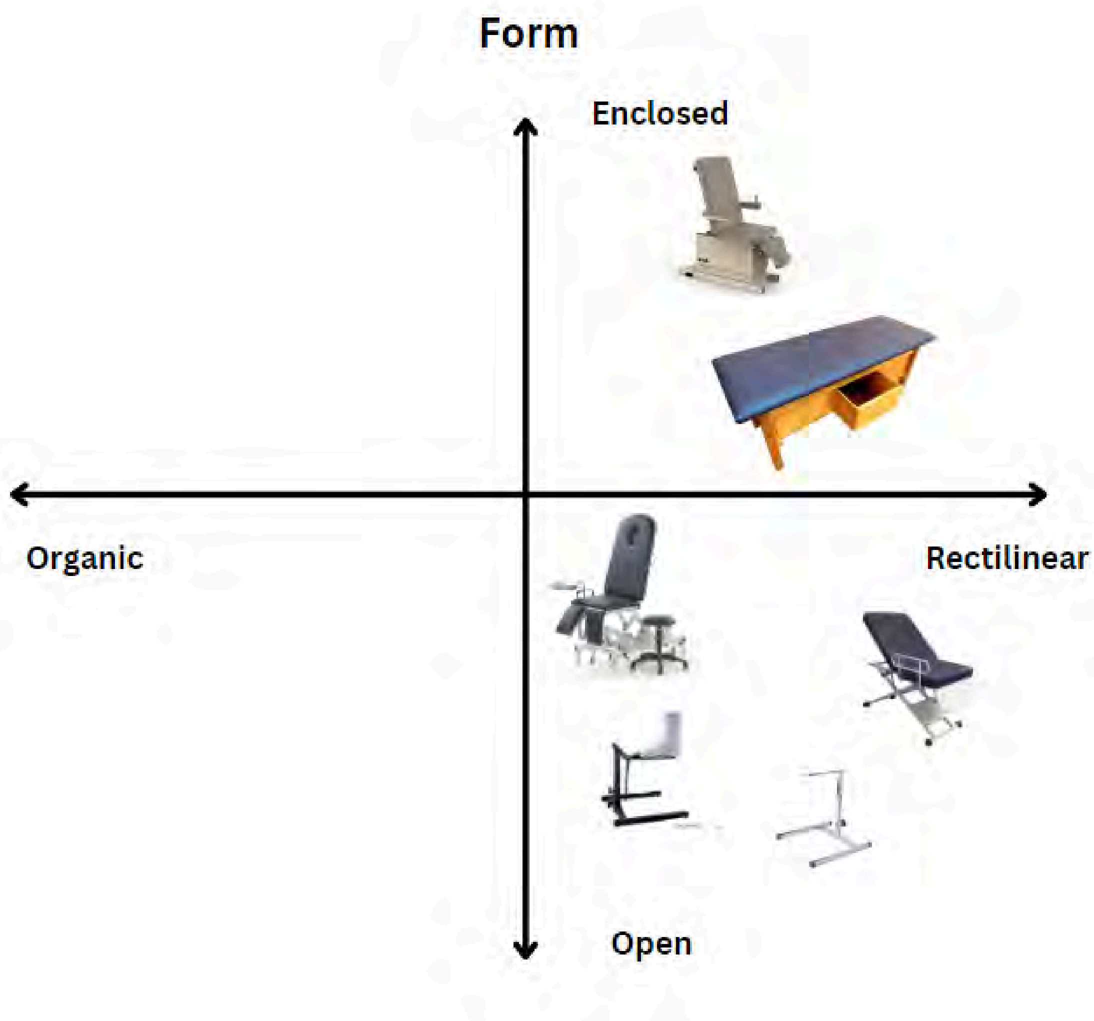


Figure 13: Benchmarked products - styling and aesthetics affinity map

Results - Comparative Analysis

This analysis uncovered a prevailing trend towards rectilinear shapes, with a focus on functional and highly adjustable designs. The material choices, predominantly stainless steel and vinyl, reflect a preference for durability and ease of cleaning. The balance between open and enclosed mechanical coverings in the products suggests a consideration for both accessibility and safety.

The aesthetic findings reveal a minimalistic approach in design, with planar symmetry commonly observed, emphasizing stability and uniformity. The color palette leans toward clinical whites, light greys, and blues, occasionally accented with blue padding or indicator lights. These trends highlight a preference for clean, practical aesthetics tailored to the medical environment, where functionality and ease of use are paramount.

2.2.4 Benchmarking - Materials and Manufacturing of Existing Products

In the benchmarking analysis focusing on the materials and manufacturing processes of orthopedic casting tables, a review of current market offerings was conducted. This review included examining current materials and technologies used in the production of these tables, and a look into emerging technologies that can benefit the manufacturing and use of orthopedic casting tables.

The analysis revealed a common use of stainless steel and vinyl in most products, chosen for their durability and ease of cleaning. Stainless steel is often used for the frame and supports of the seating which is made from a poly ethylene foam to provide padding and a vinyl cover for ease of cleaning. Trends also show the incorporation of polypropylene (PP), polycarbonate (PC) and advanced composites such as mixes of Acrylonitrile butadiene styrene(ABS) and PC , offering improved weight management and strength. Traditional manufacturing methods, such as welding and machining for steel components and injection / blow molding for engineering plastic parts.

The adoption of cutting-edge materials, such as medical-grade polymers and smart textiles, was researched. These materials offer enhanced properties, like antimicrobial surfaces and improved patient comfort (Libanori, 2022). Theres also possibility for the use of advanced manufacturing techniques like additive manufacturing and powder metallurgy, allowing the production of highly complex forms using advanced materials sich as titanium and titanium alloys (Krzeminski, 2021), reflecting a shift towards higher efficiency and customization capabilities.

The benchmarking of current products shows a gradual evolution in the materials and manufacturing processes of orthopedic casting tables, with an increasing emphasis on innovation, patient safety, and operational efficiency.

2.2.5 Benchmarking - Sustainability of Existing Products

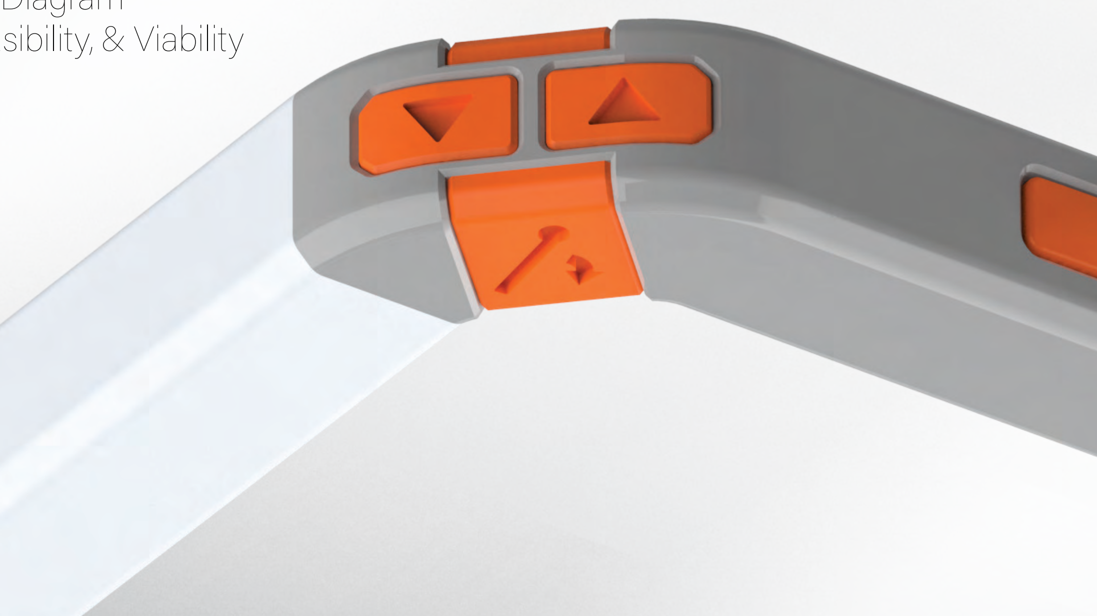
In the context of orthopedic casting tables and broader medical products, benchmarking sustainable initiatives involved analyzing the eco-friendliness of materials, manufacturing processes, and product lifecycle management. The replacement of traditional materials like stainless steel, vinyl, ABS (Acrylonitrile Butadiene Styrene), PC (Polycarbonate), and PP (Polypropylene) in medical devices, including orthopedic casting tables, is necessary to improve sustainability. These conventional materials, while durable and effective, pose environmental challenges. Stainless steel, though recyclable, requires high energy consumption for production, contributing to significant greenhouse gas emissions. Vinyl, a type of PVC (Polyvinyl Chloride), often contains harmful additives and is difficult to recycle, leading to potential environmental and health hazards. ABS and PC, though known for their strength and clarity, are petroleum-based plastics that contribute to the depletion of fossil fuels and are challenging to decompose, leading to increased plastic waste. Similarly, PP, while more easily recyclable than some plastics, still contributes to environmental pollution during its production and disposal.

The trend is shifting towards using recyclable and biodegradable materials, such as medical-grade recycled plastics and biopolymers, to reduce environmental impact (Nature Electronics, 2022). Eco-friendly manufacturing processes are being adopted, such as reducing energy consumption and minimizing waste, with techniques like precision manufacturing and additive manufacturing (3D printing) proving more resource-efficient (Battelle, 2022). In product lifecycle management, sustainability is also about the product's end-of-life, with manufacturers increasingly focusing on designing products that are easy to disassemble for recycling or safe disposal. Many medical facilities generate immence amounts of waste, as alot of product are single use due to their medical nature, for example a report on 110 Canadian hospitals published in 2019 found those institutions generated nearly 87 000 tons of waste annually — roughly the equivalent of the Great Pacific Garbage Patch, which spans twice the area of Texas (Duong, 2023). About 85% of hospital garbage is general, nonhazardous waste that can be recycled or sent to a landfill without any special processing (Duong, 2023). The transition from single-use to reusable devices and the inclusion of recyclable components in product designs are key steps towards sustainability. This approach not only reduces waste but also addresses the significant environmental impact of medical device disposal (Battelle, 2022).

2.3 Summary of Chapter 2 - Topic Understanding

- Healthcare providers in rural Northern Canada, like nurses and general practitioners, are primary users facing challenges such as extreme weather, limited resources, and reliance on telemedicine. Secondary users are patients in remote areas, facing access difficulties, and tertiary users are medical facilities with limited infrastructure and resources.
- Current orthopedic casting practice involves steps like initial assessment, deciding on immobilization type, applying padding and casting material, setting and drying the cast, post-application care, and cast removal. Challenges include delayed treatments, limited resources, and lack of trained specialists.
- User observation through activity mapping in orthopedic clinics identifies pain points in the casting process, emphasizing the need for user-friendly and fast-acting materials.
- Observations on human factors reveal issues with current products like preparation time, uncomfortable positions for medical personnel, and risk of complications. Ergonomic considerations include adjustable height, cushioned surfaces, and easy-to-clean designs.
- Safety and health concerns with existing products involve risks with fiberglass casts and cast cutters, and ergonomic issues with casting tables and chairs.
- Product research aims to streamline casting application in rural settings. Benchmarking studies on existing products focus on their benefits, features, functionality, aesthetics, materials, manufacturing, and sustainability.
- Materials like stainless steel and vinyl are common, but there's a shift towards medical-grade polymers and advanced manufacturing techniques like additive manufacturing.
- Sustainability efforts focus on recyclable materials, energy-efficient manufacturing processes, and lifecycle management, addressing environmental impacts of medical device disposal.

03
ANALYSIS



3.1 Analysis - Needs

To aid in designing an innovative orthopedic casting solution for rural and remote areas, this chapter delves deeper into the research discussed in the previous chapter inorder to get a better understanding of the users unmet needs. This will go over the research findings and analysis of current products on the market to better understand user needs. Utilizing methods such as STEEPV analysis to categorize the painpoints and potential benefits to the primary, secondary, and tertiary users. This approach ensures that the design not only reduces challenges faced in rural orthopedic casting but improves the experience for all users involved.

3.1.1 Needs Benefits Not Met by Current Products

Currently on the market of orthopedic casting tables, particularly in the context of rural healthcare, there are several unmet needs and opportunities for improvement. While existing products generally offer essential features like adjustability, durability, and patient safety, they often overlook the ergonomic needs of healthcare providers. This gap presents an opportunity to develop tables that reduce physical strain for medical personnel through more ergonomic designs and adjustable features reducing the need for medical personnel to work around the patient. Additionally, the lack of portability in current models is a significant limitation, especially in remote settings where mobility and ease of transport are crucial.

Another area for innovation is improved tool and material storage solutions. Current tables do not adequately address the need for accessible storage of casting materials and tools or reduction of the necessary tools and materials, which could streamline the casting process and improve overall efficiency. Although ease of cleaning is already incorporated, there's room to enhance this aspect with advanced materials and designs for quicker and more effective sanitation. Addressing these gaps, while aligning with economic constraints and environmental sustainability, would significantly enhance the functionality and applicability of orthopedic casting tables in rural and remote medical settings. This approach not only caters to the practical needs of healthcare providers but also aligns with the overall goal of improving patient care in rural and remote environments.

3.1.2 Latent Needs

Through the use of an initial STEEPV analysis on involved users while accessing and applying orthopedic cast, key insights were extracted in order to identify the most pressing latent needs. This includes an analysis of the fundamental needs and potential benefits.

- Social (S): Patient Comfort and Compliance: Enhancing patient comfort and ensuring compliance, especially in pediatric cases, requires designs that consider the social and psychological aspects of treatment in remote communities. Inadequate Training: There is often inadequate training for proper cast application in remote areas. Hygiene Maintenance Challenges: Difficulty in maintaining hygiene with traditional casts.
- Technological (T): Technological Integration and Connectivity: Despite the growing role of telehealth, technological barriers such as unreliable internet connectivity in rural areas highlight the need for low-tech or offline orthopedic solutions.
- Economic (E): Efficient Resource Utilization: The economic constraints of rural healthcare settings demand cost-effective orthopedic casting solutions that minimize waste and are sustainable over the long term.
- Environmental (E): Accessibility and Mobility: Geographical isolation requires casting solutions that are easily transportable and adaptable to the environmental challenges of remote locations.
- Political (P): Training and Ease of Use: The scarcity of specialized medical personnel and high provider turnover in rural areas shows the need for casting systems that are straightforward and require minimal training.
- Values (V): Rapid Application and Adaptability: Values like rapid response and adaptability in medical care are crucial in rural settings. Casting systems that can be quickly applied and adapted to various patient conditions align with the values of timely and effective healthcare.

3.1.3 Categorization of Needs

To better understand users immediate and latent needs, a workflow analysis was implemented to analyze the thought process of users throughout each stage of the activity. User, journey, and experience mapping was conducted to understand the intricacies of the users work flow and extrapolate the needs and wishes.

User Type	Immediate Needs	Latent Needs	Wishes
Primary User (Healthcare Providers)	- Fast-acting and easy-to-use casting materials - Immediate access to basic orthopedic supplies - Solutions for patient compliance during casting	- Training for advanced casting techniques - Support for the multifaceted roles due to staff shortages - Efficient patient management strategies	- Access to cutting-edge orthopedic technology - Automated processes for casting - Integration with telemedicine for remote consultations
Secondary User (Patients)	- Immediate relief from discomfort and mobility issues - Accessible and timely orthopedic care - Clear instructions for cast care and maintenance	- Enhanced comfort and breathability in casts - Personalized care and attention during casting	- Waterproof and lightweight casting options - Telehealth for follow-up care - More engaging and less intimidating cast designs
Tertiary User (Medical Facilities)	- Adequate and consistent supply of casting materials - Simple and reliable casting systems - Cost-effective solutions	- Comprehensive training programs for staff - Adaptability to fluctuating patient numbers and needs	- State-of-the-art medical equipment for casting - Enhanced infrastructure for rural healthcare

Table 1: Categorization of Needs

This categorization helps identify the specific needs of the primary, secondary, and tertiary users inorder to extract needs statements to help inform the solution. From these findings a needs statement can be formed to encompass the user needs.

Needs Statement: Medical personnel in rural and remote areas need a streamlined, efficient and timely casting application system. In order to significantly reduce the complexity and time involved in traditional casting processes.

3.2 Analysis - Usability

Identifying the pain points and poential areas for improval in the users daily activities is key to narrowing down the scope for solutions. To analyze the users work flow a journey map and user experience map where created to record the users emotional experience while performing the task. This aids in identifying pain points and areas that go beyond satisfaction that medical personnel experience through their dailly activities, specifically through the orthopedc casting process. Below is a collection of the findings of this work including the key insights from this research.

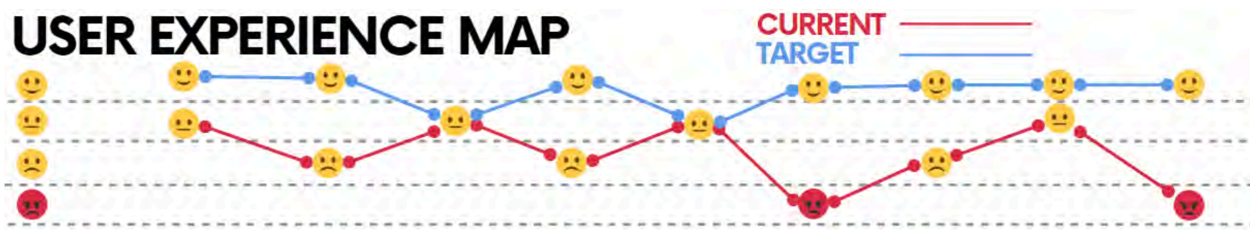
3.2.1 Journey Mapping

JOURNEY MAP

	PHASE 1 Injury Assesment	PHASE 2 Positioning Patient	PHASE 3 Sleeve & Padding Application	PHASE 4 Casting Material	PHASE 4 Fitting	PHASE 4 Mobility Check
DOING	Assessing patients injury	Elevating patients limb to begin treatment	Applying sleeve to separate skin from cast and padding to protect boney area	Gathering material and getting it ready for application	Molding material to patients limb, molding to limbs contours	Checking the patients mobility with cast to make sure there is no constraints
THINKING	This patient has a bone fracture	I need to position my patient for successful casting	Where is the skin closest to the bone	How long do I need to wet my material for this application, How much material will I need	Where do I need to use more pressure, will this cause pressure for the patient	Where do I need to remove material to improve range of mobility
SAYING	We will need to cast your limb	Can you place you elbow on the rest and hold your arm up	I'm adding this for comfort, do you have any sensitive areas	The POP will heat up during application let me know if it becomes too uncomfortable	Is there any constriction or uncomfortable pressure?	Are you able to move your fingers and elbow with a full range f motion?

Figure 14: User journey map

3.2.2 Experience Mapping



	Planning	Prep	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Post
User Goals	Assess injury and apply treatment	Prepare workspace and materials	Asses Injury	Position patient	Apply Sleeve and Padding	Gather and prep Material	Fit Casting Material	Check Mobility and trim material	Post care check up
Problems / Challenges	Managing swelling, assessing severity of injury	Sanitization, large assortment of materials and tools	Managing swelling, assessing severity of injury	Ergonomically positioning patient/medical personnel, elevating limb,	Protecting boney areas successfuly, identifying areas that need padding	Gathering sufficient materials, activating material	Properly fitting cast to limbs contours, applying material succesfully	Making sure cast doesn't rub limb, assuring patient comfort	Viewing limb under cast, checking for complications
Ideas / Take-aways	Pairing x-ray with limb scanner for accurate data	Ergonomic workstation, easier access to materials and tools on demand	Pairing x-ray with limb scanner for accurate data	Adjustable bed for positioning, extra surfaces for limb placement	Limb Scan/X-ray, custom padding, 3D print sleeve	3D printed custom cast material, automated dispensing and activation	Automatic fitment machine, computer aided fitment	Computer aided fitment, adjustable cast	Removable cast, injury assessment tech in cast

Figure 15: User experience map

In conclusion, the journey mapping (**Figure 15)** and experience mapping **(Figure 16)** analysis for the cast application process provides a overview of the user's emotional experience and identifies key pain points and moments of delight. Each phase of the process, from injury assessment to mobility checks, reveals a set of challenges and opportunities for improvement. Users undergo various emotional states as they progress through the phases, encountering problems such as managing swelling, ensuring proper positioning, and achieving the right fit for comfort and mobility.

The analysis highlights the critical role of technology and ergonomic design in enhancing the overall experience. Ideas like pairing X-ray with limb scanners for more accurate data, ergonomic workstations, and the use of 3D printed materials for custom fits demonstrate the potential for significant improvements in both the effectiveness of the treatment and the comfort of the patient. Additionally, the introduction of computer-aided fitment and adjustable casts suggests a future where precision and personalization are at the forefront of medical care.

Overall, the journey and experience mapping in **sections 3.2.1 and 3.2.2,** for cast application underscore the importance of a human-centered approach that prioritizes patient comfort and effective treatment. The insights gained from this analysis are instrumental in guiding future developments and innovations in cast application, aiming to make the process more efficient, comfortable, and tailored to individual needs. The findings from this study offer valuable learnings that can be applied to similar medical procedures, ultimately enhancing patient care and satisfaction.

3.3 Analysis - Human Factors

Ensuring the proposed design is user friendly and intuitive to the user, the actions and human factors of the medical personnel operating it and the patient receiving treatment must be considered. Inorder to accurately design a product with successful ergonomic considerations, analysis of the human dimensions in relation to the proposed product must be recorded. To achieve this, ergonomic configuration diagrams were utilized to map out the required and necessary components of proposed concepts.

Ergonomic studies are crucial in product design because they ensure that the product is tailored to the user's needs, enhancing comfort, efficiency, and safety. In designing a portable machine for applying casts, these studies are especially important due to the diverse range of users, from 5% female to 95% male patients. Through these studies, the examination of the varying anatomical structures and sizes across this user demographic to determine the optimal placement and dimensions of the machine's components. This involves analyzing hand grip sizes, arm lengths, and body contours to ensure that the machine can be easily and effectively used by healthcare professionals.

By integrating ergonomic principles, the aim is to create a product that not only functions efficiently but also minimizes physical strain for both the operator and the patient, therefor enhancing the overall user experience. The configuration diagrams will show these ergonomic considerations, showing the location and proportion of each component in relation to the human body, ensuring that the concept is both practical and user-friendly.

3.3.1 Product Schematic - Configuration Diagram

The method for achieving a successful ergonomic design was to create initial configuration diagrams. Configuration diagrams **(figures 17, 18, and 19)** help inform the 1:1 ergonomic study **(figures 20, 21, and 22)** for the proposed concept. By planning out the product's layout, these diagrams help analyze how each component interacts with the human body. From there the 1:1 mockup of the product is made, which is crucial for assessing ergonomic factors such as reach, grip size, and usability, ensuring that the design accommodates a wide range of body types and sizes, from 5% female to 95% male. This approach helps ensure that every aspect of the design is optimized for comfort, efficiency, and safety.

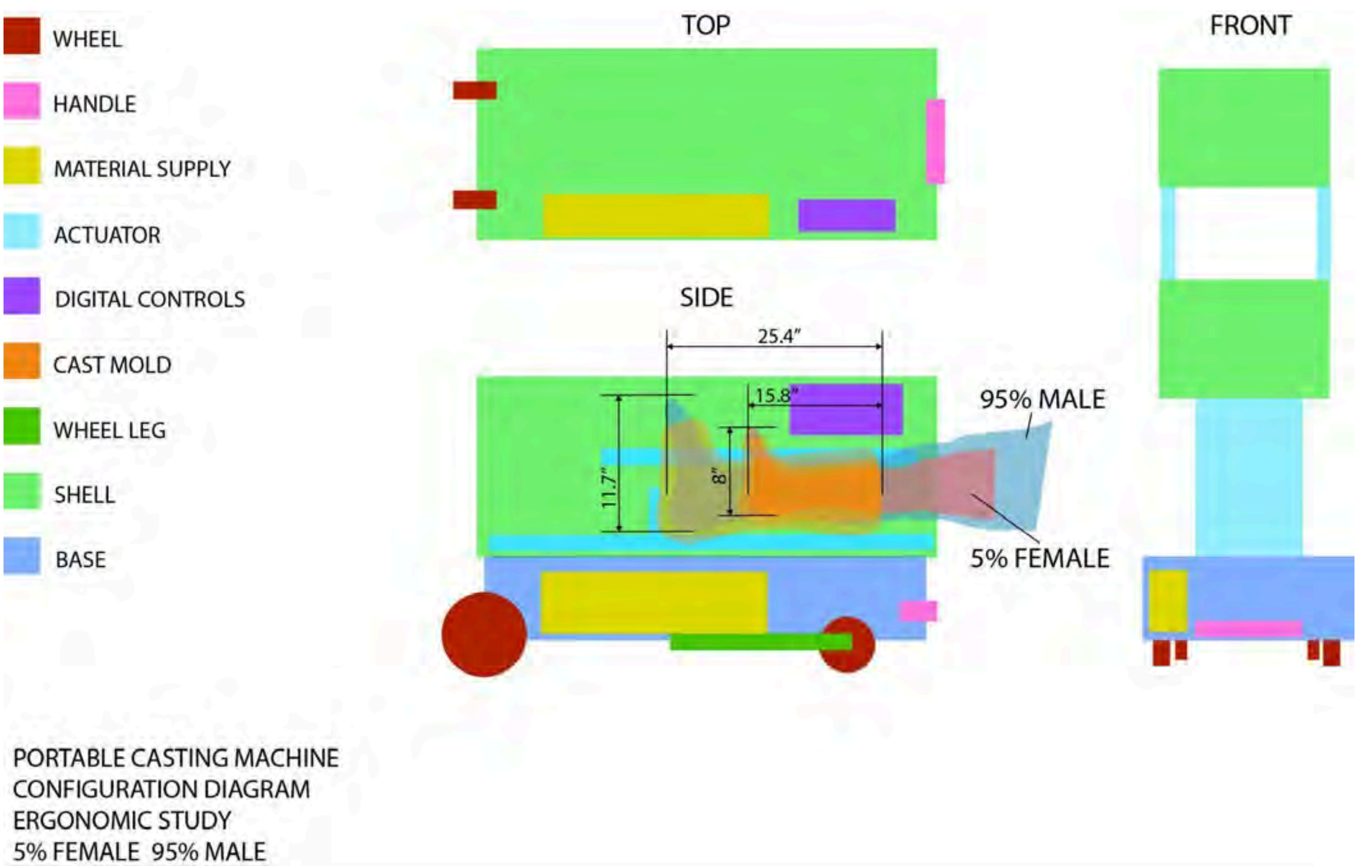


Figure 16: Configuration Diagram. Top, Front, Side View

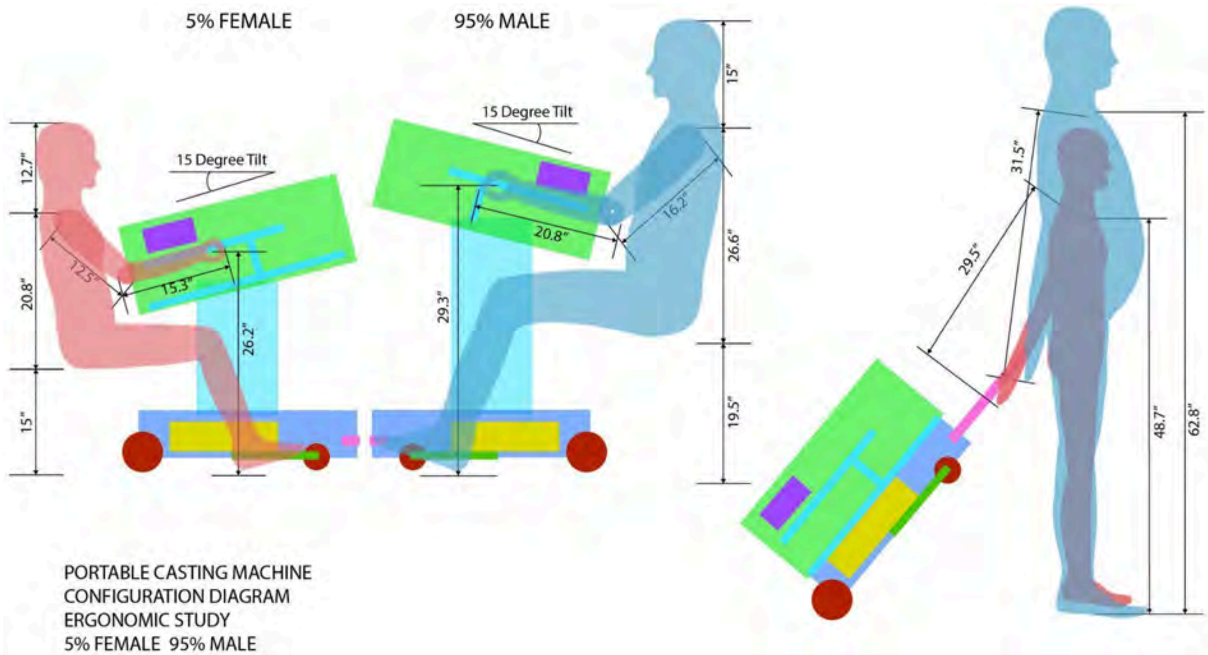


Figure 17: Configuration Diagram 2 Arm Application, Transportation.

