Botswanan Wheelchair

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Abstract

In April 2010 a collaboration of three years started between the foundation Spinalis and the ministry of health in Botswana to create permanent resources to treat persons with spinal cord injuries in Botswana. The work started immediately at the biggest hospital in Botswana located in the capital city Gaborone. They notice early that help was needed. Doctors and nurses had inadequate knowledge about spinal core injures and what it implicates and also access to aid where defective. Patients where left in their bed because the doctors didn’t know what to do with them. When they were sent home the patient still had problems to move which made most of them stuck in bed. The mortality ratio was very high during the first year after leaving hospital. Many of them died of infected pressure sores. Most patient didn’t know how to turn around in bed to depressurize the sores by them selves and where depending on people around them.

This problem where one of the first the Spinalis foundation helped to solve in Botswana. They showed how patients could learn how to turn around in bed by their own. It resulted in lower number of pressure sore and differences where notable on the mortality ratio for patients during their first year at home. By providing patients with aid and knowledge Spinals showed how a spinal core injured person can start live active and healthy. One of the most important aid for a spinal cord injured person is a wheelchair. With a wheelchair people who have difficulties to walk can start moving around by them self, independently, and have a possibility to live an active healthy life. Unfortunately Spinals had problems to provide their patients with proper wheelchairs. They had to import wheelchairs from other parts of the world, which was costly and time consuming. Spalis had to relay on donations from other organizations and foundations.

Donations are frequently made from developed countries and may appear to be an appropriate strategy to handle the situation. Donations often cause more problems then solutions. Donated wheelchairs are often used and are at the end of their useful life and are design to deal with other types of environments which often causes mechanical problems. It is often very expensive if even possible to obtain replacement parts. Donations also have been reported to have a bad impact on local wheelchair companies. When donations arrive to a community, the local store gets out of business. Later when the donated wheelchairs reach their end of life the local businesses have shut down and it gets hard find wheelchairs to supply people that need them.

This project aims to solve this problem by develop a concept of a wheelchair which is adapted for rough terrain and can be produced locally in Botswana. Hopefully this will make a proper
wheelchair available for a reasonable price and possibly also contribute to more jobs and economic growth in Botswana.

The final wheelchair concept this project resulted in has a simple design with simple joints and angels that make it easy and sheep to manufacture. The simple and neat design requires only a few tools when it is manufactured. Parts selected for the wheelchair cost in total 250USD, which can be considered to be low for an active wheelchair. The wheelchair is equipped with a long wheelbase and camber angel will allow the user to be active in the wheelchair and use it in the semi-rough environment it will be exposed to.
I started this project in hope to reach people in the wheelchair industry and acknowledge them about the situation in Botswana and similar countries. After discussion with Etac AB in Värnamo, Sweden, I am sure they have understand the problem and I am hopeful about what they do with it in the future and maybe take this project further and realize it.

I have many people to be grateful for who have helped me write my bachelor thesis in Industrial Design Engineering on the Royal Institute of Technology, KTH,

I want to thank Carl-Michael Johansson for all inspiration, helpfulness and knowledge he have shared with me. I also want to thank Bo Lindqvist who welcomed me to Etac AB and sheared his knowledge about wheelchairs and his thoughts about this project.

Thank you.

Emil Helin

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1. INTRODUCTION

This chapter describes the background, purpose and objectives of the project, also the limitations and methods used are presented here.

1.1 Background

In April 2010 a collaboration of three years started between the foundation Spinalis and the ministry of health in Botswana to create permanent resources to treat persons with spinal cord injuries in Botswana. The work started immediately at the biggest hospital in Botswana located in the capital city Gaborone. They notice early that help was needed. Doctors and nurses had inadequate knowledge about spinal core injures and what it implicates and also access to aid where defective. Patients where left in their bed because the doctors didn’t know what to do with them. When they were sent home the patient still had problems to move, which made most of them, stuck in bed. The mortality ratio was very high during the first year after leaving hospital. Many of them died of infected pressure sores. Most patient didn’t know how to turn around in bed to depressurize the sores by them selves and where depending on people around them (Spinalis, 2013).

This problem where one of the first the Spinalis foundation helped to solve in Botswana. They showed how patients could learn how to turn around in bed by their own. It resulted in lower number of pressure sours and differences where notable on the mortality ratio for patients during their first year at home. By providing patients with aid and knowledge Spinals showed how a spinal core injured person can start live active and healthy. One of the most important aid for a spinal cord injured person is a wheelchair. With a wheelchair people who have difficulties to walk can start moving around by them self, independently, and have a possibility to live an active healthy life. Unfortunately Spinals had problems to provide their patients with proper wheelchairs. They had to import wheelchairs from other parts of the world, which was costly and time consuming. They had to relay on donations from other organizations and foundations. The wheelchairs they got were not adapted to the environment in Botswana and where often used which caused mechanical problems that where hard and expensive to solve (Spinalis, 2013).

This project aims to solve this problem by develop a concept of a wheelchair which is adapted for rough terrain and can be produced locally in Botswana. Hopefully this will make a proper wheelchair available for a reasonable price and possibly also contribute to more job opportunities and economic growth in Botswana.

1.2 Purpose

Develop a concept of a manual wheelchair that can be used and produced locally in Botswana.

1.3 Objectives

The objective of the project is to develop a concept that can be used as a basis for further development and later realization of the purpose. Ultimately the goal is to make active wheelchairs more accessible to people in Botswana.

Later on it could be extended to be applicable in other countries with similar problems to supply proper wheelchairs to more people. Possibly also contribute to more job opportunities and economic growth in developing countries.
1.4 Delimitations

In this project a concept are going to be developed and thus no finished product. The concept is going to be visualized in illustrations and in a CAD-model. As a result of a tight times schedule for this project many of the parts that are going to be used are standard parts where the aim is to choose part that are available in Botswana. Only the frame is going to be developed from scratch. All objective and empiric validation of a prototype is inadequate because of lack of time.

1.5 Method

The structure of this project follow a stage-gate represented by a waterfall as shown in Figure 1.1 where each stage is represented by a flat area where the water pools before falling to the next pool. Finalized work in each stage is approved at a decision stage before continuing to the next stage (Ullman, 2010).

![Project plan in a waterfall structure.](image)

1.5.1 Project Planning

A Gantt-chart where made with all activities specified. Deadlines for when gates needed to be done where set. However, as with much design activity, this required speculating about the unknown (Ullman, 2010).

