Team FoWheel
Spring 2015
EPICS-151
Section M&N

Crutches 4 Africa
284 S. Franklin St.
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17 April 2015

Dear Mr. Talbot,

Attached is the report for Team FoWheel's response to your Build a Better Wheelchair project. This report is based on the hazards encountered by wheelchair users in Africa and addresses those hazards to the fullest extent possible. FoWheel was assigned this project on 7 January 2015.

This report explains the process FoWheel used to design a more effective wheelchair. Several ideas were conceived as to upgrades which could be applied to the basic wheelchair design. Through a decision matrix, we selected three modifications we could make. Each of these modifications was dubbed a subsystem and further analyzed. This analysis included material and cost breakdowns. Our three modifications address three distinct problems: traction, safety, and carrying objects.

Our assembly instructions have been drawn rather than written in the hopes that they can be sent to workers with limited or no English vocabulary without much revising. The rest of the report, however, is meant for you and your evaluation of the design.

It has been an honor working on a project which could improve so many lives. We hope that our design makes a difference.

Best Wishes,

Team FoWheel

Build a Better Wheelchair: Project Report

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1 Executive Summary

While wheelchairs may be common or in excess in the United States and other developed countries, wheelchairs and many other mobility devices are less common in rural locations in Africa. According to Disability Network Africa, one in four people have a mobility disability in rural communities, and most of which are in need of a mobility device[1]. Additionally, standard wheelchairs which are discarded in developed countries are unsuitable for the variable terrain in Africa.

The FoWheel team has been tasked with implementing a wheelchair modification process to improve donated wheelchair usability in rural African communities. Our team identified three main flaws with current donated wheelchairs: lack of traction, risk of falling out, and carrying liquids or supplies while simultaneously powering the chair. To address these issues, team FoWheel has implemented three modifications to the current donated wheelchairs' design: the addition of mountain bike tires, a seatbelt, and a cup holder.

To address the issue of traction, our team has added mountain bike tires to our design. These mountain bike tires wrap around the original wheelchair wheels. The tires can be removed from old bicycles, or are available at low cost.

To allow the user to carry cups or other small objects, our team has implemented a foam cup holder in our design. The foam cup holder is removable, making the addition a versatile modification. The cup holder is a low cost addition of only cents per wheelchair.

To prevent the user from falling out of the wheelchair, and additionally provide the ability to carry a variety of larger items, our design implements a seatbelt. The seatbelt secures the user in the chair and attaches in a diagonal fashion similar to car seatbelts. The user can secure larger items in their lap with the seatbelt, making this modification multipurpose. The seatbelt costs only 0.70 USD per chair.

As the assemblers of this project may not be fluent in English, this report contains illustrated installation instructions in addition to written instructions for each of our modifications.

As Crutches4Africa is a non-profit organization, our team's primary goal in our design was to keep the cost low. The total design costs a maximum of only 13.22 USD per wheelchair. Our cost estimate is under the assumption that modifications will be preformed by volunteers; however, this cost includes all materials should they need to be purchased. These retrofits not only solve all aforementioned problems, but together are under the suggested budget of 50 USD and can be more effective than many commercial solutions.

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2 | Introduction

In January of 2015, the FoWheel team was presented with a project by Crutches4Africa. Current donated wheelchairs brought to local communities in Africa are unsuitable for use in rough terrain, and do not meet the needs of the users, caregivers, and other involved stakeholders. Team FoWheel brings a design based off of retrofitting donated wheelchairs to better meet the needs of the stakeholders.

The purpose of this report is to explain how to implement team FoWheel's retrofit designs onto wheelchairs. Additionally, this report explains the team's thought processes behind our design, and analyzes the effectiveness in correcting bugs found with current wheelchairs used in rural Africa.

2.1 Background Information

The earliest wheelchair design that resembles modern day wheelchairs was invented in 1919, by Herbert Everest[2]. Everest was a mining engineer who invented the modern wheelchair after breaking his back in a mining accident[2]. This was the first automobile friendly design with a fold-up feature that made the chair compact and portable. Wheelchairs have brought mobility to many since then; however, some rural communities in Africa have only recently started to receive mobility devices. Additionally, the rough terrain in many areas makes wheelchairs impractical. Various off-road and all-terrain wheelchairs have been invented and are commercially available in developed countries[3][4][5]. These off-road wheelchairs are expensive however, and unavailable to the communities that need them in Africa.

2.2 Design Alternatives and Selection Process

Our design was chosen using a decision matrix that evaluated the adaptations based on overall usefulness, practicality, and cost. The decision matrix, as seen in Figure 2.1 shows our process in selecting our design. We also selected a secondary design, also seen in the matrix.