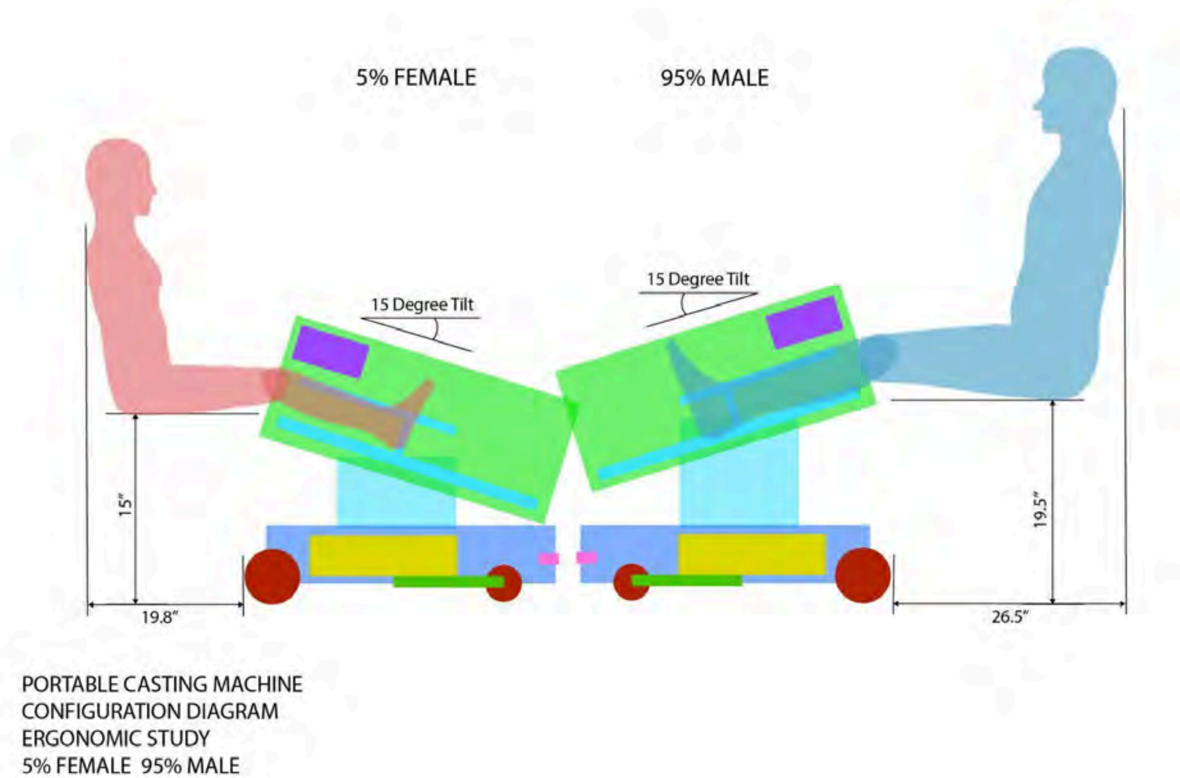


Figure 18: Configuration Diagram 3. Leg Application.

From these results in **figures 17, 18, and 19,** the overall size required to accommodate the human and mechanical factors was determined based on collected secondary research. This enabled the creation of the 1:1 scale model inorder ot test the dimensions of the product in real world situations, seen in **figures 20, 21, and 22**. This model demonstrates how the primary and secondary users interact with the touchpoints, and identify ergonomic requirements that have not been met by the current concept.

3.3.2 Ergonomic - 1:1 Human Scale Study

Figure 19: 1:1 Scale Model. 95% Male, Arm and Leg Cast Application.

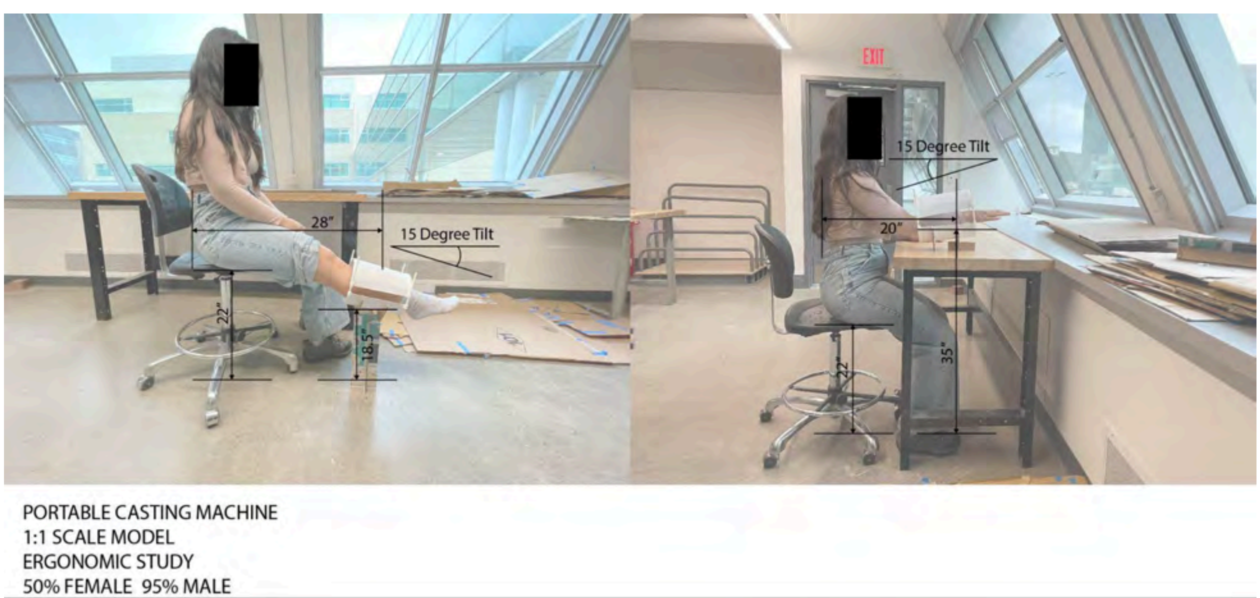


Figure 20: 1:1 Scale Model. 50% Female, Arm and Leg Cast Application.

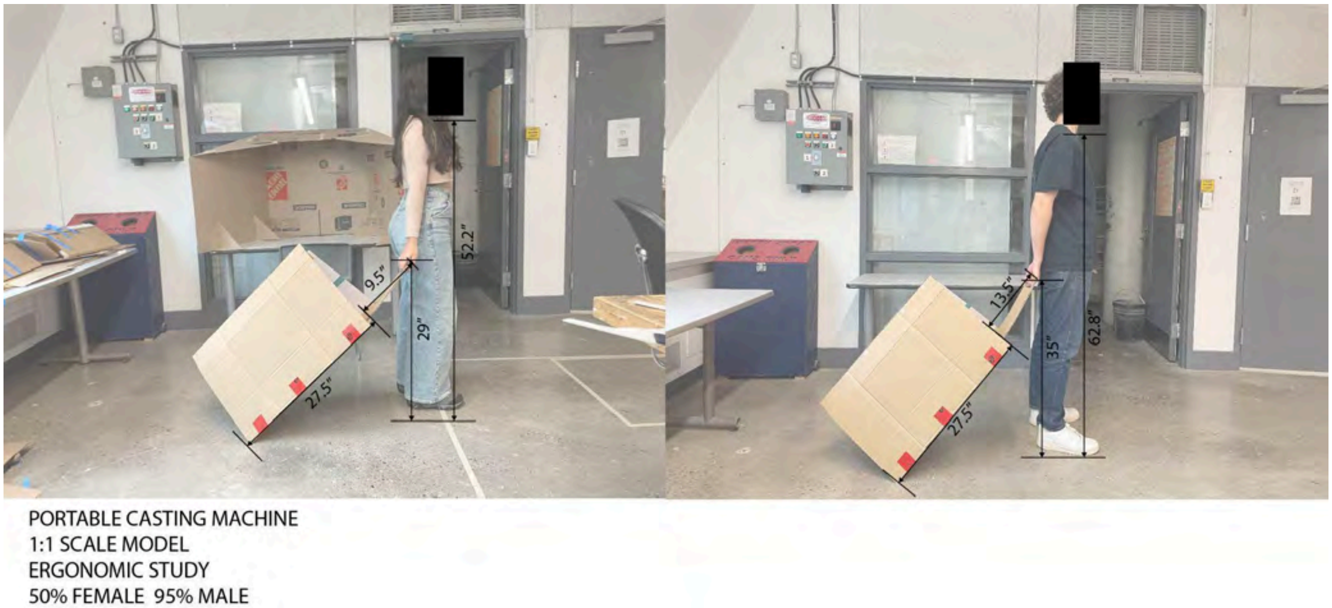


Figure 21: 1:1 Scale Model. 95% Male and 50% Female, Machine Transportation.

The main areas of focus in relation to interaction and touch points involve the patients arm and leg positioning during cast application, and the medical personnels interaction with the machine during transportation and operation.

The major considerations for the dimensions and operations of the concept involve the positioning of the patients arm and leg throuought the application procedure. The ergonomics to consider are:

- Height of machine in relation to 5% female and 95% male while sitting down with elbow held at a comfortable height and position.
    - Height Dimensions:
- The necessary tilt required to successfully position limb, involving arm elevation, and leg angle during lower leg and forearm immobilization.
    - Tilt Dimensions:
- The necessary room and range of motion in the machine to store the cast molds, and provide enough room during the application process for the patients limb.
    - Molding Machine Dimensions:

Machine Operation

- Size of handle within machines base, used for transporting machine to and from patients and clinics.
    - Handle Dimensions
- Display screen and control board used for operating machine, including cast application and machine positioning.
    - Display / Control Dimensions:
- Height and angle of the machine while transporting between operations, angle required to accommodate ease of transportation for various sized users.
    - Height/Angle during transportation Dimensions:
- Height and position during the process of loading machine in a vehicle, required for ease of transportation and storage.
    - Vehicle Loading Height Dimensions:

As seen in the results previously stated, there are many considerations involved in the design. Using a combination of the anthropomorphic research conducted, a successgfull design may be implemented based on the dimension of the 5% female and 95% male during the process of cast application and transportation/operation of the portable machine. This research now allows the design to proceed further into the body and overall styling of the machine now that the inner dimensions and ergonomic criteria have been established.

3.4 Analysis - Aesthetics & Semantic Profile

Figure 22: Aesthetic approach moodboard

In refining the potential design, product semantics play a crucial role in determining the necessary components and their functional aesthetics. The design must encompass essential elements like a cast mold, adjustable height and tilt mechanisms, and a base designed for easy transportation and portability, while aligning with current aesthetic trends.

The cast mold is the centerpiece of the design, made to be both functional and visually coherent with modern medical equipment. Its form follows a organic shape, as it follows the limbs contours to immobilize the injury. The material selection, a combination of aluminum and medical-grade plastics, reflects durability and cleanliness, resonating with the trends observed in medical device design.

Adjustability in height and tilt is another critical feature, ensuring ergonomic comfort for both the patient and the medical personnel. This aspect of the design features intuitive controls, possibly highlighted with color accents, to enhance user-friendliness while maintaining a contemporary look.

The base of the machine is designed for portability and ease of movement, a benefit in medical environments. Featuring a streamlined, lightweight structure, incorporating elements of open construction observed in current product styling. The use of materials like anodized aluminum or reinforced polymers could offer the necessary strength without adding excessive weight, aligning with the modern, clean aesthetic of medical spaces.

Overall, the design of the concept relies on each semantic aspect, from the shape and material of the cast mold to the functionality and aesthetics of the adjustable mechanisms and portable base. This approach ensures that the machine is not only effective and ergonomic but also visually aligned with contemporary medical design trends.

3.5 Analysis - Sustainability:Safety, Health and Environment

In designing a orthopedic casting product, the approach to sustainability focuses on three pillars: Safety, Health, and Environment. This section explores the reason behind key design aspects, drawing on previous research.

Safety is a primary concern, automated features help to ensure precision in cast application, reducing risks associated with improper casting. This not only enhances patient safety but also ensures consistent care quality. The health aspect is addressed by simplifying the casting process. Reduced complexity and training requirements mean a broader range of medical personnel can operate effectively, improving patient care in diverse healthcare settings.

In addressing environmental sustainability in the design of orthopedic casting products, a focus on the use of specific medical grade recycled polymers is important to understand the carbon footprint created by the process of manufacturing and processing of the proposed materials:

Looking at specific materials helps narrow down the potential carbon emissions, Eastar Renew 6763 Copolyester and Tritan Renew Copolyester from Eastman offer excellent clarity, puncture resistance, and chemical resistance, essential for medical applications. Their recycled content contributes to reducing the environmental footprint of the products they are used in (Eastman, n.d.).

Makrolon® RE Polycarbonate by Covestro offers a low carbon footprint polycarbonate, with a 70% lower carbon emission than comparable fossil fuel based plastics (Covestro, n.d.), aligning with the goal of reducing carbon emissions in the production of medical devices. By incorporating these specific recycled polymers, the design significantly advances environmental sustainability in medical device manufacturing, contributing to a more eco-friendly healthcare sector.

3.6 Analysis - Innovation Opportunity

3.6.1 Needs Analysis Diagram

As seen in the STEEPV analysis below **(Figure 24),** the main pain points and challenges were identified to be further analyzed. This helps understand the users difficulties to help inform the solution. The key insights from this activity are:

<u>Challenges</u>

In remote or resource-constrained settings, the complexity and inflexibility of existing casting systems pose significant challenges. Clinics often lack adequate training with specialized procedures, complicating the casting process. Rural areas particularly suffer from a scarcity of specialists, with a reliance on outdated methods like plaster and fiberglass, which require specific skills for proper application and has long setting / curing times. Inconsistencies in training lead to variability in cast application quality, possibly leading to further medical complications.

<u>Pain Points</u>

Especially with children, achieving compliance during cast application is difficult. This leads to increased staffing requirements and parental anxiety, impacting the overall efficiency of the procedure. Traditional materials like plaster take a long time to set, and fiberglass requires expertise for proper contouring, limiting the effectiveness of treatment. The time-intensive nature of traditional casting methods, like plaster application and setting, complicates efficient patient care, especially in high-demand situations. The use of non-biodegradable materials in casts poses significant environmental challenges. Positioning the patient for effective casting application while keeping them and the medical personnel comfortable throughout the procedure.

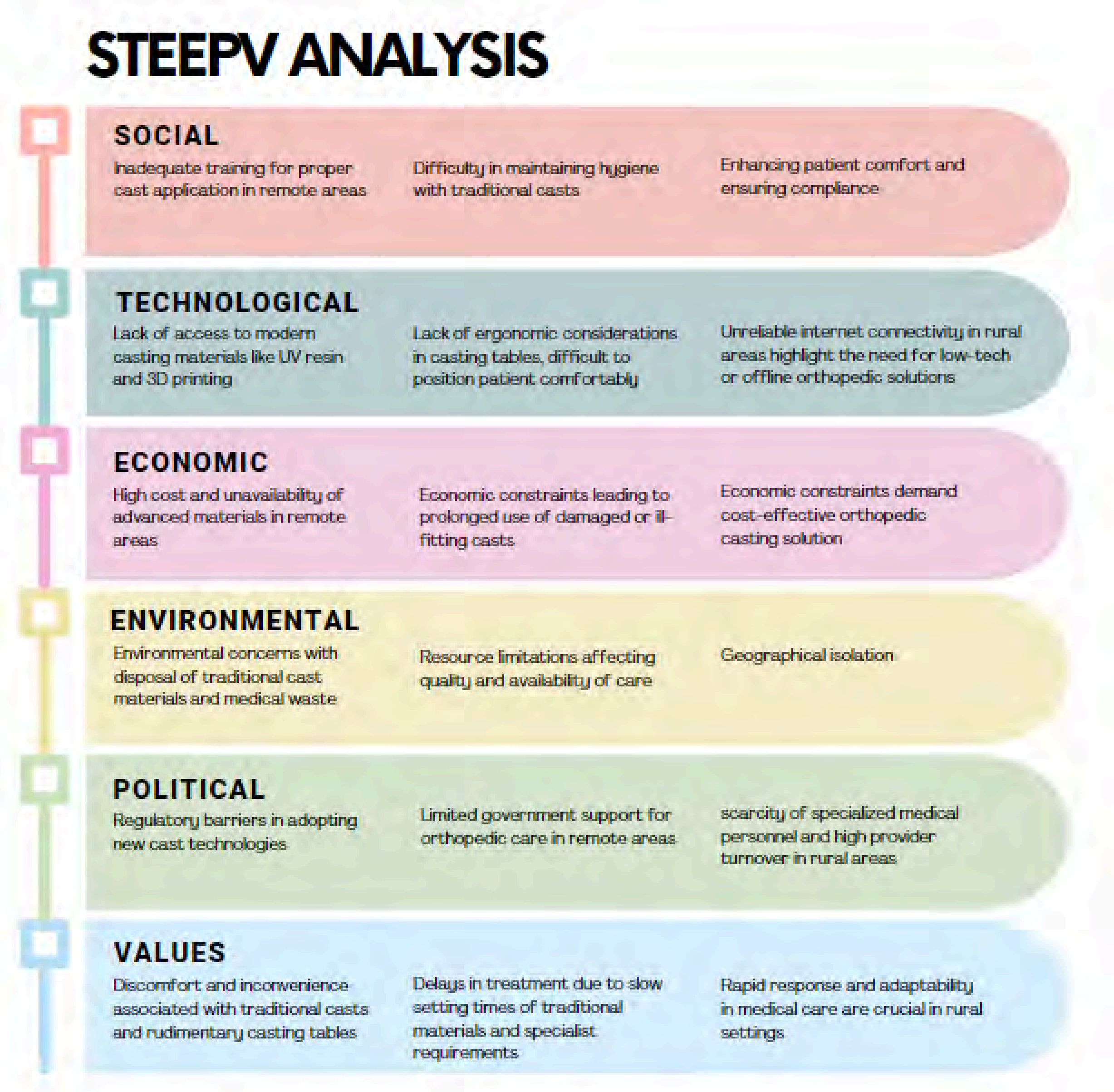


Figure 23: STEEPV analysis of user challenges and pain points

3.6.2 Desirability, Feasibility, & Viability

Considering all these insights gathered from the previous research, indicating the gaps within the current orthopedic casting market, as well as the challenges and painpoints the involved users experience. This has helped gain insights on possible opportunities involving the desirability, feasibility and viability of the concept.

Desirability (User Experience)

- High degree of adjustability (Allows ease of set up, patient limb positioning, and improved ergonomics)
- Automated process (Removes the need for excess training into specialized operations, allows non-specialized personnel perform cast application, removes chances of improper cast application leading to further complications)
- Portable (Allows ease of transportation and storage)
- Less resources required for treatment (Limits necessary material storage, less material fulfills more jobs, requires less variety of material and storage)

Feasibility (Materials and Manufacturing)

- Medical Grade Polymers (PC, TPU etc…, Allow ease of cleaning, high chemical resistance, high impact resistance, high recycled material percentage)
- Aluminum (Improved weight over current materials, infinitely recyclable, high moisture resistance, chemical resistance)
- Cast Material Foam/Resin (Improved functionality over plaster and fiberglass, improved setting and application time, anti bacterial, improved airflow, waterproof)

Viability (Current Competitors)

- Revolutionary Design (No competitors in the current orthopedic casting market as this process has not been used in the industry, Some implementation of 3D printed casts and plastic sleeves filled with UV resin but they still require training in fitment and application)

Understanding these points on the concept help identify the unique selling proposition. Overall this allows the identification of the benefits this product holds over the competitors and where this will sit within the market.

3.7 Summary of Chapter 3

Based on this chapters finding, the following list was created to detail the key guidelines that the final design should address:

1. Integrate ergonomics for medical personnel, reducing physical strain during the casting process.
2. Ensure the product is lightweight and portable, catering to the mobility needs of remote healthcare settings.
3. Simplify tools and materials, streamlining the casting process and improving overall efficiency.
4. Integrate advanced materials for easy and effective cleaning, enhancing the sanitation aspect of the product.
5. Focus on patient comfort and compliance by considering the psychological impacts of treatment.
6. Ensure successful operation in low-tech environments, addressing the challenge of limited technological resources in rural areas.
7. Integrate automation into the application process to reduce risk of further medical complicaitons during casting process.
8. Design for simplicity and ease of use, requiring minimal training, suitable for healthcare settings with limited specialized personnel.
9. Aim for rapid application and adaptability to different patient conditions, ensuring timely and effective healthcare delivery.
10. Incorporate ergonomic considerations for a range of users, ensuring the design is intuitive, and user-friendly.

04
DESIGN DEVELOPMENT

4.1 Initial Idea Generation

This chapter outlines the development of the chosen concept throughout each stage of the design process. This development process involved first identifying the issue that the proposed designs are going to solve using various methods previously described on the report. From there the initial concepts are made and further researched to determine the semantic profiles and necessary ergonomic considerations involved in the design. This research has been analyzed for the key insights and possible areas of opportunity to ensure the proposed design fulfills the needs and wants of all users involved in the orthopedic casting process.

4.1.1 Aesthetics Approach & Semantic Profile

The semantic profile for the machine was explained earlier in **section 3.4**, where the necessary components and allowances of the machine were stated. Overall the design must allow a high range of height adjustability along with tild adjustability of the cast mold. It was determined the final design must be portable, allowing ease of transportation and storage. The aesthetics of the overall machine were developed after categorizing the necessary actions of the machine, the parts configuration, and the overall aesthetic within the current market.

The current trends in the medical market involve a rectilinear approach, with a heavy use of stainless steel, and vinyl for padding and seating. This allows ease of cleaning and gives a functional feel rather than a focus on form. This allowed an opportunity in creating a medical device that not only fulfills the user pains and challenges, but also has a interesting visual appeal. Figure 25 below is the moodboard that inspires the overall aesthetic approach of the machine. This board is heavily inspired by modern Sci-Fi and medical design, It encompasses the surfaces, forms, and textures of modern sci-fi, while having the cleanliness and minimilis of medical design.

Figure 24: Moodboard - Aesthetic Approach.

4.1.2 Mind Mapping

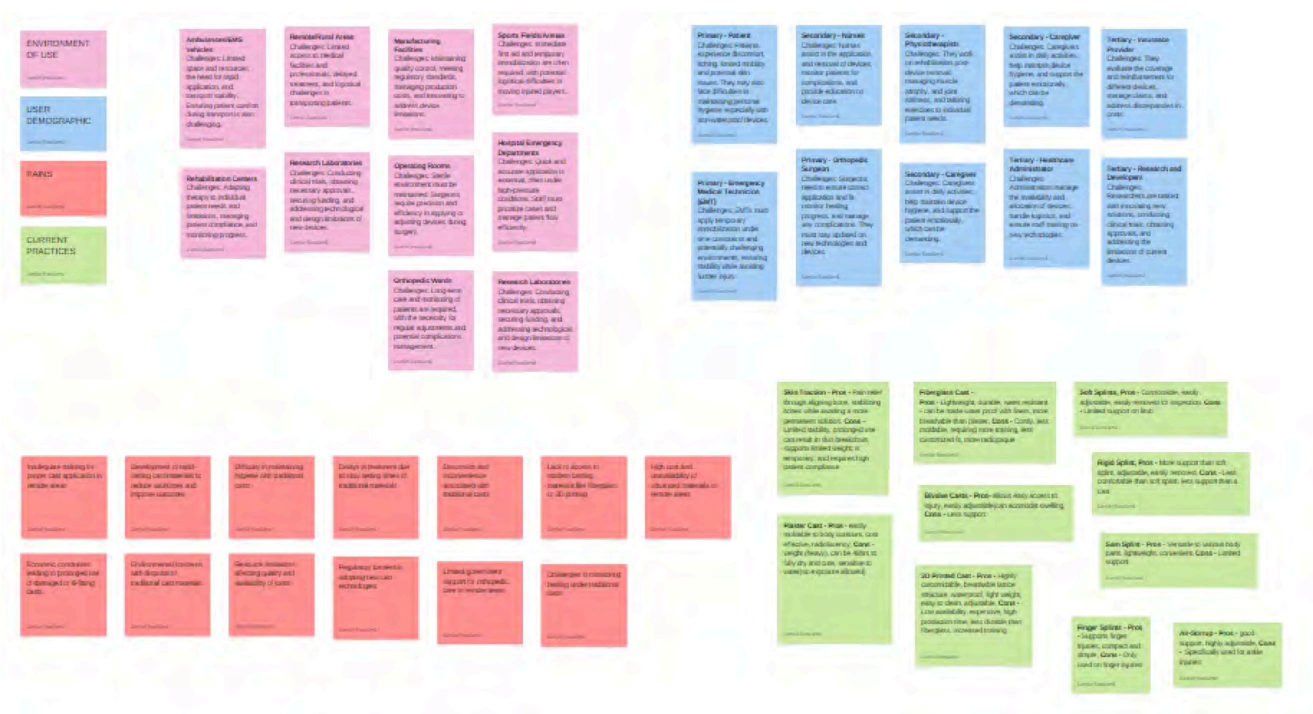


Figure 25: Initial Mind Mapping of Discovery Research

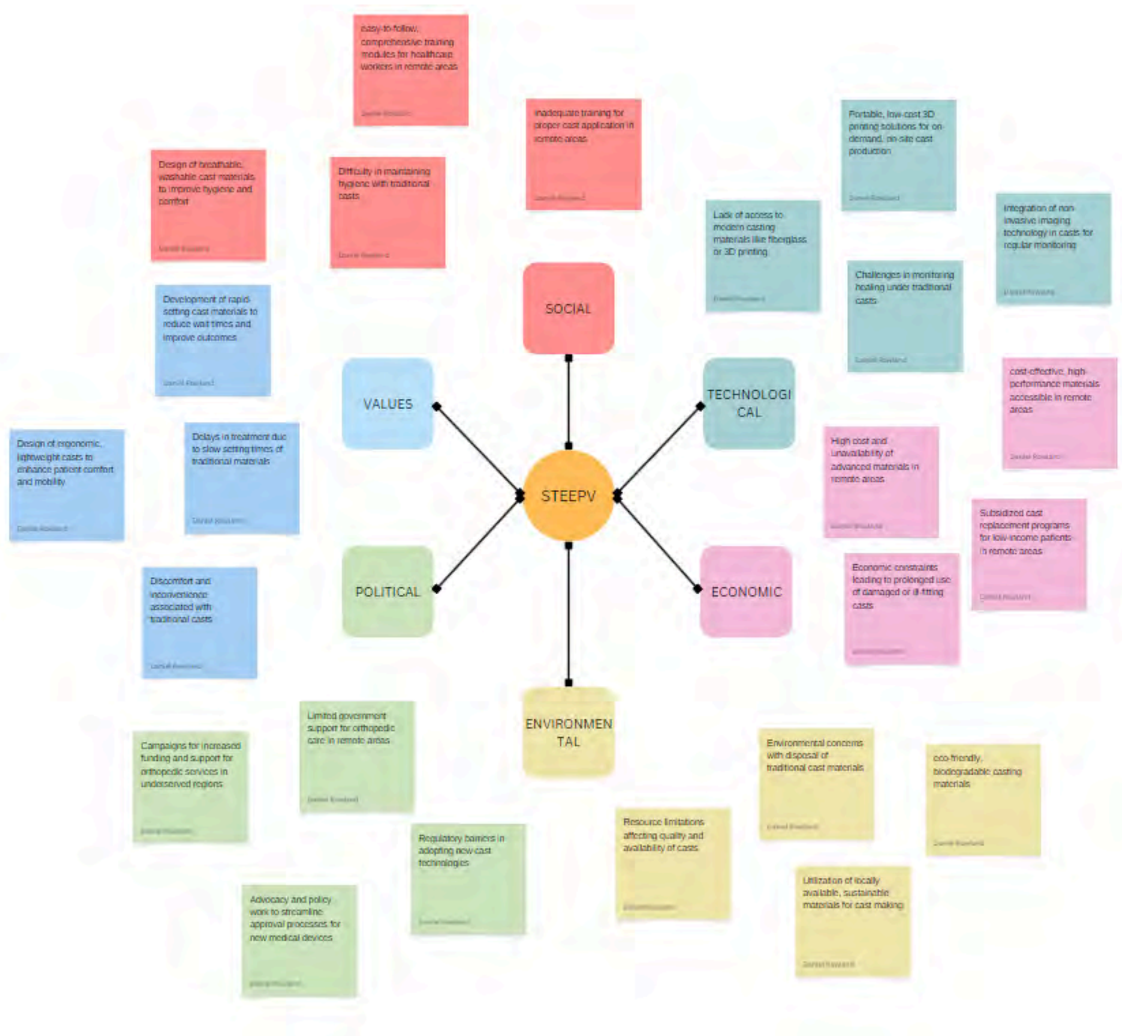


Figure 26: Mind Mapping of STEEPV.

The initial research conducted was analyzed using various methods. Mind Mapping was utilized as seen in **figures 26 and 27,** to help gather thoughts and pickout key information to focus on and further analyze. This involved research into the various user demographics involved in the casting process, the pains experienced by those user groups, current products and materials used along with benefits and drawbacks of each, and environments of use to get an understanding of the setting where the product will be used. The STEEPV analysis mind map **(Figure 27)** was then created to better identify and categorize the insights found based on the social, technological, economical, environmental, political, and value aspects of the process.

4.1.3 Ideation Sketches

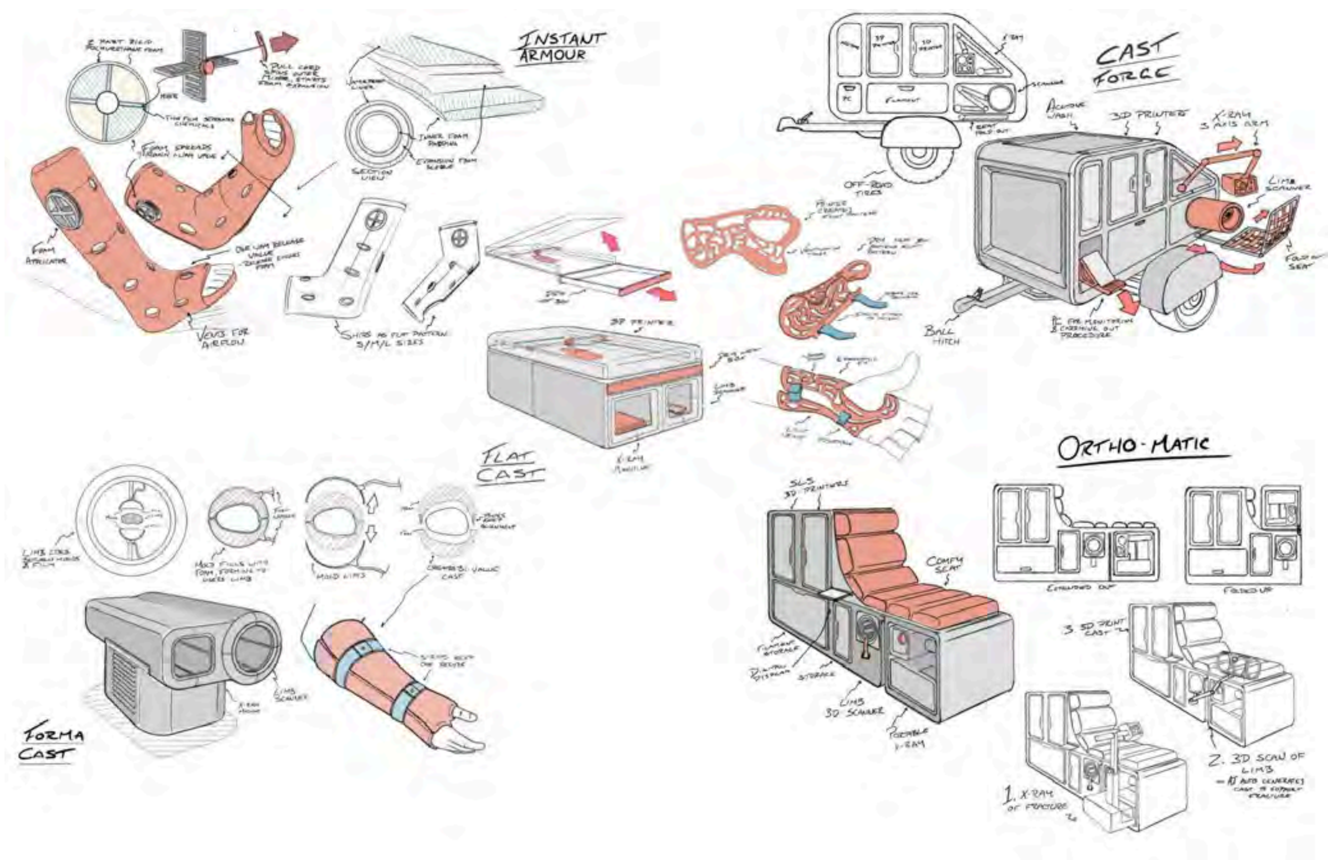


Figure 27: Initial Concept Exploration

The initial proposed concepts were created based on the discovery research previously conducted. Each of these concepts focused on a different aspect of the problem statement aiming to solve a specific issue.

