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Group 7 - Equipment Services

Custom Wheelchair Systems Design Report

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Contents

1 Executive Summary

This design report focuses on the development and improvement of custom wheelchair systems, specifically designed to enhance the quality of life for patients with Cerebral Palsy. The project aims to innovate in the production process and material selection for customized wheelchairs.

Key highlights of the report include:

2. Project Aims: The primary goal is to create a wheelchair that is adaptable to individual bio mechanical needs, thereby improving posture and most importantly comfortability. The project seeks to enhance sustainability by using lighter, recyclable materials that are easier to work with and have better infection control properties.
3. Background: Cerebral Palsy is characterized by movement disorders that vary widely among individuals. This necessitates highly customisable solutions to cater to diverse needs, which this project aims to address by leveraging advanced materials and manufacturing processes.
4. Stakeholders: The key stakeholders include patients with Cerebral Palsy, caregivers, the manufacturing team, and the client, Cerebral Palsy Alliance. The project aims to deliver a prototype of a customized seating option, detailed project charter, final presentation, and a comprehensive design report comparing current and proposed technologies.
5. Prior Art: Discusses previous and existing works of implementations as basis for brainstorm and understanding.
6. Requirements: The wheelchair system requirements are outlined and clearly addresses the main criteria that was targeted when brainstorming solutions.
7. Design Risk Analysis: The report identifies and evaluates potential risks with the respective risk analysis table and proposes mitigation strategies followed by re-evaluation.
8. Design Solutions: Various materials and design approaches are evaluated of different components of the wheelchair; the backplate and the seating. The report details the cost, time implications, outsourcing, and the attachments, emphasising ease of use for the client and the practicality of implementation for the company, Cerebral Palsy Alliance (CPA).
9. Outsourcing: Discusses the criteria involved for if CPA would like to outsource the implementation for production.
10. Sustainability: Discusses the procedures of refurbishment, reuse, and recycle and suggests methods of action in recommending available partnering companies.

This project represents a significant step towards creating more effective and sustainable wheelchair systems for individuals with Cerebral Palsy. By focusing on innovative materials and user-centric design, the project aims to set new standards in custom wheelchair production.

2 Project Aims

The overall aim of this project is to improve the quality of the production process for the Equipment Services manufacturing team as well as the general patient affected by the strains of day-to-day life with Cerebral Palsy. The wheelchair should be able to be adapted and generally customised to an individual's bio mechanical needs and thus be used as inspiration, for solutions for other patients with Cerebral Palsy that also have restricted lower extremity functional capacity.

The product will be based around improving mobility, supporting posture, alleviating pressure thereby improving comfort, increasing functionality for the patient, reducing caregiver strain, and boosting confidence and independence.

The project will involve suggesting new materials & bio manufacturing processes that can offer the same level of support but are lighter weight, easier to work with, and have better infection control whilst improving the overall sustainability of the product particularly in reusing and recycling.

In addition to the aforementioned aims, the project intends to raise awareness of Cerebral Palsy to inspire future funding and innovation of solutions for various aspects of the disease.

Some specific deliverables we aim to achieve include:

- A prototype of the final customised seating option, the bottom plate, and suggested material slabs catered towards the general patient with Cerebral Palsy
- A Project Charter that details the client, Cerebral Palsy Alliance
- A Final Presentation for the client presenting all findings
- A design report evaluating the most appropriate design to move forward with, and a comparison with the current technology currently utilised

3 Background

Cerebral Palsy is an umbrella term describing a group of movement disorders [1]. It is the most common physical disability in childhood, with every 1 in 700 Australian children born each year being diagnosed. Symptoms vary depending on the type of cerebral palsy.

There are three types and are distinguished by how they impact movement.

- Spastic is the most common form which affects 85% of diagnosed people. Characterised by stiff or tight muscles and exaggerated reflexes [2].
- Dyskinetic is a less common form impacting 10%. Characterised by involuntary movements that are intensified by fatigue or excitement [2].
- Ataxia affects 4%, and is the least common. Defined by shaky movements which can influence balance, coordination, speech and depth perception [2].

Additionally, there are three categories describing the parts of the body impacted.

- Quadriplegia is a bilateral form, meaning both arms and legs are affected. Plus, muscles of the trunk, face and mouth [2].
- Diplegia is where the legs are affected however arms to a lesser extent [2].
- Hemiplegia is a unilateral form meaning one side of the body is affected [2].

Cerebral palsy occurs as a result of abnormal development and damage to the motor cortex during the pregnancy/childbirth/post birth phases. This area of the brain controls movement, balance, and posture [3].

Although the true cause of the damage is rarely determined. Certain factors may increase the risk of developing the disorder. These include: premature birth, genetics, head trauma and infections [4].

The symptoms of cerebral palsy can become more severe over time however it is not a progressive disorder, meaning brain damage will not worsen [1]. The disorder may also be complicated by intellectual and or learning disabilities. Issues relating to growth, skeletal structure, malnutrition and others may also be present [4]. The affected areas and severity depend on the individuals.

It is evident that cerebral palsy has major implications for those with the condition. It inhibits physical movement and can also impact development.

Even though, there is no known cure for cerebral palsy. Physical, occupational and speech therapies can be applied. Spasms and spasticity can be alleviated with medications. Orthopaedic surgery and orthotics can be used to treat physical symptoms [1]. According to the severity of the condition, specialised care and equipment (wheelchairs, seats) may also be implemented. Such treatments can be used to help individuals live normal lives.

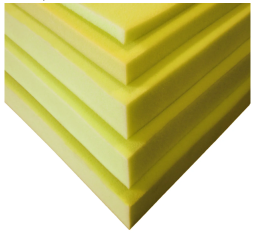
4 Stakeholders

Stakeholder	Impact of project	Influence over project direction
CPA Equipment Services Team	The project is of significant importance to the Equipment Services team as the main project aim is to improve the efficiency of their manufacturing process of custom moulded wheelchair seating. The main issues that need to be addressed include unsatisfactory materials, ineffecient manufacturing process and lack of sustainability practices in place.	The Equipment Services has great influence over the project as the final solution must meet their specified requirements. They also serve as the primary source of information for the issues that need to be addressed as well as feedback from user testing of design iterations.
Cerebral Palsy Patients	The project is of great significance to patients of cerebral palsy as the product delivered by the Equipment Services team aims to improve their quality of life. Properties of the material used to manufacture the custom moulded seat must be suited to long-term usage and should possess properties like high level of support, anti-bactertial, lightweight and breathable.	Patients of cerebral palsy have moderate influence over the project as the final material proposed and the design of the custom seating system should meet the requirements of the patient regarding postural support and comfort.
Caretakers and Occupational therapists	The project is of considerable importance to caretakers and oocupational therapists as the proposed material and design of custom seating must offer ease of cleaning and maintenance.	Caretakers and occupational therapists have moderate influence over the project, particularly with user testing concerning ease of cleaning and maintenance.