Our design implementation emphasizes using readily available materials in local communities in Africa that are either recycled or of low cost. As some local communities in Africa have a

Scale from 0 to 3 with 3 Being the Best Outcome

	A Practical design? (Possible to make)	Supplies readily available?	Cost: Can't exceed $50	Intended to fix bugs found from the User Empathy Experiences?	Estimated Helpfulness to the user	Does the design have any obvious bugs?	Times it will be used throughout the day?	Easy to retrofit?	Weighted Result
Deciding factors	**Atleast 2**	**Atleast 2**	**Atleast 2**	**Atleast 2**	**Need 3**	**Cannot be 0**	**Cannot be 0**	**Cannot be 0**	
Weighted Decision	**25%**	**25%**	**10%**	**10%**	**10%**	**10%**	**5%**	**5%**	
Chosen Retrofits									
Bike Tires on Wheels	3	3	3	3	3	3	3	3	100.00
Cup holder	3	3	3	0	2	3	3	3	86.67
Seat Belt (any material) for Baskets	3	3	3	2	3	3	3	3	96.67
Next Choices									
Gloves for users	2	1	3	3	2	1	3	3	68.33
Bike Hand Brakes with Pad Brakes on wheels (bike)	3	3	3	3	3	2	3	2	96.67
Bathroom Flap	3	2	3	0	3	3	2	3	78.33
Not Chosen									
Bike suspension	0	2	1	3	3	0	3	0	50.00
Third Wheel	2	3	2	3	3	1	3	1	81.67
Bed fold-out	1	1	1	3	3	1	0	1	43.33
front and back Stabilizer bars	1	2	2	1	1	0	1	1	43.33
Wheel Ratchets	1	0	0	2	2	1	3	1	35.00
Dolly wheels	3	0	2	3	3	2	1	3	63.33
Handle bars with a third wheel	3	3	1	0	1	0	0	3	61.67
Basketholder on back	1	3	3	2	3	2	3	3	78.33
Disk brakes	1	0	0	3	3	0	0	0	28.33

We chose designs that were ranked the highest on the Decision matrix because those designs will be most useful, relevant, practical, and cost effective. Although the cup holder came out with a higher score than the basket, we chose the basket because it is more versatile in function than a cup holder. The Bathroom flap was also close to being used as a design. The users wouldn't have to leave their chairs to use the restroom, simply open up a flap under their seat; however, this did not work because of the chair architecture. Metal bars are located directly below the seat which would prevent the user from using the flap.

Figure 2.1: The Decision Matrix

limited availability of tools, all of our adaptations are able to be retrofitted with simple tools such as a screwdriver and an adjustable wrench.

The primary stakeholder for this project is the end user. Our team identified the major problems faced by the end user as:

- Slipping when rotating the wheels on low friction surfaces
- Difficulty carrying objects when the hands are occupied rotating the wheels
- Falling out of the wheelchair

2.3 Proposed Solution

To properly address these problems, our team created three subsystems within our wheelchair retrofit design. These subsystems are:

- Mountain bike tires to provide better ground traction
- A safety strap to prevent the user from falling out of their wheelchair, that can additionally be tied to large objects to carry

- A cup holder that can be used to carry water or smaller objects

Our design also considers the local community members who will be preforming the modifications and maintaining wheelchairs as a stakeholder. These community members may not be fluent in English, and such our team provides illustrated instructions that are included in this report. Additionally, detailed installation instructions are provided in English text to help clarify the installation process to English speakers.

2.4 Report Organization

The remainder of this report will be divided into three subsystem reports, including detailed specifications, installation instructions, relevant calculations, a cost analysis for each subsystem, and relevant diagrams.

3 | Subsystems

3.1 Mountain Bike Tires

In uneven terrain commonly found in rural Africa, maneuvering on an unmodified donated wheelchair like the one shown in Figure 3.1 can be difficult. This is mainly caused by the lack of traction between standard wheelchair wheels and low friction surfaces, such as dirt. To address this problem, our design features retrofitted mountain bike tires modified to be installed on a standard wheelchair. As mountain bike tires are designed for off-road terrain, they make the perfect candidate for incorporation into our design. Mountain bike tires make more contact with the ground than slick tires (like road bike tires), and thus more friction is created[6].