1.5.2 Project Definition

The goal in this phase was to understand the problem and lay a foundation for the rest of the project. This includes an identification of the costumers and their environment. Also to acquire knowledge about wheelchairs and their market. The result of the literature studies and resource serves as the basic to the requirement specification for the product (Ullman, 2010).

1.5.3 Conceptual Design

During this phase results of the Project Definition are used to generate and evaluate concepts for the product. Costumer’s requirements serve as a basis to come up with a concept to fulfill the project purpose (Ullman, 2010).
1.5.2 Product Development
After the concepts have been generated and evaluated it is time to refine the best of them into a final concept. This phase include concept development chose of material, dimensioning, manufacturing- and assemble analysis (Ullman, 2010).
2. PROJECT DEFINITION

In the Project definition a summery of the primary studies about wheelchairs and Botswana are presented. It also includes some important definitions and methods frequently referred to in the report.

2.1 Methodology

During the working process a number of methods where used which are referred to in the report. The methods are shortly explained bellow in purpose to facilitate understanding.

2.1.1 Requirement Specification.
Requirements and wishes are specified on the concept that is going to be developed. They need to be measurable and solving independent. During the concept development a requirement specification serve as guidance (Bohgard, o.a., 2010).

2.1.2 Brainstorming
Brainstorming is a common used method during ideation. Participant’s tries unreserved come up with as many solutions as possible without any critic or evaluation during the process. Spontaneously and quantity priorities and big number of separated ideas are generated (Ullman, 2010).

2.1.3 Morphological matrix
There are three steps included in this method. First step is to identify and list decomposed functions that must be accomplished. Second step is to find as many concepts as possible that can provide each function. Last step is to combine these individual concepts into overall concept that solves all the functions required (Ullman, 2010).

2.1.3 Design for Cost
Design For Cost, DFC, means keeping an evolving cost estimate current as the product is developed. It is important to be aware of what different design choices makes of an impact on the price for the final costumer (Ullman, 2010).

2.1.4 Design for manufacture
Establish a shape of components to allow for efficient, high-quality manufacture. The key concerns are to specify the best manufacturing process to the component and ensure that the component form support the process selected (Ullman, 2010).

2.1.5 Design for Assemble
A practise used to measure the ease with which a product can be assembled. Virtually all products are assembled out of many components and assemble takes time. There is a strong inventive to make products as easy as possible to assemble (Ullman, 2010).

2.1.6 The Decision matrix- Pugh´s method
Provides a means of scoring each alternative concept relative to the others in its ability to meet the criteria. Comparison to the scores in this manner gives insight to the best alternatives and useful information for making decision (Ullman, 2010).
2.1.7 Costumer Requirements.
Requirements of what requests different costumers have on the product, not only the consumer but also the producer and marketing costumer. The key is to collect information about their different needs and demands and transfer it to requirements.

2.2 The country Botswana
Botswana is located on the plateau in the centre of southern Africa. The country has an average height of about 1000m above sea level and has no seacoast. The population was 2,15 million people in 2013 (indexmundi, 2014).

2.2.1 Climate.
The climate is continental and semidry. About 85% of the land is covered with sand and supports a savannah type of vegetation. The temperature varies between 40 degrees Celsius during the hot summer months and 25 degree during the warm winter but the temperature can drop drastic during night-time and can be below 0 degree.

2.2.2 Economy.
In a few years back Botswana had big issues with the economy but thanks to diamond access they have in just a few decades developed to be considered as a middle-income country. They now have a BNP of 17600 million dollars witch is the 103 highest among all countries (International Montary Found, 2012). The fast economic recovery is mainly an effect of the highly profitable mines which is almost the only on going industry and unfortunately they do not need a very big working labour. It has resulted in huge income gaps in Botswana and almost half of the population is outside the formal economy.

Almost all consumer habits are imported, including food. It makes the country vulnerable and dependable on other countries. Also the money they get from diamond industry is spent outside Botswana, which doesn’t contribute to higher turnover for local industries. Local business and manufacturing industries have problems to make profit and the unemployment is as a result very high. Even if a part of the country are doing very well Botswana in some cases be considered as a developing country because of the living situation for the low income earners that are a very high part of the population (Deléchat & Gaertner, 2008).

2.2.2 Health care
Among people of age between 15 and 49 the prevalence rate are almost 25%, which is the second highest in the world. Botswana’s government are putting a lot of effort and money in health care. As a result of the high number of HIV/AIDS infected in Botswana a high part of the money go to that problem area. As for most other goods medical products, aid and medicines are imported from other countries (Avert, 2014).

2.3 Importance of wheelchairs
A wheelchair is an aid to people who are not able to, or have difficulties, to walk. It exists a high range of different types and models of wheelchairs depending on widely diverse requirements from the user. But the purpose of all wheelchairs is to provide mobility to people who are not able to use their leg to move around (Spinal outreach team, 2013).
Wheelchairs can be split into two categories; electric- and manual-wheelchair. Electric-wheelchairs are driven by an electric motor. They are used by people who need a higher degree of assistance to maneuverer their wheelchair or by people who want to use their wheelchair for longer and faster transportation. A manual-wheelchair is totally driven by the user or an assistant person pouches the wheelchair using handles placed on the backrest. Manual-wheelchair is often divided into two groups; Active wheelchairs and Static wheelchairs. Static wheelchairs have a comfort seat where the user have a good position to rest and relax but not in a position to be active and propel it. Instead it is supposed to be pushed around by an assistant or caretaker using the handles on the backrest. This is the type of wheelchair often used in hospitals and airports. An active wheelchair is design to encourage the user to control and propel it. The seating is comfortable but the user can easily move around and reach the push rim to drive the chair (Engström, 2002). This project wants to encourage people with disability to live a more active life, that is why this paper manly focuses on active wheelchairs.

2.2.1 Wheelchairs in developing countries
Approximately 10% of the global population has a disability, 75% of them lives in developing countries. Of them some 10% needs a wheelchair (World Health Organization, 2008). There is no accurate data on how many number of people in developing countries that require a wheelchair but in 2003 estimations was made that 20 million of those requiring a wheelchair did not have access to one and indications say that only a few of them who had access to a wheelchair had an appropriate one (Armstrong, 2008). A wheelchair is appropriate when it meets the users individual needs and the environmental conditions (Jacobs, 2007). Donations are frequently made from developed countries and may appear to be an appropriate strategy to handle the situation. Donations often cause more problems then solutions. Donated wheelchairs are often used and are at the end of their useful life and are design to deal with other types of environments which often causes mechanical problems. It is often very expensive if even possible to obtain replacement parts (Mulholland & Kim, 1999). Donations also have been reported to have a bad impact on local wheelchair companies. When donations arrive to a community, the local store gets out of business. Later when the donated wheelchairs reach their end of life the local businesses have shut down and it gets hard find wheelchairs to supply people that need them (Mulholland & Kim, 1999).

