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IDS Project Report

Wheelchair add-on design for improved utilisation and Nordic Walking

Group 2

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Abstract

The aim of the project was to improve the so far very little developed locomotion of a wheelchair by using walking-poles. Based on already existing devices for wheelchairs and the state of the art materials and designs, different concepts were created. The challenge was to translate the typical arm movement done when doing Nordic-walking or Cross-country-skiing onto a forward motion of a everyday wheelchair. Furthermore aspects like attachment, weight, functionality and costs had to be put into account. The team delivered a final concept, that considering the existing knowledge and the offered instruments, seemed to answer the given task in the best way. In the future further work and improvement might be appropriate to fully enable the double-pole-technique on a standard wheelchair and to preferable make it accessible to many handicapped people.

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1 Introduction

People with physical disabilities have been facing a lot of challenges every day because of lack of infrastructure. For them getting around in a city is a difficult task. Roads, stores, parks, offices, schools, theatres and even houses have been designed without taking this group into consideration. It has been a difficult challenge to design a device for wheelchairs, which could improve their mobility while experiencing Nordic Walking/Cross-Country Skiing.

This report goes through the process of the concept development for this wheelchair add-on.

1.1 Task

The project's objective was to develop a product concept to improve mobility in a wheelchair based on Nordic Walking. This is a common sport in the Scandinavia area, which consists on using arms and not just legs when going for a walk by moving a couple of ski sticks on both hands.

The challenge was to make the product comfortable to use and easy to attach on a wheelchair. It also had to be light and cheap in order to make it accessible to people. It is important to empower and enable wheelchair users to lead a full and active life by helping them have the right mobility equipment.

1.2 Problem

Wheelchairs are common devices among people with physical disabilities on their legs. It is an object in which they spend a long time with. The problem is that there are still some problems the users have with them.

The team faced various problems during the concept developing faces. The first one was to understand the life of a person that uses a wheelchair. None of the team members had ever used a wheelchair before or been in contact with people who used one. Understanding the mechanics and how the real users use it was an important issue in this task for identifying their problems and needs.

Understanding Nordic Walking was another main point. This sport is barely known around the world because it is a fairly new sport and until now mainly practiced in Scandinavia and a few other areas in the north like Canada, Germany and the US. It was also complicated to relate this sport to an improved use of the wheelchair. The motions made in this sport are not

suitable to be used on a wheelchair so they had to be reconsidered. Cross-country skiing, being similar to Nordic Walking, was used as an important point to focus on motion. Moving both arms at the same time is more efficient for propelling a two-wheel device.
Nordic Walking is not very popular among young people; they see it as an “uncool” sport. This fact was also considered important for the task. This add-on had to prove the sport’s value for life improvement.

Urban infrastructure is not very well suited for wheelchair users. That is why it was important that the product was adaptable to the urban environment so that users can interact in it more easily. In Denmark exists a big advantage for wheelchair users. Wheelchairs can benefit from the country’s infrastructure for bikes (roads, access to public transportation, ramps, etc.) and that was also considered on the add-on.

1.3 Aim

Wheelchairs are products which have very little changed since the first industrialized ones where made. Its design has remained almost the same, with a few different options on materials and various kinds of frames but not any radical changes have been made. It is an object with which its user has a really deep bond; the user is in contact with it almost all the time. There is always a relationship between an object and its owner. Sometimes objects become more valuable to someone because of all the experiences one goes through with them or because they are reminders of something else. These bonds are always related to experiences and in this case it is an everyday experience. Product personalization has been taken into consideration as well as the fact of creating new experiences, both important for user-object identification. A gratifying everyday experienced is what the product has been aimed for.

Phase 0
Planning and research

2 Background Information

2.1 Wheelchair

2.1.1 Definition of wheelchairs

A wheelchair is a chair mounted on large wheels for the use of a sick or disabled person. It is also used by invalids or others for whom walking is impossible or temporarily inadvisable. For them it is often the only possibility to be mobile.[1]

The device is propelled either manually (by turning the wheels by hand) or via various automated systems.

2.1.2 History of the wheelchair

To mention every part that is important for the history of the wheelchair it is necessary to go back in human history a thousand years Before Christ. The main components of a wheelchair are as the word itself already mentions the wheel and the chair.

The chair was invented around 4000 years Before Christ. Back then the chair was a place to sit on and at the same time portable. It was used to sit, eat, talk and socialize and improve the early housing. The invention of the wheel, one of the most revolutionary inventions of mankind, occurred around the same time. From now on it was possible to freely transport hunted animals, belongings or oneself.[2]

Later on the first record of the combination of these two is shown on Greek vases where a wheeled child's bed can be seen dated back to 530 B. C. Almost 1000 years earlier engravings report the use of spoked wheels on chariots. The pictures show a chair that is compatible to the ones today. Back then they were used to carry important people.

[1] http://www.thefreedictionary.com/wheelchair
[2] http://houseplanssite.com/the-lost-history-of-the-wheelchair

Figure 2.1 Greek child's bed[3]

Figure 2.2 Chinese chariot[4]

By the year 200 the story of the "Fountain of Youth" spread around in China. In order to go there with their immobilized relatives Chinese invented a wheelbarrow, a bed on wheels, which was carried by family members or servants.[5]

The wheelchair was driven further in Europe. In 1595 the Spanish King, Philip II of Spain was drawn by an artist sitting in his wheelchair. On every leg small wheels were mounted and it was possible to adjust the platform for his feet and the back rest. The next step was the invention by the disabled watchmaker Stephen Farfler, who created a chair the user was able to propel himself for the first time (1655). It had a box-like design with a lever connected to the front wheel to make it move, similar to modern handbikes. Bath, in western England, which still is known as a health resort, was the perfect scene for the next invention. A lot of people, handicapped too, came to drink and bath in the spa water. In 1783 John Dawson created a chair, with a third wheel in the front, which the occupant could steer by using an attached rigid handle. These wheelchairs came in a number of variations: some open, some with hoods and glass fronts; they could be pushed or pulled. However it was not possible for the patients to propel themselves like Farfler did.[6]

Figure 2.3 King Philip[7]

[3] http://www.wheelchairnet.org/WCN_WCU/SlideLectures/Sawatzky/WC_history.html
[4] http://houseplanssite.com/the-lost-history-of-the-wheelchair
[5] http://houseplanssite.com/the-lost-history-of-the-wheelchair
[6] http://www.chairdex.com/history.htm
[7] http://www.wheelchairnet.org/WCN_WCU/SlideLectures/Sawatzky/WC_history.html

Figure 2.4 First hand-operated wheelchair[8]

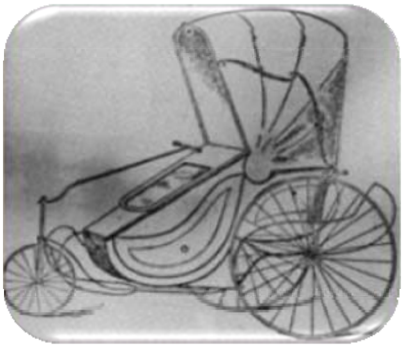


Figure 2.5 Bathing chair[9]

The most important steps were now done. What was missing was a bit of comfort. During the nineteenth century wheelchairs became less cumbersome. Users were able to propel themselves by turning the larger rear wheels with their hands. The problem was that no matter what weather condition the chair was used in their hands always became dirty. This was solved in 1881 when manufacturers began to add a second rim (push rims) with a smaller circumference to each wheel. Wire-spoked wheels, adjustable seat backs, movable arm and feet rests and lightweight made of wicker mounted on metal frames followed.