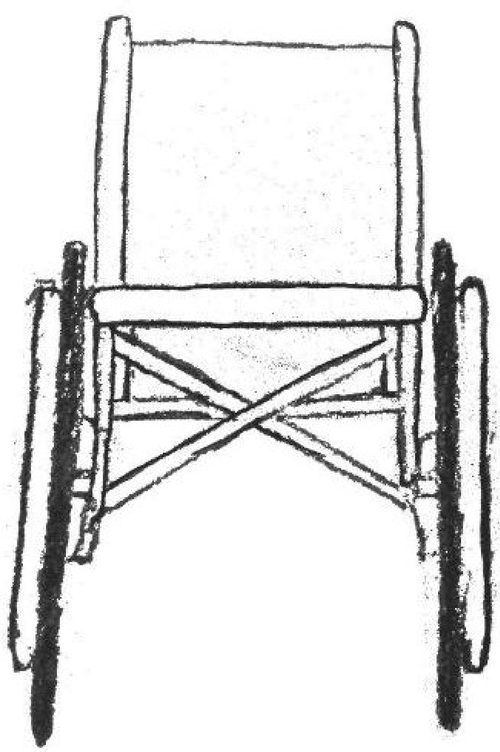

Figure 3.1: A Standard Unmodified Wheelchair

3.1.1 Stakeholder and User Requirements

The mountain bike tire subsystem addresses user and stakeholder needs by improving the quality of life of the end user. The addition of mountain bike tires extends the user's range of mobility. Locations that may have been inaccessible with an unmodified wheelchair may become more accessible with the mountain bike tires. In addition, caregivers will be able to maneuver the user more easily on rough terrain, reducing the work required for simple tasks.

The addition of mountain bike tires to the wheels extends the life of the wheels, and as a result, extends the life of the wheelchair. This directly addresses client concerns of wheelchair life in variable terrain.

3.1.2 Installation Manual

In addition to the illustrated installation instructions, the FoWheel team provides the following instructions. The installation process takes roughly 30 minutes to 2 hours.

To install the bike tires:

1. Find bike tires that are slightly larger than the wheelchair wheels. Before you take the wheels off of the old bike, make sure the bike tires are deflated.
2. Figure 3.2 shows the diameter of the bike tire is 66 cm and the width is 5 cm, while the wheelchair wheel has a diameter of 61 cm with a width of 3.05 cm.
3. The best way to put the tires on the wheelchair is to first unscrew the wheels and separate them from the wheelchair. To do this, remove the center cap on the wheelchair wheels to access the hex bolt as shown in Figure 3.3
4. Use an adjustable wrench to remove the hex bolt.
5. Figure 3.5 shows the correct side the tire should be placed on the wheelchair wheel. It is easier to put the tire onto the wheelchair wheel starting on the side of the wheel opposite of the handle bars. If the tire is a snug fit, make sure to use a solid piece of metal like a screwdriver to carefully stretch the tires onto the wheels.
6. Afterwards, screw the wheels back onto the chair.

To remove the bike tires, follow the instructions in reverse.