2.3 Wheelchair technology
A wheelchair is supposed to enable mobility and creativity. It is important that the wheelchair is prober designed to suit the user and the environment it is going to be used in.

2.3.1 Rolling resistance
Wheels always have a breaking influence caused by friction in the bearings. The breaking influence is depended on load, fringe velocity in the bearing and contact space to ground. Fringe velocity is depended on the diameter of the wheel. Big wheels do not need to rotate as fast as small wheels. It is because a big wheel doesn’t need to rotate as fast as small wheels. This can be viewed in equation

\[
\omega = r \cdot v_p
\]

\(\omega\) is the rotation speed, \(r\) is the radius of the wheel and \(v_p\) is the fringe velocity at \(r\).

When contact against the ground is big rolling resistance is high and when it is smaller the rolling resistance gets smaller. It makes it better with hard tyres to reduce rolling resistance. Small wheels with small diameter have easier to sink into soft ground that causes big contact area and high rolling resistance (Engström, 2002).
2.3.2 Load distribution
Load on the wheels depends on weight of wheelchair and the user. It also varies on location of the systems centre gravity, referred as CG henceforth. The back wheels are bigger and have a lower rolling resistance which means it is preferable to have as much weight on the back wheels as possible when a low rolling resistance is preferable. It makes the wheelchair easier to propel and manoeuver. Adjustments of CG location can be achieved by rearrangement of components or by adjustment of seating position for the user.

If CG is located to far back the wheelchair is going to have a tendency to rotate backwards wish can be dangerous for the user. When CG is located in front of the back wheels, gravity causes a torque that pushes the front wheels down to the ground. The torque is proportional to the horizontal distance \( d \) between CG and the back wheels. A big distance \( d \) reduces the tendency for the wheelchair to tip backwards. The torque is only affected by the distance \( d \) and not by height. But when a wheelchair stars to tip backwards the distance is going to decrease and also the torque. The level of degrading when it tips is affected by the height of CG. A high-located CG causes the torque to reach zero earlier then with a low-located CG.

If location of CG is not possible to adjust the distance between front wheels and back wheels also modifies the load distribution. This is because force balance says

\[
\uparrow: F_F + F_F - m \cdot g = 0
\]

where \( m \) the systems total mass. When looking at the torque around the back wheel.

\[
\bigcirc: a \cdot m \cdot g - (a + b) \cdot F_F
\]

which after rewriting is

\[
a \cdot F_B = b \cdot F_F.
\]

If distance \( a \) is kept constant and distance \( b \) is increased the force \( F_B \) has to increase and force \( F_F \) has to decrease. By making the distance between front- and back-wheels longer the load on front-wheels can be reduced (Engström, 2002).

2.3.3 Frame
Wheelchair frames can be divided into two main categories; Rigid- and folding frame.

A rigid frame does not centrally fold; folding down backrest and removal of the rear wheels can collapse it. Rigid frame are easier to propel and turn due to the stiffness of the frame, no energy lose in frame movement. It often has good adjustment abilities and a compact style. Unfortunately it becomes more difficult to transport due to the lack of folding ability. Folding frames folds via a cross brace underneath the seat. It makes it more practical to transport especially if the rear wheels are removable. But it is often harder to propel than wheelchair with rigid frame and takes up a bigger place witch can be a disadvantage when riding in tight environment (Spinal outreach team, 2013).

Frames can be made of a vide range of materials but the most common are aluminium, stainless steel or mild steel (Spinal outreach team, 2013).

- **Mild steel** is inexpensive, easy to work with and is freely available. It has a low strength to weight ratio.
- **Stainless steel** is expensive, hard to work with. It has dissent strength to weight ratio.
- **Aluminium** is inexpensive and has a good strength to weight ratio. It is complicated to construct with and can be challenging to get (Spinal outreach team, 2013).
2.3.4 Rear Wheels

Normally the rear wheels are large and have a push rim for self-propulsion. The size varies where the most common for adults are 24”. Also 22” and 26” are available although 26” are very unusual and hard to find. The wheel rims can be made from different types of material including aluminium, plastic and steel. Plastic wheels are light and durable but more expensive than steel and aluminium. Steel is much heavier than aluminium rims but have similar durability.

Rear wheel tyres can be pneumatic or solid. Pneumatic tyres provide a more cushioned ride due to vibration absorption by the air but can have a higher rolling resistance on solid surface due to high contact area. Pneumatic tyres are normally easy to find and inexpensive. Solid tyres are maintenance free have a low rolling resistance on solid surface. But provide less vibration absorption and have bad capacity to when used outdoors on rough terrain (Spinal outreach team, 2013).

2.3.5 Casters

Casters are the front wheels of the wheelchair. They manoeuvre and steer the wheelchair. To make the casters to work in a satisfying way it is important to mount them with the turning axis perfectly perpendicular to the ground. If not so, the bearing is not going to work proper and cause problems when turning. The bearing is not going to have the load where it designed to have it and this will cause higher turning resistance and an earlier failure. This makes it important to adjust the height and angle of the front wheels to minimize the possibility to have wrong angle of the axis (Engström, 2002). Normally wheelchair are provided with two small front wheels but in some cases there is just one. Size on casters varies between 3” to 10” and the construction materials available include aluminium, plastic and urethane. When considering the type of caster it is important to observe what type of surface it will be propelled on and how much space that are allowed for them (Spinal outreach team, 2013).

2.3.6 Camber

To make the chair more ergonomic the back wheels are tilted and leaning into the chair, it is called camber. It makes the wheels come closer to the user to reduce the static load on shoulders and neck (Engström, 2002). The User can propel it more powerful and can be more active. It also makes it more stable and easier to keep it on a straight course. It also reduces tendency for it to tip over to a side when driving on an angled surface. But if the camber is to big the wheelchair is going to take up a bigger space then necessary and clumsy in tight environment. The angled Wheels also can create unnecessarily high tension at bearings and where it is attached to the wheelchair frame (Dirkjan 1989). Camber in everyday use wheelchairs varies between 0 to 4 degrees. With a 26” rear wheel, each degree of camber makes the wheelchair 2,5cm wider (Engström, 2002).