Motorized wheelchairs came up in 1916 in Britain. As wheelchairs were still very rigid and difficult to store and transport the American engineer Herry Jennings designed and built a folding wheelchair in 1932. Together with his friend Herbert Everest for whom he invented the chair, soon realized the potential and established a company to mass-produce these portable chairs.[10]

2.2 Nordic Walking

Nordic walking combines both simplicity and accessibility of walking with simultaneous core and upper body conditioning similar to Nordic skiing. The result is a full-body walking workout that can burn significantly more calories without a change in perceived exertion or having to walk faster.

8 http://www.wheelchairnet.org/WCN_WCU/SlideLectures/Sawatzky/WC_history.html
9 http://www.wheelchairnet.org/WCN_WCU/SlideLectures/Sawatzky/WC_history.html
10 http://www.chairdex.com/history.htm

2.2.1 History of Nordic Walking

The beginning of Nordic Walking was in the 1930s, when the Finnish team of Nordic ski started to practice "walking with sticks" to train during the summer. In 1996, Suomen Latu, Finnish Institute of Sports and Exel (manufacturer of sticks) joined their effort to formalize its technique. Exel proposed, in 1997, the name Nordic Walking, and manufactured the first special stick for this sport. In 2000 INWA (International Nordic Walking Association) was formed in Finland.

2.2.2 Benefits of Nordic Walking

One of its more important facts is that it can be done anywhere, by anyone, whatever age or fitness level. It is very easy to learn and no special clothes are needed.

Moreover, Nordic Walking offers more health benefits than regular walking, jogging, biking or running.

- Using sticks, you reduce the load of the legs and backbone's bottom.
- It strengthens the trunk's muscles and reduces the pressure on knees and joints.
- Burns more calories (46% more efficient than ordinary walking).
- Increased oxygen consumption and heart rate.
- Reduces cholesterol.
- One of the most effective cardiovascular workouts, because it works all major muscle groups in the body. (90% of the body muscle)

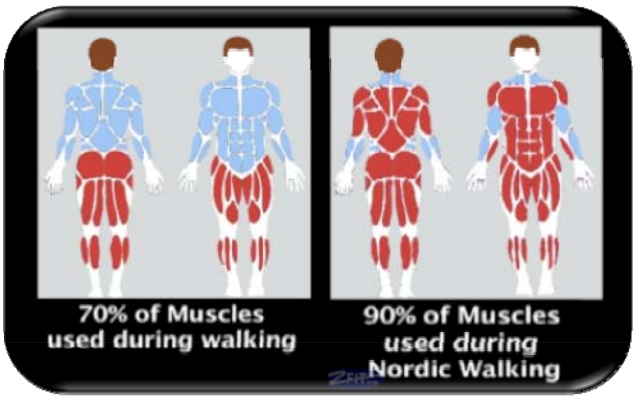


Figure 2.6 Used muscles during Nordic Walking[11]

[11] http://www.nordicwalkingonline.com/benefits.php

2.2.3 Techniques and Styles

It is a simple exercise, but it is necessary to use the right technique to gain all the benefits.

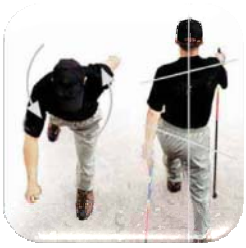
Basic Technique

Every step should begin with the heel touching the ground and finish when the toes push and separate from the ground.

Figure 2.7 foot positioning[12]

The hands and sticks must be close to the body. They should grip the stick every time the stick hits the ground, and then let it go behind the body, finishing up with an open hand. The left foot and the right hand move forward at the same time.

Figure 2.8 Nordic Walking[13]



As the arms continue to move the sticks, the torso and hips should be involved in a counter-swinging motion from the lower body.

Figure 2.9 Basic technique[14]

Rise

You should do longer strides, light inclination towards ahead, and intensify the arm and leg movement.

Descent

It is done with smaller strides, light inclination towards behind, bending the knees and keeping the sticks behind. The center of gravity is lower.

Typical Mistakes

- Not using the torso correctly.

[12] http://www.marchanordica.com/tecn_2.php
[13] http://www.nordicwalkingdorset.co.uk/images/nordicwalkeranim.gif
[14] http://www.marchanordica.com/tecn_2.php

- Having the sticks too wide.
- Keeping the hands closed or opened all time.
- If the pole and leg are placed on the same side, you are not able to perform the proper diagonal stride with the hips involved in a counter-swinging motion.

2.2.4 Equipment

Sticks/Poles

Getting the correct poles is the most important thing to concentrate on when starting to Nordic Walk - it is also important not to confuse these with ordinary sticks and choose the right size.

The best are the adjustable ones. They are specifically designed for Nordic Walking. They have a special 'glove' for the hand to aid the correct technique and removable rubber paws to enable the walker to vary terrain from pavements to country paths.

Figure 2.10 Pole[15]

Figure 2.11 Correct usage of the pole[16]

Figure 2.12 Different tips[17]

[15] http://www.nordicwalking.co.uk/?page=retail&c=64
[16] http://feetace-walking-sticks-trekking-poles-hiking.com/
[17] http://www.rebuildingyou.com/articles/35-physical-articles/182-nordic-walking-poles-for-fitness-and-perfect-exercise-especially-to-help-rebuilding-after-trauma

2.2.5 Nordic Walking for handicapped people

At the moment Nordic Walking in a wheelchair more or less only exists in Norway (Rullestolpigging). Here people just use their normal wheelchair and propel themselves with common Nordic Walking poles. This is of course the most simple way to do this kind of sport, as you additionally just need poles and maybe gloves and a helmet. But the big problem is that safety issues are not at all met. Because of the small front wheels still being used, the moving is restricted to very flat surfaces. Furthermore the movement sitting in a normal wheelchair might be limited, as the wheelchair is not specially made for both daily use and sports. Another handicap could be the sticks themselves. Users have to be pretty skilled not to put the pole inside the wheel and to get a nice grip on the ground. That also depends on the surface.

Figure 2.13 Propelling the wheelchair with poles[18]

There are also special-made wheelchairs for the sticks which are a lot safer because of a third front wheel, but they cannot be used in daily life as they are too long and need a too big turning radius.

Figure 2.14 Three-wheel wheelchair for pole-use[19]

[18] www.bhss.no/files/Vedlegg/hjelpemidler/rullestolpigging.pdf
[19] http://www.handinor.no/hXGYyTMRHG4t.11.idium

At last there are vehicles that cover the same movement but are used as an alternative for Cross-Country during summer. This of course does not fulfill the required needs a usual wheelchair user needs.

Figure 2.15 Cross-Country during summer[20]

You can easily see that work and improvement is needed to combine the wheelchair and the sticks in a reasonable way to make this original idea a fun, safe and convenient thing to do.