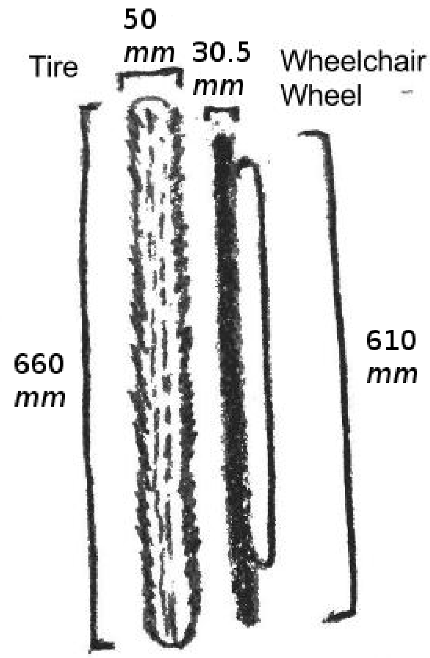

Figure 3.2: Standard Wheel Sizes and Dimensions

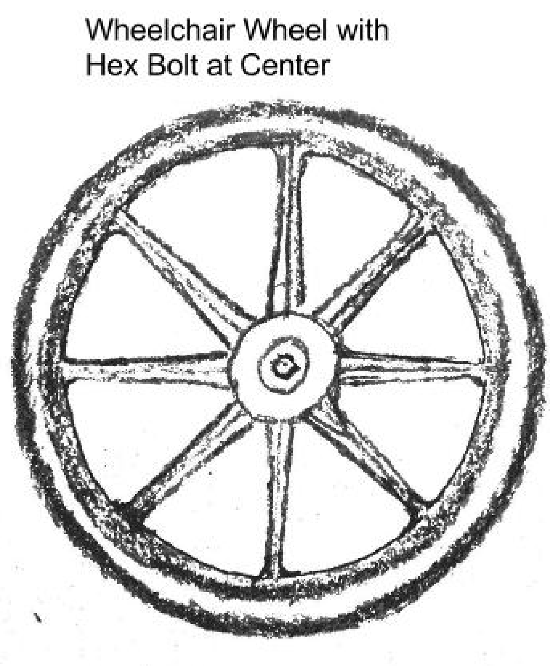

Figure 3.3: Detaching wheels from wheelchair by removing hex bolt

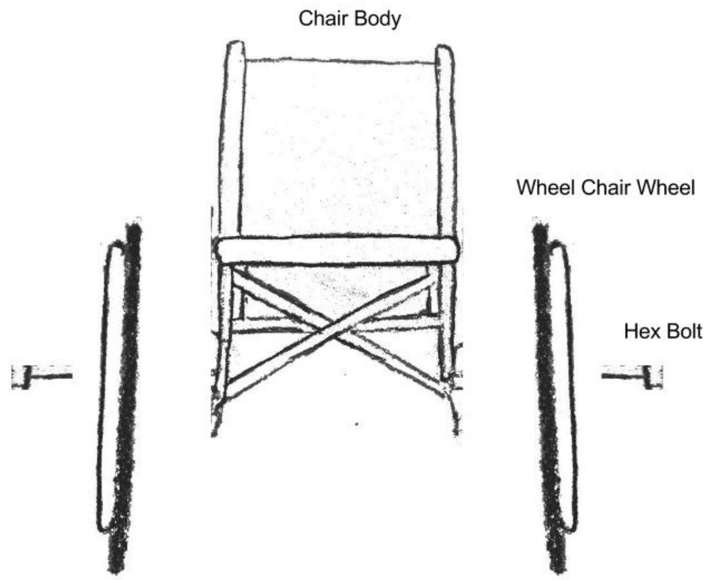

Figure 3.4: Removing both wheels from wheelchair body

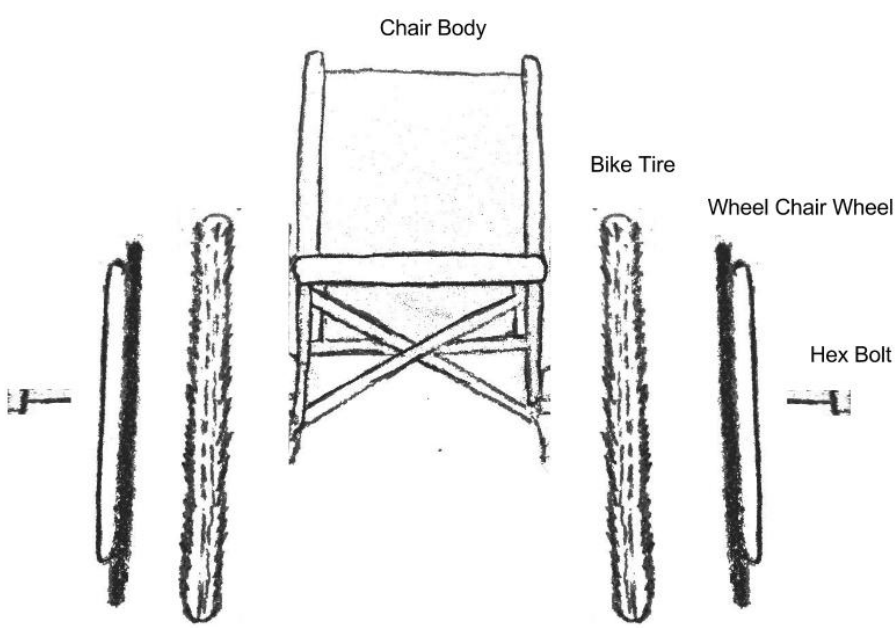

Figure 3.5: Inserting bike tires on the inside of the wheels

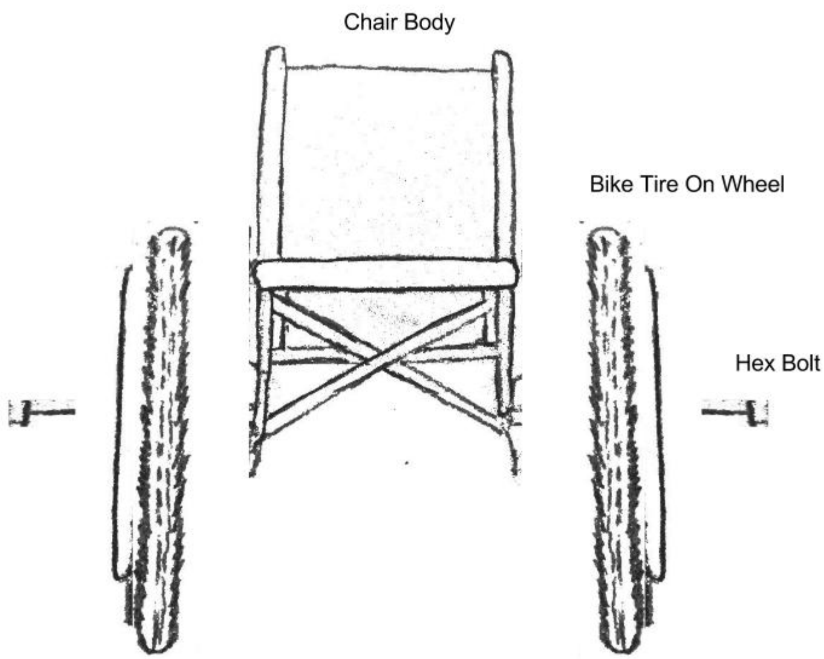

Figure 3.6: Wrapping tires over the wheels

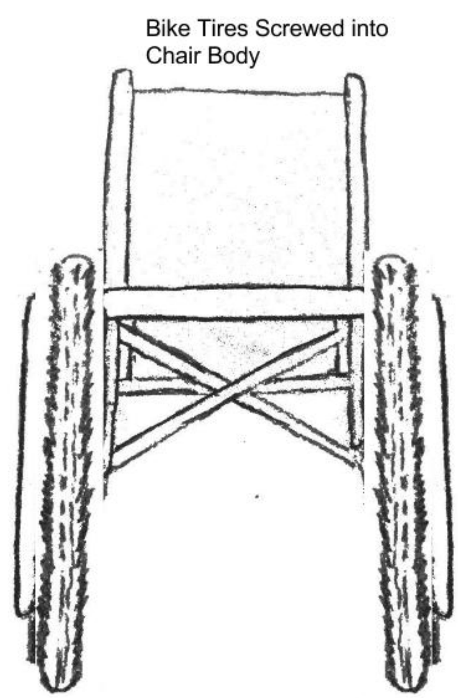

Figure 3.7: Replacing the hex bolt and installing the wheels

3.1.3 Materials

The following materials are required to install the mountain bike tire treads:

- Mountain Bike Tire Treads
- Adjusting Wrench - For loosening and tightening any size hex bolt from the wheelchair wheels.
- Screwdriver - Used to edge the tire onto the wheelchair wheel.

3.1.4 Cost Analysis

Table 3.1 shows the cost of the parts for this subsystem, as well as the estimated total cost of the subsystem. The table also provides the preferred dimensions for the mountain bike tires.

Table 3.1: Cost Analysis for Mountain Bike Tire Tread Installation

Description	Estimated Cost
Mountain Bike Tire Treads *66 cm diameter, 5 cm width*	12.00 USD[7]
Labor Costs	0.00 USD[1]
Estimated Subsystem Cost	12.00 USD

The intention of our design is to use recycled bicycle parts rather than purchasing new parts. However, Table 3.1 shows the cost of the parts should they be unavailable.

3.1.5 Calculations

The amount of surface area touching the ground can be calculated:

Standard Wheelchair Wheels

$$\begin{aligned} width_{wheel} &= 3.05\,cm \\ r_{wheel} &= 61\,cm \\ S.A._{wheel} = 2\pi \times r_{wheel} \times width_{wheel} &= 1160\,cm^2 \end{aligned}$$

[1]Assuming volunteer labor

Mountain Bike Tires Added

$$\begin{aligned} width_{tire} &= 5.0\,cm \\ r_{tire} &= 66\,cm \\ S.A._{tire} = 2\pi \times r_{tire} \times width_{tire} &= 2073\,cm^2 \end{aligned}$$