2.3.7 Seating

Seating shape should follow the skeleton shape to allocate pressure distribution and create stability (Michiel, De Looze, Lottie, Kuijt-Evers, & Jaap Van Dieen, 2003). Every user is going to have a unique anatomic structure that makes it important that the seating is adaptive to handle the differences. A horizontal seat is good for most people but a totally even horizontal seat makes it hard to sit on for long periods, local pressure points make it uncomfortable. Back tilted seats makes the pelvic bone to tilts backwards which stabilize it and the upper body. If the backrest also is tilted backward the pressure is going to be higher on the backrest and create a more stable and comfort position. Unfortunately it also creates more static position to move, it gets harder to move forward and rotate the shoulders. If the backrest is kept in an upright position while the seat is tilted backwards a stable position is created while maintaining activity of the upper body (Engström, 2002). Usually the seat angel is between 0 and 12 degrees (Spinal outreach team, 2013). The height of the backrest should be just under the shoulder blades to
maintain stability but allow activity of the shoulders (Engström, 2002). Seat height is very individual and is depended on body length and environment. It is important to be able to adjust the footrest to adapt it to the seating. The user should have about five centimetres, or two fingers, from calf to seat. It makes the seat support most of the thigh without creating pressure point onto the calves (Michiel, De Looze, Lottie, Kuijt-Evers, & Jaap Van Dieen, 2003).

2.4 Market research

It is impossible to create a wheelchair that fulfils the needs for all users. Disability, environment, riding context, producing process and economy is some of the factors that need to be considered when designing a wheelchair. An investigation was mad on the market of wheelchairs in developing countries to find strength and weaknesses in different. Primary companies and organisations with a mission to provide people in developing countries access to a wheelchair have been studied. Their working strategy has been acknowledged and their wheelchair’s specifications.

2.4.1 Free Wheelchair Mission

Produces cost-effective and durable wheelchair with basic design and simple solutions. Their wheelchairs are designed to handle regular use in roughed terrain common in developing countries. Their wheelchairs are manufactured in China and later shipped to distribution partners where they are assembled and delivered to the recipients (Free Wheelchair Mission, 2014).

- **GEN_1** is a multipurpose wheelchair designed for use in roughed terrain. Provides basic mobility to a broad range of costumer. The wheelchair is not adjustable and has no folding capability. The frame is made of mild steal to lover the cost in the manufacturing process and the chair is made out of plastic. The wheelchair cost 72USD to buy.

- **GEN_2** has adjustability in mind, allows user to customize it to fulfil theirs personal needs. Provides basic mobility but and can be used to travel longer distances. It are not design to handle roughed terrain as good as **GEN_1**. The wheelchair frame is made out of mild steal. It has no folding capability and cost 72USD. The Free Wheelchair Mission GEN_2 can be viewed in figure 2.1.

![Figure 2.1: Free wheelchair mission GEN_2.](image)
2.4.2 Leveraged freedom chair
Instead of pushing on wheels, like a regular wheelchair, Leveraged freedom chair is provided with levers to propel it. With the levers the wheelchair can move 76% faster on flat ground and have 50% more torque when riding over obstacles or rough terrain. The levers are removable which enable users to use it like a regular wheelchair. It can be beneficial in certain situations when the wheelchair needs to be more flexible. It has three wheels with a bigger front wheel then regular wheelchair to reduce the rolling resistance. It also allows the chairs to have a longer wheelbase that is beneficially in rough (GRIT, 2013).

![Leveraged freedom chair](image)

**Figure 2.2:** Leveraged freedom chair, developing wheelchair.

- **Developing** wheelchair is made to provide the developing world with a rough terrain adapted wheelchair. It is made out of locally available materials. They have taken advantage off all bicycles and bicycle-shops that exists in developing countries and have made all moving parts on the wheelchair of bicycle parts. The frame is made out of mild steel that is cheap and available in developing countries. The wheelchair can be observed in figure 2.2.

- **Industrialized** wheelchair has the same basic technology with the leverage system and three-wheel concept as the developing model. But has been updated to fit the developed countries wheelchair market with lover weight, high-end material and a refined design to better suit users in more developed countries. The income of this chair will help finance the production of the developing country adapted wheelchair.

2.4.3 Motivation
Makes wheelchairs specifically designed for use in developing countries. Motivation makes robust, affordable, reparable and adjustable wheelchairs by using locally available materials and simple design. They provide all chairs with pressure reliving cushions and design the chairs to fit their users. All chairs are manufactured in china and shipped to their clients (Motivation, 2014).

- **Active folding wheelchair** is designed to be an active style wheelchair to provide self handled propulsion. It is developed to suit the terrain of semi-urban terrain in developing countries. It has two bicycle wheels at the back and two medium-sized caster wheels in front to handle uneven ground. It is made to be easy to repair and replace spare parts by using common wheel and bearing sizes. The frame is made out of mild steal. It can be folded together. The wheelchair can be viewed in figure 2.3.
Rough terrain wheelchair is designed to handle rough terrain. It has two bicycle wheels at the back and one single large castor wheel at the front with a long wheelbase. It helps the user to propel the chair over uneven and rough terrain.

2.4.4 Whirlwind
Whirlwind wants to serve wheelchairs riders in the developing world with quality wheelchairs who can handle the roughed terrain. They try to build a worldwide franchise network, which include designers, manufactures, assembly centers, distributers and riders. This degreases shipping costs, time and environmental impact. This combines whit the material used on their wheelchair degreases the prise and makes it affordable for their clients (whirlwind, 2010).

RoughRider is the only wheelchair model whirlwind provide. The frame is made out of steel and most parts are replaceable in local bicycle shops. The most obvious difference with the RoughRider compere with other wheelchairs is the long wheelbase. It is 50% longer then on a regular wheelchair. It provides the user stability and prevents users to tip over. The wheelchairs centrum of gravity is close to the back wheels that make it easier to propel it in rough terrain. Roughrider can be viewed in figure 2.4.

Figure 2.3: Active folding wheelchair.

Figure 2.4: Whirlwind RoughRider.
2.5 Conclusion of Project Definition

To fulfil this project aim to make a manual wheelchair that’s adapted to be used and produced in Botswana. It is relevant to adopt it to the semi-urban terrain it is going to be subject for. To be able to propel in that kind of terrain the theory study showed it is relevant to;

- Have a low rolling resistance. It is gained by distributing as much of the total weight as possible to the rear wheels. It is fulfilled by ether locate the CG to the back of the wheelchair or create a long wheelbase.