2.3 Cross-Country Skiing

The movement done in Nordic Walking is based on a pendulum-like motion, arms going in opposite directions, not a parallel movement. This unparallel movement is not suitable for a wheelchair user because it would not allow a proper forward motion but a zigzag movement instead. That is why the group is focusing on the motion done in Cross-Country Skiing.

Cross-Country Skiing is a winter sport in which participants propel themselves using skis and poles. It is popular in Northern Europe, Canada, and the U. S.

As a sport, Cross-Country Skiing is one of the most difficult endurance sports, as its motions use every major muscle group and it is one of the sports that burn the most calories per hour in execution. When skiing the arms work with the poles during all its stages or gears. The strongest muscles working in the poling are believed to be pectoralis major, teres major, latissimus dorsi and triceps long head.

Today's Cross-Country Skiing technique is developing to be more and more focused on frequency. To be able to ski with high frequency it is often important to, for example in the

[20] http://images.bt.no/btno/multimedia/dynamic/00373/699852__INTEGRERING_373115e.jpg

double-poling technique, make the time for the poling cycle short.

It is believed within Cross-Country Skiing that an arm pendulum needs a good range of motion in the pectoralis major to be performed properly. This is because the arm needs to pendulate up a little bit behind the body to give time for the centre of mass to move from the poling ski to the other ski.

There are three main styles used in Cross-Country Skiing: classic, skating and telemarking. The one the team decided to focus on was the double-poling classic technique for being more adaptable to the wheelchair system. Its advantages for this project are stated bellow.

DOUBLE POLE TECHNIQUE

In contrast to the asymmetrical arm and leg motions of other techniques like diagonal stride, the double poling technique involves both arms acting in unison and minimal leg involvement, which is a good feature for a wheelchair user. Also unlike diagonal stride, considerable trunk flexion is involved in double poling and contributes to enhance poling forces. All propulsive force generated in this technique is via arm and trunk activity delivered axially through each pole.

Several physiological tests of technique have compared double poling with other skiing techniques that suggest that double poling on flat terrain may involve lower aerobic cost but higher lactate concentrations than other techniques. On uphill terrain, relative economy measurements have not been done comparing ski techniques. In diagonal stride during the latter part of poling, propulsive force is about 70% of poling force. In double poling, the more effective positioning of the poles allows as much as 90% of poling force to be propulsive.[21]

Mechanical factors contribute to the effectiveness of double poling.

Poling forces, ski reaction forces and drag forces are those that change with technique. Poling force effectiveness is perhaps the most complex of these relationships. Ski reaction forces in double poling involve relatively little horizontal component of force; vertical ski forces are uniformly distributed across both skis and average less than half body weight due to vertical poling force during part of a cycle. Thus the skis will be only moderately loaded during double poling and probably experience drag forces, which are reduced from those of diagonal stride. Air drag force during double poling is also slightly reduced compared to diagonal stride due to the trunk flexion associated with poling. This reduces frontal area of

[21] Lund, Marie, 2005: Biomechanical study of Cross Country Skiing.

the skier and probably drag coefficient; together these would reduce air drag acting against a double poling skier.

Poling force effectiveness depends on positioning of the trunk, shoulder, elbow, hand and pole. Axial force is transmitted through each pole and has force components in the vertical and horizontal (propulsive) directions. As a pole is inclined away from vertical, the propulsive component increases, for a given applied force. In double poling, pole inclination is affected by the complex interaction of trunk flexion, shoulder and elbow positioning. Pole positions with the greatest horizontal, propulsive force components will be quite inclined forward of vertical. To get into such positioning requires trunk flexion combined with elbow extension. But in addition to larger pole inclination, arm positioning of shoulder and elbow may allow for generation of greater poling forces during later portions of poling phase where the pole is most effectively inclined. This advantage of double poling is due to trunk flexion, which not only lowers the arm and pole but also allows the shoulder and elbow to remain in mid-range positions where greater joint torque resulting in greater poling force can be generated compared with diagonal stride. For this reason the weight change to the front was necessary, in order to keep this propulsive force.

In high speed double poling, at pole plant the shoulder is flexed slightly beyond mid-range and then extends throughout poling. The elbow in contrast is often somewhat extended at pole plant and initially flexes to 80 or 90Á before extending late in poling. This pattern is a more dramatic example of a muscle stretch-shortening cycle. Elbow flexion followed by extension likely is associated with triceps eccentric activity which may enhance force development followed by triceps concentric activity during elbow extension in later poling phase. This combination allows for greatest force development when the pole is inclined at large angles and propulsive force generation can be maximized. Whether a similar stretch-shortening cycle occurs across the shoulder is uncertain. In some skiers, a small amount of shoulder flexion follows pole plant. Whether shoulder extensor musculature (largely latissimus dorsi in this case) is stretched after pole plant in double poling is unknown. Muscle activation patterns during double poling have not been measured; the kinematic characteristics of the elbow and shoulder suggest the possibility of muscle stretch shortening but do not confirm such patterns. In addition, poling force relationships to various arm-trunk positioning have not been systematically researched. These conjectures were based on observed movement patterns and anatomical principles but have not been directly measured.

Trunk motion during double poling is a central feature of the technique and may involve more than 45 degrees of flexion during poling phase. Due to the large mass of the head and trunk and the considerable flexion that occurs, total body center of mass oscillates vertically some 25 to 30 cm during a double poling cycle. Coaching descriptions of double poling often highlight the importance of abdominal muscles to effective force generation. While both the abdominal and back extensor muscle groups are recognized as important contributors to dynamic trunk responses in skiing, it is not clear that the abdominal group is more important in double poling than it is in other techniques. In particular, poling forces are what propel a skier in double poling. The reaction forces acting on the poles and skis reflect the acceleration of the body's center of mass. It is upward acceleration of the center of mass that enhances pole reaction forces. Downward acceleration of a skier's body would serve to diminish the poling forces, thus forceful abdominal action to increase trunk acceleration downward would be counterproductive for poling force generation. Instead, trunk flexion during poling is probably controlled largely through the back extensor musculature, which allows gravity to flex the trunk. The trunk's weight contributes to poling forces as it is partially supported through the arms and poles, but probably the most important role that trunk flexion plays in double poling is to put the arms into an advantageous position for generating propulsive force during poling.

3 Methodology

3.1 Team

The team was composed of four students from different cultural and educational backgrounds. The different experiences and knowledge of each team member were very important in the development of this project. A brief description of team's members:

- **Belén Marzo Gasca**
    - Industrial Designer by Escuela Universitaria de Ingeniería Técnica Industrial de Zaragoza (EUITIZ)
- **Julia Voigt**
    - Master in Packaging Technology by Beuthhochschule für Technik Berlin
- **Ignacio López Martin**
    - Mechanical Engineer and Business Management by Universidad Europea de Madrid
- **Rafael Canales Durón**
    - Industrial Designer by Tecnológico de Monterrey, Mexico City

3.2 Structure

The main part of the report was structured by the book "Product Design and Development" by Karl T. Ulrich and Steven D. Eppinger. When creating a new product it is essential to first of all figure out if there is a potential market for this kind of product. For this reason the report mentions facts about the potential target users, possible handicaps, common prices and materials on the market.