<u>Direction 1 - Instant Armour</u>

The first proposed direction, named the ‘Instant Armour’, is a response to the long wait times for traditional casting methods to set, along with more modern solutions, such as 3D printed casts to be created. This solution works using a waterproof sleeve with a built in expansion foam material pack. Upon injury occuring the patient can immobilize the injury without the need for medical personnel for cast application. The patient simply pulls the sleeve over the injury and pulls the activation pin, this mixes the 2-part chemical mix allowing the sleeve to rapidly fill with expansion foam, perfectly contouring to the patients body and instantly setting.

Direction 2 - Cast Forge

The second direction explored, named the ‘Cast Forge’ was aimed towards the problem of a lack of transportation. This solution stemmed from the lack of transportation among the demographics in rural and remoe locations. This solution is able to be set up in mobile clinics, possibly in relief camps for natural disasters or in military situations. The ‘Cast Forge’ holds all the necessary equipment for injury assesment and treatment, involving a limb scanner and 3D printer for on-site cast manufacturing.

Direction 3 - Flat Cast

The third direction explored, ‘Flat Cast’ was aimed at simplifying the process of casting along with increasing the portability of the materials and machines involved. This solution involves a limb scanner and 3D printer to create flat patterns of the necessary cast. The medial personnel scans the limb while the imbedded computer analyzes the information to create a CAD model for FDM 3D printing. The cast is then printed flat then put in a dry heat hot box to warm the material enough to be formed to the patients limb. This allows medical personnel to quickly and accuratly apply a cast to a patients injured limb.

Direction 4 - Forma Cast

The fourth proposed concept, the ‘Forma Cast’ is an in-clinic casting machine aimed at rapid cast application. This machine would be sent to small clinics in rural and remote communities enabling less trained personnel to successfully apply casts without potential medical complications. The machine is made up from a 2 piece mold that the patient inserts there limb into, where the molds fill fill with a material such as UV resin, allowing the automatic applicaion of a fitted cast. This concept removes any potential human error resulting in later medical complications while allowing rapid application.

Direction 5 - Ortho-matic

The final concept proposed during idea generation, named the ‘Ortho-matic’ was an in-clinic machine that would be delivered to small rural and remote medical clinics. This machine is a orthopedic casting table allowing the ergonomic positioning of the injured patient. Inside the machine, an x-ray machine, limb scanner, computer for analyzing, 2 3D printers, and an acetone smoothing bay for post manufacturing prep. This machine simplifies the process for the medical personnel, keeping all needed tools in short reach allowing efficient injury analysis and application of a modern 3D printed cast.

4.2 Concept Exploration

Initial concept ideation helped identify what directions to proceed researching and developing. The aspects and allowances of the proposed concepts have been refined to further align with the identified problems in the current orthopedic casting market.

4.2.1 Concept One

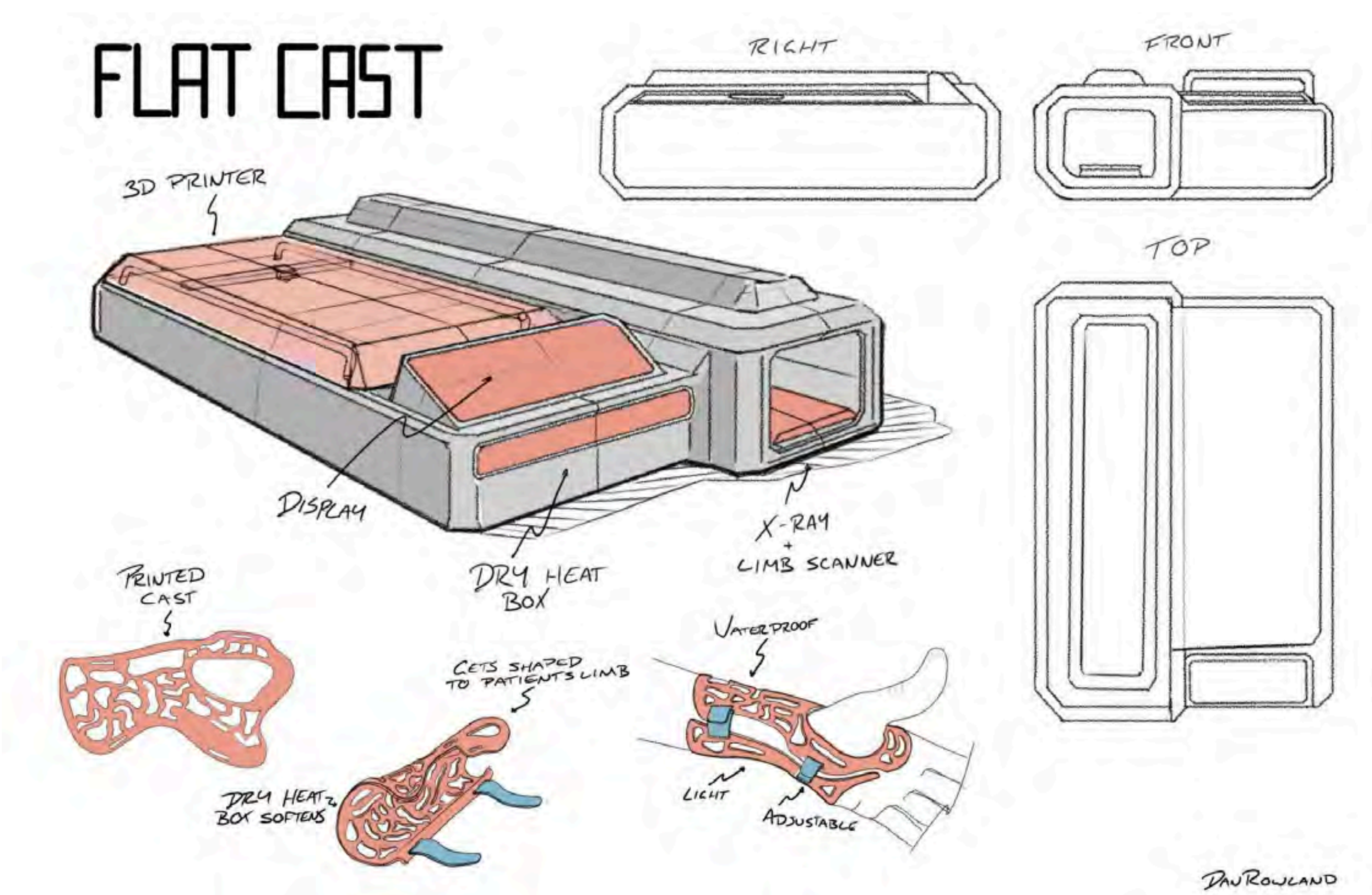


Figure 28: Concept Exploration: Concept 1 - Flat Cast Portable Machine

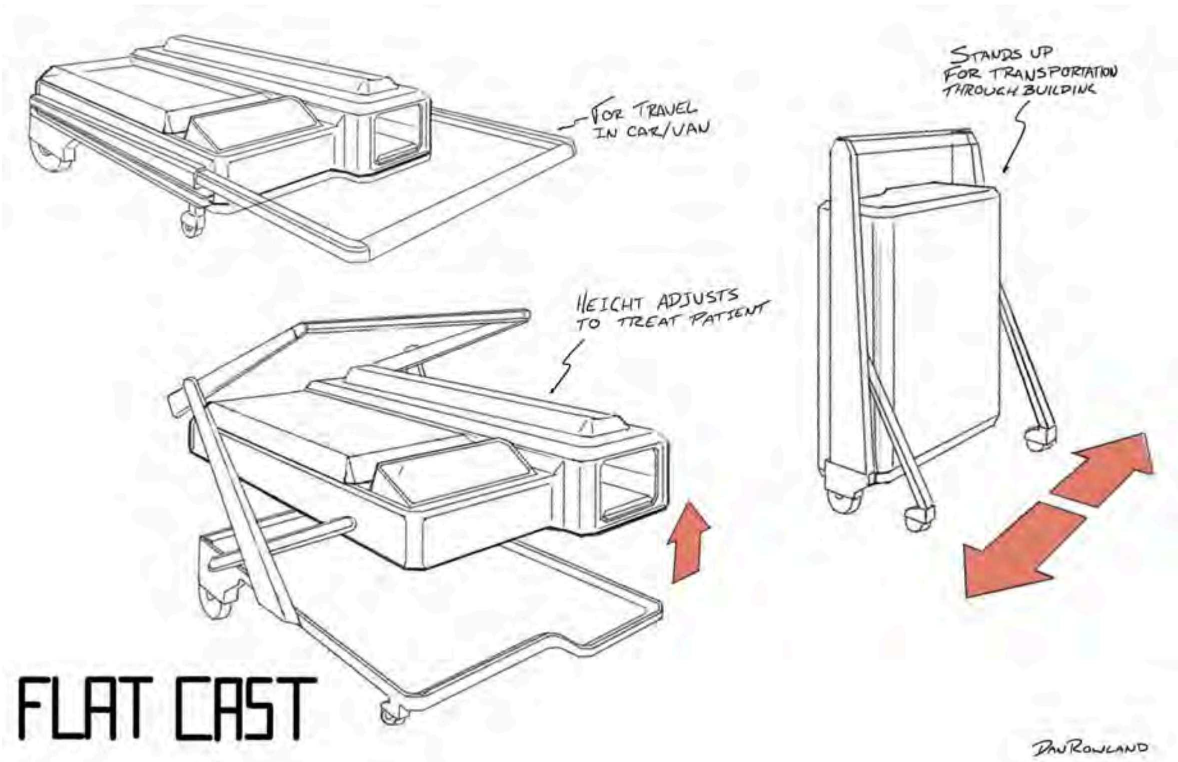


Figure 29: Concept Exploration: Concept 1 - Flat Cast Portable Machine, Portable Base 1

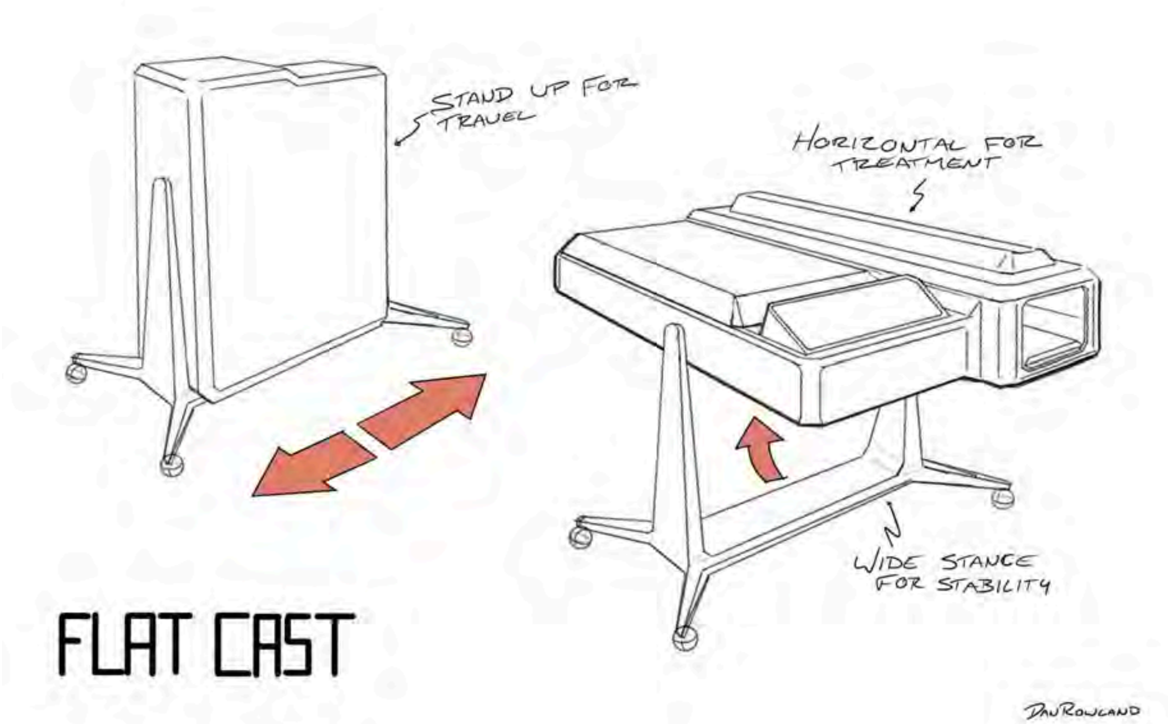


Figure 30: Concept Exploration: Concept 1 - Flat Cast Portable Machine, Portable Base 2

Concept one, named the ‘Flat Cast’ is a portable casting machine aimed at improving the material used in the casting application, with a transportation base allowing easy portability of the machine. This concept contains a bay where the patient inserts there injured limb, the machine contains a portable x-ray machine and limb scanner for accurate measurements of the patients limb contours. The x-ray identifys where the most support needs to be added on the cast and where the bone is closest to the skins surface. From there the machine prints a flat pattern cast that gets heated up on the print bed itself, allowing the medical personnel to simply grab the flat pattern and fit it to the patients limb, removing many steps in the current casting process for relatively low cost. The portable base allows lifting of the machine to reach a patient in a bed or chair, this allows the scanners to come to the patient rather than the patient moving their injured limb.

4.2.2 Concept Two

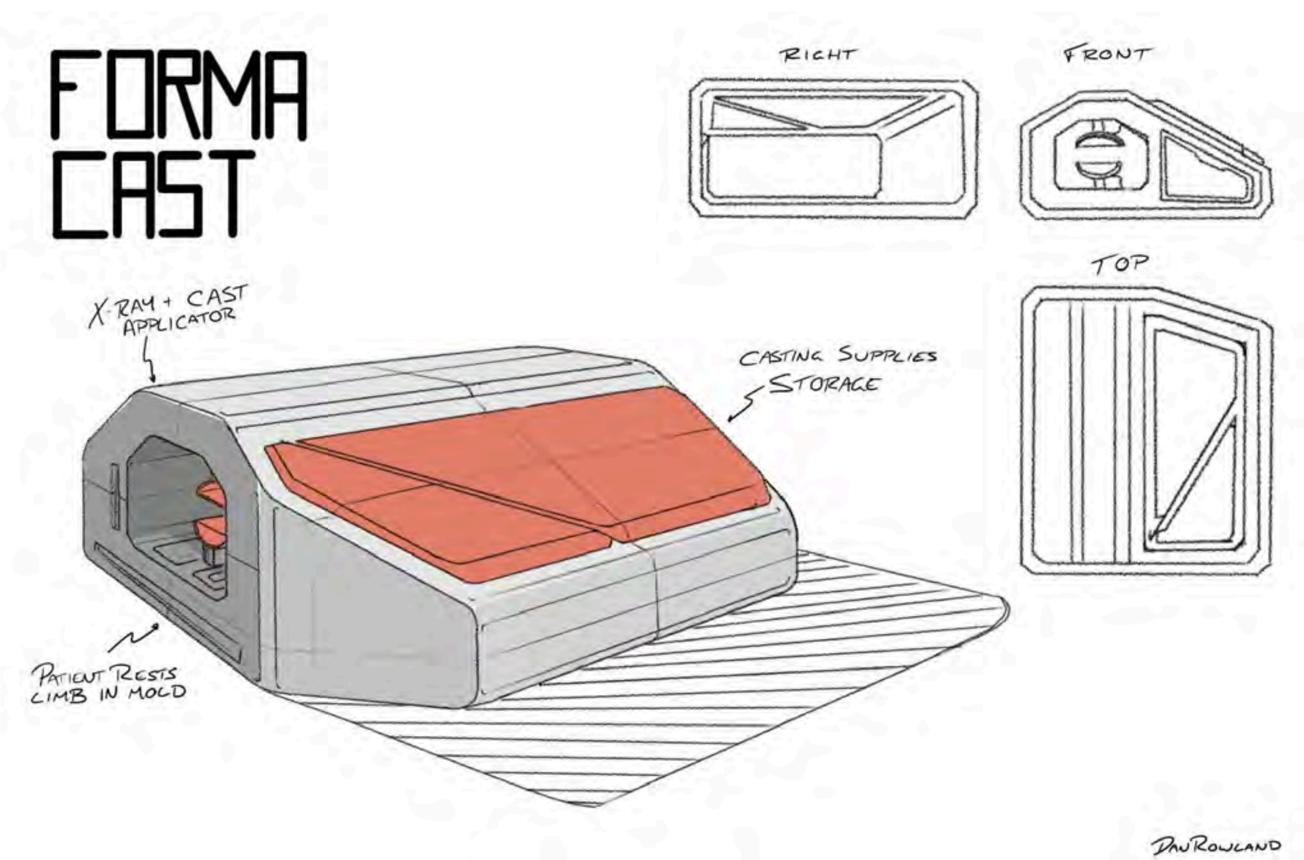


Figure 31: Concept Exploration: Concept 2 - Forma Cast In-Clinic Machine

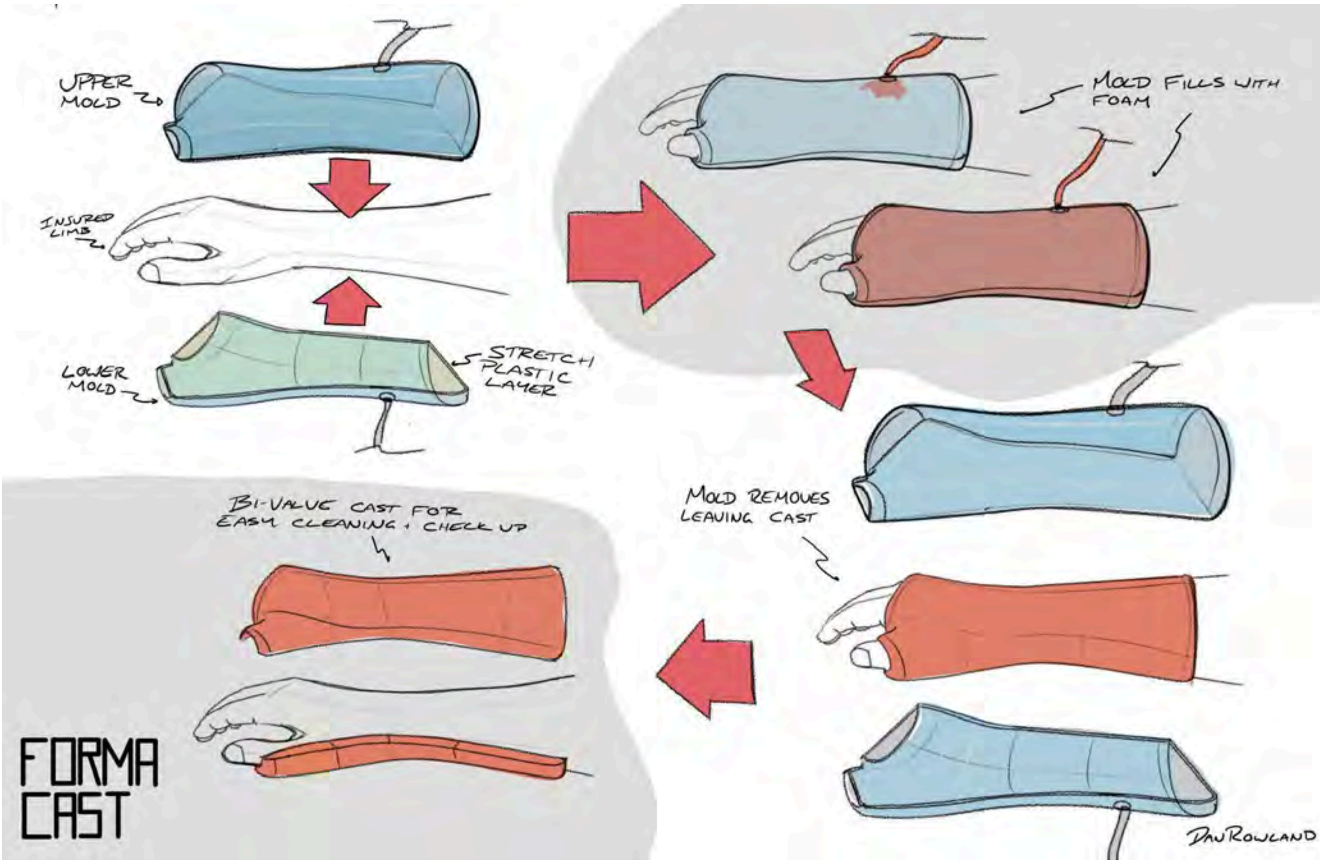


Figure 32: Concept Exploration: Concept 2 - Forma Cast In-Clinic Machine, Cast Mold Operation

Concept two is an in-clinic casting machine aimed at simplifying cast aplication and speeding up the process for setting and curing times of casting materials. The process described in this design allows the patient to place there limb within the cast mold and receive a cast within minutes. When the mold closes on a patients limb it fills with an anti-bacterial expansion foam. The foam expands, perfectly contouring to the patients limb, immediatly immobilizing the injury. Avoiding excessive pressure is necessary to prevent pressure sores, therefor a relief valve within the mold allows material to be released. The nature of the molding process creates a 2 piece mold, or bi-valve cast, allowing easy checkups during the process of treatment.

4.3 Concept Strategy

Based on the previous concepts, the strategy to further refine the products was to focus on a dedicated in-clinic device that provides a all-in-one ergonomic layout, and a portable machine addressing the lack of transportation and resources in rural and remote clinics. These concepts were made into two distinctly different product schematics to identify the necessary components involved in human interaction and the machine processes.

4.3.1 Concept Direction & Product Schematic One

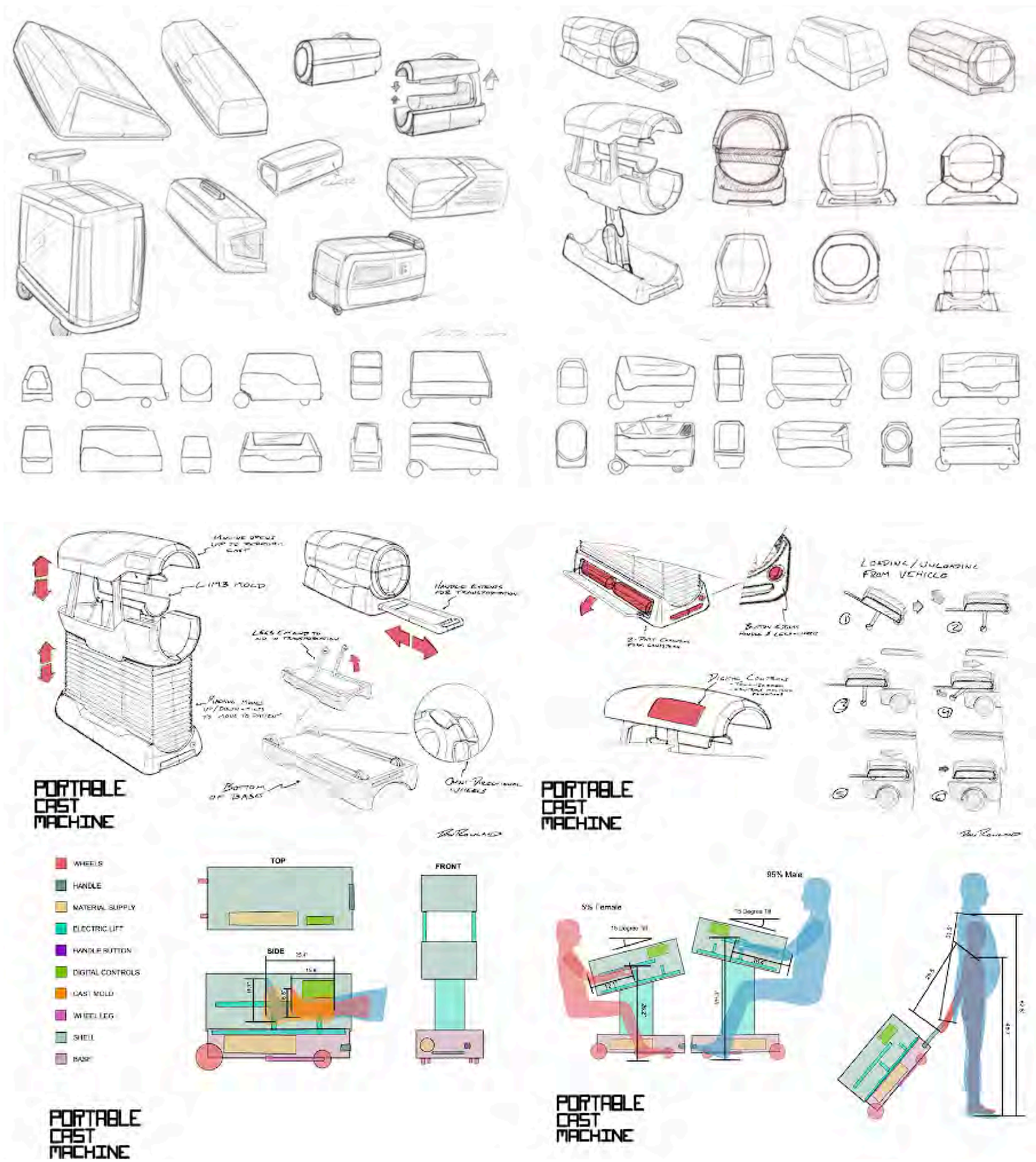


Figure 33: Concept Direction & Product Schematic One

Portability requires the precise placement of various components in a small form factor for ease of transportation. Concept one consists of a portable casting machine using the expansion foam and mold method previously described in **section 4.2.2,** mounted on a portable base allowing ease of mobility and transportation. The machine raises and tilts on an electric actuator inorder to accommodate the patients limb positioning. The base contains extendable arms allowing ease of storage in the back of a vehicle using simple leverage similar to a wheelbarrow. This machine allows any medical personnel to apply orthopedic casts in various environments without requiring specialized training in cast application. Various environments other than rural and remote areas could benefit from a rapid cast application machine such as natural disaster relief, military application, and areas needing temporary medical relief due to unforseen circumstances. The diagrams created during this phase help identify the size and allowances required in the product to ergonomically accommodate the 5% female and 95% male.

4.3.2 Concept Direction & Product Schematic Two

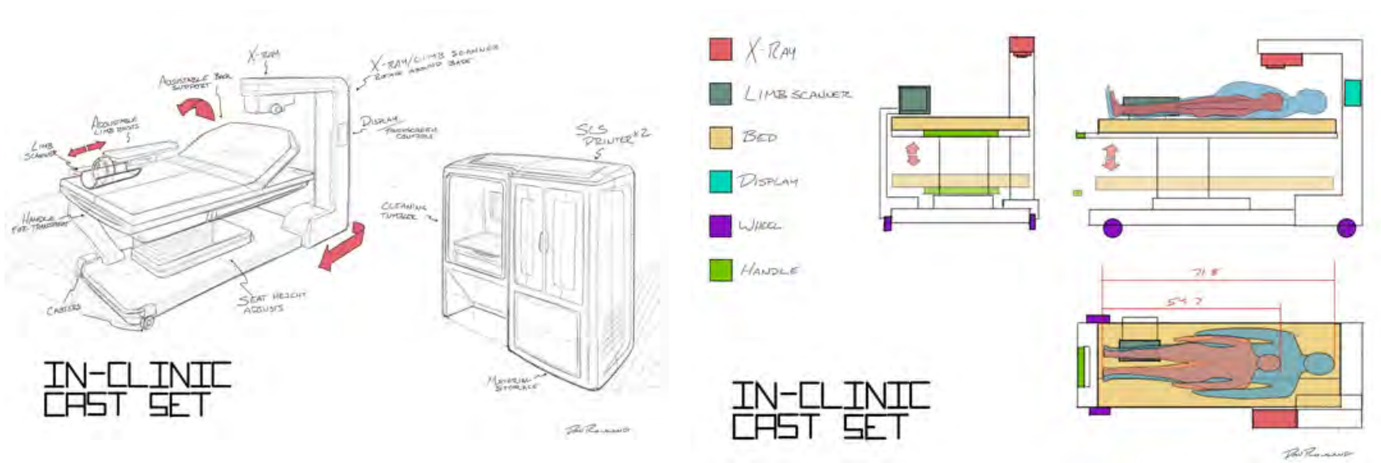


Figure 34: Concept Direction and Product Schematic Two

The second concept developed at this stage was an in clinic solution aimed at providing an ergonomic workstation for medical personnel when assesing and treating a bone fracture. This concept consists of a orthopedic casting bed with adjustable platforms for limb positioning, a built in limb scanner for detailed CAD models for printing, and a x-ray machine on a track for ease of use. The schematic diagram for this concept was used to identify the necessary size for the bed to ergonomically accommodate 5% female to 95% male for treatment, as well as the positioning for necessary components.

4.4 Concept Refinement and Validation

Concept one, the Portable Cast Machine, was chosen to further refine with a focus on simplicity of use and efficiency of cast application. The goal was to refine the casting and transportation procedures to allow untrained personnel to use this machine and successfully apply treatment.

4.4.1 Design Refinment

Based on the Portable Cast Machine concept, the design was refined to become more streamlined and efficient to use. The main focus being on simplicity of use, efficiency of application, and comfort of the patient. On the visual side of things, the design was refined to follow the same design principles across the entire concept, as well as increasing the visual interest in the form.