CPA Clinical Governance Team	The project is of high importance to CPA's clinical governance team as they aim to provide quality products and services to its clients.	CPA's clinical governance team has a major influence over the project as they impose regulations that govern material selection and the design solution.
NDIA (National Disability Insurance Agency)	The project is of low importance to members of NDIA itself as it serves to help improve the quality of life of their clients instead, i.e. patients of cerebral palsy.	NDIA has a moderate influence over the direction of the project as the funding of the final solution that is to be presented to patients of cerebral palsy is to be provided by them. As such, approval processes must be ran through NDIA.
TGA (Therapeutic Goods Administration)	The project is of low importance to members of TGA itself as it serves to help improve the quality of life of patients instead.	TGA has a major influence over the project as they impose laws and regulations that govern material selection and the design solution.
Outsourced companies and suppliers	The project is of low importance to outsourced companies and suppliers as they only serve to supply materials to the client.	Outsourced companies and suppliers have a major influence on the direction of the project as the availability of their materials determines the viability of the design solution where in the situation a supplier is unable to provide the client with the materials required, then the proposed solution will not be accessible to patients.

5 Prior Art

Name / Category	Description	Strengths	Limitations	Ref
CreateItReal 3D Printed Seats 	Uses 3D printing technology, specifically using the company's Programmable Foam made of medically certified TPU material to create customised seats that provide pressure relief and support through tailored hardness zones. The seats gyroid infill structure allows customisation of the seat's hardness to ensure the most comfort for the patient.	**Customisable**: Ability to tailor hardness and softness zones for individual needs. **Hygiene and Washability**: Materials are easy to clean and maintain, ensuring long-term hygiene and washability **Sustainability**: Minimal waste and sustainable production. Ease of recycling due to using only one material for the seating.	**Initial Cost**: The initial purchase and setup of 3D printing equipment can be expensive.	[5]
Layer's GO Wheelchair 	The world's first 3D printed consumer wheelchair, with a custom manual 3D printed seat and footrest. The prototype was completed using a combination of stereolithography and light sintering to print the integrated cushioning seat structure and foot rest.	**Customisable**: Allows for consumers to customise seat design parameters such as height of the back support and width of the seat.	**Not Custom-Contoured:** The GO wheelchair is not custom-contoured, so its design and manufacturing process differs from CPA's CCS system. **Cost**: Materialise's stereolithography and light sintering processes are somewhat expensive.	[6]

PU36/130 Yellow Foam 	High density open cell polyurethane foam with a medium firmness typically used for commercial seating, commercial backs and office furniture.	**Durability**: High density (36kg/m3) ensures long-lasting support **Support**: Helps distribute weight evenly and reduce pressure points **Customisability**: " Can be cut and shaped to fit specific dimensions and contours.	**Lack of Ventilation**: Can result in moisture accumulation and absorption which can be unhygienic. **Heat Retention**: Can lead to build up of heat and be uncomfortable for user over time, **Waste Production**: Significant waste produced from offcuts. Can take longer to break down in landfills.	[7]
Ethylene-vinyl acetate (EVA) Foam 	Closed cell foam that is flexible and lightweight often used for footwear, sports gear, cushions and other uses.	**Durability**: High durability even at low temperatures. Can withstand regular use without significant wear and tear. **Elasticity**: Superior elasticity that can conform to different shapes. Offers high level of rebound and compression recovery suitable for long-term use.	**Cost**: Relatively more expensive compared to other types of foam **Non-biodegradable**: Not biodegradable, making it a significant contributor to landfill.	

Memory Foam 	Memory foam, also known as viscoelastic foam is polyurethane foam combined with various compounds and additives. The material is often used for mattresses and designed to slowly mold to the body in response to pressure.	**Provides Pressure Relief**: Contours to the body which can provide relief in areas of high pressure, reducing discomfort.	**Heat Retention** : High density of foam tends to trap heat and become uncomfortably warm. **Not Waterproof** : Can be damaged by water and moisture which can degrade the foam and reduce the lifespan. **Durability** : Tends to lose its shape over time and may require replacement. **Sustainability** : Mostly petroleum based and not easily recyclable due to its chemical composition	[8]

6 Requirements

This section outlines the specific features and criteria that the solution is aimed to satisfy and fulfill. The requirements outlined in the following table focuses the following categories:

- User Requirements (SPR 1): Properties that enhance the usability and user-friendliness of the solution.
- Technical Requirements (SPR 2): Technical constraints of the solution.
- Functional Requirements (SPR 3): Properties describing what the solution is expected to do.
- Regulatory Requirements (SPR 4): Regulation and standards the solution must comply with.

Requirement	Category	Explanation	Priority
Lighter Weight	User	The wheelchair should be lighter for ease of travelling and physical management	8
Minimal Maintenance	User	Material should be easy to clean and require minimal upkeep.	9
Airflow or breathable material	Technical	Selected material and design should have good airflow and breathability for more comfortable seating.	5
Recyclable Material	Technical	Selected material and design should have improvements in recycling method and proportion to which it can be recycled.	10
Durability	Technical	Selected material and design should have a similar or better lifespan to the currently used materials.	6
Modular Design	Technical	Material and design should be able to allow easy adjustments if needed.	7
Pressure Distribution	Functional	The material and design for the seating should be designed with minimal discomfort to prevent accumulating pain and aches.	3
Infection Control	Functional	The selected material needs to be good at providing ease at managing and handling hygiene.	4

ISO16840	Standards/ Regulations	ISO 16840 is a multi-part international standard for wheelchair seating. It sets out requirements and test methods for various aspects of wheelchair seat cushions and backs, particularly those designed to manage pressure and provide postural support for users with conditions like cerebral palsy. Here's a summary of its key areas: • **Physical and Mechanical Characteristics**: Defines standards for seat cushions to ensure they properly distribute pressure and minimize risk of skin breakdown. (ISO 16840-2) • **Strength and Durability**: Specifies tests to measure the strength of postural support devices under static, impact, and repetitive loads. (ISO 16840-3) • **Simulated Use and Wear**: Provides methods to assess how a seat cushion's properties change over time with simulated use. (ISO 16840-6) • **Fire Safety**: Sets requirements and testing methods to ensure seat and back cushions resist ignition from sources like cigarettes. (ISO 16840-10) • **Other Considerations**: Additional parts of the standard address moisture management, pressure distribution characteristics, and lateral stability of seat cushions. (ISO 16840-11, 12, 13)	1