Then it was necessary to gather all the information needed which is important to create a functional Add-on for the wheelchair. Here some general ergonomic facts were described. To keep in mind that every product has to follow some rules, norms and restrictions are listed.

The next part dealt with all thinkable needs and must-haves the customer would expect from the device. This went along with some specifications to clearly identify what was most wanted by the users.

Finally all concepts were put together and ranked to decide which idea was worth to work on and which ideas could be combined and improved. Here all concepts were shown as well as different ways to communicate them.

After deciding on the final concept some additional research was done. The Product Architecture made sure no part and function of the new product was missing. The Industrial Design table classified its need's importance and showed were the focus should lie on.

At last the final concept was described in all its details and the materials and processing were chosen to estimate the overall costs of the Add-on.

3.3 Responsibility

All team members were responsible for the work as good as possible in equal amounts. The tasks were divided among all team members according to each one's particular ability. The very first research work was done by all team members so everyone was able to get familiar with this topic and its peculiarity. The responsibility matrix on Appendix 1 shows in detail which person did what and if the person had a responsible or supporting roll. The group considers all tasks as almost equally time-consuming, which is why all cells have the same width. The table follows the same order as the table of contents.

3.4 Project Plan

The general work frame followed was having weekly meetings where all members discussed which tasks were done and which had to be done. All work done was put together and checked by everyone. At the end of every meeting a new appointment was made and new tasks were delegated. Every step contained in the book "Product Design and Development" by Karl T. Ulrich and Steven D. Eppinger the group considered important and helpful for the final solution was worked off. Alongside, work on the concept took place. In order to keep track of the work a Gantt chart was established, which can be seen on the second entry of Appendix 1. The most important tasks and their dependencies are shown here. For each topic, a start and finish date were fixed on which the group tried to stick to.

4 Market Research

The market of wheelchairs in Scandinavia was explored with the aim to identify the number of wheelchair users that might use the new product. This market is focused in Scandinavia and the north of Germany where it is more common to practice Nordic Walking.

During the research process there were some difficulties to find any information about the number of wheelchair users in Denmark. It was impossible to find any statistics or to get a reply of connected organizations (Email in Appendix 1). Therefore the German numbers of wheelchair users were used to estimate a rough figure for the Danish population. Germany has a population of approximately 82 Million people of which 1.5 Million people are wheelchair users. That means 1,8 % of the population is using a wheelchair. Applied to Denmark, which has 5.5 Million inhabitants, that would lead to approximately 100.600 wheelchair users. As not all of these people are willing or able to propel a wheelchair by using poles the team considered a number of 1000 possible target users as reasonable.[22]

4.1 Materials and prices

4.1.1 Sticks

There are many different models of Nordic walking poles, prices range from 60 Euros up to 140 Euros[23]. This great price difference relies on the materials the poles are made of; the most common ones are iron (cheap but heavy), aluminum (better quality price relation) and carbon fiber (very light but expensive).

4.1.2 Wheelchairs

There are many different types of wheelchairs in the market, made with a great variety of materials and designed for diverse situations.

Manual wheelchairs are the most common to find in the market and also the most useful. Prices start at 100 Euros for a transport wheelchair (that means the user cannot use it by himself, he will need someone else to push him) made of iron. Some standard wheelchairs (the user can make it move) can also be found from 100 Euros for the simpler ones, but some are sold for up to 2000 Euros like some ultra-light titanium wheelchairs. The most

[22] http://www.simotec.de/RolliBox/Statistik_3/statistik_3.html
[23] http://www.nextag.com/nordic-pole-walking/search-html

common material used in standard wheelchairs is aluminum, which has a good price-quality relationship. Ultra-light carbon fiber is another typical material used for standard wheelchair but can also be quite expensive.

There are other types of wheelchairs that are designed for more specific purposes like sport wheelchairs. They are more expensive than common wheelchairs because they require being lighter and having a different design. Prices go from around 1000 Euros up to 4000 Euros depending on the sport; some require different materials in order to fulfill their purpose, which can make them even more expensive. There are all sorts of sports people can practice on a wheelchair; some examples are baseball, basketball, tennis, rugby, shooting and racing, but almost every sport can be done on a wheelchair.

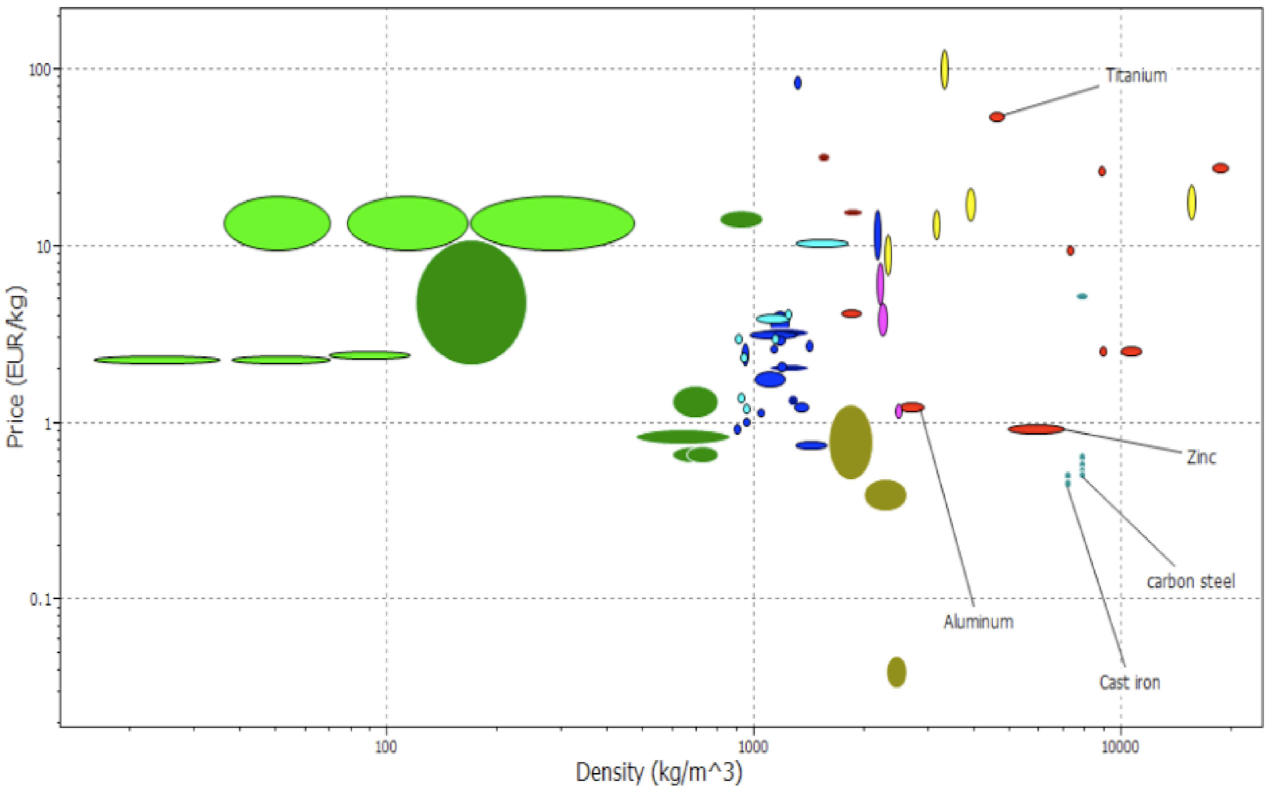


Figure 4.1 Price vs. density for designated materials

4.2 Target group

The target group on which this project is aimed was users with the following features:

- Scandinavian people with the possibility to extend to other regions.
- People with leg disability.
- People with upper body mobility.
- Adults from 18 up until the age they can practice this activity.
- Active people.
- Healthy people.
- Desire to practice Cross-Country Skiing.
- Wheelchair users.
- Need for efficient and fast mobility.