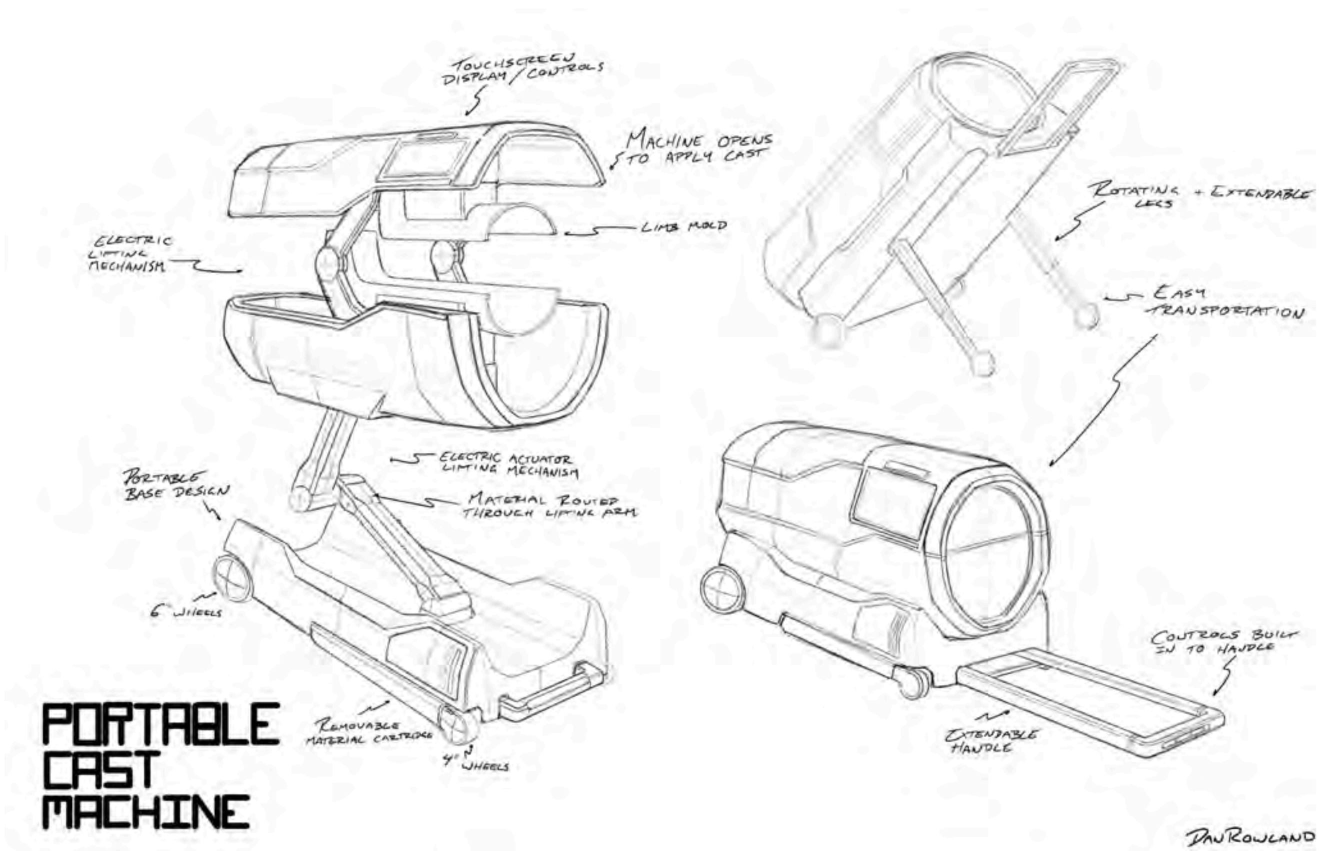


Figure 35: Refined Concept Direction

4.4.2 Detail Development

The overall concept was pulled into a more cohesive design language, however the fine details must be honed in on to address the issues of simplicity, efficiency, and comfort. Each of these individual issues can be solved with specific and intentional design. Transportation was simplified with leg controls on the handle, allowing the user to operate the support legs in motion. A removable tablet designed to control positioning of the machine aswell as facilitate cast application. Removable cast molds make treating a large variety of patients possible.The casting proccess uses thin latex sheets to block the casting material from the users skin, as well as creating a waterproof barrier for the casting material once the application is complete. Overall this refinement stage was focusing on the users needs and what specific designs allow these needs to be met.

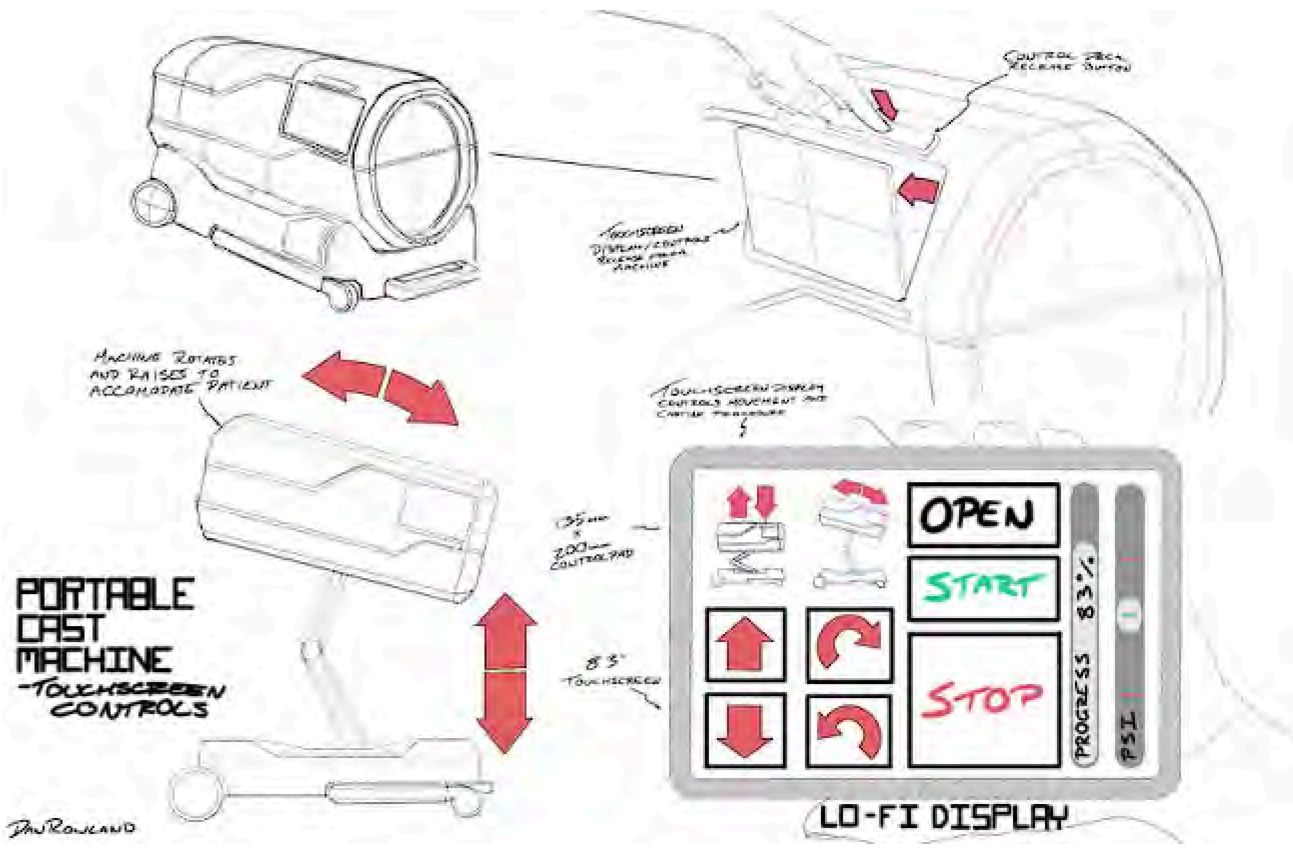


Figure 36: Refined Concept Direction: Detail Design - Touchscreen

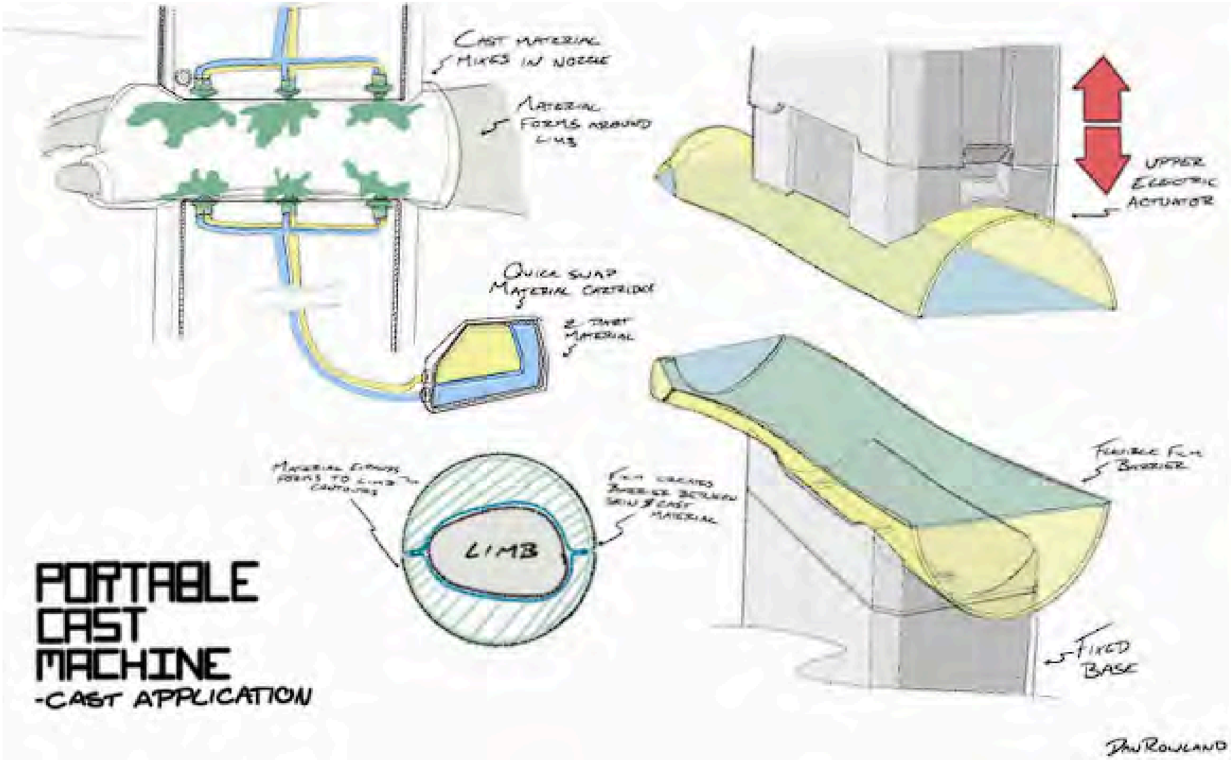


Figure 37: Refined Concept Direction: Detail Design - Cast Application

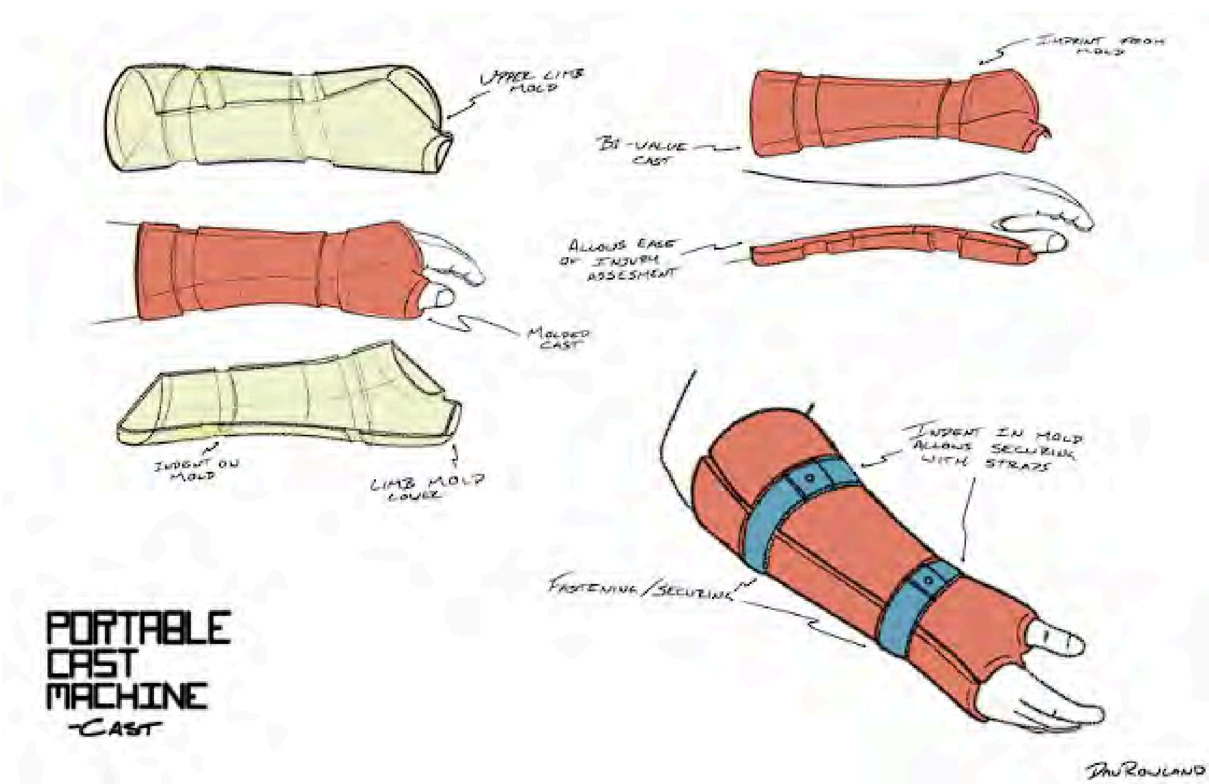


Figure 38: Refined Concept Direction: Detail Design - Bi-Valve Cast

4.4.3 Refined Product Schematic & Key Ergonomic

The development of new product schematics in **figure 39** and ergonomic assessments in **figure 40** were utilized in the refinement of the portable casting machine concept. The refined product schematic was used to develop the layout of the overall machine, and how each individual component will fit within the product, continued refinement helps position the specific details of the concept for increased efficiency during treatment procedures. The refined ergonomic assessment in **figure 40** helps record the necessary measurements in various concepts in order to have enough clearance to treat patients from the 95% male to the 5% female. The ergonomic assessment in this case focused on the fitment of patients arms and legs, patients sitting and using the machine, and medical personnel transporting the concept.

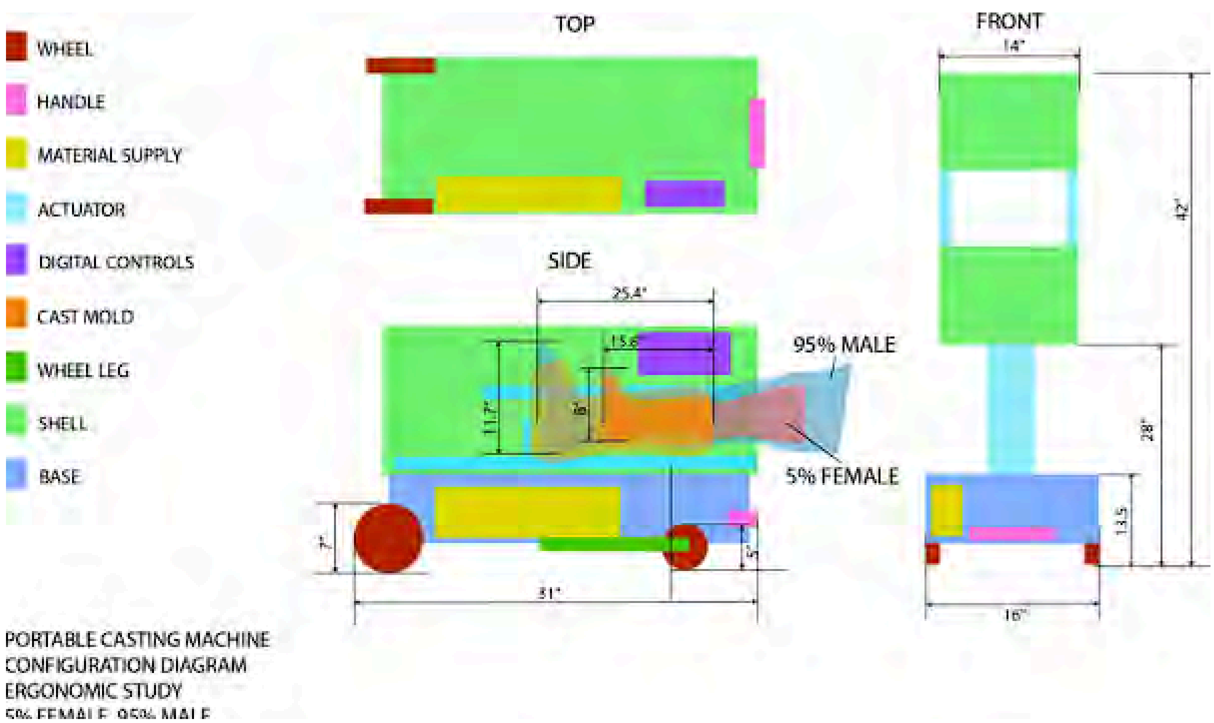


Figure 39: Refined Concept Direction: Product Schematic

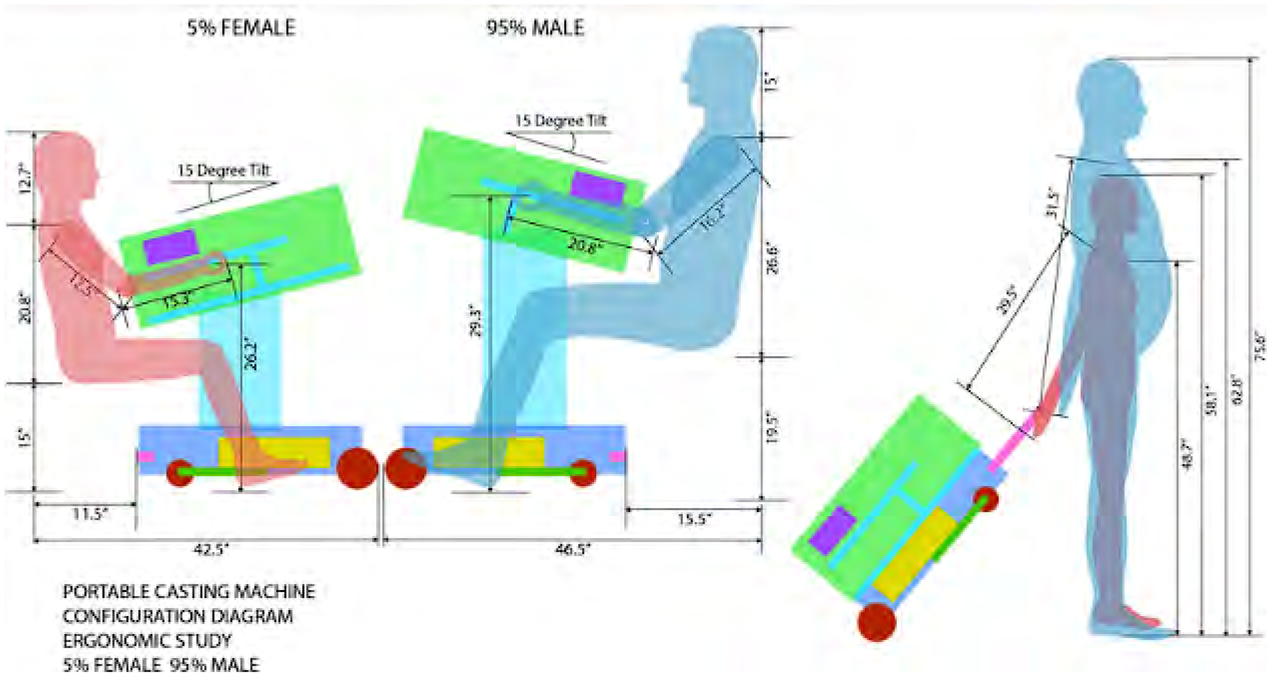


Figure 40: Refined Concept Direction: Ergonomic Assesment

4.5 Concept Realization

This section will outline the design finalization of the portable casting machine concept. First the final sketches will be presented to create an overall understanding of the final design, including stylization, process of operations for the main components as well as supporting parts. Later creating the design within CAD to hone in on the specific details and create accurate 1:1 scale models to assess the probability of the concept working for the intended uses.

4.5.1 Design Finalization

The finalized sketches for the portable casting machine concept outlines all the features and affordances necessary to satisfy the primary, secondary, and tertiary users needs. The concept was intentionally designed through each step of the process considering cast application procedure, and transportation. The design is easily transported with the improved portability of the base, using electrically actuated support legs to reduce stress on the user while loading and unloading the machine into a vehicle. The material canister uses a quick connect valve to increase efficiency of refilling the cast material. An updated 8.3” touchscreen display allows medical personnel to position the cast machine to an ergonomic height and angle, as well as facilitate the casting application procedure. The goal here to simplify the casting process to allow a wider range of user to successfully apply a cast without the potential for further medical complications from pressure sores and skin irritation. The cast liner placed inside the casting molds allows the expanding material to fill the liner without contaminating the mold or making contact with the users skin, the liner allows the cast to be waterproof, helping patients live daily life more comfortable during the healing process. Bi-valve casts are created as a result of the cast liner, this increases accessibility to the injury, allowing medical personnel to asses the healing process without having to cut off and re-apply the cast. Finally the revised configuration diagrams and ergonomic assessments indicate the required measurements for the final design. This includes leg and arm measurements for the patient during the application process, as well as the measurements to ensure ease of transportation for the medical personnel.