With the retrofitted bike tires, there is nearly twice as much wheel surface area now making contact with the ground giving the user twice as much more stability and control over their wheelchair.

3.1.6 Relations to the Other Subsystems

As the seatbelt is installed within close proximity to the bike tires, the seatbelt placement must not interfere with the wheels or the bike tires. Additionally, as the bike tires provide a significant amount of additional traction, the user may be more inclined to participate in potentially dangerous activities. Additionally, the seatbelt must have the safety features to accommodate for potentially dangerous activities.

Both the seatbelt and the cup holder provide storage area for items while the user is operating the wheels.

3.2 Seat Belt

Many modern devices, like cars, in which a user is in motion, contain seat belts. Seat belts are a proven method to protect a user's safety in motion[8]. In the unpredictable terrain of rural communities in Africa, a seatbelt can protect a user from injury.

Our design implements a seatbelt not only to protect the user, but also to assist the user in carrying larger objects in their lap. The seatbelt can strap around these objects to allow the user to operate the wheels while concurrently carrying items.

3.2.1 Stakeholder and User Requirements

The seatbelt helps reduce risk of injury when using the wheelchair. The wheelchair user can safely maneuver through inclines and rocky terrain without slipping out of the seat. During our user empathy tests, we found getting in and out of the wheelchair to be a difficult task. With the seatbelt:

- The wheelchair user will not fall out of the chair and have to lift themselves back, saving time and energy.

- Caregivers will be able to move the wheelchair without injuring the user.
- Locals responsible for installing the seatbelt can easily be taught the strongest types of knots in order to ensure maximum safety.
- The seatbelt is a lightweight addition with all materials available locally, removing extra weight for distributors.