Users are required to have all these features in order to use this product. In order to identify more specifically the target group a research on the different types of paraplegia was made:

Handicapped classification (Paraplegic only)

Paraplegia results when an injury to the spinal cord is below the first thoracic spinal nerve. This results in the loss of feeling and movement, to some degree, of the legs. Paraplegics can experience anything from impairment of leg movement to complete loss of leg movement all the way up to the chest. Paraplegics are able to move their arms and hands. The degree of function that a person with paraplegia will experience depends upon the level of injury, type of injury, and whether the injury was complete or incomplete.

Types of Incomplete Spinal Injuries

An incomplete lesion is the term used to describe partial damage to the spinal cord. With an incomplete lesion, some motor and sensory function remains. People with an incomplete injury may have feeling, but little or no movement. Others may have movement and little or no feeling. Incomplete spinal injuries differ from one person to another because the amount of damage to each person's nerve fibers is different.

The effects of incomplete lesions depend upon the area of the cord (front, back, side, etc) affected. The part of the cord damaged depends on the forces involved in the injury.

Anterior Cord Syndrome

Here the damage is towards the front of the spinal cord, this can leave a person with the loss or impaired ability to sense pain, temperature and touch sensations below their level of injury. Pressure and joint sensation may be preserved. It is possible for some people with this injury to later recover some movement.

Central Cord Syndrome

The damage is in the centre of the spinal cord. This typically results in the loss of function in the arms, but some leg movement may be preserved. There may also be some control over the bowel and bladder preserved. It is possible for some recovery from this type of injury, usually starting in the legs, gradually progressing upwards.

Posterior Cord Syndrome

Here the back of the spinal cord is damaged. This type of injury may leave the person with good muscle power, pain and temperature sensation, however they may experience difficulty in coordinating movement of their limbs.

Brown-Séquard syndrome

The damage is towards one side of the spinal cord. This results in impaired or loss of movement to the injured side, but pain and temperature sensation may be preserved. The opposite side of injury will have normal movement, but pain and temperature sensation will be impaired or lost.

Cauda equina lesion

The Cauda Equina is the mass of nerves that fan out of the spinal cord at between the first and second Lumbar region of the spine. The spinal cord ends at L1 and L2 at which point a bundle of nerves travel downwards through the Lumbar and Sacral vertebrae. Injury to these nerves will cause partial or complete loss of movement and sensation. It is possible, if the nerves are not too badly damaged, for them to grow again and for the recovery of function.

Segmental Spinal Cord Level and Function

The following should give an outline of how different spinal cord segments affect different muscle groups. This is only an outline, and should not be used as a diagnostic tool, but it may be useful in determining the level of spinal cord injury.

Level Function

Cl-C6 Neck flexors

Cl-Tl Neck extensors

C3, C4, C5 Supply diaphragm (mostly C4)

C5, C6 Shoulder movement, raise arm (deltoid); flexion of elbow (biceps); C6 externally rotates the arm (supinates)

C6, C7 Extends elbow and wrist (triceps and wrist extensors); pronates wrist

C7, T1 Flexes wrist

C7, T1 Supply small muscles of the hand

T1 –T6 Intercostals and trunk above the waist

T7-L1 Abdominal muscles

L1, L2, L3, L4 Thigh flexion

L2, L3, L4 Thigh adduction

L4, L5, S1 Thigh abduction

L5, S1, S2 Extension of leg at the hip (gluteus maximus)

L2, L3, L4 Extension of leg at the knee (quadriceps femoris)

L4, L5, S1, S2 Flexion of leg at the knee (hamstrings)

L4, L5, S1 Dorsiflexion of foot (tibialis anterior)

L4, L5, S1 Extension of toes

L5, S1, S2 Plantar flexion of foot

L5, S1, S2 Flexion of toes

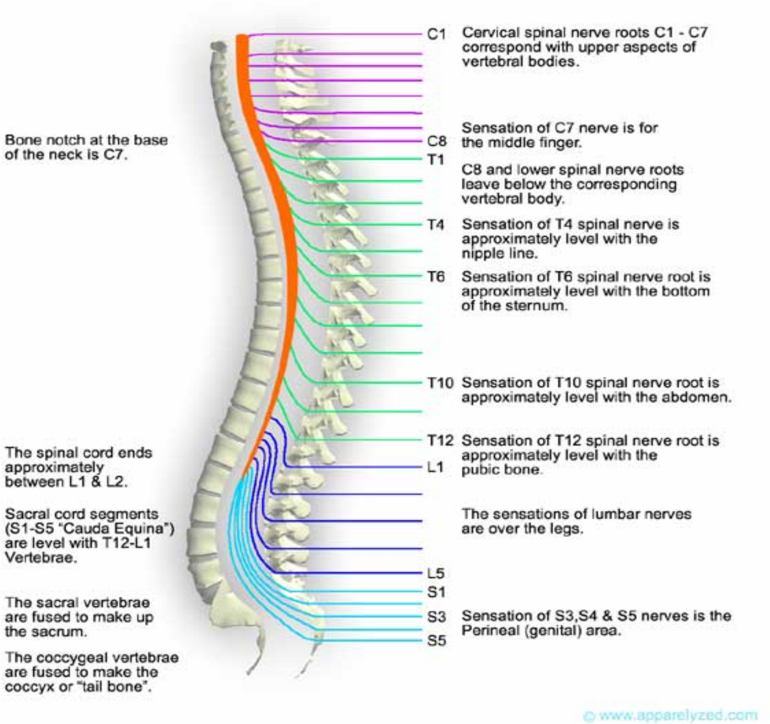


Figure 4.2 Segments of the human's spinal column[24]

[24] http://www.apparelyzed.com/spinalcord.html

5 Wheelchair ergonomics

Ergonomics play a decisive roll in the creation, building and usage of wheelchairs. For those who have to sit in it every day, the correct design of the wheelchair is important in order to prevent further injuries. The goal is to prevent damages and to develop and/or keep vital functions.

Quite often people ignore what a good seating position means exactly, which can lead to serious injuries. People sitting in a wheelchair are in a static position, like in any other seat. Sitting like this for a long time can lead to a bad-seating posture. In most cases it is possible to find an adequate seating position that can prevent injuries. The most common damages are dents, reduced mobility, contracture of articulations and muscles, reduced muscle power and increased or minimized muscle tonus.

The challenge was to make the device adaptable to many people and for different environments. When it is designed and adjusted to the customer exact needs and features, a wheelchair can be regarded as an assistive device for functional seating and healthy mobility. This also includes the wheels. They need to be of good quality and set up in an ergonomic and user-friendly way. If they are wrongly connected, the user can feel even more handicapped because of the limited movement.