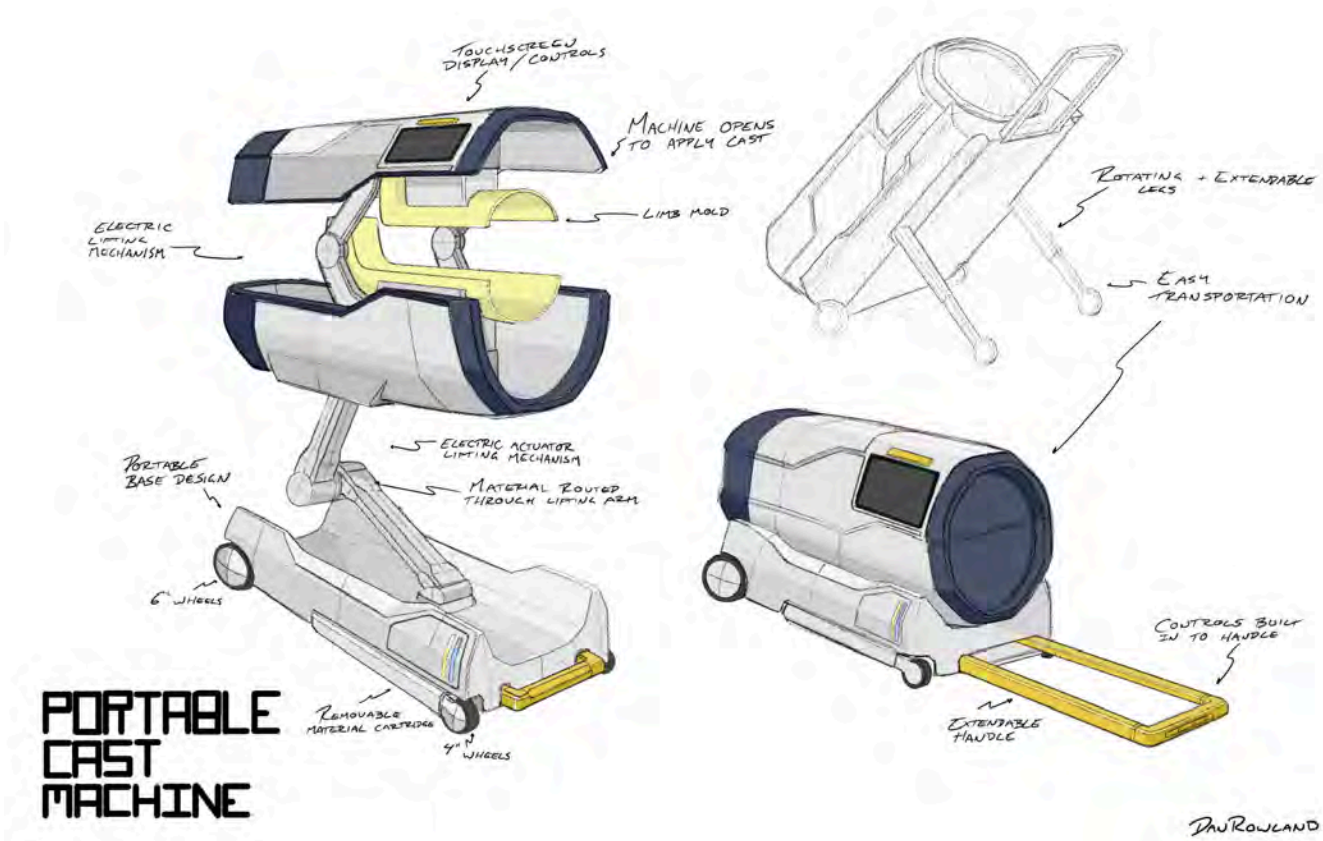


Figure 41: Design Finalization

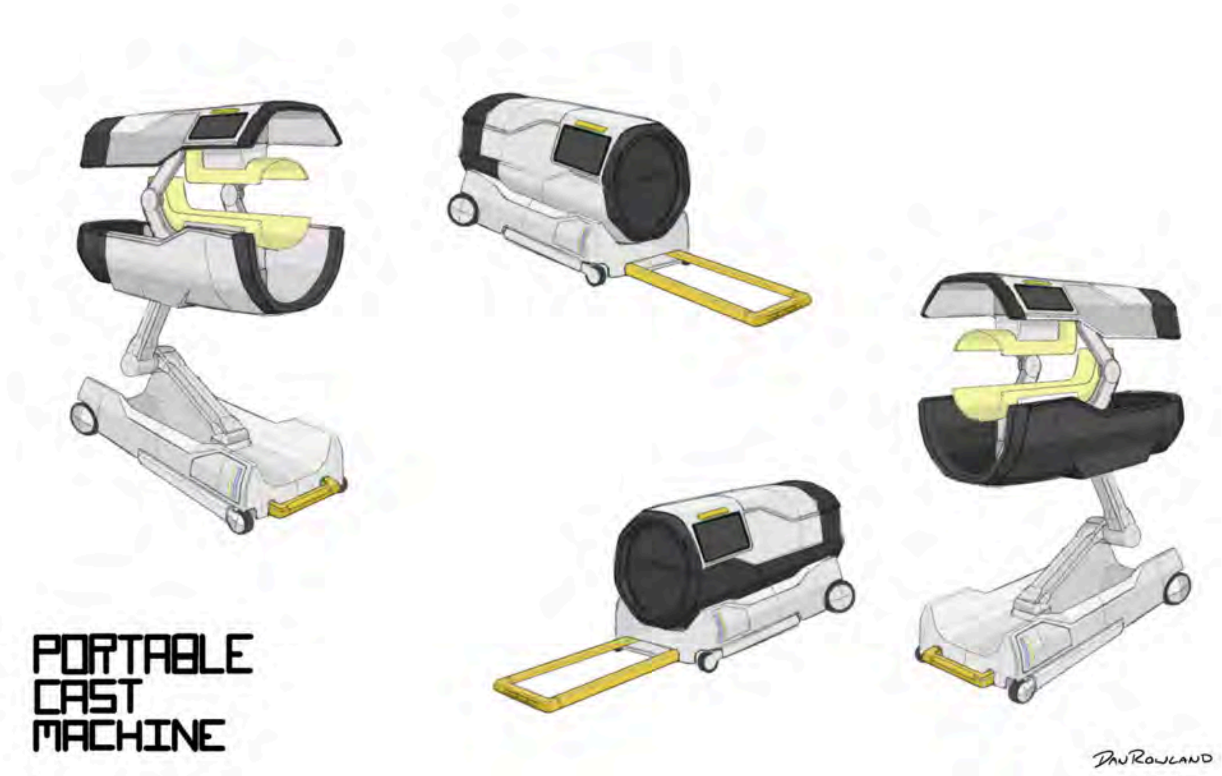


Figure 42: Design Finalization: Color way exploration

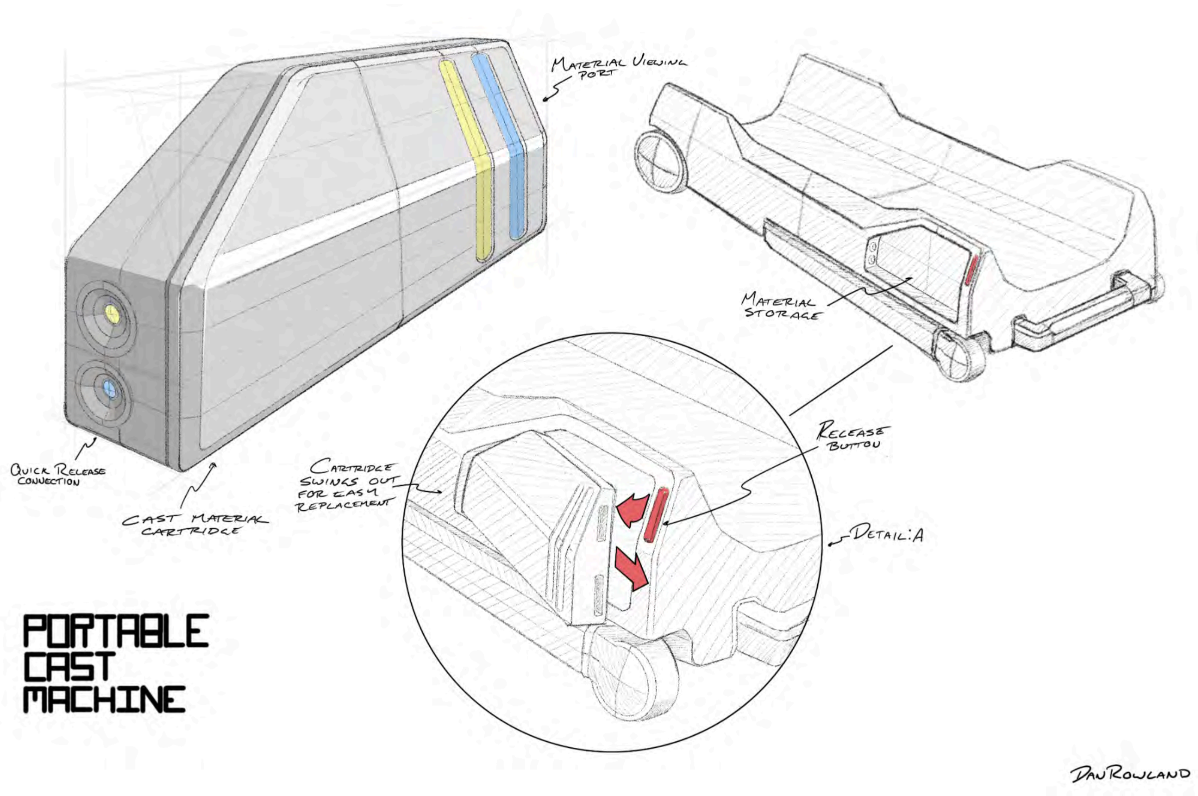


Figure 43: Design Finalization: Material Canister

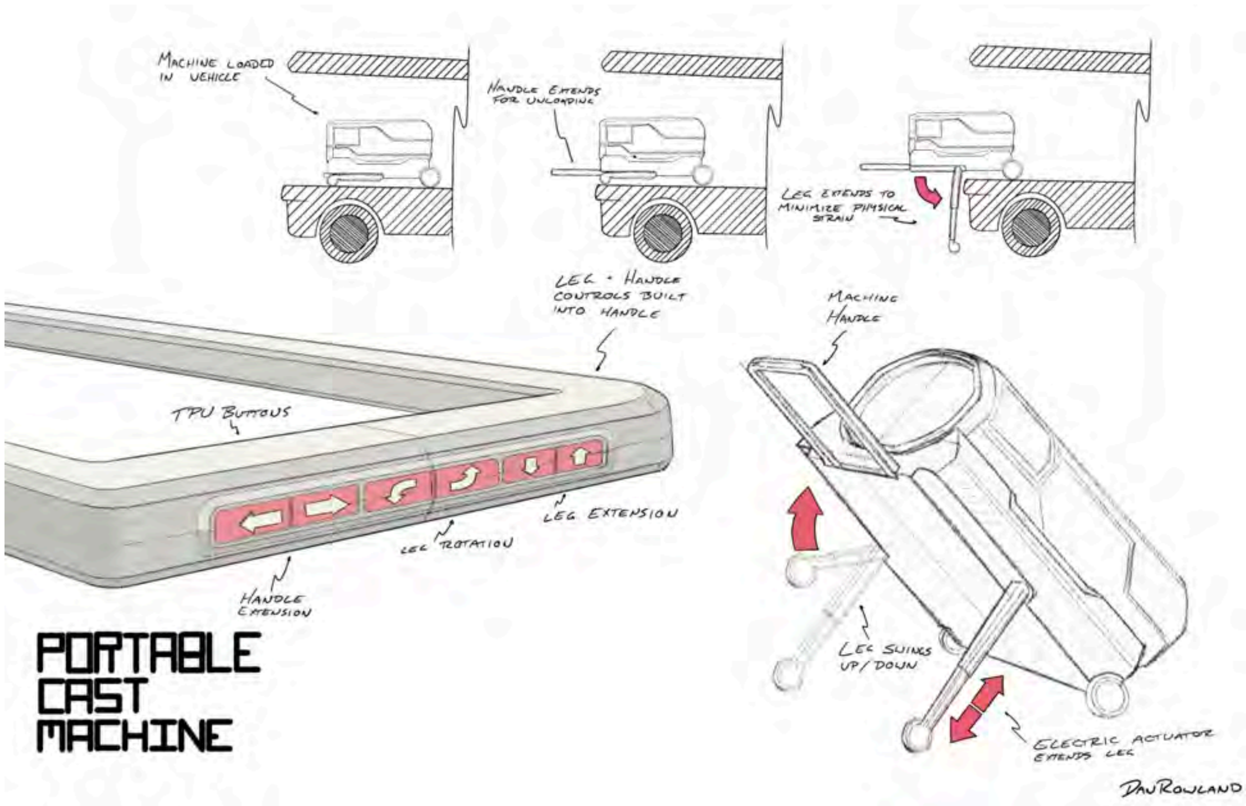


Figure 44: Design Finalization: Handle Controls

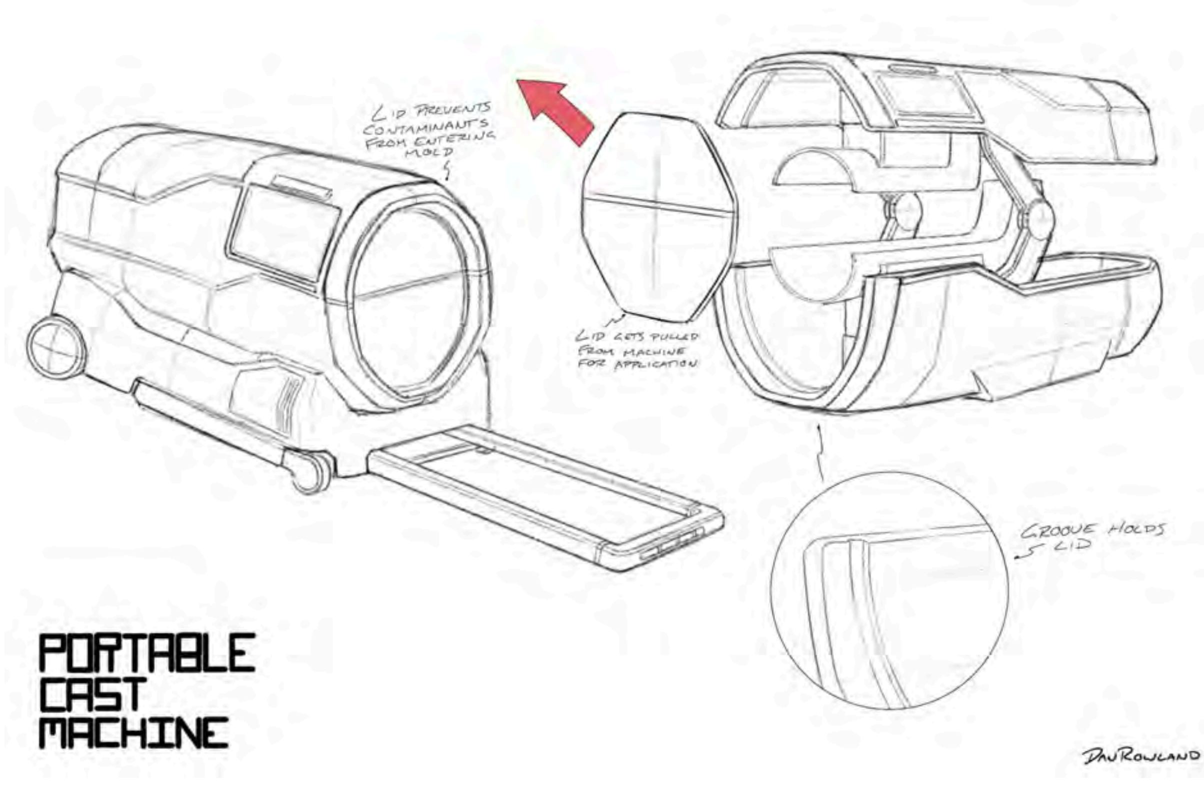


Figure 45: Design Finalization: Travel Lid

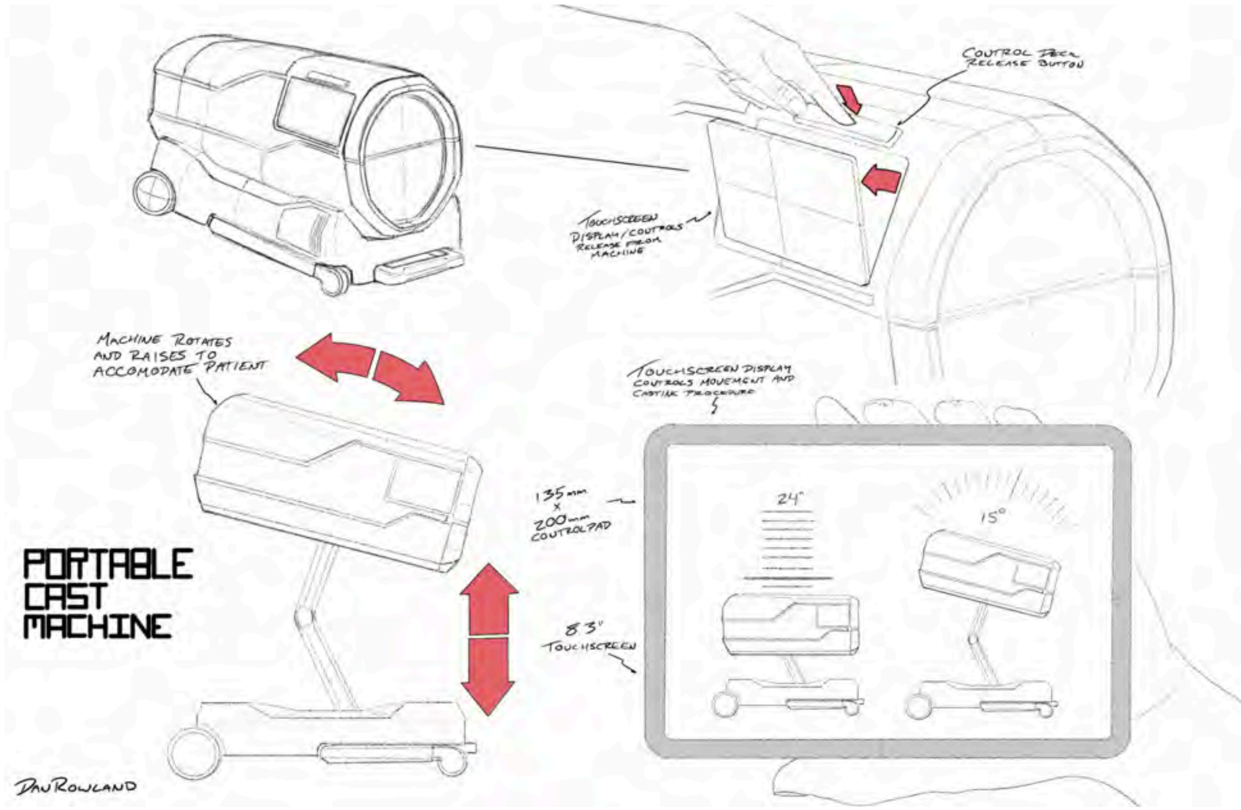


Figure 46: Design Finalization: Tablet Release

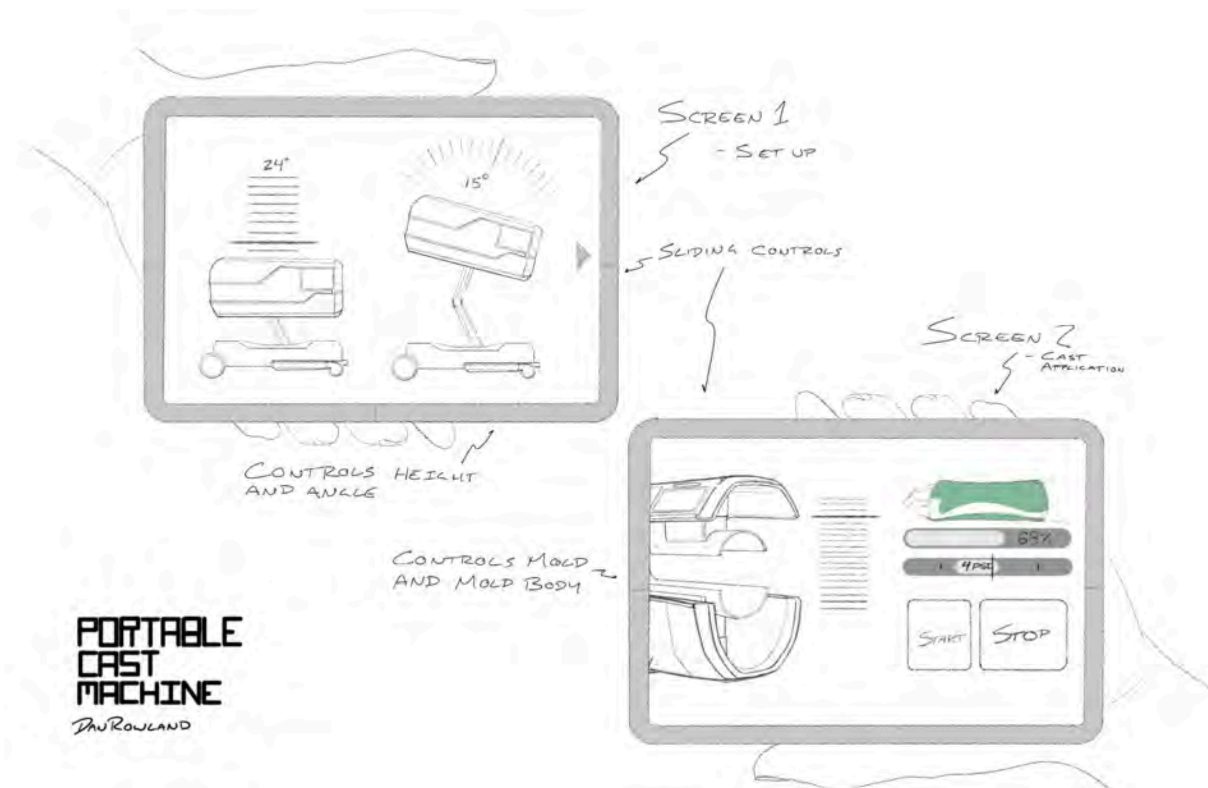


Figure 47: Design Finalization: Display 1 and 2

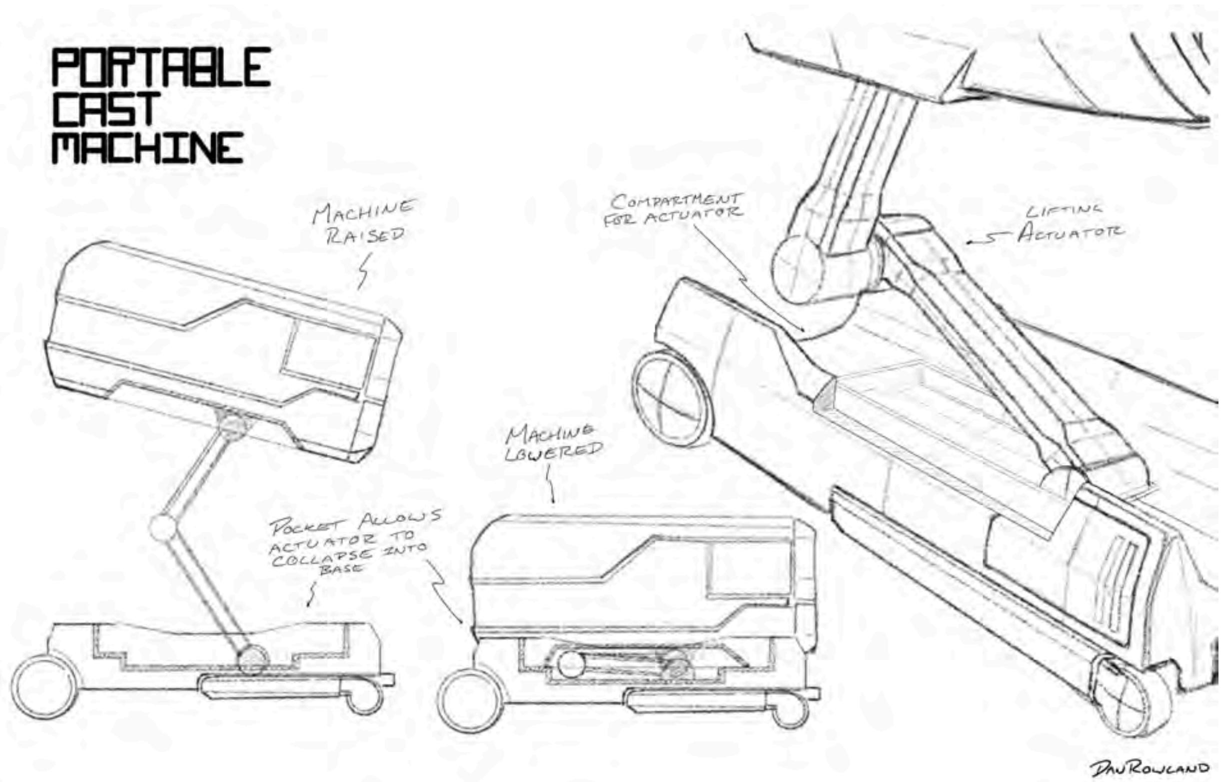


Figure 48: Design Finalization: Main Actuator

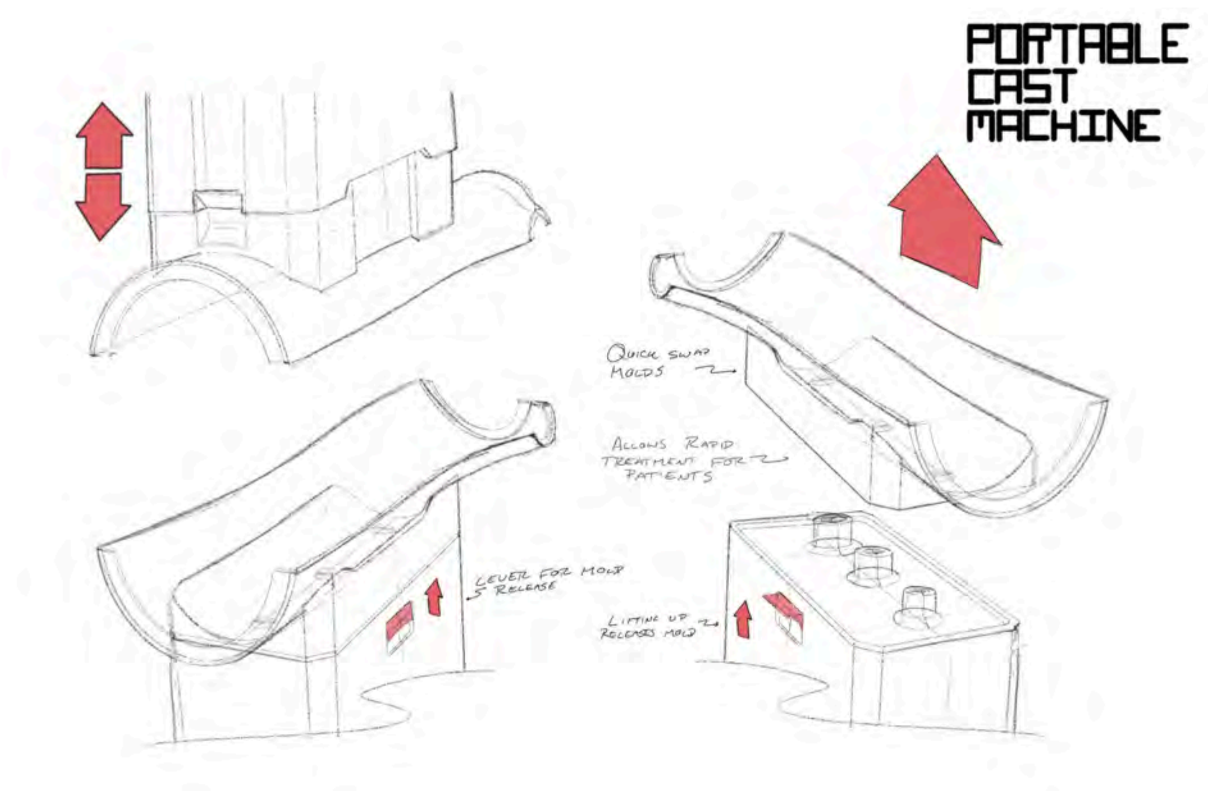


Figure 49: Design Finalization: Cast Mold Swap

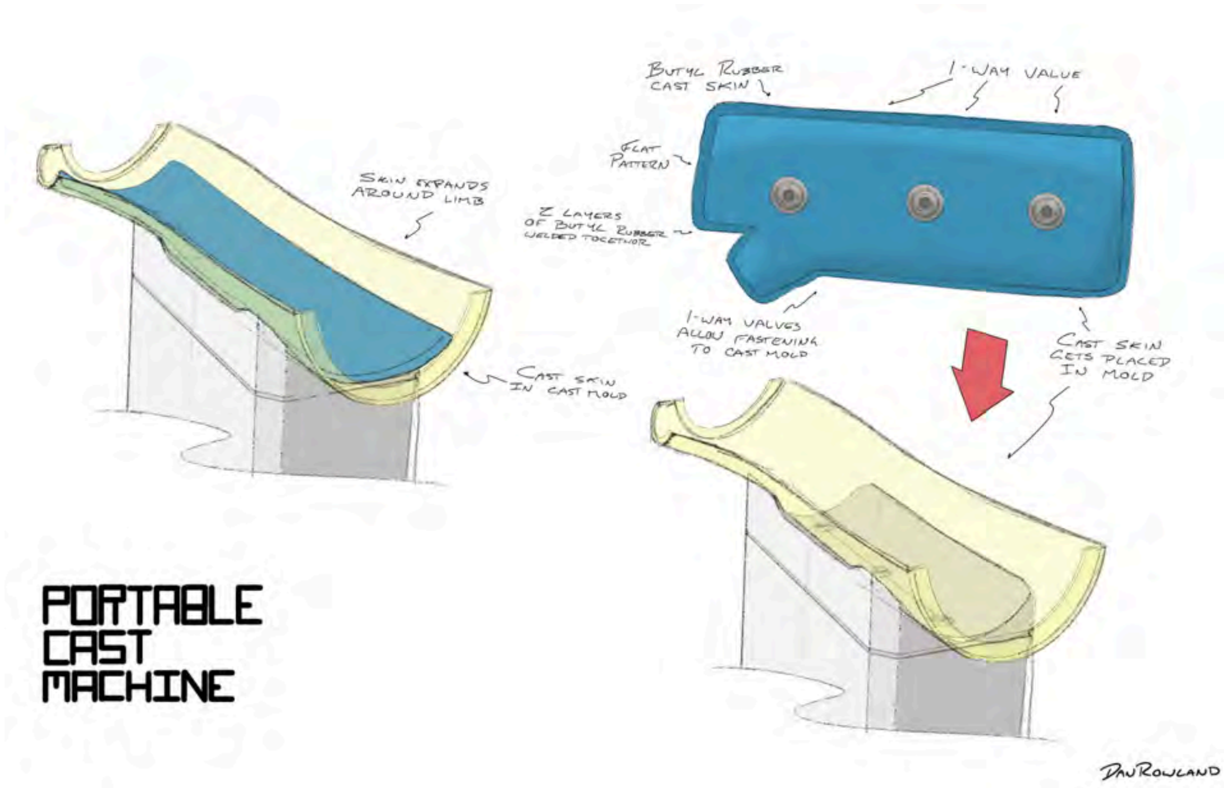


Figure 50: Design Finalization: Cast Liner

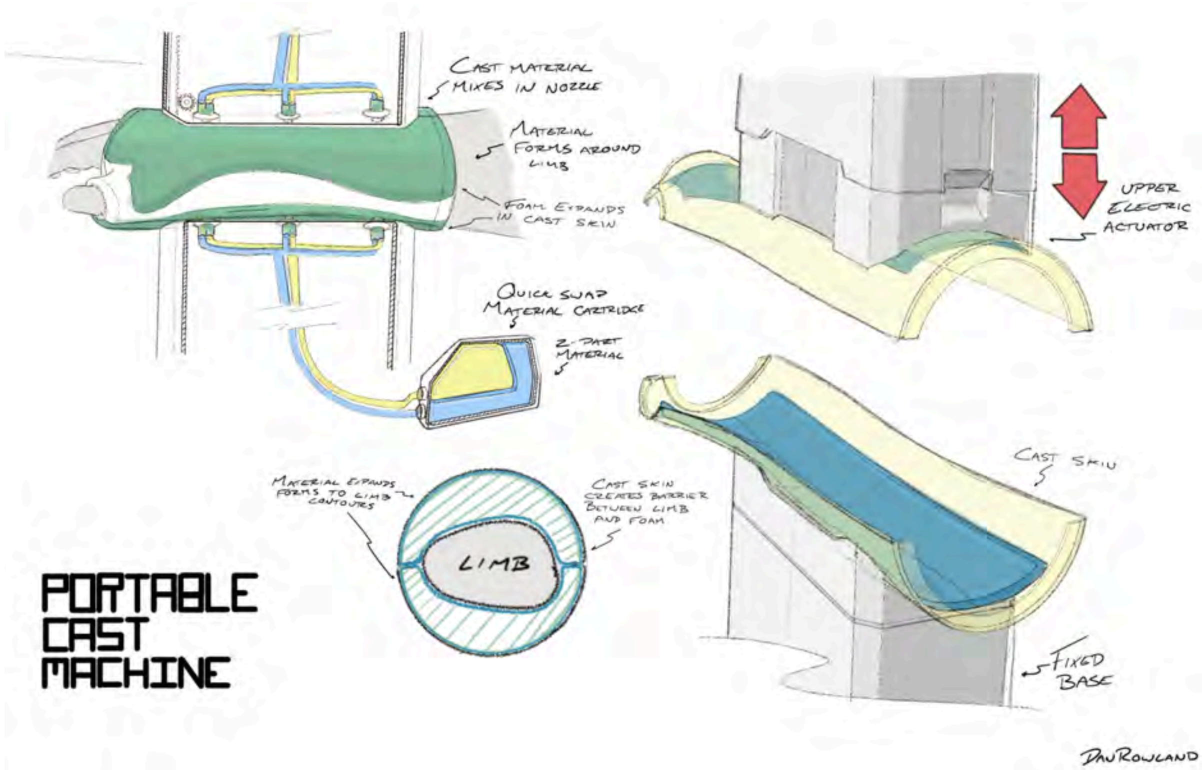


Figure 51: Design Finalization: Cast Application

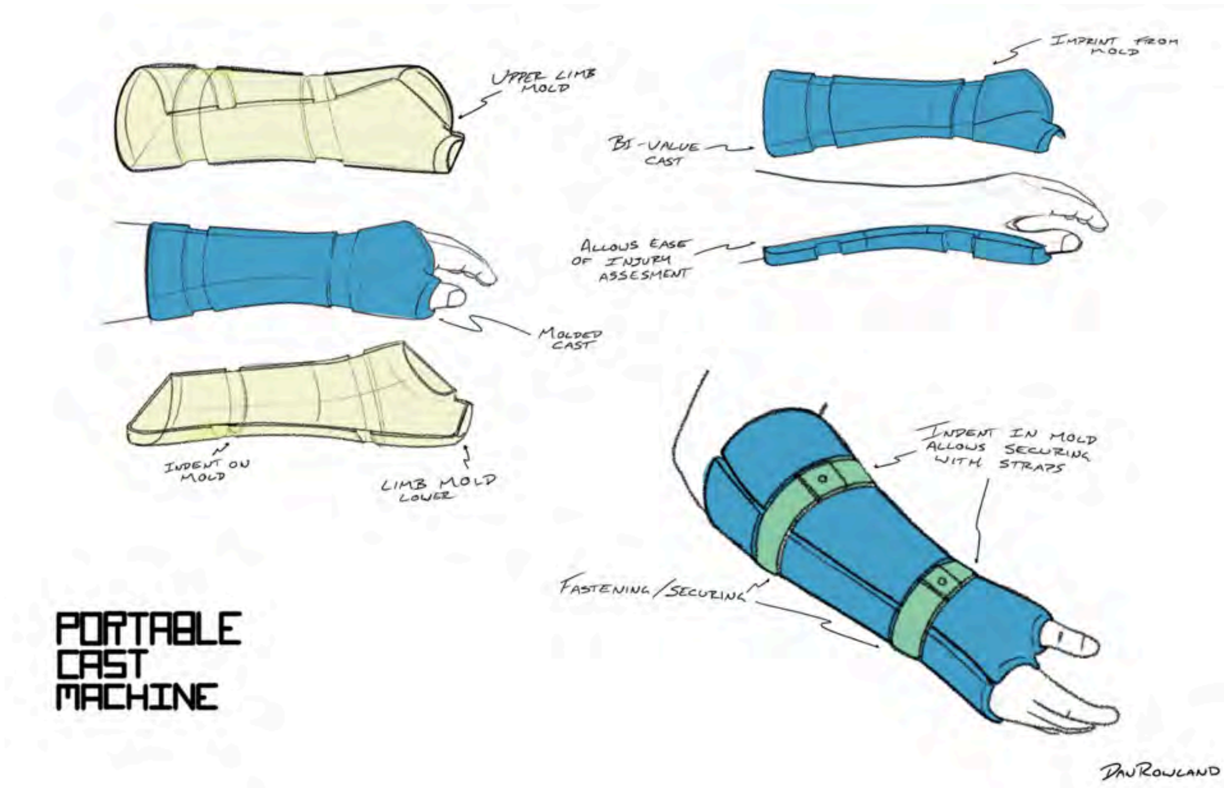


Figure 52: Design Finalization: Bi-Valve cast

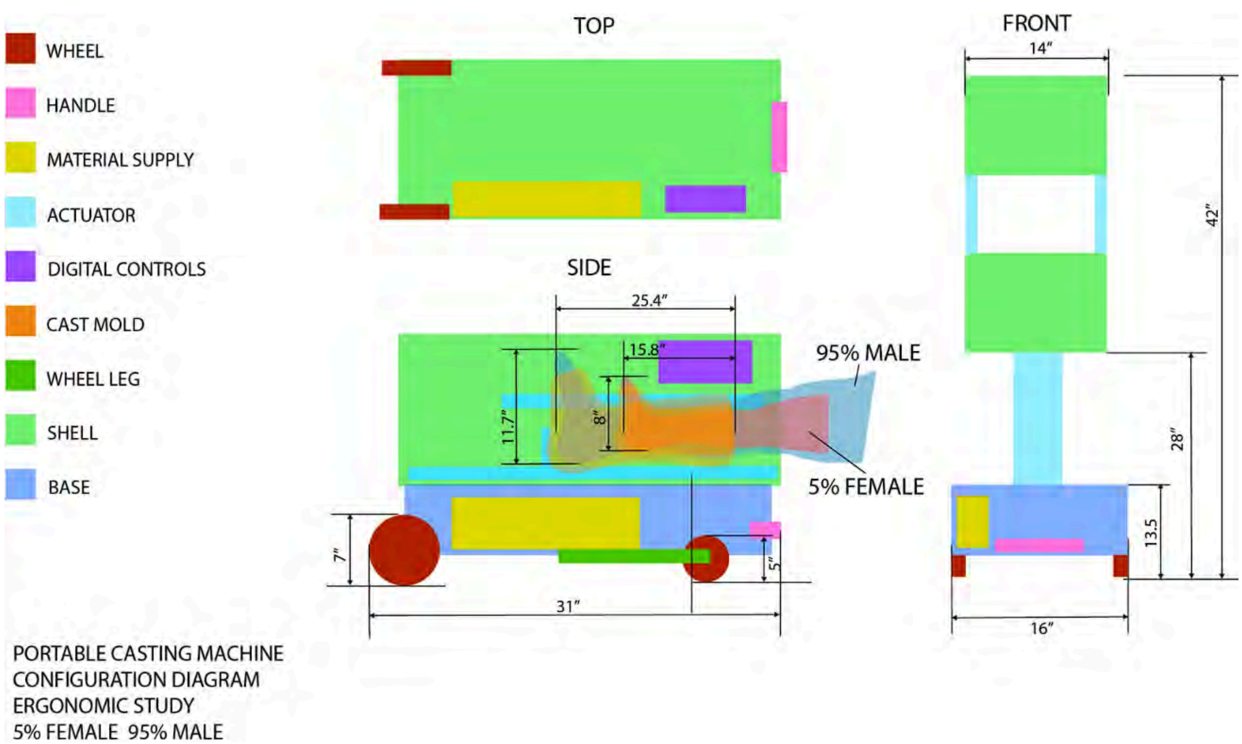
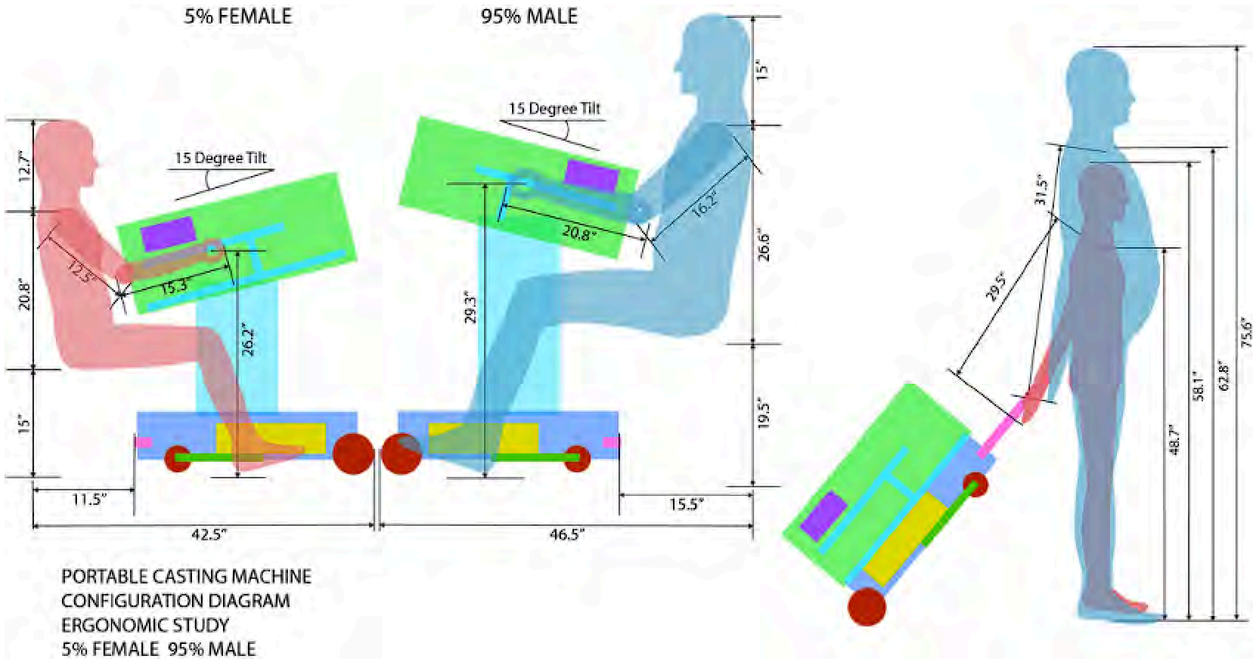