- Adding camber to the wheelchair can make it more stable to handle angled surface. To not cause to much stress in rear wheel bearings and to not make the wheelchair take up to much space the camber angel is set to be 3 degrees. It is a normal setting among every day used wheelchair and are considered enough to create stability, see chapter 2.3.6.

- Pneumatic tyres should be used due to increase durability when operating it outside and make the drive smoother.

To make the wheelchair able to be processed in Botswana it has to be constructed with available and cost effective materials and components. The best Material to construct the frame of is main steals. It is cheap, available and easy to work with. Market resource showed wheelchair developed for developing countries is constructed by main steel.

It is seems to be important to make a simple shape on part that is going to be constructed as possible. It needs to be able to manufacture it with as few tools and machines as possible. It would be preferable if the wheelchair could be constructed in a regular bicycle shop and with the machineries and tools they have available in Botswana.

In Botswana the access to cars is pretty low among the middleclass inhabitants. It can be concluded that the wheelchair doesn’t need to be foldable. Instead a rigid frame with better driving characteristics should be used.

2.5.1 Requirement specifications

A requirement specification was made based on the literature studies. It includes specifications about what the wheelchair should provide and be able to do. It also includes costumer requirements that are essential for the wheelchair to satisfy in the best manner possible.

*Table 2.1:* Costumer requirements that is essential for the wheelchair to satisfy.

<table>
<thead>
<tr>
<th>Costumer Requirements</th>
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<tbody>
<tr>
<td>Handling rough terrain</td>
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<tr>
<td>Handling inside environment</td>
</tr>
<tr>
<td>Active design</td>
</tr>
<tr>
<td>Adjustable to meet user needs</td>
</tr>
<tr>
<td>Material demand</td>
</tr>
<tr>
<td>Designed for Assemble</td>
</tr>
<tr>
<td>Designed for Manufacturing</td>
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</tbody>
</table>
The costumer requirement include that the wheelchair needs to be able to handle the rough terrain provided in Botswana and at the same time be able to propel inside in tight environment. The wheelchair needs to have a design that invites the user to be active and to be adjustable to adapt for different users. To make the wheelchair producible in Botswana it has to be made by available materials. It also needs to be easy and cost effective to assemble and manufacture the wheelchair.
3. CONCEPTUAL DESIGN

In this chapter the process to generate concept ideas are presented, from ideation, concept evaluation to concept selection.

3.1 Ideation

The first step was to generate ideas to select from. The aim for the ideation was to come up with as many ideas and solutions as possible that could please the customer criteria’s.

3.1.1 Brainstorming

With Brainstorming a series of proposals were generated. Most of them where suggestions on frame design with a long wheelbase in purpose to create a stable wheelchair, inspired by whirlwinds wheelchair RoughRider. Brainstorming was done a number of times during the ideation phase, sometimes to come up with new ideas and sometimes to develop an existing idea.

![Picture of brainstorming in progress.](image)

Figure 3.1 Picture of brainstorming in progress.

3.1.2 Morphology matrix

To make the ideation easier and more structured it got divided. Five sub functions where identified;

- Frame shape
- Foot rest
- Push handles
- Backrest
- Rear wheel axle.

These functions where the focus of the new design effort. Solutions and concept suggestions on each function got generated true brainstorming. The result where presented in a matrix that can be viewed in figure 3.2.
By combining the individual concepts for each function a complete conceptual design can be made. Selection of one concept for each function and combine those into one single design. In this phase of the project two combined concepts where selected for further development. One with a long wheelbase and a box shaped frame that is market with a red in figure 3.2 and one triangle shaped frame with its combined concepts market with blue in figure 3.2.

### 3.1.3 Concept 1: Box frame
The first idea is marked with red in the morphologic matrix, figure 3.2. It is a concept with a box shaped frame. The box shape makes a stable and rigid wheelchair frame. The box shape makes it easy to adjust the wheelbase during further development. It has a long wheelbase that makes it possible to place the centre gravity close to the rear wheels and make the wheelchair stable and easy to manoeuvre in rough terrain. Also the position of seat, footrest and rear wheel should be easy to adjust further into the developing process. The box shaped frame makes it possible to have a long wheelbase but to still use large castor wheels that are preferable in rough terrain.
The box shape is potentially easy to manufacture. It has minimum number of complicated angles to consider. The corners can be connected by welding, screws or by bending the pipes into 90 degrees corners.

In this stage of the process only a rough draft of the concept has been done in the shape of a CAD model that can be viewed in figure 3.3. In this draft welding connects the corners, the frame is made by 20mm steel pipes. The wheelbase is set to 600mm and the footrest is placed 50mm in front of the seat. The camber angle is supplied by an angle on the frame that may not be preferable regarding to DFM. In this draft the backrest is connected to the frame with an adjustable arm. It has a 3-degree camber that will provide a comfortable and stable ride. The camber will also make the wheelchair easy to keep on the right course. It makes the backrest angle adjustable but makes it more difficult to manufacture but easier to adapt to the users needs.

3.1.4 Concept 2: Triangle frame

The second idea is a triangle shaped frame that is marked with blue in the morphological matrix figure 3.2. The frame is tilted down from the rear wheels to provide support to the castor wheels. The angle is going to variety depending on the length of the wheelbase. The idea is to have the footrest straight upon the castor wheels that is going to force them to be small. This can be a problem when propelling the wheelchair on soft surface. Small wheels have a higher possibility to sunk down into the surface and increase rolling resistance for the wheelchair.

The triangle frame has angled corners that need to be connected correctly. It can be hard to mount them correctly which makes the manufacturing process complicated.

A draft in CAD has been made of the triangle concept and can be viewed in figure 3.4. It is made by 20mm steel pipes that is welded together. The wheelbase is 45mm long that gives the lowest bar a 20-degree angle relative to the surface. The footrest is placed straight upon the castor wheels. Camber angle is 3 degrees and is provided by a camber axle. The backrest is mounted rigid to the frame tilted 5-degree backwards.

Figure 3.4 Concept 2, Triangle Frame.
3.2 Concept evaluation

To evaluate what concept that has best potential to meet the requirements and is realistic to realize an evaluation process was preceded. The recourse from the literature studies and the requirement specification where used during this phase.