The whole system wheelchair-add-on needed to be suitable for every user and ensure a more active lifestyle at the same time. Because of social and environmental interaction the users lifestyle changes to make it possible. The adjustment and fine-tuning of the propulsion unit (hand rims) and the wheels harmonized with an ergonomically set up seat unit were essential. Like it was said before one of the main objectives was to improve and stimulate healthy activity for a long time.

Wheelchairs are mainly moved by the arms. The way the user uses his arms to move the wheelchair, depends on how the wheels are placed in relation to the person's body. Most wheelchairs have the tubes for the back rest attached to the rear wheels. This means the center of the wheels is placed here. For most wheelchair users this is too far behind their upper body. An ergonomic working of the arms is impossible.

Usually the drive wheels are 24 inches in diameter. But depending on the person, this could be good or bad. For tall people this might be appropriate but for short people or people with a bent trunk this could cause serious problems.[25]

Every adjustment on seat and backrest has direct influence on the wheelchair user. Whatever change is made on a wheelchair's design, it will always have an effect on the comfort of the user and therefore his or her mobility. For more information see Appendix 1, entry number 4. Concluding here are the most important demands to achieve an ergonomic wheelchair:

1. Flexible and dynamic seating.
2. Adjustment accurate to the centimeter.
3. Little rolling friction.
4. Light weight[26]

Criteria that must be fulfilled are mobility, seating and comfort.

Figure 5.1 Incorrect seating[27]

The seating unit has a good shape but the relation to the back wheels is not ideal, shoulders of the user are too far ahead.

Figure 5.2 Optimized seating [28]

Seating unit and wheels harmonize. Shoulders are directly located above the axis.

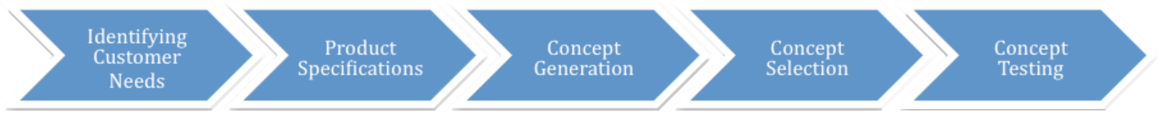
[25] http://www.engstromconcept.com/pdf/beskrivntyskbok.pdf
[26] http://www.o4.eu/downloads/booklet.pdf
[27] http://www.o4.eu/downloads/booklet.pdf
[28] http://www.o4.eu/downloads/booklet.pdf

There already exist wheelchairs that try to realize all the needed criteria by changing the seating unit and making all parts adaptable.

6 Restrictions and norms

To complete the information about wheelchairs, it was necessary to search for restrictions and norms concerning the use and design/building of a wheelchair. There are many organizations that work on this, depending on the country or subject you are looking for. The problem with this is that this product was developed for Scandinavian countries but could probably later expand around Europe. Because of that the normative of the International Organization for Standardization was taken into account. A table with specific restrictions and norms can be found in Appendix 1, entry number 5.

Phase 1
Concept Development



7 Concept Development

7.1 Identifying Customer Needs

There are many different ways to identify customer needs. An interview was used in this case. Thomas, a man who had been sitting in a wheelchair for five years, agreed on having a meeting with the development teams in order to provide some feedback and useful information for the project. He compelled many of the characteristics the team was focusing on for the target group: Danish, young, active and sporty. The interview was held inside the classroom in a relaxed environment and it was more of a casual chat. He talked about his life as a wheelchair user: the problems he had faced, his likes and dislikes, the advantages and disadvantages of his device, etc. Later he made a demonstration on how his handbike add-on worked. This helped as a mind opener and inspiration for the design process.

Furthermore, two different standard wheelchairs were provided so that all the developers had the opportunity to take a look at them and experience personally how it was like to use a wheelchair. After this feedback the customer statements shown on the table below were made.

The customer statements were then translated into customer needs, which express what the product is supposed to do and they were stated as attributes of the product. The phrasing had to be positive and had to avoid words like must and should.

Question/Prompt	Customer Statement	Interpreted Need
Typical uses	I carry a backpack	The wc can carry a backpack
	I grasp the push rim easily	The wc is ergonomic
	Don't hurt myself when grapping the rims	The wc has to protect the hands from the wheel
Likes	I'd like a not too heavy wc	The wc is as light as possible
	I'd like a slim wc	The wc is as narrow as possible
	I want an easy and quick installation	The wc is easy and quick to install
	I want a stable wc	The wc is stiff enough
	I would choose the same wheelchair again	The wc is identified by the user
	I want to get around easily	The wc is easy to drive
	I want a quick Add-on to install	The wc is feasible to attach to the Add-on
Dislikes	I don't like not to have enough space to store things	The wc offers some place to put things
	I don't like to have to remove any part to lift the chair when I'm going through rough surfaces	The wc has to keep the front clear
	I don't want to spend too much money	The wc is affordable
Suggested improvement	I don't find Nordic Walking interesting for young people	The wc makes the NW "cool"
	I can't go around using the sticks	The wc can be used for NW
	I'd like to increase safety	The wc covers more security aspects
	I'd like the WC to last a life-time	The wc is durable
	I'd like to be able to fit the wheelchair to my needs	The wc is adjustable
	I don't want to waste time to get on and off the wheelchair	The wc has easy access
	I don't want to fall	The wc is safe and has an adjustable gravity point

Table 7.1 Customer statements with interpreted needs.

Some conclusions are given from Table 7.1. Aspects as security, comfort and ease of driving are very important for the user, so they were put into consideration for the designing process.

7.2 Product Specifications

The customer expressed his needs using his own words, so there was a big margin for subjective interpretation. Because of that a set of precise and measurable specifications was established.

Needs / Metric	Total mass	Maximum time to attach	Size	Clear Interface	Manufactu-ring costs	Long-Lasting	Comfort	Successful movement	Security	Aesthetics	Price
The wc can carry a backpack	x		x								
The wc is ergonomic				x			x				
The wc has to protect the hands from the wheel				x			x		x		
The wc is as light as possible	x				x		x	x			
The wc is as narrow as possible			x		x		x	x			
The wc has easy and quick installation		x			x			x			
The wc is stiff enough					x		x	x	x		
The wc is identified by the user							x			x	
The wc is easy to drive	x		x	x				x			
The wc is feasible to attach to the add on		X						x			x
The wc has less volume as possible			x				x	x			x
The wc has to keep the front clear							x	x	x		
The wc is quite cheap					x					x	x
The wc makes the NW "cool"							x			x	x
The wc can be used for NW	x	x		x	x						
The wc cover more security aspects									x		
The wc is durable					x	x					x
The wc is adjustable		x		x	x						x
The wc has easy access				x			x				
The wc is safe and has an adjustable gravity point									x		

Table 7.2 Needs-metrics matrix

Metric	Importance	Units/Test
Total mass	3	6 kg
Maximum time on attachment	1	10 – 20 seconds
Size	2	22 x 20 x 10 cm
Clear Interface	4	Customer testing
Manufacturing costs	3	Below 400 EUR
Long-Lasting	3	10 years
Comfort	2	Customer testing
Successful movement	1	Using it outside
Security	1	Crash and balance test
Aesthetics	5	Customer testing
Price	2	Around 1500 EUR

Table 7.3 Final specifications with units and tests (1=Highest, 5=Lowest).