ISO13485	Standards/ Regulations	ISO 13485 is an internationally recognized standard for quality management systems (QMS) in the medical device industry. It outlines the requirements for organizations designing, developing, producing, and distributing medical devices. The core focus is on ensuring consistent delivery of safe and effective medical devices that meet regulatory requirements. Here's a breakdown of ISO 13485: • **Focus on Patient Safety**: The standard prioritizes patient safety by emphasizing risk management throughout the entire life-cycle of a medical device. • **Process-Based Approach**: It requires organizations to establish documented processes for all critical activities, ensuring consistency and traceability. • **Regulatory Compliance**: Following ISO 13485 helps organizations meet regulatory requirements for medical devices in many countries. This can streamline the approval process. • **Continual Improvement**:The standard promotes a culture of continuous improvement within the organization, ensuring the QMS remains effective over time.	2

7 Design Risk Analysis

#	Risk	Category	Severity (1-5)	Likeli -hood (1-5)	Rating (/25)	Mitigation Method	Severity (1-5)	Likeli -hood (1-5)	Rating (/25)	Accept [Y/N]
RSK 1.1	**Allergic Reactions**: Seating may cause allergic reactions, leading to minor irritations and compounding into new risks.	User	4	2	8	• Choose hy-poallergenic materials • Conduct thorough testing for potential allergens • Consult with clients about known allergies	2	1	2	Y
RSK 1.2	**Infection Control**: Seating may harbour pathogens, leading to disease and further health complications.	User	5	3	15	• Use antimicrobial materials • Implement strict hygiene protocols. • Ensure compliance with infection control standards.	2	1	2	Y

RSK 1.3	**Temperature Regulation**: Seating may not disperse temperature effectively, leading minor irritations, may exacerbate to other risks.	User	3	3	9	• Use breathable materials. • Incorporate thermal insulation layers. • Regularly gather client feedback on comfort.	2	1	2	Y
RSK 1.4	**Pressure Ulcer Development**: Seating may impact underlying tissue with prolonged pressure on the skin from ineffective pressure distribution.	User	4	3	12	• Use pressure-relief materials (e.g., memory foam, gel cushions). • Conduct regular pressure mapping assessments. • Provide customizable seating solutions.	2	2	4	Y

RSK 1.5	**Excessive Sweating**: Insufficient breathability in seating leads to excess sweating, and cause blistering/discomfort.	User	3	3	9	• Further seat adjustments to improve breathability. • Regular checks and gather client opinion to evaluate breathability of the design.	3	2	6	Y
RSK 1.6	**Undetected Injury due to inability to communicate**: CP patients may be non-verbal, involving a lack of immediate feedback. This leads to a delay in addressing issues / increases risk of new injuries.	User	4	3	12	• Regular consultations with therapist and gather client opinion to evaluate injury and comfortability.	3	2	6	Y

RSK 2.1	**Material Deterioration due to water permeability**: Seating could experience structural failure due to water permeability affecting the material, causing it to break, compromise its support, or lose its custom shaping.	Technical	4	4	16	• Select water-resistant materials. • Apply waterproof coatings. • Conduct regular inspections and maintenance.	2	2	4	Y
RSK 2.2	**Material Degradation**: Interior Materials may degrade due to force/overuse, causing the seating to break or compromise its support.	Technical	2	5	10	• Select durable materials in prototyping. • Frequent servicing of wheelchair by CPA technicians.	2	4	8	Y

RSK 2.3	**Inaccurate Customisation**: Errors in user measurements could lead to inaccurate fit, reducing its support and causing further damage/discomfort.	Technical	4	4	16	• Obtain accurate scan file (.obj). • Use precise tooling during production methods (3d printing).	3	3	9	Y
RSK 2.4	**Poor seam/stitching quality**: Can lead to discomfort and irritation for users with sensitive skin, as well as pressure injuries in those regions.	Technical	4	3	12	• Train staff on proper sewing techniques. • Implement strict quality control measures. • Use protective covers or padding. • Ensure surface stitching does not coincide with areas of high pressure concentration.	2	4	8	Y

RSK 2.5	**Inaccurate Support**: Can lead to inadequate support or discomfort, therefore inhibiting mobility / causing further injury.	Technical	4	4	16	• Obtain accurate scan file (.obj). • Use precise tooling during production methods (3d printing).	3	3	9	Y
RSK 3.1	**Product Too Heavy**: Excessive weight of material / seating design could impact user comfort and increase risk of crushing.	Functional	3	3	9	• Utilise light materials in design . • Establish a weight limit.	2	2	4	Y
RSK 3.2	**Maintenance/Cleaning**: Difficulty in maintenance/cleaning could lead to irritation, hygiene concerns and other risks.	Functional	2	4	8	• Select easy-to-clean materials. • Provide clear maintenance instructions. • Establish a regular cleaning schedule.	1	2	2	Y

RSK 3.3	**Incompatibility With Assistive Devices**: Seating impacts use with other assistive devices from general convenience devices to rendering seating to completely unusable.	Functional	4	3	12	• Conduct compatibility testing with existing devices. • Follow universal design principles. • Design with adjustable features.	1	1	1	Y
RSK 4.1	**Inadequate User Training**: Lack of proper user training could result in incorrect usage.	Other	3	2	6	• Develop operational and maintenance guide for user.	2	1	2	Y
RSK 4.2	**Cost**: Seating design may become too expensive to ensure accessibility, due to the expense of materials during manufacturing, and customisation.	Other	4	3	12	• Cheaper material. • Recycled materials and component.	3	2	6	Y
RSK 4.3	**Supply Chain Failure**: Seating can no longer be made, as company no longer produces the material leading to delays / cancellations of orders.	Other	4	2	8	• Ensure other contingencies are prepared in case of failure.	4	1	4	Y

8 Design Solutions

8.1 Backplate Coating Solution

The client (CPA) has enquired about improving the current custom wheelchair backplates. The existing wooden plates have significant issues with mould growth, while metal plates have minor drawbacks related to weight, customisation, and difficulty in repair.