3.2.2 Installation Manual

In addition to our illustrated instructions, the FoWheel team provides the following installation instructions. The installation process will take approximately 5 minutes.

To install the seatbelt:

1. Measure out two pieces of rope or similar material, one of 120 *cm*, and another of 30 *cm*.
2. Taking the shorter piece, tie two tight loops on both ends.
3. Take one loop, place the loop over one of the handles of the wheelchair.
4. Taking the longer piece, attach it to the opposite side of the wheelchair.
5. Take the loose end of the long rope and pull the rope through the other loop.

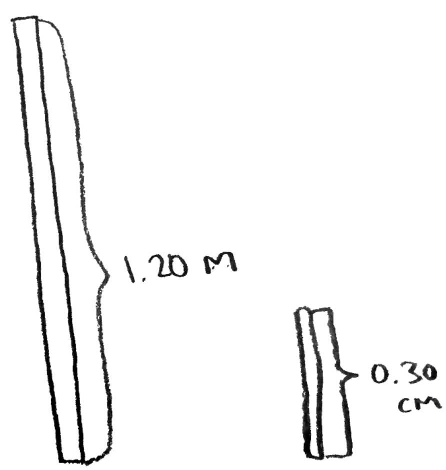

Figure 3.8: Rope Dimensions for the Seatbelt

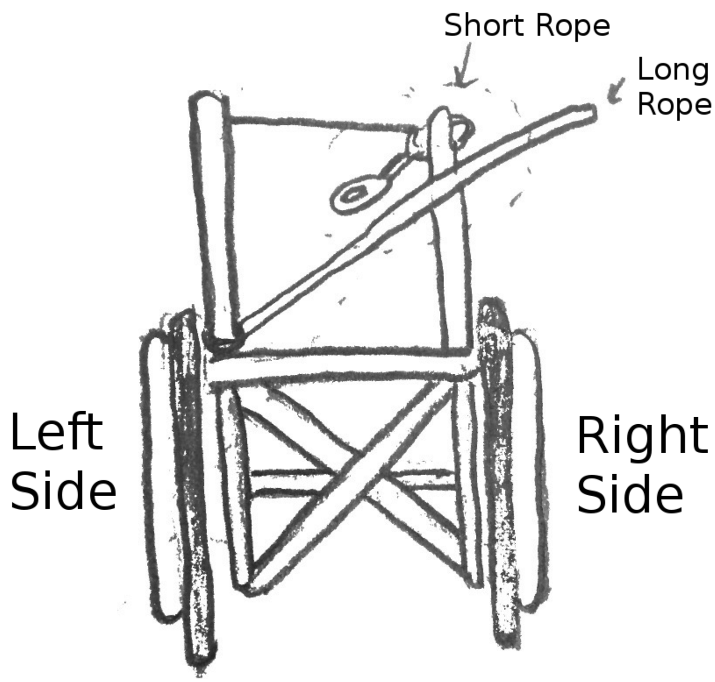

Figure 3.9: Seatbelt Assembly

3.2.3 Materials

In order to install the seatbelt, the following materials are required:

- Rope or similar material – To use as the seatbelt
- Scissors or a knife – To cut the rope with
- Measuring tape – To get precise rope measurements

Additionally, fastening points on the wheelchair for the rope can be attached will be required to install a seatbelt.

3.2.4 Cost Analysis

Table 3.2 on the next page shows the cost estimation for the installation of a seatbelt on a wheelchair.

Table 3.2: Cost Analysis for the Seatbelt

Description	Quantity	Estimated Cost
Seatbelt	120 *cm* long rope 30 *cm* short rope	0.70 USD
Labor costs	5 *min*	0.00 USD[1]
	Estimated cost per chair	0.70 USD

3.2.5 Relations to the Other Subsystems

The addition of the bike tires allow for the user to travel over rocky or uneven terrain. By travelling over such dangerous terrain, a seatbelt is necessary to ensure the user's safety.

3.3 Cup Holder

One of the challenges a wheelchair user faces is carrying objects while having to propel the chair. In order to solve this problem, we have installed a carrying mechanism: a cup holder. This subsystem consists of a foam cup holder attached to the top of the arm of the wheelchair with duct tape. The cup holder allows the user to carry small objects without the need to use their hands, freeing them to spin the drive wheels.

3.3.1 Technical Specifications

This subsystem must be attached firmly so the cup holder does not slide sideways and end up under the chair arm. The cup holder is created using a foam cup holder, scissors, and a roll of tape (duct tape is used here). The scissors are used to cut a slit in two opposite sides of the cup holder, slits long enough to fit the tape through. A portion of the tape should be folded over upon itself so the tape does not stick to the cup holder while attached. The tape is then pushed through the cup holder so the folded over portion sticks out the opposite end and the sticky side is still on the original side. The cup holder is then taped tightly to either

[1] Assuming volunteer labor

arm of the chair.