Once the Customer Needs were translated into the Metrics it was easier to focus on the important aspects. The design had to fulfill some requirements, combining successful movement with comfort and safety, but keeping a low price at the same time. All of them were related to the mechanism that drives the wheelchair, so it became the main point of the design. The design had to support easy driving and should not had to be too big or heavy. Moreover it had to be comfortable and safe for the user. For this reason different materials and mechanisms were analyzed to find the best solution.

As a result the following product specifications were considered for the development of the wheelchair Add-on:

- Scandinavian attractive
- Clean materials and manufacturing
- Long-lasting product
- Comfortable for the user
- Adaptable for sports/everyday life
- Increase safety
- Minimize cost: selling price <1500 €
- Cool/fun look (no handicap)
- Easy transport and mobility (stability/turns)
- Easy assembly for the user
- Nordic Walking
- Less than 6 kg
- Adaptable to existing wheelchairs types and sizes
- Apply new technology

7.3 Concept Generation

For a better understanding of the main problem, it was decomposed into simpler subproblems that helped to clarify what the approach had to be. Once this was established, different concepts were developed that helped to solve the problem. All these product concepts are shown with a description of their technology, working principles and formal aspects.

7.3.1 Clarify the problem

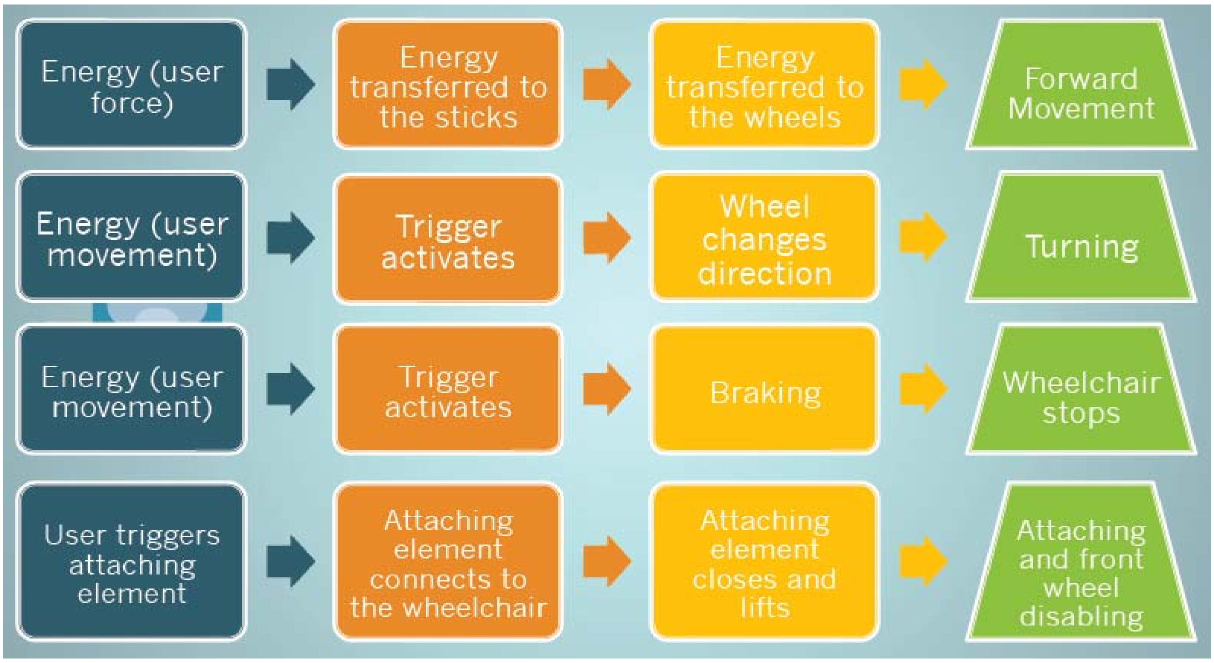


Figure 7.1 Function diagram of the Add-on showing its sub functions.

The figure above shows that there are four main inputs which all trigger different functions of the Add-on and wheelchair. The user provides the energy for moving the device, which is then transferred to one part of the Add-on to fulfill a certain function.
Clarifying the subproblems led to a further analysis of what the critical aspects were. These critical aspects are the ones that were more relevant to solve.

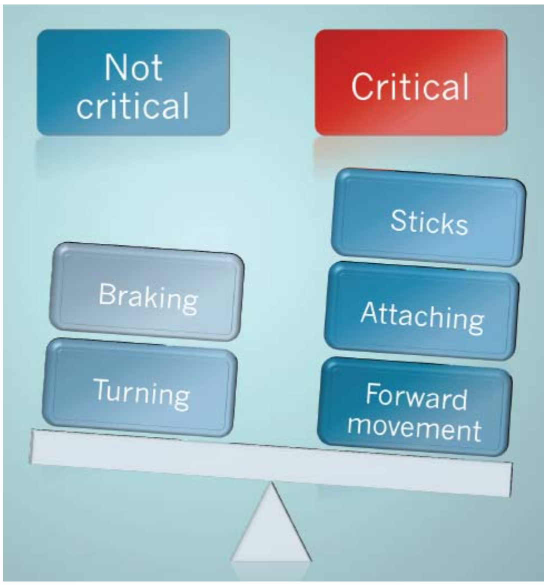


Figure 7.2 Critical aspects

7.3.2 Wolturnus W5

Wolturnus, a Danish company that manufactures wheelchairs, was one of the companies involved within the project. For this reason, one of their wheelchairs was used as a reference for designing. The wheelchairs provided in the classroom were not state of the art. For this reason a new and more modern wheelchair was taken as a reference.

Figure 7.3 Wheelchair Wolturnus W5[29]

[29] http://www.ottobock.de/cps/rde/xbcr/ob_de_de/646D296-D-01-0909w.pdf

The Wolturnus W5 is a wheelchair for active use that puts the basis for a couple of other chairs from that line. Its characteristics are:

1. Individually made, custom-made wheelchair for daily and active use.
2. Different materials can be chosen.
3. Extreme stability while having little net weight.
4. Anodized frame offers high resistance to impact and scratches.
5. Best utilization of the existing left forces.
6. Option to choose from welded or adjustable version.

The weight varies from six to seven kilograms that depends on the used wheels. The wheelchair has a width of 38 cm and a depth of 40 cm. The Wolturnus communicates the energy of the user very efficiently and it is meant for demanding and experienced wheelchair users.[30] This clearly is identifiable with the target group established by the group, because when using an Add-on you should have some experience already.