3.2.1 Decision Matrix

To make a definite decision on which concept to choose for continued development a decision matrix where used. The concepts where evaluated on how well it satisfy customer requirements versus a datum. The datum where choose to be Whirlwinds wheelchair the RoughRider, see more in chapter 2.5.4. The other concepts where compared to the datum as measured by each of the criteria. If it was better then the datum the concept where given a + score. If it is judged to be about the same as the datum a 0 score was used and if the concept did not meet the criteria as well as the datum it was given a – score.

Table 3.1: Decision matrix or Pugh’s method. Criteria’s are weighted between 1 for the least important and 5 for the most important criteria.

<table>
<thead>
<tr>
<th>Criteria:</th>
<th>Weight</th>
<th>Datum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handling rough terrain</td>
<td>3</td>
<td>RoughRider</td>
</tr>
<tr>
<td>Handling inside environment</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Active design</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Potential to meet user needs</td>
<td>3</td>
<td>RoughRider</td>
</tr>
<tr>
<td>Material demand</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Potential to be DFA</td>
<td>4</td>
<td>+</td>
</tr>
<tr>
<td>Potential to be DFM</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total: -1</td>
</tr>
<tr>
<td>Weighted total:</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

None of the concept where developed very far so most of the evaluation was regarding to speculations and assumptions. The Box frame concept got a lower score on the criteria Handling inside environment because of the longer wheelbase which cause a bigger turning radius. The Box frame is also made of more pipes that will make it more material demanding. The box frame only has right angels that are easy to connect and work with during manufacturing. It is assumed that the frame is going to be easier to design for manufacture then the datum product.

The triangle frame has some similarity to the RoughRider, which is the datum product, and is evaluated with equal score in most of the criteria’s. It is assumed that the Triangle frame can be designed for assemble better then RoughRider. It is assumed that most semi functions can be integrated into the frame with makes it less depended on other parts. With few parts to assemble it is going to be easy to assemble it.

With the information from the evaluation process and the decision matrix it was decided that the concept with a triangle shaped frame where going to be further developed.
4. PRODUCT DEVELOPMENT

In this chapter the process of further development of the concept are presented. The Chapter begins with a new research phase and ends in the resulted product.

4.1 Product Research

Another research phase was initiated to gather information about manufacturing, material and part alternatives.

4.1.1 Manufacturing technology

To manufacture a wheelchair frame it is assumed that the steel pipes has to be truncate, drilled, welded together and bended to the right angel. When steel is bent, one side is subject to tension and the other side to compressive stress, but as long as these stresses are within the safe stress limit there is no problem. Steel bending is a plastic deformation process and not one carried out within the elastic region of the material. This is why algebraic relationships cannot be applied on steel bending. An important factor when bending a material is the thickness of the bend produced, it is defined as the thickness of the material divided with the bend radius. The more acute the bend is the greater the stress in the material would be. Further more with tight bends, low thickness of the bend, high local stress will occur and make the material liable to crack. When the bending load is realised the material realises the elastic strain energy it had absorbed before it started to deform plastic. This results in that the material will bend back slightly from the angel that it has been bent to, it is called springback. It is typical small numeric but has to be accounted for in the manufacturing process (Waters, 1996).

Assembling a number of parts that need to be joined together makes most components. To minimize the number of parts in a component it is preferable to weld the parts together permanently. To make the joint hold up for as high tension as possible it is preferable to have a big connection area to weld on (Waters, 1996).

To make a product designed for cost it needs to be good designed for assemble and in the same time be designed for manufacturing. To be design for assemble it is preferable to have as few parts to assemble as possible; fewer parts to assemble will be faster to assemble (Ullman, 2010). When designing for manufacturing it is preferable to use as few tools as possible and with as low accuracy demand as possible (Waters, 1996).

4.1.2 Part selections

Early in the project a decision was made to concentrate on manufacture the frame and to choose appropriate parts to make the rest of the wheelchair. The parts that are going to be brought in are

- Rear Wheels
- Castors
- Cautions
- Bearings

When evaluations and selections where made for parts to the wheelchair, the main factor was the price. Things like environmental factors and performance was concerned secondary. Prices for buying parts in Botswana where not found during the research, instead the price and selections are based on what it would cost to deliver it to Sweden.
4.2 Product Design

The final concepts design where designed from to fulfil the costumer requirements. To make the wheelchair have a good propel ability in rough urban terrain it was decided to have a long wheelbase on the wheelchair, like there is on the Roughrider. To make it easy to manufacture it was decided to let it be constructed with standard profile steel bulks and it needs to be able to manufactured with as few machines as possible.

4.2.1 Frame Design

The frame was constructed from the triangle concept. The base beam where changed to a rectangular tube pipe with greater capacity. The rectangular shape also makes it easier to work with and weld together. The wheelchair frame will be made by mild steel 1312-00. It is cheap, easy to work with and have good mechanical capacity.

The frame is designed to be tilted 15degree to make the caster wheels squared to the ground. The wheelbase is set to 600mm, which will make the wheelchair easy to manoeuvre in rough terrain. Attachments for the seat are welded in place and borehole to the footrest and rear wheel axle is made. The connections for the seat where designed to place the seat in an 8 or 6-degree angle. The frame can be manufactured with only a welding machine, saw or cuter and a drilling machine to make it easy to manufacture, possible in a regular bicycle shop.

To make it easier to manufacture the frame only has squared angles apart form the 15 degree angle between the caster wheel that are considered necessary. The base is made of rectangular tubes, which are 25mm high 15mm wide and 1.5mm thick. The attachments for the seating are made of 25mm wide and 3mm thick flat steel.

4.2.2 Seat Design

The seat is designed to have a rigid 90-degree angle between backrest and seat. It have been considered the best angle for most people and it can be slightly modified with different cushions if necessary (Engström, 2002). The seat is constructed with steel pipes with a diameter of 15mm. The pipes are welded together in squared connections, which makes the manufacturing process easy. In standard execution it wont have any cautions, insteed belts will make up for the seating surface and cautions will be able to mont on them. The seat can be viewed in figure 4.2.

![Final design of the wheelchair frame.](image)
4.2.3 Footrest Design
The footrest is inspired of the footrest that can be observed on Phanteras wheelchairs and also on the box frame concept in chapter 3.1.3. To keep the manufacturing cost down the footrest is design to be produced with only welding, saw and drilling equipment. The result is presented in figure 4.3 and is made of two 15mm steel pipes and two 25mm flat steels. It makes the manufacturing process easy and the equipment required remained to saw, drilling machine and a welder. The positioning of the footrest can be adjustable by using different boreholes when attaching it to the wheelchair frame. The footrest can be viewed in figure 4.3.