Table 3.3: Cup Holder Cost Analysis

Description	Quantity	Estimated Cost
Foam Cup Holder	1	0.27 – 0.52 USD[9]
Scissors	1 per worker	Negligible
Duct Tape of $\leq 50\ mm$ width	$\sim 250\ mm$	0.01 USD[1]
Labor Cost	$\sim 1\ min$	0.00 USD[2]
	Estimated cost per chair	0.28 – 0.53 USD

3.3.2 Stakeholder and User Requirements

This subsystem addresses the concern of users ability to carry objects. It gives them a convenient place to carry small objects.

During the user empathy activities and the client's presentation, this topic appeared often. People in Africa are expected to provide for themselves as much as possible, and being able to carry necessary objects or fluids reliably is a step in that direction. Often, wheelchair users place objects in their laps to carry them. They cannot usually grip these objects, as they must use their arms to move the wheelchair. This is especially common with very large or very small objects. The cup holder addresses the problem of carrying small objects.

3.3.3 Relations to the Other Subsystems

The cup holder works with the seat belt to allow for carrying objects. While the cup holder allows the user to carry small objects, the seat belt allows the user to carry larger objects. Together, these subsystems solve the problem as completely as possible.

[1] The labor cost per chair is negligible as this will be done by volunteers.

[2] The cost of tape per chair was determined by finding the cost of a roll of 18288 mm of duct tape (~3.50 USD[10]) and applying this to an estimated length per chair. This length was intentionally overestimated.