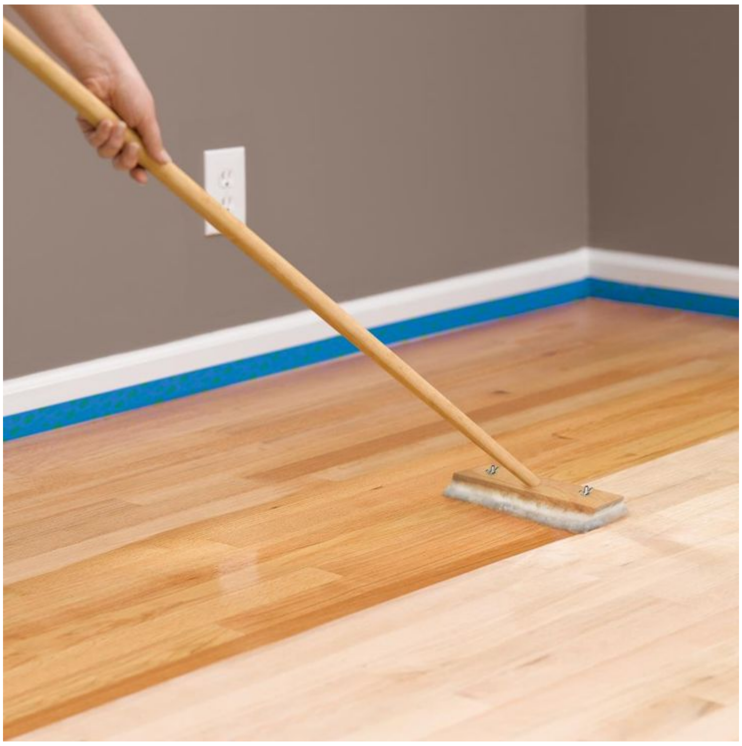
Continuing with the wooden backplates appears to be the most suitable option. They remain a lightweight choice and are easier to repair compared to other materials. Applying a coating to the wooden backplates can prevent mould growth and enhance the aesthetic appeal of the backplate.

The following are options for the wooden backplate coatings:

- **Linseed Oil**: Linseed oil, extracted from flaxseeds, is a traditional and natural choice for wood finishing. It penetrates deeply into the wood, nourishing and enhancing its natural grain. While it offers a beautiful, warm finish, linseed oil is relatively soft and requires regular maintenance. Its protective properties against moisture and scratches are limited compared to other options. Linseed oil also has a long drying time and can be susceptible to yellowing over time. However, it is eco-friendly and non-toxic, making it a popular choice for those seeking a natural and sustainable finish.

- **Beeswax**: Beeswax is a natural wax derived from honeycombs. It creates a warm, protective layer on wood, enhancing its appearance and providing a gentle water resistance. Beeswax polishes are easy to apply and maintain, offering a soft, satin sheen. However, beeswax alone is not highly durable and offers limited protection against scratches and wear. It requires more frequent reapplication compared to other finishes. Despite its limitations, beeswax is a popular choice for furniture and woodwork due to its natural beauty and non-toxic properties.

- **Water-Based Polyurethane**: Water-based polyurethane is a modern and versatile option for wood finishing. It offers excellent durability, protecting wood from scratches, water damage, and UV rays. It dries quickly and is available in various finishes, from matte to high gloss. Water-based polyurethane is also more environmentally friendly than traditional oil-based polyurethane, with lower VOC emissions. However, it may not penetrate the wood as deeply as oil-based finishes, and it can raise the grain, requiring additional sanding before subsequent coats. While it provides a strong protective layer, it may not enhance the wood's natural beauty as much as some other options.



Feature	Linseed Oil	Water-Based Polyurethane	Beeswax
Material	Natural (flax seeds)	Water-based acrylic resin	Natural (beeswax)
Eco-Friendly	Yes	Yes (low VOCs)	Yes
Durability	Low (frequent reapplication)	High	Low (not scratch-resistant)
Water Resistance	Moderate	High	Low (not ideal for wet areas)
Mould Prevention	Moderate (requires maintenance)	Good (with proper ventilation)	Low
Drying Time	Slow (several days)	Fast	Fast
Application	Easy	Moderate (may require more coats)	Easy
Cleanup	Oily rags (flammable disposal)	Soap and water	Buffing with a soft cloth
Finish	Natural, enhances grain	Can appear slightly plastic-like	Warm, satin sheen
Sheen Options	Limited (natural)	Matte, satin, gloss	Limited (satin)
Repairs	Easy (buff and re-oil scratches)	Difficult	Not Recommended

Table 1: Comparison of Linseed Oil, Water-Based Polyurethane, and Beeswax for Wood Finishing

8.2 Backplate (Bamboo, Aluminium Composite Material, Carbon Fibre)

Plant alternatives

1. **Bamboo:** Bamboo panels are a sustainable material that offer superior strength compared to currently used MDF boards while still remaining lightweight. In addition to this, it possesses better moisture resistance as well as antibacterial properties that are advantageous in application as an assistive medical device for long-term use.

Key properties

- **Strength**: Achieves superior compressive strength of 40-80 MPa compared to current MDF backplates currently used which have a strength of 10 MPa.
- **Weight**: Bamboo is comparable in weight to MDF with a density of 500-800 kg/m3 while MDF has a density of 600-800 kg/m3.
- **Durability and infection control**: Bamboo offers moisture resistance, fire resistance and antibacterial properties.
- **Recyclable**: As a natural material, bamboo can be composted after being shredded however, some manufacturing companies like House of Bamboo are able to refurbish or recycle their bamboo panels at the product's end of life.

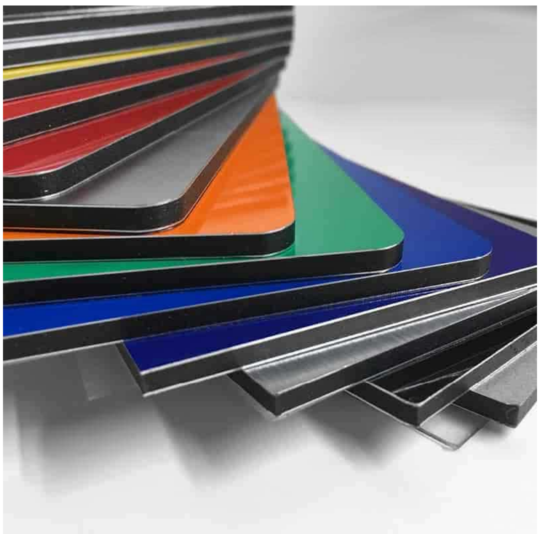
2. **Birch:** Birch plywood is another sustainable option that offers better strength compared to MDF and is also lighter in weight. It is also moisture resistant and antibacterial but typically is subjected to treatment processes to enhance these properties.

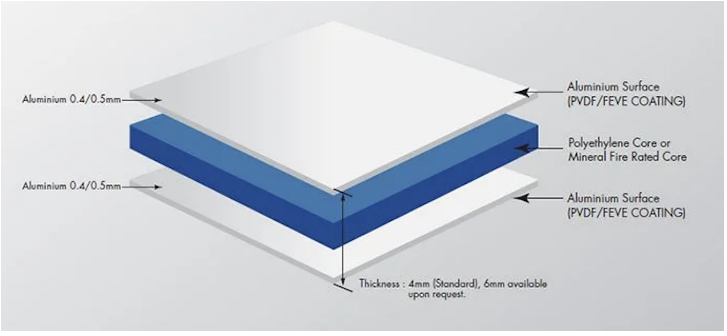
Key properties

- **Strength**: Achieves higher compressive strength of 54-60 compared to current MDF backplates currently used which have a strength of 10 MPa.
- **Weight**: Birch is comparable in weight to MDF with a density of 680-7600 kg/m3 while MDF has a density of 600-800 kg/m3.
- **Durability and infection control**: Birch is moisture resistant and fire resistant
- **Recyclable**: Birch plywood can be recycled but is a class B (treated) wood meaning that it has to be separated from untreated class A wood prior to recycling.