4.2.4 Rear Wheels
The rear wheels that are selected for the wheelchair is two 24”x1” metal spoke wheel assembly. The assembly include urethane rubber tyre and all bearing and axle. It can be brought for 95USD apiece (mpsource, 2014). The wheel axles are attached to the frame with blocks that can be mounted to the frame. The blocks would have a 3 degree angle that makes the camber angle.

4.2.5 Castors
The long wheelbase and the design of the wheelchair frame allows the castor wheels to be big which is preferable to reduce the rolling resistance. The wheels selected are 8” and has a steel caster fork. Barings and axels are included for a 28,5USD (hdsupplysolutions, 2013). The tyres are made of solid hard rubber that makes the wheels easy to propel and maintain.

**Figure 4.2: Seat frame.**

**Figure 4.3: Footrest design.**
4.3 Analysis
Basic analysis was made to make sure that the wheelchair holds up when it is used. The first step was to find out what forces that are operating on the wheelchair with a steady state force analysis. The second step was to use the computer software Ansys Workbench to simulate how the wheelchair frame construction reacts on the external loads.

4.3.1 Force analysis
The steady state analysis that was analysed was when a person sits on the wheelchair. To find what force that are reacting on the frame; an active force diagram on the wheelchair frame was made, it can be viewed in figure 4.4.

Forces in axial directions are assumed to be negligible small and are not taken regard to in this analysis. Parameters that was used in the force analyse can be observed in table 4.1 where it can be observed that four forces are unknown.

![Figure 4.4](image)

*Figure 4.4  Active force diagram of the wheelchair frame.*

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Label</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of user/person</td>
<td>$m$</td>
<td>150kg</td>
</tr>
<tr>
<td>Acceleration due to gravity</td>
<td>$g$</td>
<td>9.81m/s²</td>
</tr>
<tr>
<td>Length parameter</td>
<td>$L_m$</td>
<td>170m</td>
</tr>
<tr>
<td>Length parameter</td>
<td>$L_f$</td>
<td>380m</td>
</tr>
<tr>
<td>Length parameter</td>
<td>$L_{sr}$</td>
<td>720m</td>
</tr>
<tr>
<td>Length parameter</td>
<td>$L_{sf}$</td>
<td>300m</td>
</tr>
<tr>
<td>Length parameter, wheelbase</td>
<td>$W_p$</td>
<td>600mm</td>
</tr>
<tr>
<td>Force on frontal seat attachment</td>
<td>$S_f$</td>
<td>Unknown</td>
</tr>
<tr>
<td>Force on rear seat attachment</td>
<td>$S_r$</td>
<td>Unknown</td>
</tr>
<tr>
<td>Force from caster wheels</td>
<td>$R_c$</td>
<td>Unknown</td>
</tr>
<tr>
<td>Force from rear wheels</td>
<td>$R_f$</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

In accordance to Newton’s laws of motion force equations are could be made on the seat
\[\uparrow: S_f + S_r - m \, g = 0 \quad (1)\]
\[\bigodot \bigodot \bigodot \bigodot: S_f \cdot L_f - m \, g \cdot L_f = 0 \quad (2)\]

and on the wheelchair frame the force equation became

\[\uparrow: R_c + R_f - S_f - S_r = 0 \quad (3)\]
\[\bigodot: S_f \cdot L_{sf} + S_r \cdot L_{sr} - R_f \cdot W_b = 0. \quad (4)\]

The four previously unknown forces that are active on the wheelchair frame can be identified with equation 1-4. The results can be viewed in table 4.2.

**Table 4.2: Result of force analysis on wheelchair frame.**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Label</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force on frontal seat attachment</td>
<td>(S_f)</td>
<td>660N</td>
</tr>
<tr>
<td>Force on rear seat attachment</td>
<td>(S_r)</td>
<td>813N</td>
</tr>
<tr>
<td>Force from caster wheels</td>
<td>(R_c)</td>
<td>167N</td>
</tr>
<tr>
<td>Force from rear wheels</td>
<td>(R_f)</td>
<td>1305N</td>
</tr>
</tbody>
</table>

**4.3.2 Ansys**

To analyse how the wheelchair will react on external load a simulation is made on the wheelchair frame. It was made to identify how the main stress is distributed within the wheelchair frame and also how it deforms. With deformation refer to how far it will move in compared with its starting position because of external load. The analysis is important to make sure that the frame can handle the load it will be exposed for when it is used without being damaged.

In the simulation the active forces that are presented in table 4.2 where used, but all forces where divided in two because it affects both sides. For example the caster force \(R_c\) affects both left and right castor wheel and are divided between both sides.

![Diagram of stress locations within the wheelchair frame.](image)

The external load on the wheelchair frame resulted in a maximum main stress within the frame \(\sigma_{max}=74\text{MPa}\). The frame is made by main steel 1312-00 with limit of stretching strain \(\sigma_s=240\text{MPa}\). The frame will therefore have a safety factor according to
\[ \eta_s = \frac{\sigma_s}{\sigma_{\text{max}}} = \frac{240}{74} = 3,2 . \]  

\textbf{Figure 4.6}  
\textit{Deformation diagram deformation of the wheelchair frame.}

The wheelchair frame will according to the simulation deform the most in front of the wheelchair close to the castor wheels. The highest deformation will be 1,5mm that can be considered to be acceptable. More results from simulations in Ansys are presented in appendix 2.

\section*{4.4 Final Concept}

The resulting wheelchair concept can be viewed in figure 4.3. It has a simple design with easy joints and angels that make it easy and sheep to manufacture. The simple and neat design requires only a few tools when it is manufactured. Parts selected for the wheelchair cost in total 250USD. The simple designs have not affected the performance of the wheelchair. The long wheelbase and camber angel will allow the user to be active in the wheelchair. The camber angel is accomplished with a small block with a small angel where the rear wheel axle can be mounted on. The solution has been used before and has previously worked well.
5. RESULT AND DISCUSSION

This chapter considers discussion about the project final outcome and the process leading to its result. The discussion is concluded with comments about further work.