Figure 53: Design Finalization: Product Schematic



Figure

Figure 54: Design Finalization: Ergonomic Assesment

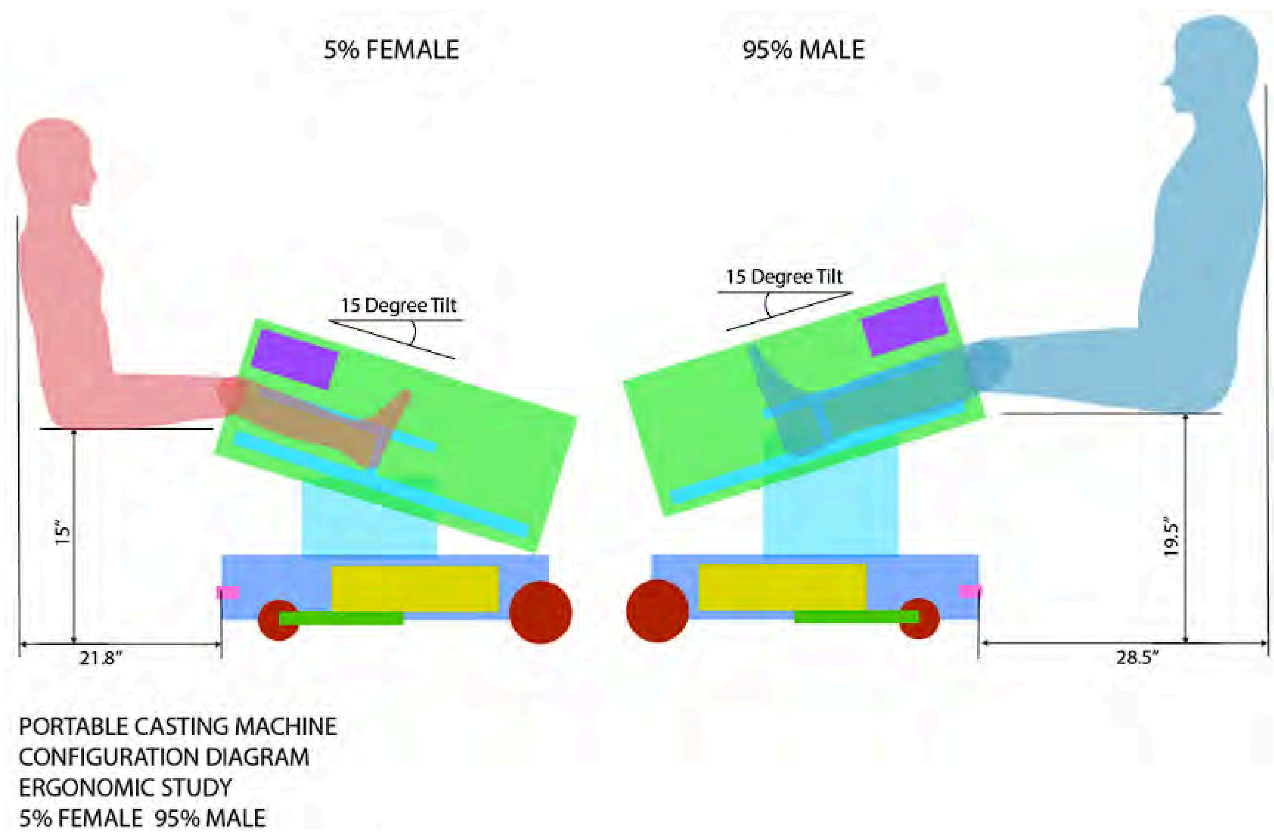


Figure 55: Design Finalization: Ergonomic Assesment

4.5.2 Physical Study Models

To fully understand the design finalization of the concept, a 1:1 scale model was created in CAD, this allowed the application of the measurements recorded in the ergonomic assessments and configuration diagram. This CAD model was then used to create a 1:4 scaled physical model in order to see the design operating outside of a computer and to analyse the fitment, placement, and operations of the overall concept. From this process, some issues were discovered with the button placement on the handle to control the support legs during transportation, the current placement could potential cause inputs to be pressed without the users intention. There was also some flaws found in the movement of the actuators making it difficult to keep the top and bottom cast molds aligned. Overall the model was a succes as it confirmed the stability of the machine and the range of motion needed for ergonomic position during cast application.

Figure 56: Physical Study Model: Portable

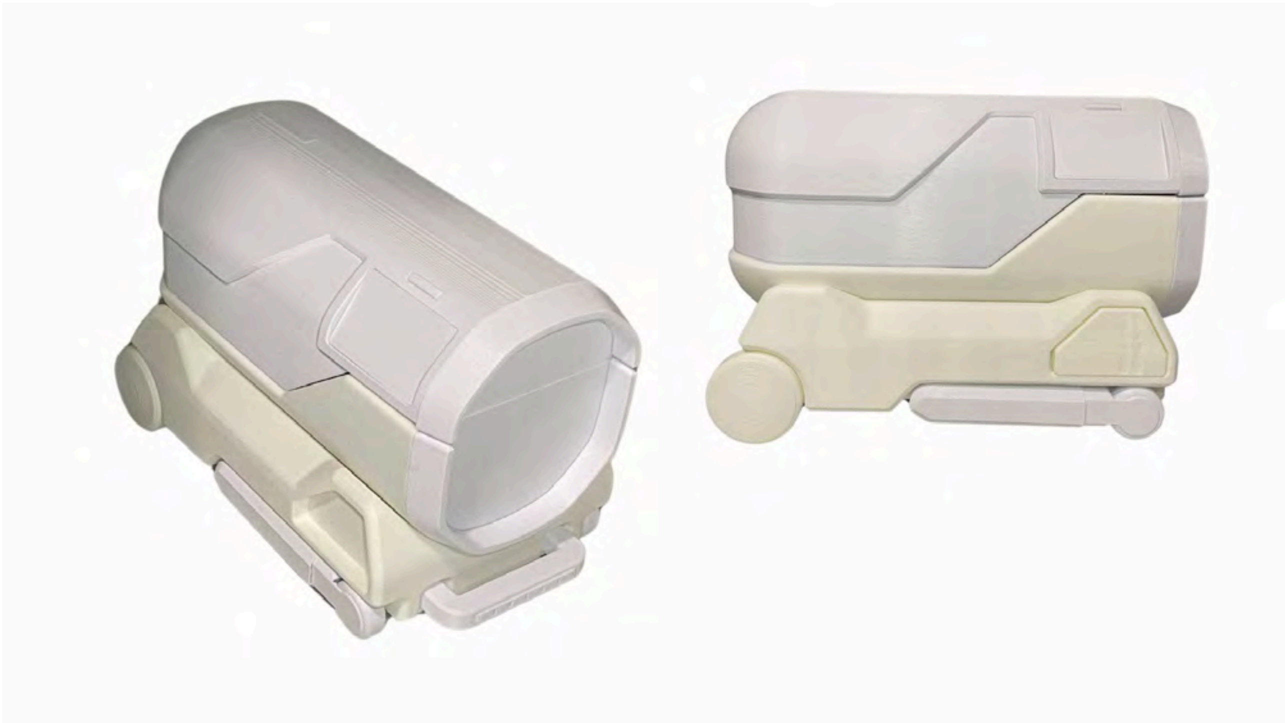


Figure 57: Physical Study Model: Closed

Figure 58: Physical Study Model: Extended

4.6 Design Resolution

From the design finalization stage, there were some edits to the design to improve either efficiency, comfort, or stylization. The main focus was on interaction points such as the display release tablet, the handle containing support leg controls, and the operation of the actuators. The actuators were designed to improve the strength through a steel core and thicker outer shell. The body actuators separating the main body were redesigned to open laterally rather than rotate open, this helps maintain alignment and accuracy during the application procedure. A redesign on the handle button layout was done to better position the interactions and prevent accidental inputs.

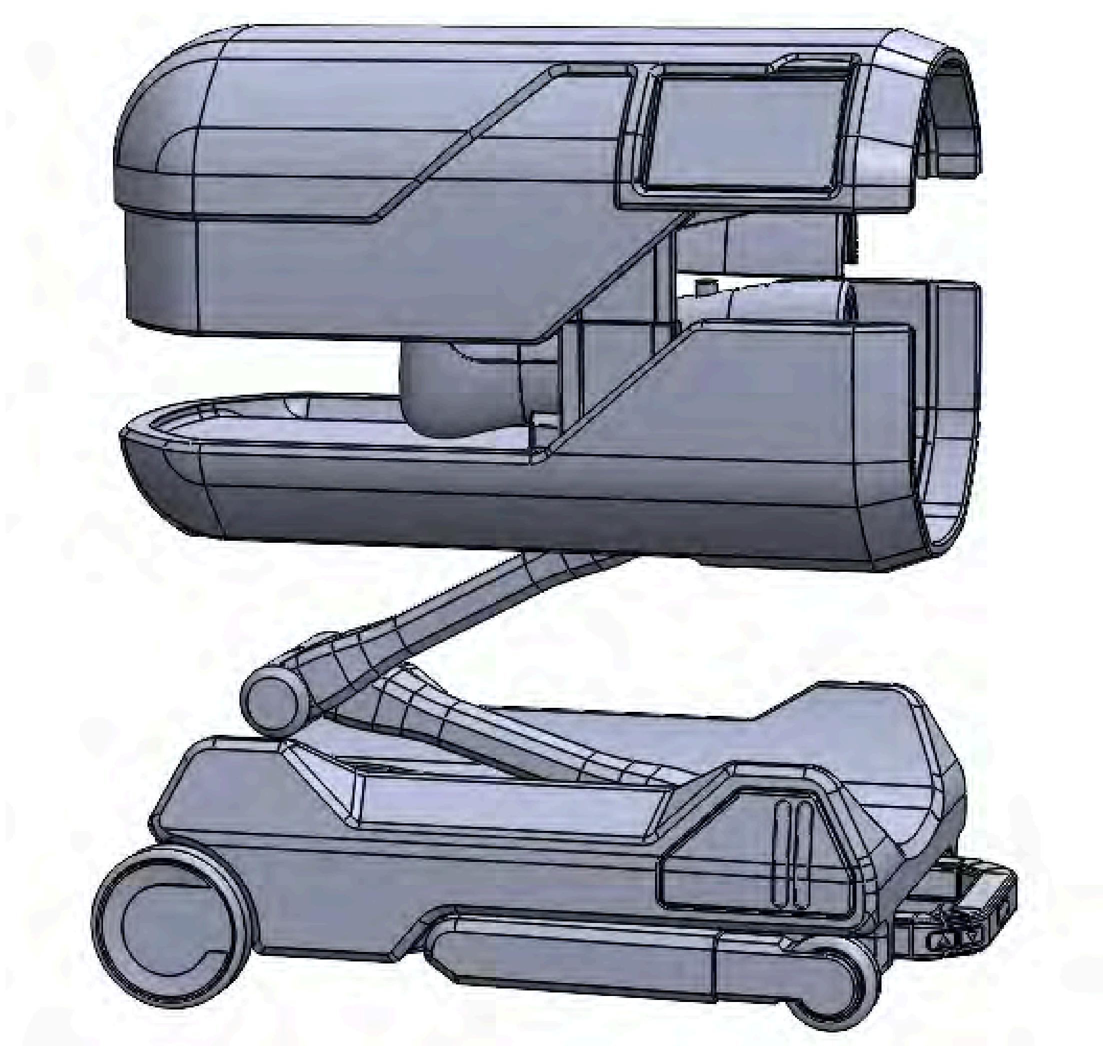


Figure 59: Design Resolution: Visual Consistany in Auto Cast

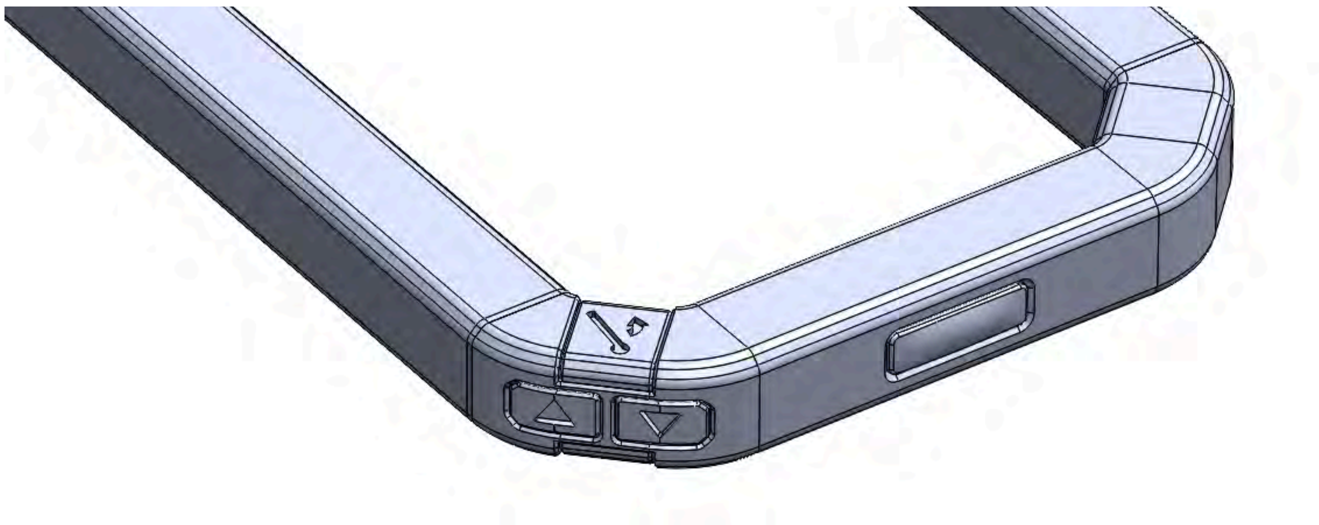


Figure 60: Design Resolution: Handle Controls

4.7 CAD Development

CAD development helped refine the concept to a successful and efficient product. CAD modeling of the concept took place over 2 months. Many revisions of the design and re-modeling of parts was necessary to better satisfy the needs of users involved. Created in Solidworks, it started with rough models to get the overall sizing and movement correct, then refining how each component acts when interacting with the rest of the model. The ergonomics and visuals were designed with high attention to detail inorder to create an efficient product. The components were designed separately in part files, then pulled together into an assembly to check fitment, movement, and ergonomics. This was necessary to confirm the treatment positioning and range of motion. Renders and decals were then done in Keyshot, the decals were initially designed in illustrator then place on the models as a texture.

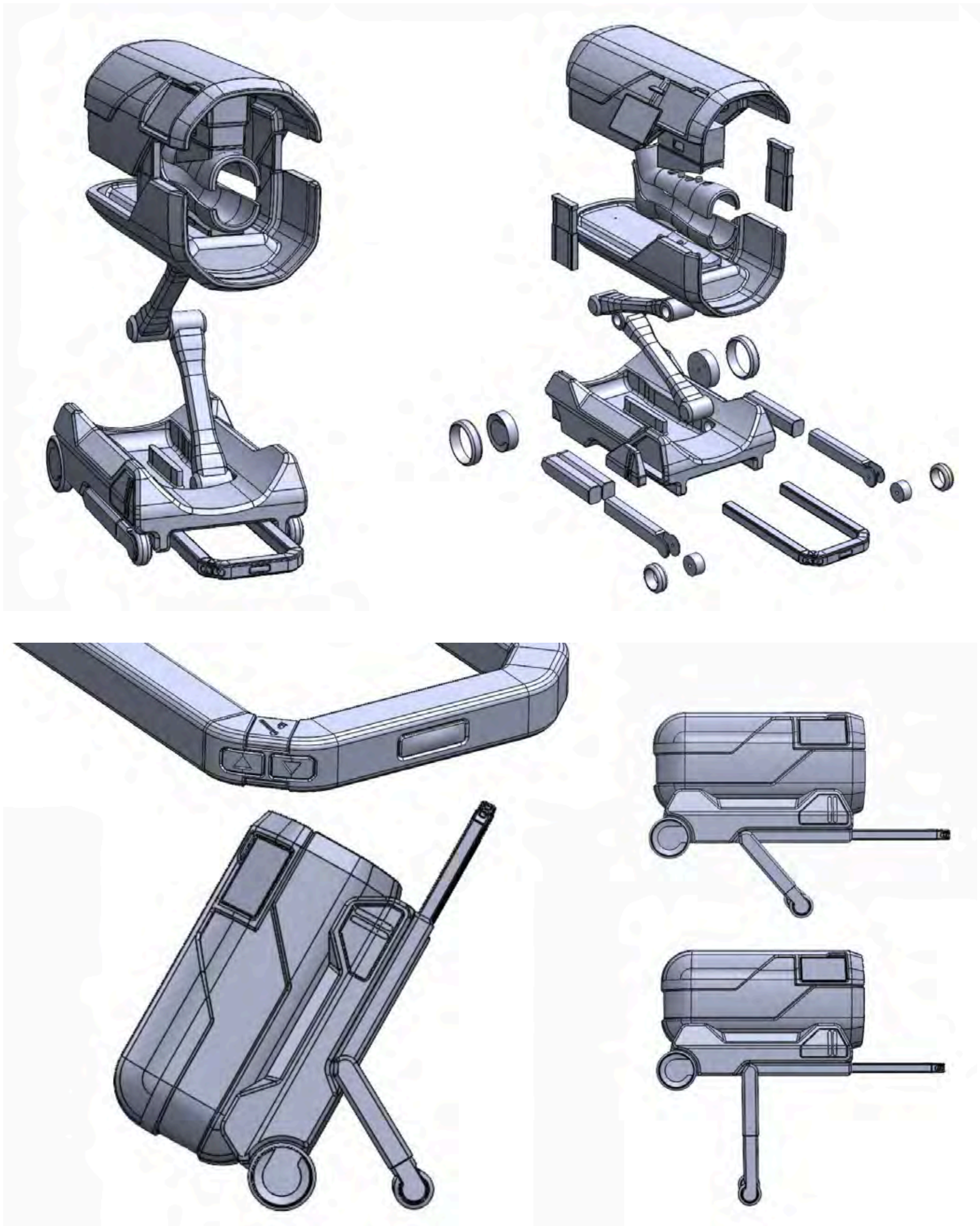


Figure 61: CAD Development: Extended, Exploded, Support Leg Positioning

Figure 62: CAD Development: Material Canister, Display Release, Auto Casting

Figure 63: CAD Development: Cast Mold, Cast Procedure, Bi-Valve Cast

4.8 Physical Model Fabrication

The completion of the CAD model allowed the start of physical model making. Two models were created to showcase the capabilities of the Auto Cast, one set to show the machines configuration during transport, and the second, a high quality accurate model to show the cast application procedure including a patient with their leg in the cast mold, and medical personnel using the touchscreen display. To complete this, the first model was printed on a FDM printer in PLA, the parts were then sanded and primed to improve the quality of the surfaces. From there the model was configured to showcase the portability of the product. The second model was SLA printed in resin by Agile Manufacturing. Parts were sanded with varying grits from 220 to 600 to get a smooth surface finish, from there the parts were primed, and masked depending on whether the component has a 2-tone color way. Parts were then painted in there respective color with the cast molds only receiving a clear coat to maintain the transparency of the resin. Decals were printed on a matte transparent vinyl using an online sticker service, than applied after assembly of the components.

Figure 64: Physical Model Fabrication: Printed Parts, Sanding, Painting, Masking

Figure 65: Physical Model Fabrication: Parts Ready for Assembly, Decals Applied

05
FINAL DESIGN

5.1 Design Summary

The Auto Cast project addresses a critical gap in rural healthcare: the lack of accessible, and effective orthopedic care. In these areas, patients often travel great distances for treatment, which leads to delays and increased risk of complications. Traditional plaster or fiberglass casting methods, while effective, require specific skills and often cause discomfort, impacting patient recovery.

The Auto Cast is a portable, automatic casting device designed for resource-limited rural settings. It enables healthcare providers without specialized orthopedic training to accurately and efficiently apply casts. This innovation significantly improves patient comfort by providing lightweight, waterproof casts, reducing treatment times and complications. By simplifying the casting process and making advanced casting materials and technology more accessible, the Auto Casr aims to improve treatment outcomes in rural areas, promoting health equity.

5.2 Design Criteria Met

5.2.1 Full Bodied Interaction Design

Full bodied interaction design requires three touchpoint or more to be considered successful. The design of the Auto Cast fulfills this by incorporating ease of positiong allowing users to set up the Auto Cast to the patient rather than move the patient to the product. The touchscreen display in **figure 66,** used by medical personnel during set up allows using the range of motion from the main actuators for ergonomic positioning, allowing patients from 95% male to 5% female to comfortably be treated. The cast mold was designed to be easily swappable to allow the treatment of a large range of users by utilizing a S/M/L mold for both the arm and leg, the cast molds then allow perfect fitment of an orthopedic cast.

Transport requires users to interact with the Auto Cast in a few ways, the main body must first be locked in place using the display tablet once treatment is completed. Users then extend the handle similar to a suitcase, where they can then use the built in handle controls to operate the support legs, reducing the stress on the user when loading / unloading the Auto Cast.

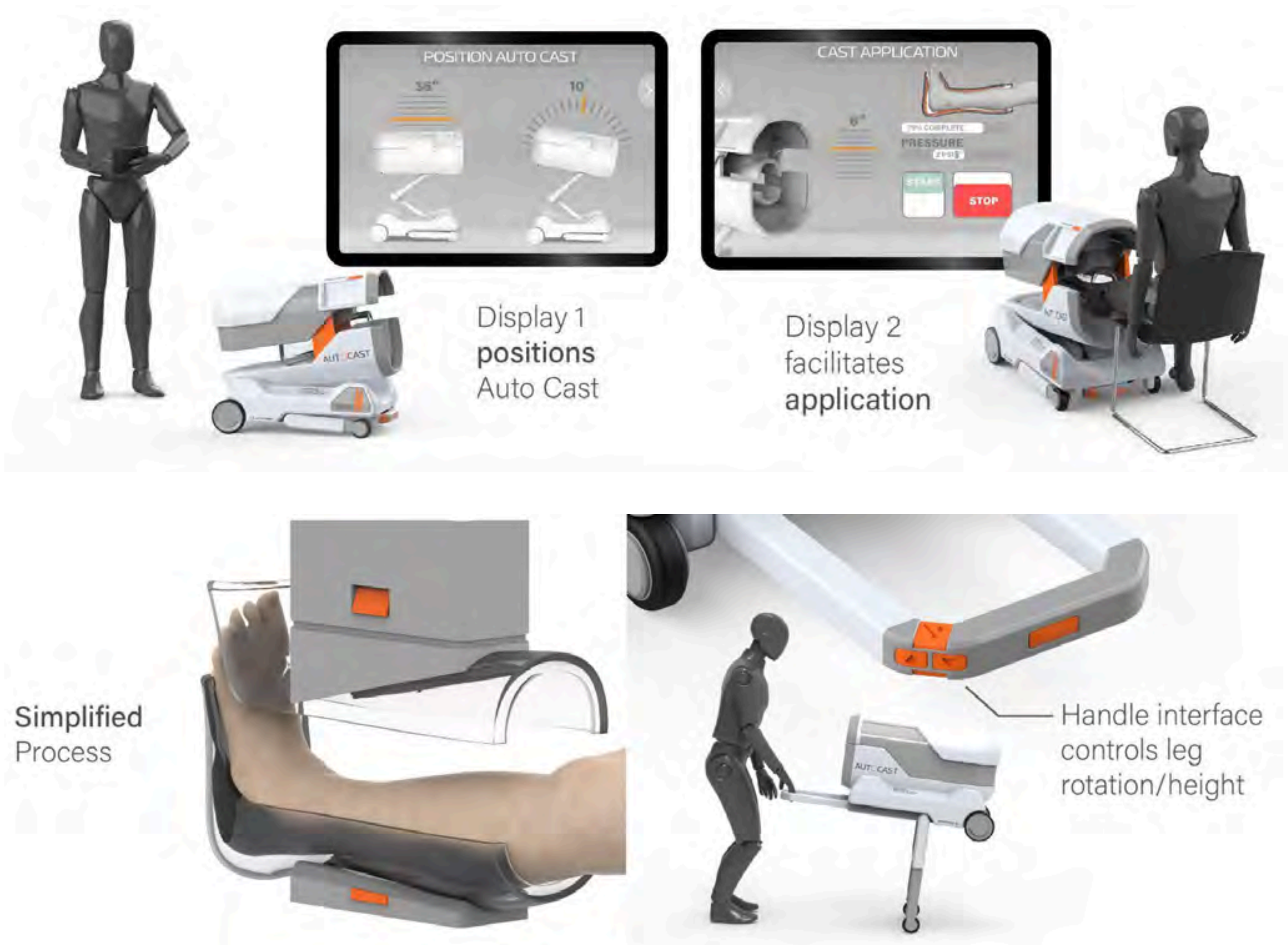


Figure 66: Human Interaction Design

5.2.2 Materials, Processes and Technology

This section details the materials and manufacturing methods utilized in the design of the Auto Cast. The overall design was focused on durable materials and reparable components in order to reduce waste throughout the product's lifecycle.

The main body, base, and many smaller components are made from injection molded ABS due to its high strength and chemical resistance, this is a key factor as medical equipment is subjected to a high cycle of decontamination and cleaning. The actuators are encased in ABS and reinforced with steel cores to add rigidity and strength to the mechanism, reducing movement during cast application. The cast molds are manufactured from a high strength poly carbonate, this allows repeated applications as the molds undergo stress from the expansion process, repeated stress on weaker materials may cause warping, requiring a high strength composite.

The material used in the casting process is a closed-cell, rigid polyurethane expanding foam. The reaction is a result of mixing an isocyanate and a polyol blend, the nature of the reaction is exothermic meaning it creates heat during the process, however, the temperature is comparable to that of a traditional plaster or fiberglass cast application. The material is stored in a quick-connect canister where it is fed into the cast liner within the molds. The cast liner then expands uniformly around the patients limb creating a perfect fit and improving comfort over traditional materials.