Aluminium Composite Material (ACM)

Aluminium Composite Panels are very light whilst also being strong and durable, making it a superior choice for various applications where weight is a concern.





Composition

Aluminium composite materials are a three-layer sandwich panel comprising:

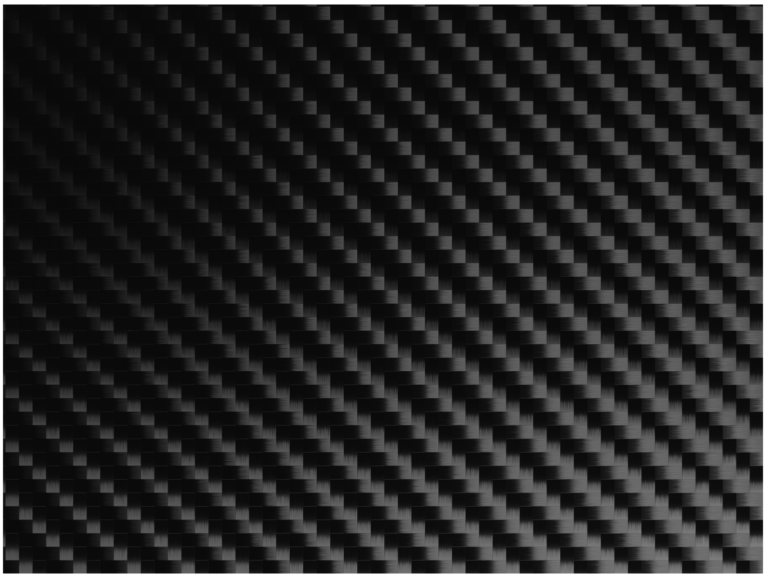
- Two pre-painted aluminium sheets of thicknesses either 0.3mm, 0.5mm, 0.8m, 1.0mm
- A polyethylene (PE) core for durability and good dimensional stability

Key Properties

- **Weight** : ACM is 1.6 times lighter than aluminum for equal rigidity. This reduction in weight is beneficial for ease of portability of the wheelchair backplate [9].
- **Strength and Durability**: It is stronger than wood or stainless steel, water-resistant, moisture-resistant, and fire-resistant. Aluminum composite panels do not deform, mold, or rust, and have a water expansion rate of zero. Also offers higher elastic limit and less prone to bending compared to single-layer aluminum plates, thus maintaining good flatness over time without excessive external force.[10].
- **Infection Control** : The panel is compounded with PET color film, which has antibacterial effects and avoids the breeding of germs.
- **Ease of processing**: ACM can be cut, folded, drilled, bent, and perforated without losing structural integrity. This allows clinicians to tailor the curvature, contour, and support to meet individual needs.
- **Versatility**: ACM can be cut, folded, drilled, bent, and perforated without losing structural integrity. This allows clinicians to tailor the curvature, contour, and support to meet individual needs. [10]
- **Recyclable**: ACM are fully recyclable, making them an excellent sustainable choice. Companies such as PanelCycle and Ecoloop recycle and repurpose these wastes. Every component of an ACM panel can be recycled - the aluminum and the polyethylene. To recycle, the panels are transported to recycling centres and shredded. The shredded material is then separated out, bagged and sent off to metal and plastic manufacturers to be transformed into new products. [11] [12]

Carbon Fibre

Carbon fibre is a lightweight material made of thin, strong crystalline filaments of carbon making it highly durable and a clear ideal choice for the wheelchairs backplate without sacrificing comfort and providing specialised support to maintain posture. The adaptability of the carbon fibre composites allows for precisely moulded backplates that can be customised to the patient's needs, offering superior mechanical properties that enhance the overall functionality and comfort of the wheelchair.



Key Properties

- **High strength to Weight Ratio**: Exceptionally strong and stiff while only being a half of the density of aluminium that CPA currently utilise for their backplates. Withstands 3,500 MPa to 6,000 MPa. [13]
- **Durability**: Offers excellent resistance to wear, fatigue, and corrosion, ensuring long lasting performance even under continuous use. Carbon fibre composites typically exhibit a fatigue limit around 60-70% of their ultimate tensile strength. [14]
- **Support and Pressure Distribution**: The high stiffness (Young's modulus) of carbon fibre, which ranges from 230 GPa to 600 GPa, allows for the creation of supportive structures that maintain shape and provide consistent pressure distribution. The material can also be moulded to fit the contours of the body more effectively [15]
- **Maintenance**: With low porosity reducing the likelihood of staining, resistance against cleaning agents, and a smooth surface finish, carbon fibre is relatively easy to clean and maintain. It can also be designed for quick replacement which ensures that repairs/adjustments can be made efficiently [16].
- **Infection Control**: Can be treated with antimicrobial coatings with the availability of various isothiazolinone treatments to comply with infection control guidelines [17].

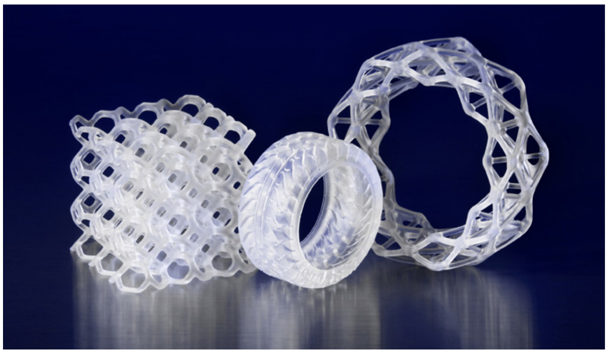
Criteria	Bamboo	Birch	Aluminium Composite	Carbon Fibre
Meets relevant standards (AS 3695, AS 12182):				
1. Resistant to ignition (AS 3695)	✓	✓		✓
2. Resistant to corrosion (AS 12182)			✓	✓
3. Resistant to contamination from urine incontinence or can be cleaned/disinfected (AS 3695, AS12182)	✓	✓	✓	✓
4. Biocompatible/non-toxic (AS 12182)	✓	✓	✓	✓
Lighter weight	✓	✓	✓	✓
Similar or higher strength	✓	✓	✓	✓
Moisture Resistant	✓	✓	✓	✓
Ease of manufacturing, maintenance and/or replacement	✓	✓	✓	
Recyclable	✓	✓	✓	

Table 2: Requirements for backplate material

8.3 Seating Solution

3D Printing

3D printing has revolutionised manufacturing methods, with it boasting high degree of freedom in design and material choice. For alternative foam, there has been a variety of different materials that offer similar properties, with **Thermoplastic Polyutherane (TPU)** as one of the most common choices for medical devices.