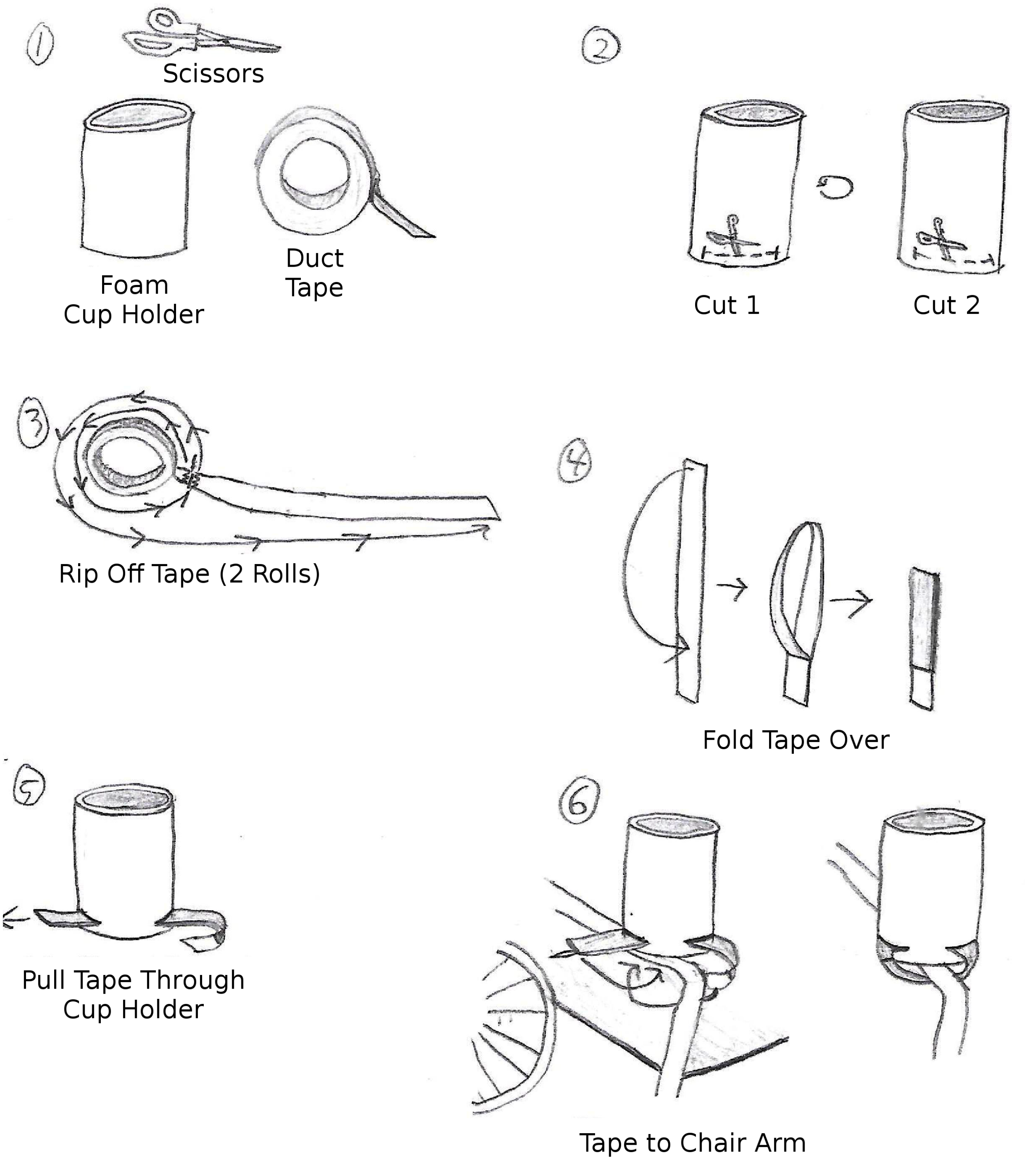

Figure 3.10: Illustrated Assembly for the Cup Holder

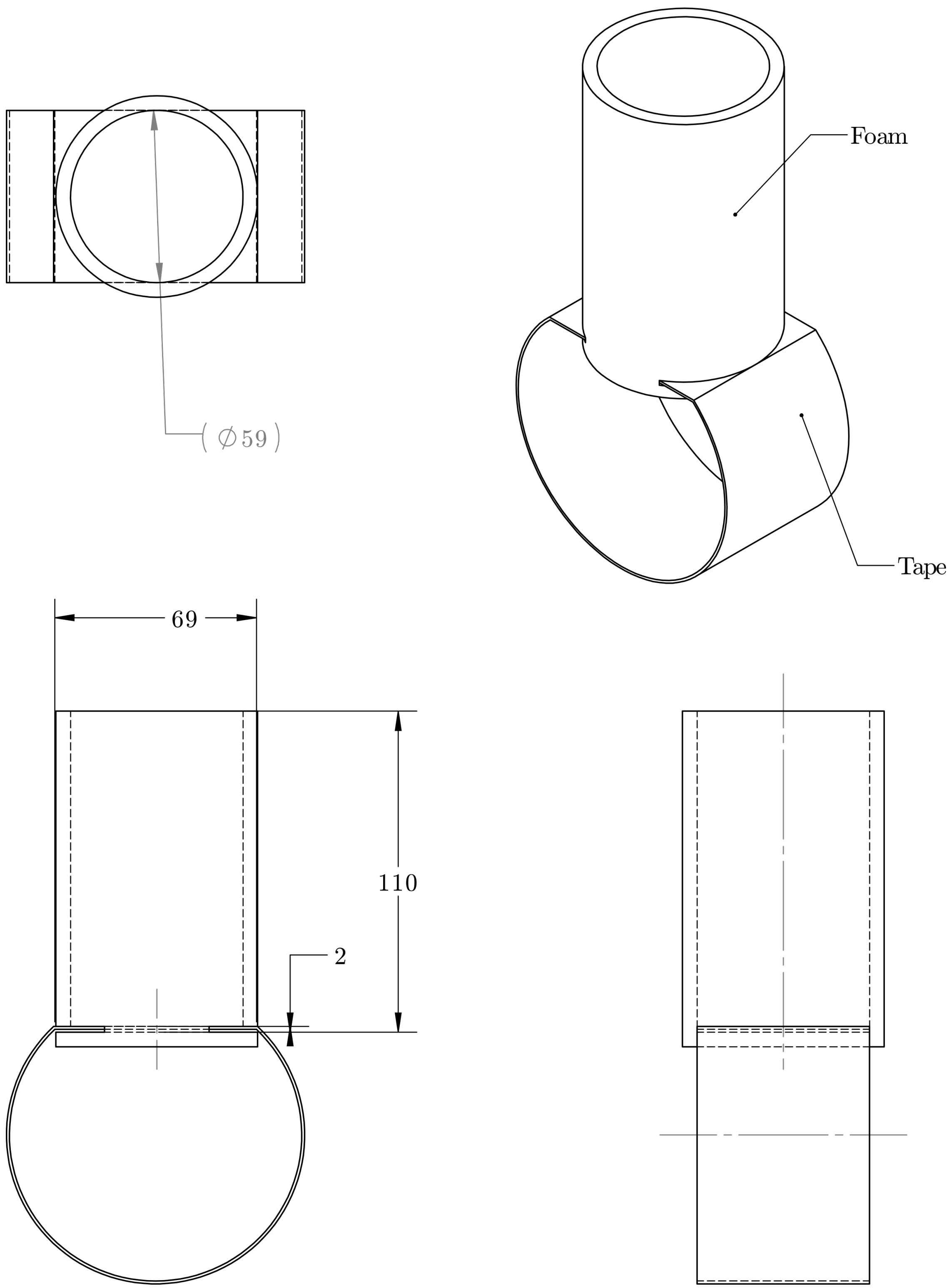

Figure 3.11: Cupholder 3D Sketch with Dimensions
Dimensions calculated using standard can sizes[11] using large tolerance

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