5.2.3 Design Implementation

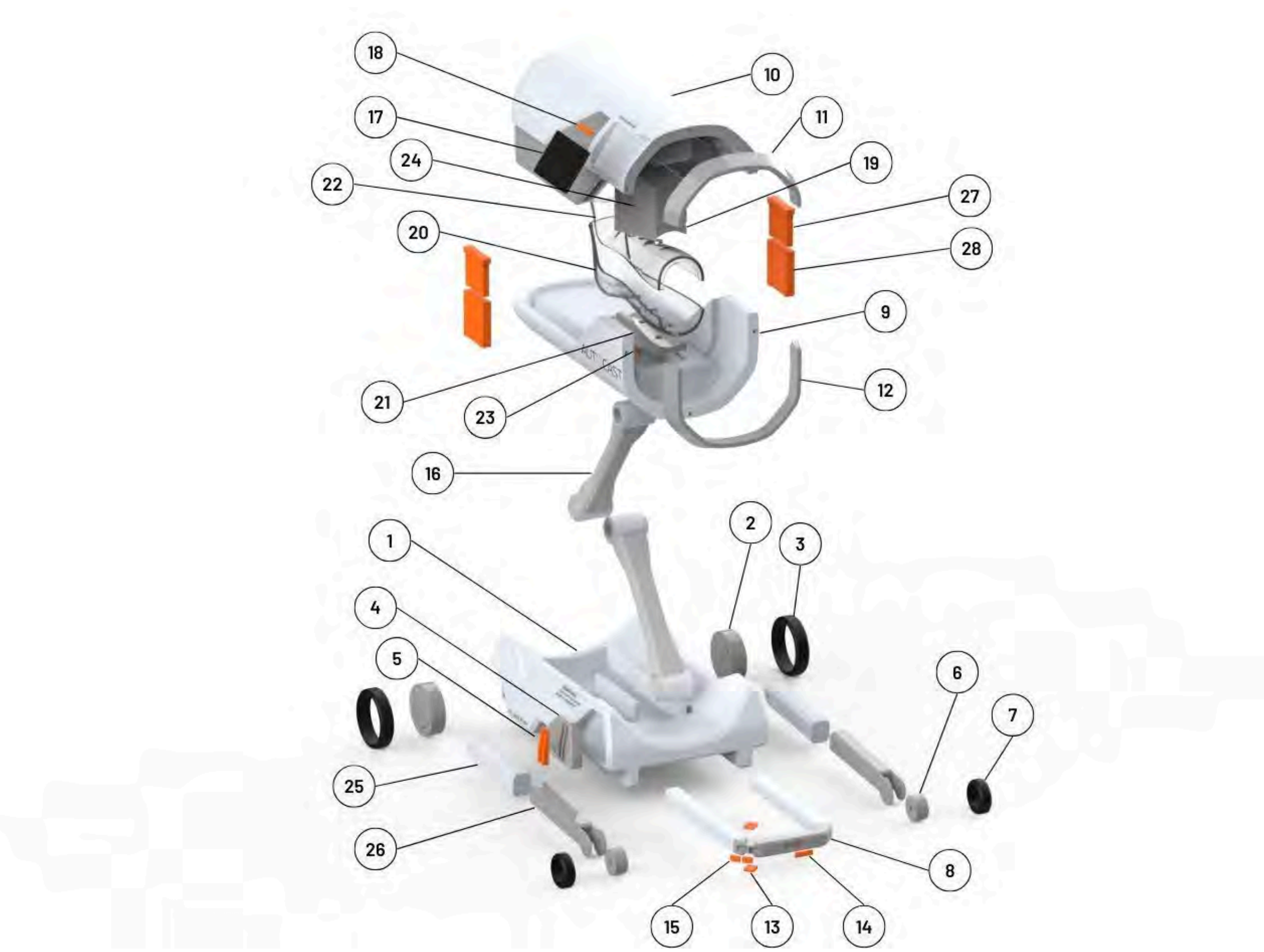


Figure 67: Design Implementation: Exploded View

Item #	Description	Material	Manufacturing	Quantity
1	CM - Base	ABS	Injection Molding	1
2	CM - Rear Wheel	ABS	Injection Molding	2
3	CM - Rear Tire	TPU	Injection Molding	2
4	CM - Material Canister	ABS / Aluminum	Injection Molding / Stamping	1
5	CM - Material Canister - Window	Polycarbonate	Injection Molding	2
6	CM - Front Wheel	ABS	Injection Molding	2
7	CM - Front Tire	TPU	Injection Molding	2
8	CM - Base - Handle	ABS / Steel	Injection Molding / Extrusion	1
9	CM - Main Body - Bottom	ABS / Steel	Injection Molding / Stamping / Welding	1
10	CM - Main Body - Top	ABS	Injection Molding	1
11	CM - Main Body - Cap - Top	ABS	Injection Molding	1
12	CM - Main Body - Cap - Bottom	ABS	Injection Molding	1
13	CM - Base - Handle - Rotate Button	TPU	Injection Molding	1
14	CM - Base - Handle - Release Button	TPU	Injection Molding	2
15	CM - Base - Handle - Height Button	TPU	Injection Molding	2
16	CM - Actuator	ABS / Steel	Injection Molding / Stamping / Welding	2
17	CM - Display Tablet	Aluminum / Glass	Various	1
18	CM - Main Body - Release Button	TPU	Injection Molding	1
19	CM - Top Mold - Actuator	ABS / Steel	Injection Molding / Stamping / Welding	1
20	CM - Bottom Mold	Polycarbonate	Injection Molding	1
21	CM - Bottom Mold - Mounting Block	ABS	Injection Molding	1

22	CM - Top Mold	Polycarbonate	Injection Molding	1
23	CM - Bottom Mold - Button	TPU	Injection Molding	2
24	CM - Top Mold - Button	TPU	Injection Molding	2
25	CM - Base - Support Leg - Leg Shaft	ABS / Steel	Injection Molding / Stamping / Welding	2
26	CM - Base - Support Leg	ABS / Steel	Injection Molding / Stamping / Welding	2
27	Linear Actuator	ABS / Steel	Injection Molding / Stamping / Welding	2
28	Linear Actuator - Inner Lift	ABS / Steel	Injection Molding / Stamping / Welding	2

Table 2: Bill of Materials

5.3 Final CAD Rendering

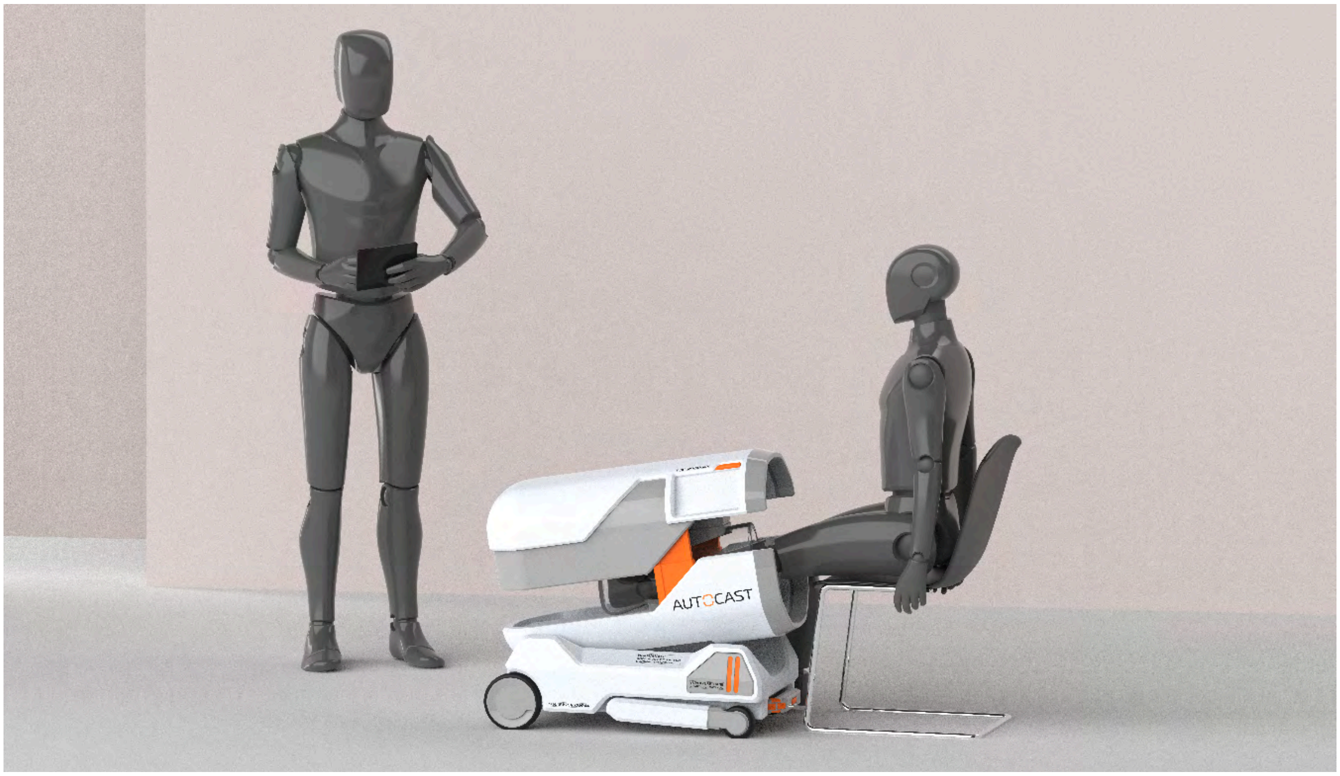


Figure 68: Final CAD Rendering: Hero Shot

Figure 69: Final CAD Rendering: Extended and Exploded

Figure 70: Final CAD Rendering: Handle, Transport Mode

Figure 71: Final CAD Rendering: Display Release, Mold + Cast Liners

Figure 72: Final CAD Rendering:Automatic Cast Applicaiton, Material Expanding around patients limb.

Figure 73: Final CAD Rendering: Quick Connect Material Canister

5.4 Physical Model

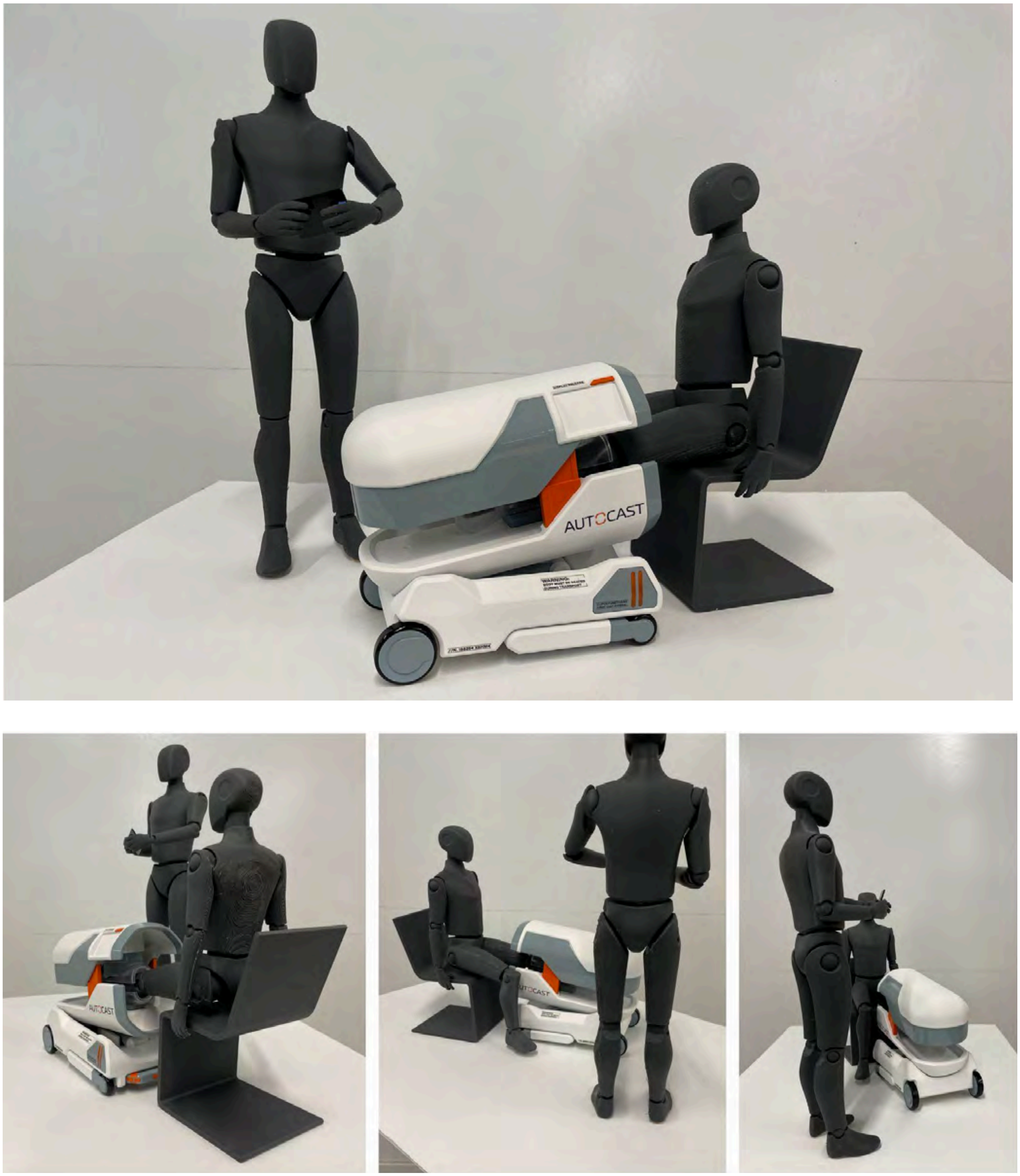


Figure 74:Physical Model: Front, Right, Rear, and Left Images

Figure 75: Physical Model: Cast Application Procedure, Display Tablet

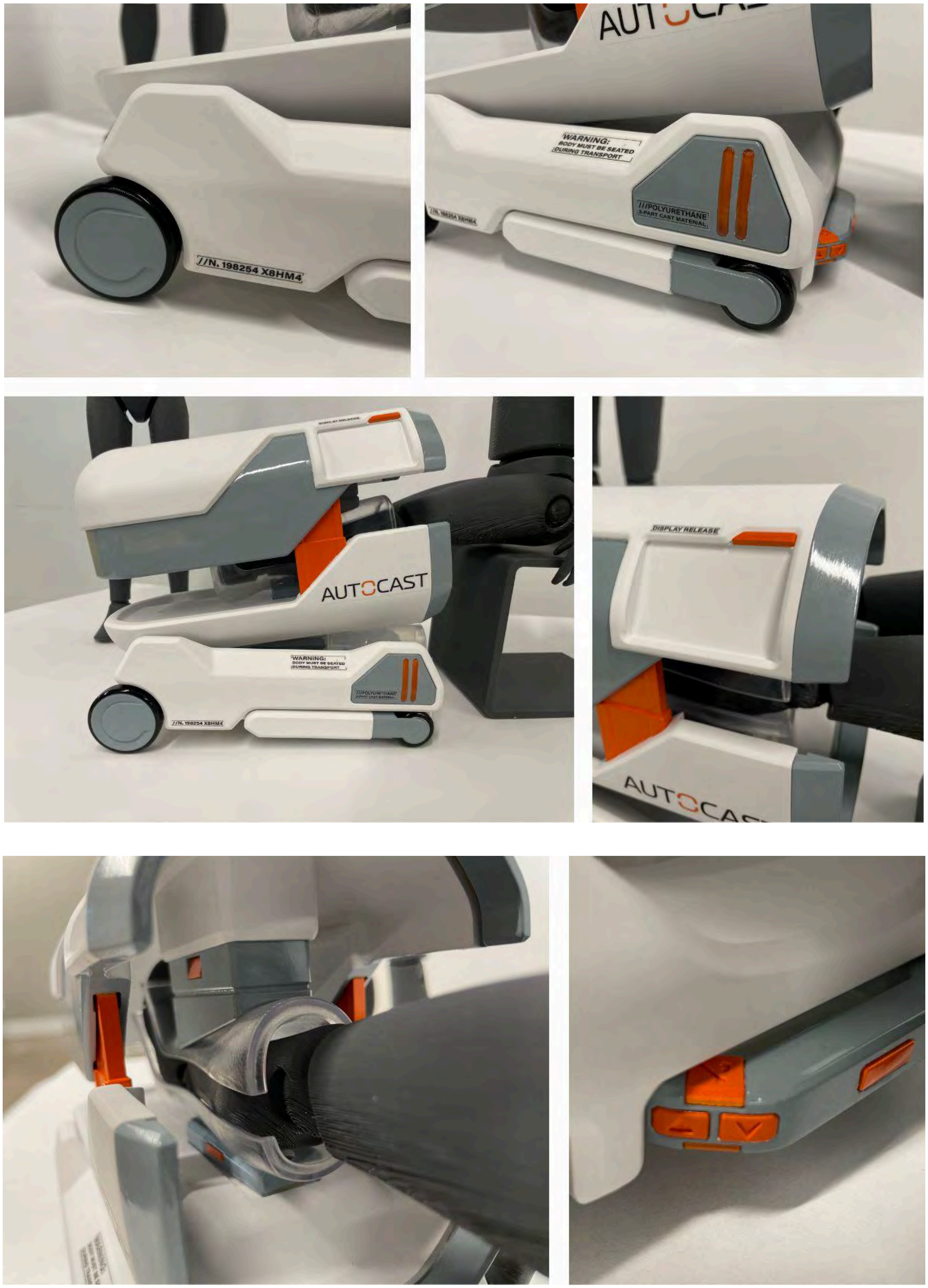


Figure 76: Physical Model: Decals + Details

Figure 77: Physical Model: Extra Model to Showcase Transportation Mode

5.5 Technical Drawings

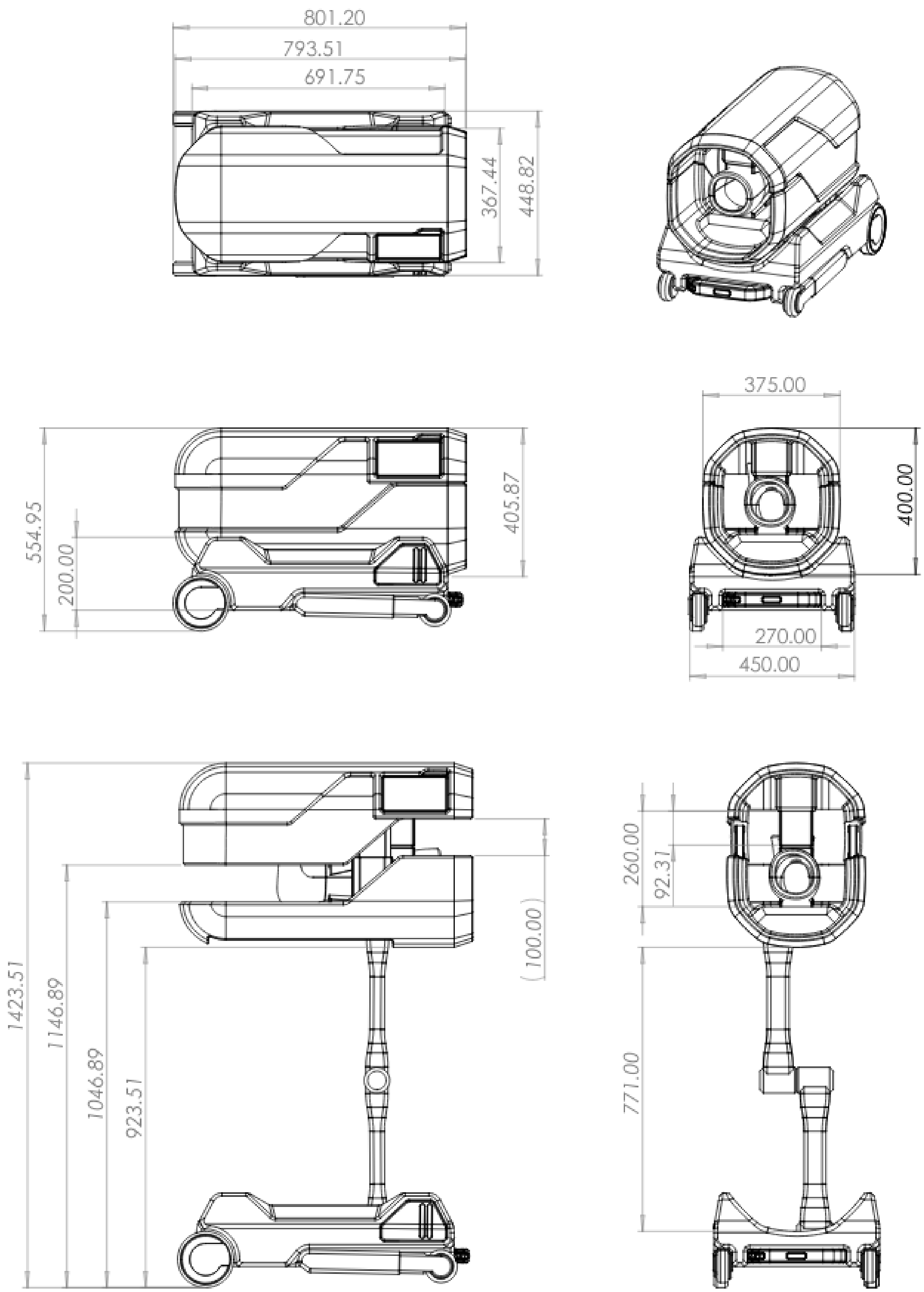


Figure 78: Technical Drawings: Closed, Extended Measurements

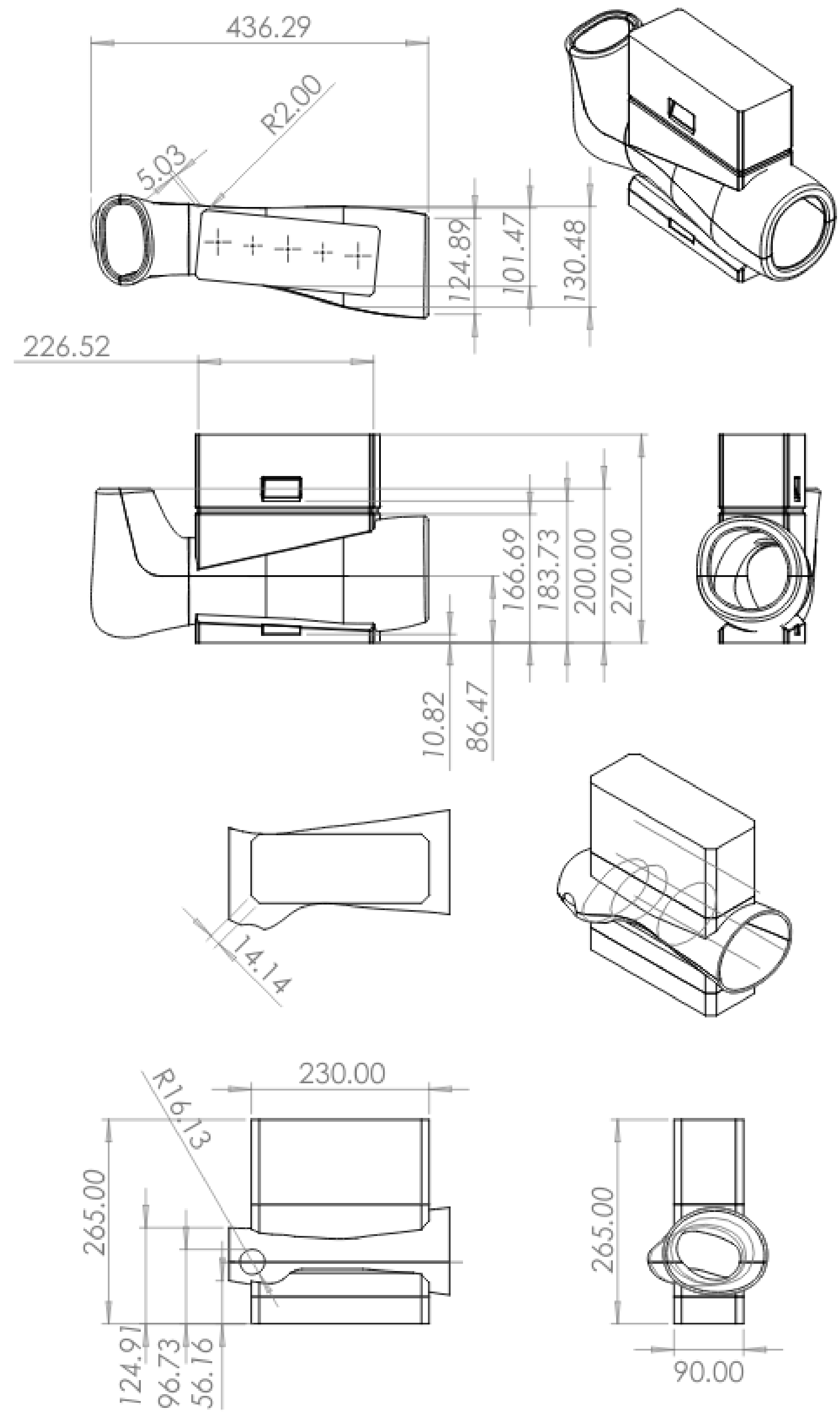


Figure 78: Technical Drawings: Arm and Leg Molds

5.6 Sustainability

The Auto Cast aims to incorporate sustainability in orthopedic care through utilizing responsible material use and manufacturing processes. For the casts themselves, polyurethane foam is selected for its light weight and rigidity, offering an alternative to traditional casting materials. This choice not only enhances patient comfort, but also aligns with efforts to reduce environmental impact. The Auto Cast design contributes to the reduction of single-use plastics, a common issue with the packaging of traditional casting methods. By minimizing reliance on such materials, the Auto Cast aids in decreasing plastic waste.

In terms of manufacturing, the Auto Cast uses manufacturing processes that emphasize efficiency and reduce waste production. Durable materials are used in its construction, and the design includes replaceable parts to extend the product's lifecycle. This approach not only reduces waste at the end of the product's life but also aligns with sustainable manufacturing practices.

Furthermore, the Auto Cast aligns with U.N. Sustainable Development Goals 3 (Good Health and Well-being) and 10 (Reduced Inequalities). Its design and implementation increase access to affordable healthcare in underserved areas, addressing global inequalities in health services. By providing a cost-effective, sustainable solution for orthopedic care, the Auto Cast contributes to improving health outcomes and reducing disparities in healthcare access.

06 CONCLUSION

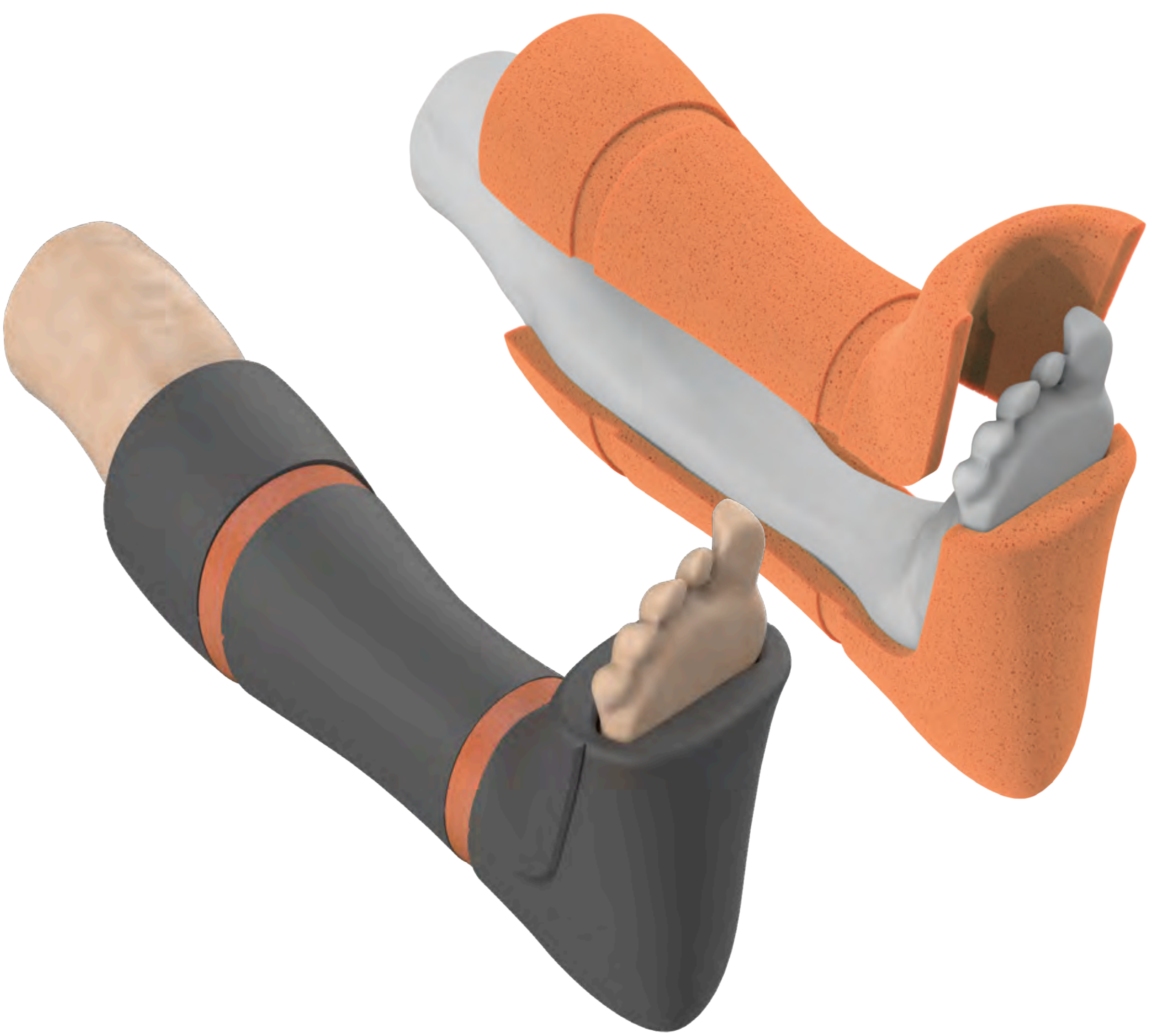


Figure 79: Conclusion: Cast Application Render

The Auto Cast project addresses the challenges associated with traditional orthopedic treatments in rural settings, where limited medical facilities and the scarcity of specialists create delays in receiving timely and appropriate care. This innovation not only fulfills the need for enhanced patient comfort and environmental sustainability but also crucially improves access to orthopedic care in underserved areas. The design of the Auto Cast uses polyurethane foam, for its lightweight, rigidity, and ability to automatically form to a patient's limb. This reduces discomfort and allows patients to continue with daily activities, supporting quicker recovery times. The waterproof properties of the cast liner further prevent typical complications associated with cast wear.

Recognizing the challenges in rural areas, such as long travel times to medical centers and a lack of specialist care, the Auto Cast offers a portable, automatic casting device that enables a broader range of healthcare providers, not just specialists, to apply casts accurately and efficiently. This capability is critical in resource-scarce settings, ensuring that quality care can be delivered rapidly, reducing the likelihood of delayed healing and treatment complications.

By facilitating easier and more precise cast application, the Auto Cast reduces the dependency on traditional casting techniques that require specific training and are often cumbersome. Its ease of use, facilitated by a touchscreen interface and intuitive controls, allows healthcare providers to administer treatment with minimal training. The system's portability is beneficial in rural settings, where it can be transported to patients who cannot easily travel to healthcare facilities, effectively bringing the treatment to the patient.