Key Properties

- **Flexibility**: TPU exhibits high flexibility and elasticity due to its loose molecular chain structure and weaker bonds. It allows it to absorb impact and deform without breaking. Tests typically show that it can elongate from 200% to 1000% before breaking [18].
- **Breathability**: Due to its soft nature, TPU can ensure comfort and breathability depending on the printed structure. If used in a seating alternative, can reduce any heat generated from friction.
- **Strength and Durability**: The strength of TPU exceeds conventional rubber while still maintaining its flexibility. It can withstand between 20-100MPa of strength and 10-80kN/m of tearing force [18].
- **Antimicrobial**: TPU offers a high level of fungal and bacterial resistance due to its water repellency. It prevents any microbial growth on the surface suiting the use case for wheelchair seatings. Addition coatings can be applied to further enhance the antimicrobial resistance.
- **Compatibility**: TPU is known as a very versatile biomaterial in medical applications. Multiple tests have shown its compatibility and is shown to be safe with direct contact to skin [19].
- **Recyclability**: One of the main advantages of TPU is its sustainability. TPU is a biodegradable material which takes roughly 3-5 years to break down [20] and does not impact any soil or groundwater quality during the process. Additionally, TPU is recyclable in most countries and Australia has begun to open more services for recycling TPU. Recently a new facility had opened to recycle 3D printing filament [21].

Production Process

In order to produce a foam alternative using 3D printing, TPU will be required to be printed through a specific method. By printing with a lattice structure, it can produce a material that mimics similar properties to foam. It exhibits the bounciness and springiness of foam and can return to the original shape after deformation. It becomes shock absorbent, allowing it to be compressed and distribute the forces evenly throughout the body. 3D printing provides high customisability allowing the adjustment for firmness and strength based on the printing settings.

- **Lattice Infill Density** is something that can be adjusted through the 3D printing software. All software are able to adjust the percentage of infill the body of the print will have for the printing. By increasing, it can create a firmer solid can be provide better support at the lower areas of the seating. Lowering the density can provide better support for areas with higher pressure from the unique seating position of the patients.
- **TPU Filament Hardness** is rated based on the Shore Hardness level. Recommended TPU hardness is suggested at 85A which most prototypes are printed in. By using a higher Shore hardness rating, the print will become firm and may be too stiff for support. Softer would collapse too easily from weight however that may be useful for support
- **Lattice Infill Pattern** can also affect the rigidity of the final print. 2 types of patterns were researched, 3D honeycomb and gyroid which were presented in the physical prototype deliverables.

10% infill density 12% infill density 20% infill density

Figure 1: Different lattice densities

Current Applications

Applications of TPU are already widely used within multiple industries as it is an extremely versatile material. Due to its rubber-like nature and strength it has been used in industries such as automotive, sports and medical applications as well.

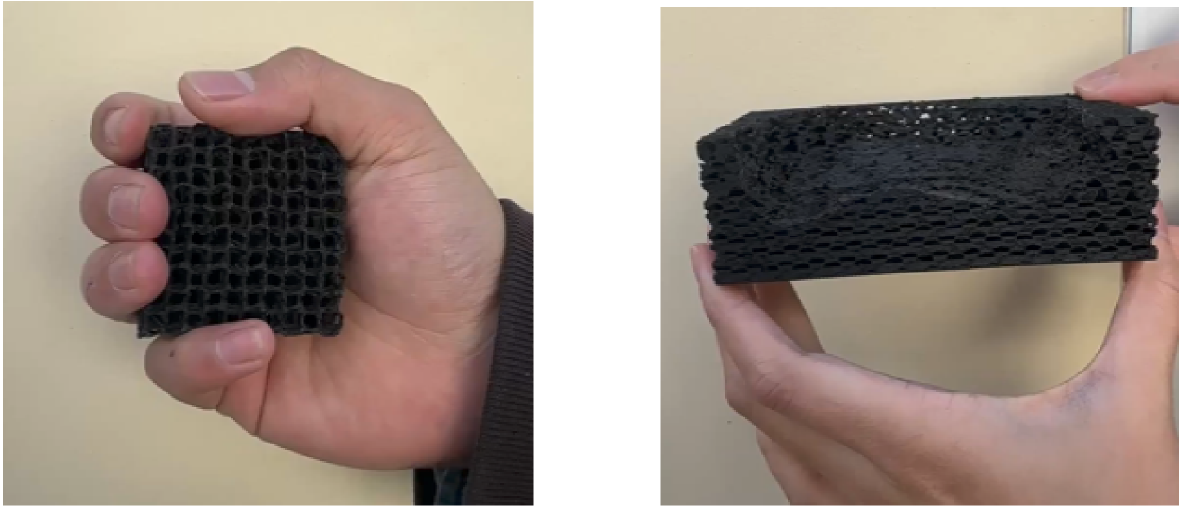
- **3D Printed shoes** are beginning to show more diversity in recent times with a major sport/athletic clothes and footwear manufacture Adidas recently releasing a mass produced 3D printed shoe 4DFWD first appearing in 2017. It uses a unique polyurethane blend for increase absorption and UV protection [22].

Figure 2: Adidas 3D printed shoe [23]

- **CreateitReal** [5], a company located in Denmark has began commercialising 3D printed posture aids through their in-house material **Programmable Foam**. It is their own TPU they have developed and tested which is being used in multiple different industries such as automotive, healthcare and sports and fitness. One of their main products utilising this TPU technology is for 3D printed custom seating and cushions **'Embrace Seats'**.

Figure 3: 3D printed seat from CreateItReal [5]

- **Prototypes** were printed to demonstrate the implementation of 3D printing TPU as a foam alternative. Different densities and lattice patterns were tested to verify ideas on the best designs. Figure 1 show the different densities testing firmness and Figure 4 show the 2 lattice patterns that were tested. Figure 4b also demonstrates how 3D printing can print the unique contour of the 3D scans.