5.1 Result

The resulting concept of the wheelchair is a simple and functional model that can be considered as an active wheelchair. It is made by materials that are easy to work with and it has no complicating angles or parts that would slow down the production. It makes it possible to manufacture the wheelchair with limited access of tools, machineries and knowledge that possible can be the case when it is produced in Botswana. Parts have to be brought in to finalize the wheelchair but with smart part selections the wheelchair sustained the low price of 250USD. This price comes from suppliers in Sweden. Potentially it can be degreased if it is brought in from China or local producers in or close to Botswana.

The wheelchair frame is made with a rectangular tube pipe that handles the potential forces it will be exposed to.

The project was presented to Bo Lindqvist, research and product development responsible at Etac AB. The presentation was made to verify that the concept is realistic to make and to give Etac an insight about what they can do to make wheelchairs more accessible in Botswana and other developing countries in a long-term perspective. Bo Lindqvist thought it is a realistic concept that has great potential to function well as an active wheelchair. It was his opinion that the long wheelbase is necessary to make the wheelchair drivable in rougher terrain that it will be exposed to in Botswana. Bo Lindqvist believed that the wheelchair needs to be adjustable to function for different users and body types. He saw great potential in starting a production in Botswana with simple wheelchair designs that can be produced with easy manufacturing methods.

5.2 Discussion

Botswana is a country that has been on its way up; the economy is overall good for the government and for some wealthy social classes. But the economic growth has degreased and the salary gaps are huge together with the unemployment. A big part of the economic problems that exists in Botswana is a result of the high import that is made. Botswana have almost none production inside the country which forces them to import almost everything, including wheelchairs. Establishment of a wheelchair production in Botswana would not only make wheelchair more assessable in Botswana, but also make more job opportunities and increase the welfare in Botswana. Maybe the wheelchair industry can be a pioneer industry and be a role model for other industries that can start productions in Botswana and help to push Botswana’s economy in the right direction. The concept can also be established in other countries with similar problems as Botswana.

It is my opinion, together with Bo Lindqvist’s, that the longer wheelbase on the wheelchair is necessary to make it functional in Botswana’s environment. Although the bigger size will make it harder to propel the wheelchair inside.

The wheelchair concept presented in the report is potentially a functional and realistic suggestion of a wheelchair for use in this type of context. Although it has not been made any type of functional model or prototype of it that suggest it needs some adjustments and corrections of its design. The wheelchair needs to be tested when it is used, corrections on measurements and
angles may be required to improve its performance. Also the manufacturing of it may suggest corrections to make it easier to produce and assemble.

5.3 Future Work

The next phase if this project would be continued is to visit Botswana to get information on where parts can be found and for what cost. The research that was done from Sweden made it hard to get exact information on how part could be supplied to a local production in Botswana and how much it would cost. During the field trip it would also be needful to do some investigation on what kind of tools and machines that are available in Botswana. If it is possible to produce the suggested concept or if more machines is available than what has been assumed in this project it would allow a more complex wheelchair design. It would also be needful to make sure the right knowledge are available. The wheelchair concept is simple and is not very complicating to produce; however some knowledge is required to make it functional.

It will also be essential to make a functional model of the wheelchair. The concept that is presented in this report is only made in CAD and visualized in different sketches and illustrations. Calculations suggest it will work but it is only tests on a functional prototype that can confirm that. Also improvements and adjustment on the concept will be necessary.
6. WORKS CITED


APPENDIX 1: Requirements specifications

Bachelor’s degree thesis in Industrial Design Engineering, Royal institute of technology, KTH, 2014.

Background

In April 2010 a collaboration of three years started between the foundation Spinalis and the ministry of health in Botswana to create permanent resources to treat persons with spinal cord injuries in Botswana. The work started immediately at the biggest hospital in Botswana located in the capital city Gaborone. They notice early that help was required. Doctors and nurses had inadequate knowledge about spinal core injures and what it implicates. Patients stayed in hospital until the pain went down and they where send home with no rehabilitation plan. Patient still had problems to move and most of them stayed in bed when they where home. The mortality ratio was very high during the first years after leaving hospital. Many of them died due to infected pressure sores. Most patient didn’t know how to turn around in bed to depressurize the sores by them self and where depending on their people around them.

This problem where one of the first Spinalis helped solve. They showed how patients could learn to turn around in bed by them self. It resulted in lover level of pressure sours among spinal cord injured patients and differences where notable on mortality ratio for them during their first year home. By providing patients with aid and knowledge about how they can rehabilitate Spinals showed how a spinal core injured person start live active and healthy. One of the most important aid to start their rehabilitation is the wheelchair. With a wheelchair people who have difficulties to walk can start moving around by them self, independently and have conditions to live an active life. But Spinals had problems provide their patients with proper wheelchairs. They had to import wheelchairs from other parts of the world, which was costly and time consuming. The wheelchairs they got where not adapted to the environment in Botswana and where often previously used which caused mechanical problems that where rough to solve.

This project aims to solve this problem by develop a concept of a wheelchair who is adapted for tuff terrain and can be produced locally in Botswana. Hopefully this will make a proper wheelchair available for a reasonable price and possibly also contribute to more jobs and economic growth in Botswana.

Purpose

Develop a concept of a wheelchair that can be used and produced in Botswana.

External Criteria

Requirements

- Be able to propel in semi-urban terrain.
- Materials have to be available in Botswana.
- Parts have to be available in Botswana.
Wishes
- Product should be able to be repaired locally in Botswana
- Product should be made in recoverable materials.

Functional Criteria

Requirements
- Weight of wheelchair must not exceed 20kg.
- Provide hip support.
- Provide break ability.

Wishes
- Provide adjustable backrest.
- Provide adjustable footrest.
- Provide adequate armrests
- Minimize total size.
- Allow rear wheel position adjustments.
- Allow front wheel position adjustments.

Defining criteria

Requirements
- Main portion of manufacturing process needs be able to execute locally in Botswana.

Wishes
- Product should last 2 years of regular use in semi-urban environment.

Remaining criteria

Requirements
- No sharp edges.

Wishes
- Product should have a target aiming style.
1. APPENDIX 2: Ansys

The appendix includes illustrations of the calculated simulations in the software program Ansys. In the following two pictures the result of a steady state case where all load are on the footrest is simulated.

Main Von-misses stress, the stress is under the allowed for carbon steel.

Deformations within the wheelchair frame according to simulation in Ansys. The wheelchair frame will according to the simulation deform the most in front of the wheelchair close to the castor wheels. The deformation is small and can be considered to be acceptable.