The sustainable design of the Auto Cast, featuring materials that minimize environmental impact and replaceable parts that extend the product's lifecycle, aligns with global sustainability goals. Enhancing access to effective care in underserved regions, the Auto Cast supports health equity, aligning with the U.N. Sustainable Development Goals related to good health and reduced inequalities.

The Auto Cast system successfully addresses the initial project goals by offering an innovative, practical, and effective solution to orthopedic care challenges, particularly in rural and resource-limited environments. It improves patient outcomes, facilitates access to care, and promotes sustainability in medical practic.

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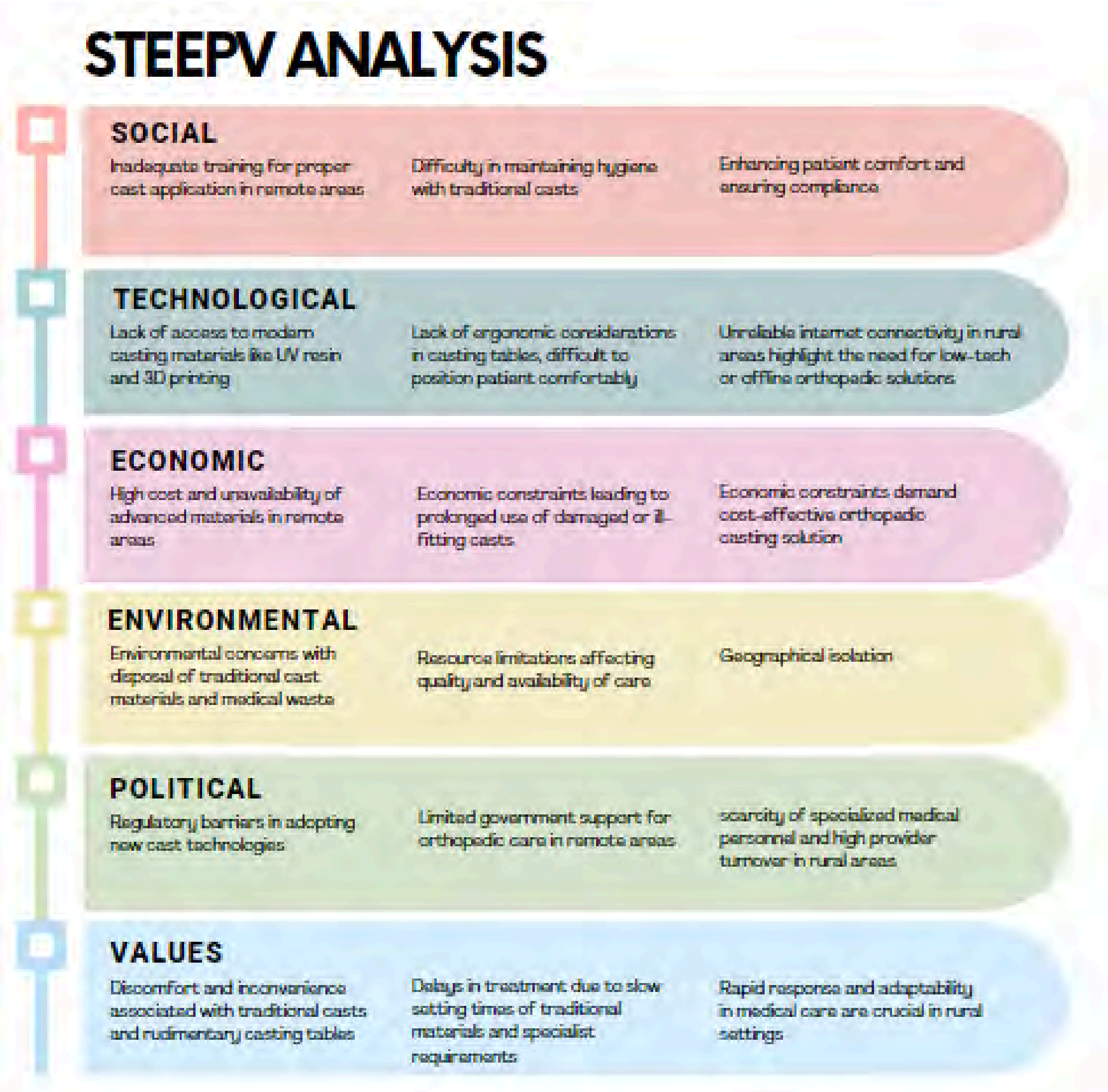
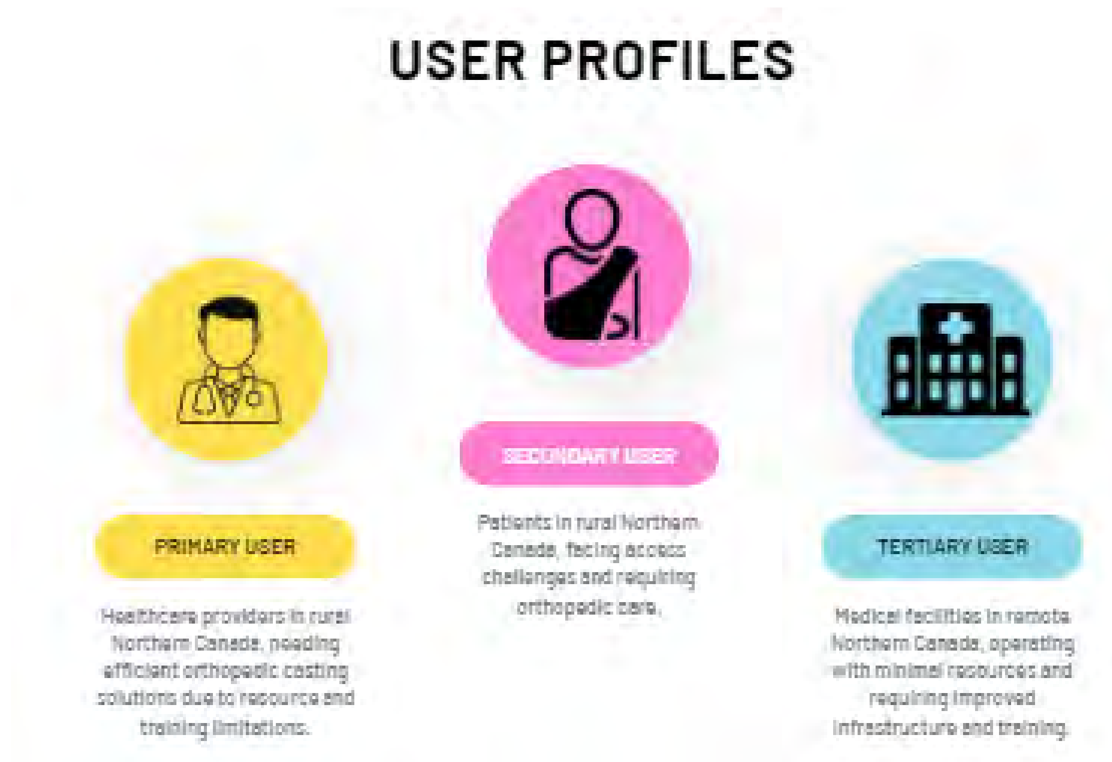
Appendix A – Discovery

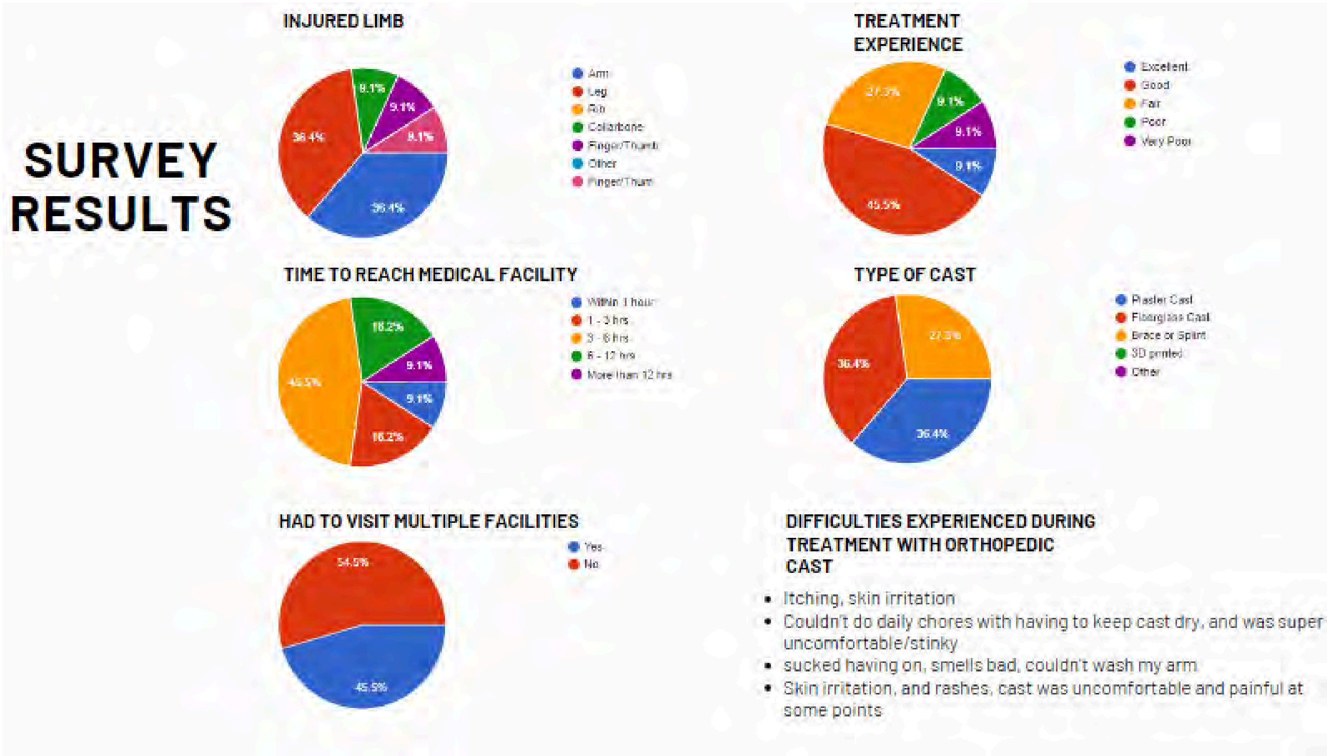


Source	Description
PubMed	Provides data and studies on various healthcare topics,

	including rural orthopedics and the impact of health system factors on physician burnout in northern Canada.
Battelle Blog	Discusses sustainability in medical device design, focusing on orthopedic devices.
CMAJ	Covers healthcare challenges in rural areas, particularly in northern Canada.
Nature	Articles on innovations in healthcare technologies, including the use of 3D printing in orthopedic treatments.
ODT Magazine	Offers insights into the design of orthopedic devices for additive manufacturing.
BMC Health Services Research	Analyzes healthcare accessibility and the challenges faced by healthcare providers in remote areas, especially in northern Canada.
Digital Health at Brown University	Provides information on portable diagnostics and their application in rural healthcare.
Rural Health Information Hub	Focuses on telehealth usage in rural healthcare settings.
Crimson Publishers	Discusses remote rehabilitation and its significance in overloaded healthcare systems.
Hindawi	Presents research on the application of 3D-printed orthopedic casts for the treatment of forearm fractures.
MSD Manuals	Offers practical guidance on orthopedic procedures like casting.

Appendix B – Contextual Research




SURVEY RESULTS
INJURED LIMB
Arm
Leg
Rib
Collarbone
Finger/Thumb
Other
36.4%
36.4%
9.1%
9.1%
9.1%
TREATMENT EXPERIENCE
Excellent
Good
Fair
Poor
Very Poor
27.3%
45.5%
9.1%
9.1%
9.1%
TIME TO REACH MEDICAL FACILITY
Within 1 hour
1 - 3 hrs
3 - 6 hrs
6 - 12 hrs
More than 12 hrs
45.5%
18.2%
18.2%
9.1%
9.1%
TYPE OF CAST
Plaster Cast
Fiberglass Cast
Brace or Splint
3D printed
Other
36.4%
36.4%
27.3%
HAD TO VISIT MULTIPLE FACILITIES
Yes
No
54.5%
45.5%
DIFFICULTIES EXPERIENCED DURING TREATMENT WITH ORTHOPEDIC CAST
• Itching, skin irritation
• Couldn't do daily chores with having to keep cast dry, and was super uncomfortable/stinky
• sucked having on, smells bad, couldn't wash my arm
• Skin irritation, and rashes, cast was uncomfortable and painful at some points


Dan, I've tried and wanted to leave you a few inspiration/references, but am having issue with Canva, is there any other way we could communicate so that I could share a few things from time to time?
_CC

Appendix C – Approval Forms and Plans

THESIS TOPIC APPROVAL

Bachelor of Industrial Design / FALL 2023

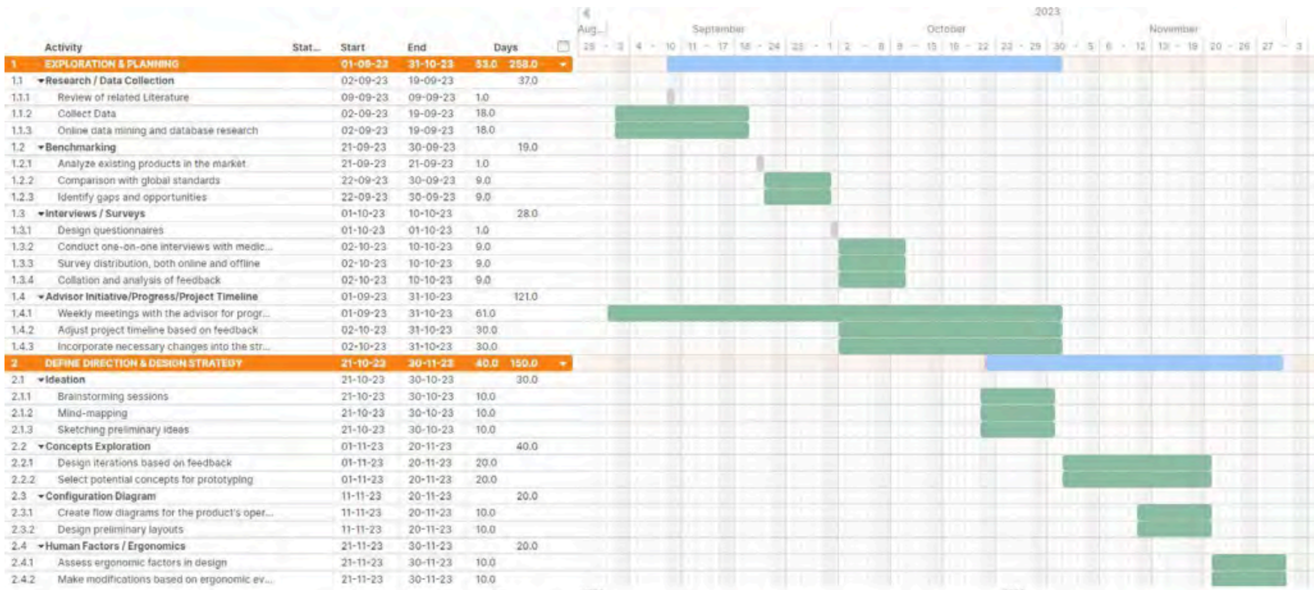
Student Name:	Daniel Rowland
Topic Title:	How might we improve accesibility to orthopedic casts in remote areas.

TOPIC DESCRIPTIVE SUMMARY (PRELIMINARY ABSTRACT)

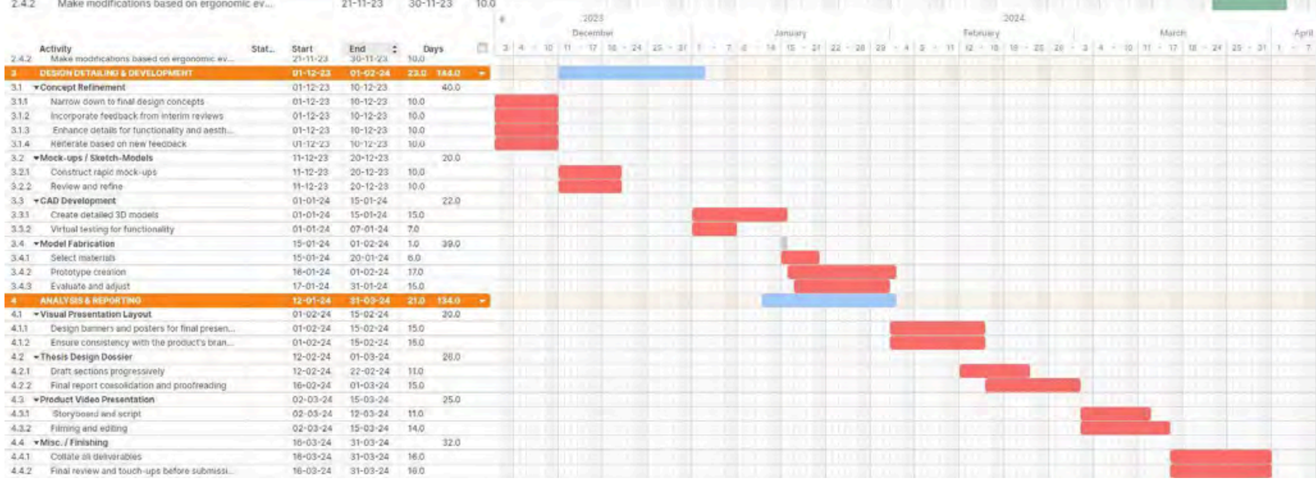
According to the Journal of the American Academy of Orthopedic Surgeons data, half of the world's population lacks adequate primary health care, and two thirds lack access to orthopedic care. This thesis seeks to increase access to orthopedic casts, emphasizing accessibility and proper application in rural areas. The rural population, constituting half of the global population, often travel long distances to access rudimentary orthopedic care, facing challenges from inadequate training, facilities, and technology. This thesis emerges from a critical examination of the drawbacks associated with traditional casts and the prohibitive costs of advanced solutions, aiming to alleviate the complications and economic burdens induced by improper cast application. By leveraging ergonomic and human-centered design principles, this thesis aims to develop an all-encompassing system that simplifies cast application, minimizes user error, and universalizes access to modern casting materials and technology. This not only aims to enhance individual quality of life by reducing healing times and mitigating adverse outcomes, but also endeavors to contribute to a broader societal advancement by fostering equitable healthcare solutions in underserved rural settings.

Student Signature(s):	Daniel Rowland
Date:	29 / 09 / 2023

Instructor Signature(s):	Catherine Chang
Date:	12 October 2023



	Activity	Stat...	Start	End	Days	
1	EXPLORATION & PLANNING		01-09-23	31-10-23	53.0	258.0
1.1	Research / Data Collection		02-09-23	19-09-23		37.0
1.1.1	Review of related Literature		09-09-23	09-09-23	1.0	
1.1.2	Collect Data		02-09-23	19-09-23	18.0	
1.1.3	Online data mining and database research		02-09-23	19-09-23	18.0	
1.2	Benchmarking		21-09-23	30-09-23		19.0
1.2.1	Analyze existing products in the market		21-09-23	21-09-23	1.0	
1.2.2	Comparison with global standards		22-09-23	30-09-23	9.0	
1.2.3	Identify gaps and opportunities		22-09-23	30-09-23	9.0	
1.3	Interviews / Surveys		01-10-23	10-10-23		28.0
1.3.1	Design questionnaires		01-10-23	01-10-23	1.0	
1.3.2	Conduct one-on-one interviews with medic...		02-10-23	10-10-23	9.0	
1.3.3	Survey distribution, both online and offline		02-10-23	10-10-23	9.0	
1.3.4	Collation and analysis of feedback		02-10-23	10-10-23	9.0	
1.4	Advisor Initiative/Progress/Project Timeline		01-09-23	31-10-23		121.0
1.4.1	Weekly meetings with the advisor for progr...		01-09-23	31-10-23	61.0	
1.4.2	Adjust project timeline based on feedback		02-10-23	31-10-23	30.0	
1.4.3	Incorporate necessary changes into the str...		02-10-23	31-10-23	30.0	
2	DEFINE DIRECTION & DESIGN STRATEGY		21-10-23	30-11-23	40.0	150.0
2.1	Ideation		21-10-23	30-10-23		30.0
2.1.1	Brainstorming sessions		21-10-23	30-10-23	10.0	
2.1.2	Mind-mapping		21-10-23	30-10-23	10.0	
2.1.3	Sketching preliminary ideas		21-10-23	30-10-23	10.0	
2.2	Concepts Exploration		01-11-23	20-11-23		40.0
2.2.1	Design iterations based on feedback		01-11-23	20-11-23	20.0	
2.2.2	Select potential concepts for prototyping		01-11-23	20-11-23	20.0	
2.3	Configuration Diagram		11-11-23	20-11-23		20.0
2.3.1	Create flow diagrams for the product's oper...		11-11-23	20-11-23	10.0	
2.3.2	Design preliminary layouts		11-11-23	20-11-23	10.0	
2.4	Human Factors / Ergonomics		21-11-23	30-11-23		20.0
2.4.1	Assess ergonomic factors in design		21-11-23	30-11-23	10.0	
2.4.2	Make modifications based on ergonomic ev...		21-11-23	30-11-23	10.0	



	Activity	Stat...	Start	End	Days	
2.4.2	Make modifications based on ergonomic ev...		21-11-23	30-11-23	10.0	
3	DESIGN DETAILING & DEVELOPMENT		01-12-23	01-02-24	23.0	144.0
3.1	Concept Refinement		01-12-23	10-12-23		40.0
3.1.1	Narrow down to final design concepts		01-12-23	10-12-23	10.0	
3.1.2	Incorporate feedback from interim reviews		01-12-23	10-12-23	10.0	
3.1.3	Enhance details for functionality and aesth...		01-12-23	10-12-23	10.0	
3.1.4	Reiterate based on new feedback		01-12-23	10-12-23	10.0	
3.2	Mock-ups / Sketch-Models		11-12-23	20-12-23		20.0
3.2.1	Construct rapid mock-ups		11-12-23	20-12-23	10.0	
3.2.2	Review and refine		11-12-23	20-12-23	10.0	
3.3	CAD Development		01-01-24	15-01-24		22.0
3.3.1	Create detailed 3D models		01-01-24	15-01-24	15.0	
3.3.2	Virtual testing for functionality		01-01-24	07-01-24	7.0	
3.4	Model Fabrication		15-01-24	01-02-24	1.0	39.0
3.4.1	Select materials		15-01-24	20-01-24	6.0	
3.4.2	Prototype creation		16-01-24	01-02-24	17.0	
3.4.3	Evaluate and adjust		17-01-24	31-01-24	15.0	
4	ANALYSIS & REPORTING		12-01-24	31-03-24	21.0	134.0
4.1	Visual Presentation Layout		01-02-24	15-02-24		30.0
4.1.1	Design banners and posters for final presen...		01-02-24	15-02-24	15.0	
4.1.2	Ensure consistency with the product's bran...		01-02-24	15-02-24	15.0	
4.2	Thesis Design Dossier		12-02-24	01-03-24		26.0
4.2.1	Draft sections progressively		12-02-24	22-02-24	11.0	
4.2.2	Final report consolidation and proofreading		16-02-24	01-03-24	15.0	
4.3	Product Video Presentation		02-03-24	15-03-24		25.0
4.3.1	Storyboard and script		02-03-24	12-03-24	11.0	
4.3.2	Filming and editing		02-03-24	15-03-24	14.0	
4.4	Misc. / Finishing		16-03-24	31-03-24		32.0
4.4.1	Collate all deliverables		16-03-24	31-03-24	16.0	
4.4.2	Final review and touch-ups before submissi...		16-03-24	31-03-24	16.0	

PANEL ON RESEARCH ETHICS
Navigating the ethics of human research

TCPS 2: CORE 2022

Certificate of Completion

This document certifies that

Daniel Rowland

successfully completed the Course on Research Ethics based on the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2: CORE 2022)

Certificate # 0000952797

8 September, 2023

Appendix D – Approval Forms and Plans

IDSN 4002 /4502

SENIOR LEVEL THESIS ONE & THESIS TWO

HUMBER

Bachelor of Industrial Design / FALL 2023 & WINTER 2024

INFORMATION LETTER

Research Study Topic: Accessible Orthopedic Care in Remote Areas

Investigator: Daniel Rowland / 705-890-1343 / danrowland2022@gmail.com

Sponsor: Humber ITAL, Faculty of Media & Creative Arts (IDSN 4002 & IDSN 4502)

Introduction

My name is Daniel Rowland, I am an industrial design student at Humber ITAL, and I am inviting your participation in a research study on various problems that are experienced when trying to access orthopedic care in remote areas. These problems include lack of transportation, lack of medical facilities, medical specialists, and lack of access to new materials. The results will be contributed to my Senior Level Thesis project.

Purpose of the Study

This study is being conducted as an aid in designing an orthopedic casting solution that is capable of correctly applying an orthopedic cast without the need for a orthopedic specialist, this aims to make a system that can be placed in local medical facilities or temporary medical facilities to broaden the scope of care and treatment and reduce the need for training while limiting potential complications. With your help, I plan to address problems that patients and medical specialists face on a regular basis of care. This study is primarily based on understanding ergonomics, human interaction design activities, and user experience aspects of the research area.

Procedures

If you volunteer to participate in this study, your activities in interacting with a patient or medical specialist will be recorded and documented. Your activities will be documented through interviews and verbal walkthrough of the application and healing process . You will also be asked questions pertaining to the various bone immobilization methods and how they are applied..

Confidentiality

Every effort will be made to ensure confidentiality of any identifying information that is obtained during the study. In the case of being recorded visually, your face will be masked /blurred or hidden. The information and documentations (photographs) gathered are all subject to being used in the final presentation of the study.

Participation and Withdrawal

Your participation in this study is completely voluntary and you may interrupt or end the study and the session at any time without giving a reason or fear of being penalized.

If at any point during the session, you feel uncomfortable and wish to end your participation, please let the moderator know and they will end your participation immediately.

Humber Research Ethics Board

This research project /course has been approved by the Humber Research Ethics Board. If you have any questions about your rights as a research participant, please contact Dr. Lydia Boyko, REB Chair, 416-675-6622 ext. 79322, **Lydia.Boyko@humber.ca**

IDSN 4002 /4502

SENIOR LEVEL THESIS ONE & THESIS TWO

HUMBER

Bachelor of Industrial Design / FALL 2023 & WINTER 2024

INFORMATION LETTER

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.**

BB	BB	Dec 13
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: 705-890-1343

Email: danrowland2022@gmail.com

My supervisors are:

Prof. Catherine Chong, **catherine.chong@humber.ca**

IDSN 4002 /4502

SENIOR LEVEL THESIS ONE & THESIS TWO

HUMBER

Bachelor of Industrial Design / FALL 2023 & WINTER 2024

PARTICIPANT INFORMED CONSENT FORM

Research Study Topic: Accessible Orthopedic Care in Remote Areas

Investigator: Daniel Rowland / 705-890-1343 / danrowland2022@gmail.com

Courses: IDSN 4002 & IDSN 4502 Senior Level Thesis One & Two

I, Brennan Bempong *(First Name/Last Name)*, have carefully read the Information Letter for the project Accesible Orthopedic Care, led by Daniel Rowland. 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 Daniel Rowland 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 principal investigator /researcher, Daniel Rowland and Prof. Catherine Chong 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 **Daniel Rowland / danrowland2022@gmail.com / 705 890 1343.**

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.

Brennan Bempong	BB	Dec 13
Participant's Name	Participant's Signature	Date

Name: Brennan Bempong
Position: Orthopedic Technician
Location: Humber River Hospital, Mackenzie Health, McMaster Childrens Hospital, Mount Sinai Hospital
Contact Method: Voice Call, LinkedIn
Meeting Time: Thursday, 12:30 (Interviewee changed time to 10:45)
Meeting Duration: 15 min (10:45 - 11:00)

Interview Questions

Do you agree to your voice to be recorded andconsent to participate in the research study? - Yeah of course
(Recording didnt work - Interviewee changed meeting time last minute and I didnt have time to set it up properly)

1) **Have you encountered or witnessed complications from improper cast fitment and application?** - Patient compliance, getting the patient to sit still while casts is being put on, Holding the right position, care after cast application, maintaining a proper care routine. Plaster can take a really long time to set, fiberglass is more difficult to contour to the body without experience
2) **I noticed you work at McMasters Childrens Hospital, Are there any differences in treating children vs adults? If so what accomodations are involved in treating children?** - Parents having anxiety towards getting casts applied, children cannot sit still, harder to get them to stay in right position, uses more staff, usually they need 2-3 but with kids it takes 5.
3) **What is the typical availability of resources and facilities in rural settings to treat fractures appropriately?** - Like anything resources are limited in remote areas, theres less facilities in the same areas compared to urban, main drawback is specialists, less people want to ,ive in rural areas leading their to be limited trained specialists aviable
4) **Could you describe any challenges faced in providing orthopedic casts to patients in rural or remote locations, vs urban areas?** - Lack of training for the specialists is the main thing
5) **Have you used any emerging tech recently in patient care, for example 3D printed casts? what are some constraints with these processes?** - No, mainly just plaster of paris and some fiberglass, not sure why they dont have access to newer tech, most of what they are using is outdated
6) **How does the number and availability of orthopedic specialists in rural areas compare to those in urban centers?** - Surgeons and technicians are limited, less people want to live in these areas therefore there is less available resources to patients and under staffed facilities, they still have access to the materials such as plaster and fiberglass, its just getting someone to apply them
7) **How common are delays in receiving casts in remote areas vs urban, and what are the implications of such delays for patient outcomes?** - Limited resources can prevent patient care, they decide what is more urgent and send more resources to that, where something less urgent may have to wait as the available resources are limited and it may take longer to get everything out there
8) **Based on your professional experience, do you have any advice or suggestions for developing a system or product aimed at increasing the accessibility of orthopedic casts in rural and remote locations?** - Make something easy to follow as lack of training is the main issue, not many people know how to apply casts, make something very easy to follow, and simple to use
9) **Are there any other insights, perspectives, or challenges that you think are essential for me to consider as I proceed with this project?** - Want things that are fast acting, plaster takes longer to set than other materials, look for fast acting materials that you can put on immediately in the places that have limited resources you want something that goes on and immediately sets, just because its harder to get people in rural ares, think of materials that are easy to use and include instructions so that someone who isnt as well trained or versed is able to apply it