(a) 3D Honeycomb Lattice (b) Gyroid with Seating Contour

Figure 4: Different Lattice Patters

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Requirements

Criteria		Support
Lighter Weight	✓	TPU is known as a lightweight material however can get dense and heavier than the current foam that is being used. However if 3D printed in a lattice formation, the weight can heavily depend on the print settings and potentially be lighter than foam.
Minimal Maintenance	✓	TPU demonstrates high wear and tear resistance allowing it to require less maintenance. Printing using a lattice structure also provides ease in washing as fluid can flow through.
Airflow or Breathable Material	✓	Printing method will allow a breathable nature of the foam-like structure. Using an infill lattice structure, the material will remain breathable.
Recycable Material	✓	TPU has been labeled as a recyclable material in many countries and Australia has recently opened a recycling centre that will allow TPU recycling [21].
Durability	✓	One of the main advantages of TPU is its durability to wear, tear, impacts and also UV exposure.
Modular Design	✓	The solution will incorporate 3D printing as the main form of manufacturing the seat in TPU. This provides high amount of customisability and modularity.
Pressure Distribution	✓	Pressure distribution will depend on the lattice structure used to print. Using a test print with a 3D honeycomb lattice structure, it exhibited high absorbption and behaved very similarly to a sponge.
Infection Control	✓	TPU has shown to be hydrophobic as mentioned previously in key properties. This prevents any microbial growth reducing fungal or bacterial build up. This can be further enhanced through different coatings and treatments that can be applied to the surface of the material.

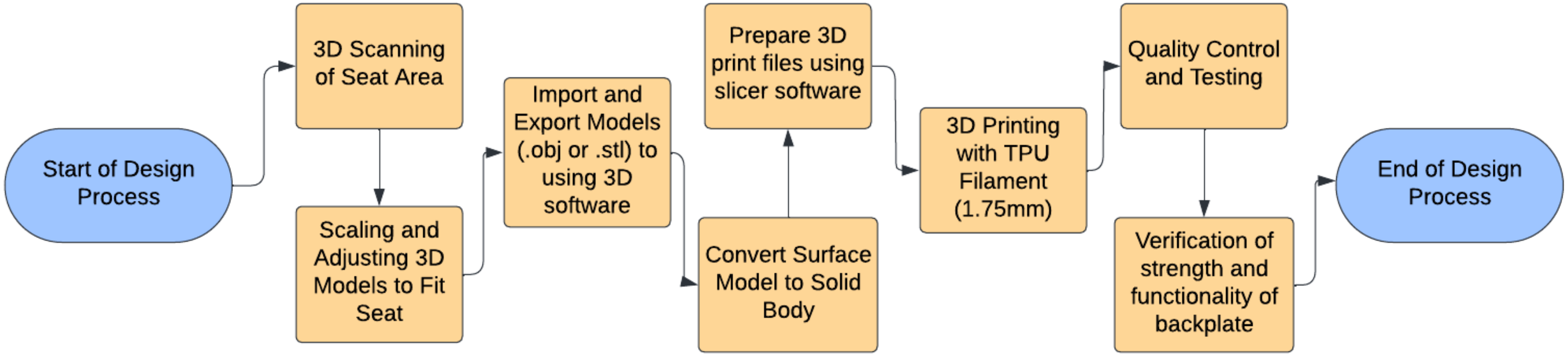

Figure 5: Flow Diagram of Design Process

8.4 Cost and Time

GLIDE [24] is an Australian manufacturer of high-quality manual and electric wheelchairs, offering extensive customization to meet individual mobility needs in Western Australia. Established in the 1970s, Glide provides tailored solutions with a focus on comfort, safety, and durability. It is a registered NDIS provider and achieved ISO 9001 Quality Assurance accreditation in 1993. Glide's product range includes wheelchairs and seating solutions for adults and children. As previously mentioned about **CreateitReal** [5], Glide collaborates with them and offers theirs advanced 3D printing technologies to enhance the customization and performance of their seating solution in Australia starting in August 2024. In addition, they currently provides CNC carving foam and moulded seating similar to CPA's current manufacturing method. We successfully obtained some estimated cost of services after providing the 3D scanning surface file to Glide. Note that CPA currently spends $ 2200 for each CNC Carved Foam, including seat base and back, but it will take 10-14 weeks to manufacture and get shipped from the UK.

Services	**Cost per Seat (Base & Back)**
CAD Modeling	$280 - 800
TPU 3D Printing (Approx. 72 hours)	$2800
CNC Carved Foam (Approx. 1 hour)	$2000
Shipping to Sydney From WA	$200

Table 3: Services and Costs

8.5 Out of Scope

This section concerns the engineering implementations that are outside the scope of our project. In specific, the connection of the custom seating solution to the structural elements of the wheelchair.

Fortunately TPU is an infinitely customisable and versatile material. On one hand it can possess the pliable characteristics perfect as a foam replacement. However if infill density is increased, it can be made stiffer and becomes structurally stable. Which is ideal for connection points and as a platform for attachments.

The following diagrams depict conventional methods of connection (bolted, ties, sewn) and a conceptual design which uses zippers, with one half being secured to the custom seating and the other on the structural base. The use of zippers would provide sound structural strength whilst also allowing the seat to be removed from the greater wheelchair, improving the ease of maintenance.

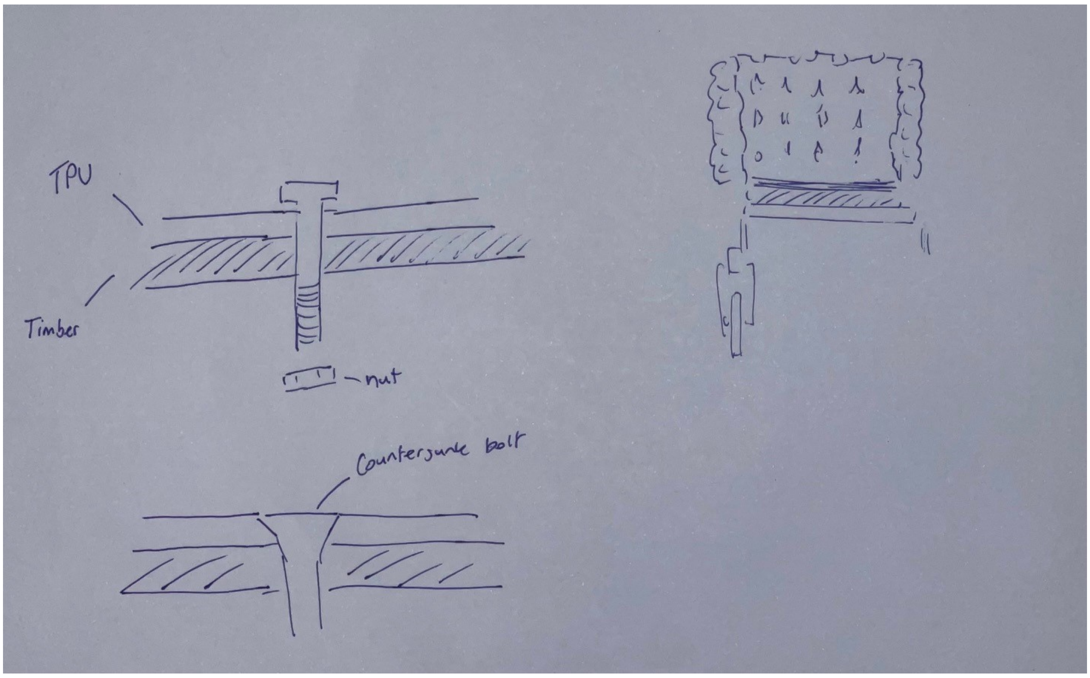

Figure 6: Bolting Attachments

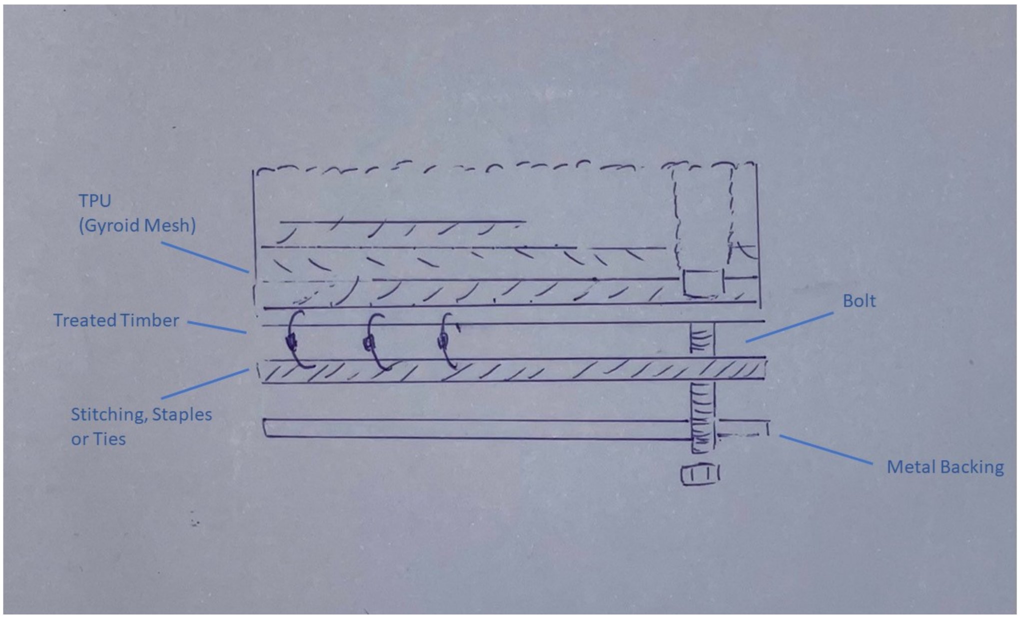

Figure 7: Conventional Attachments

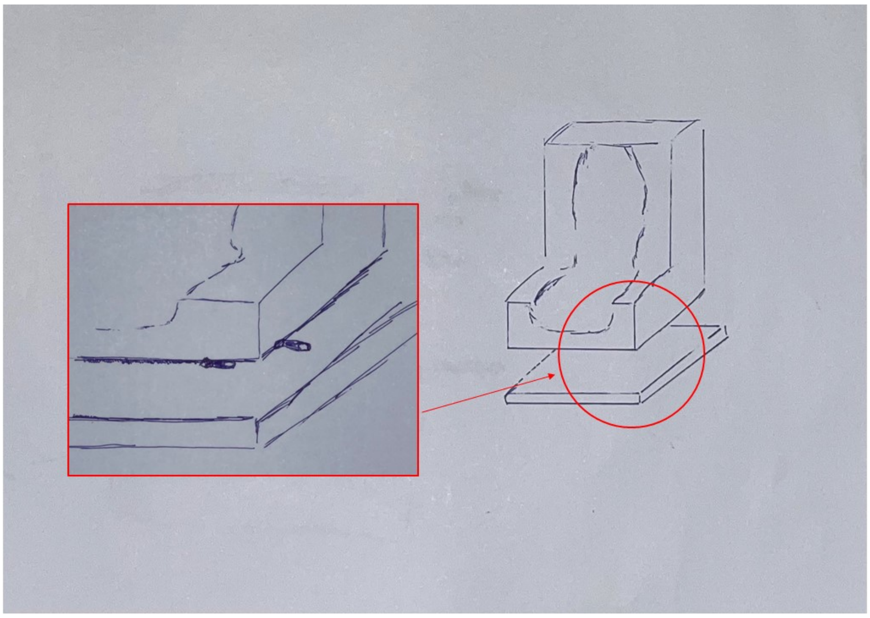

Figure 8: Zipper Attachment

A general remark would be that glue and adhesives have been greatly avoided when conceptualising attachment methods. As it had been mentioned in the current manufacturing process, the adhesive used greatly diminishes the recyclablilty of the seating material and the overall sustainability of the wheelchair.

9 Outsourcing

If the recommended company (GLIDE) [24] is unfit or for other reasons is not desirable for the outsourcing component of producing the product, the following checklist can be utilised to correctly identify the best suited company to meet the demands of the task.

Criteria	Requirements	Checklist
3D Scanning & Modelling	Experience in scaling and adjusting 3D models to precise specifications.	
3D Modelling Software	Proficiency with any 3D printing software capable of importing and exporting .obj and .stl file types.	
	Expertise in converting surface models into solid bodies.	
3D Printing Capability	Access to direct-drive extruder printers capable of printing with TPU filament.	
	Experience in printing with 1.75mm standard TPU filament.	
Material and Filament Standards	Ability to source and print with 1.75mm standard TPU filament.	
	Ensures high-quality prints with fine filament for better product results.	
DESIRED		
Quality Control and Testing	Rigorous quality control processes to ensure precision and durability.	
	Testing procedures to verify the strength and functionality of the printed backplate.	
Cost & Efficiency	Competitive pricing for 3D modelling and printing services.	
	Efficient turnaround times to meet project deadlines.	
Experience	Previous experience in projects related to medical devices or assistive technology.	

Table 4: Outsourcing Criteria and Requirements

10 Sustainability

Provided below is a table that refers various methods and companies for possible refurbishment, reuse and/or recycling practices to improve overall product and company sustainability.

Refurbishment	Reuse	Recycle
Applicable to wheelchairs	Applicable to current polyurethane foam	Applicable to wheelchairs, TPU seat, bamboo backplates, ACM backplates
Suitable materials are cleaned and repaired, and are resold or delivered to people in need	Custom seating foam is reused for other applications e.g. production of carpet underlay	Paid services and take-back programs that processes recyclable materials
EnableNSW, MediShare, GIVIT, Active Rehab, ATRIS PME	Dunlop Flooring, Airstep	**Wheelchairs**: Gregory's Metals Recycling Bins, Ecocycle **TPU**: DIY recycled TPU filament **Bamboo**: House of Bamboo, LETOBamboo **ACM**: Ecoloop

Table 5: Options for Sustainability

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