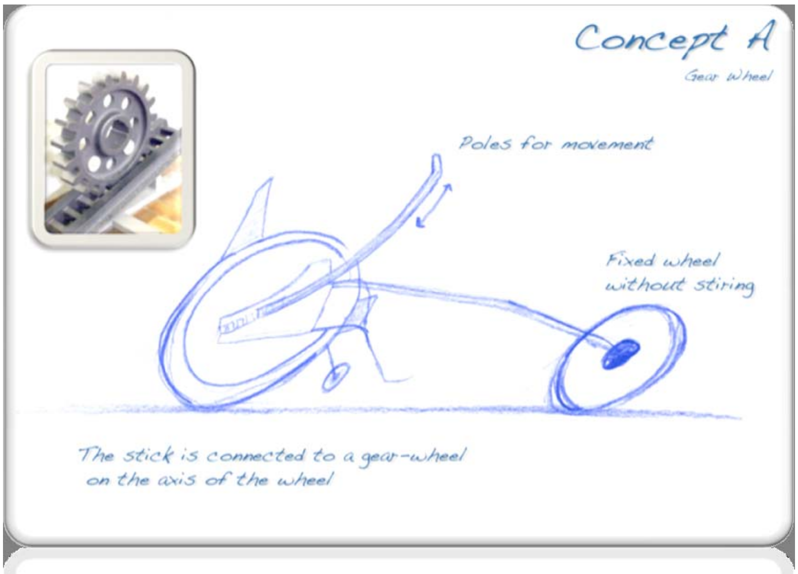
The final outcome was designed to match the Wolturnus W5, but that doesn't mean it is only for that exact model of wheelchair. It was thought to be compatible with most regular wheelchairs too.

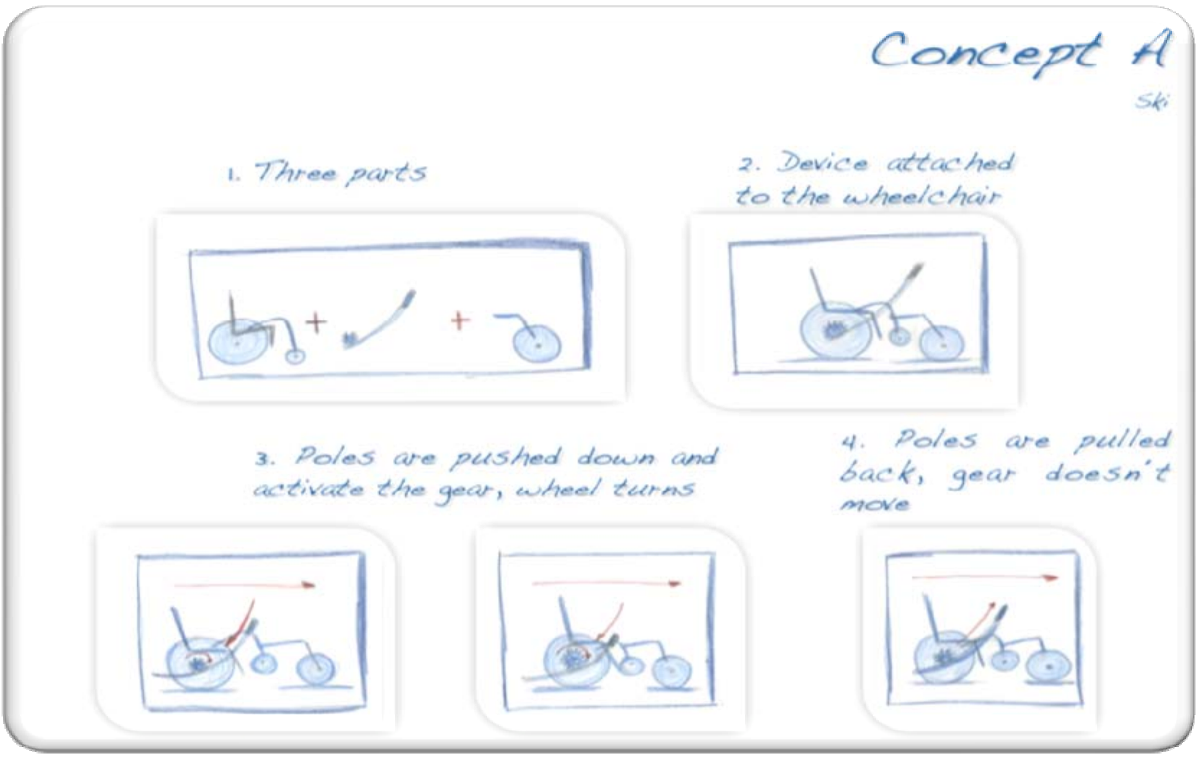
[30] http://www.ottobock.de/cps/rde/xchg/ob_de_de/hs.xsl/26189.html

7.3.2 Concepts

Concept A – Gear Wheel

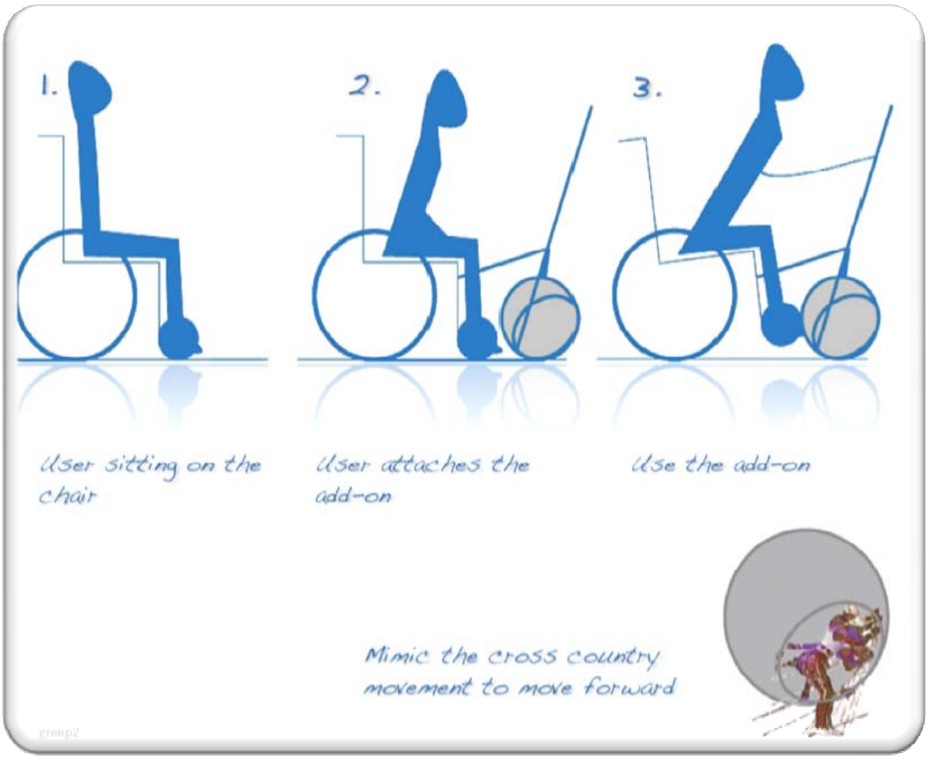
Inspired in the movement of Cross-Country Skiing. The motion done by the arm was kept as similar to the real one as possible. Propulsion is achieved by transmitting the energy from the arm movement in the sticks onto a gear mechanism. The movement is back and forth, like a pendulum. This gear is connected to the main wheels and a third wheel is attached to the front to stabilize the device. For stirring, the chair is lifted and then a one-arm only movement.



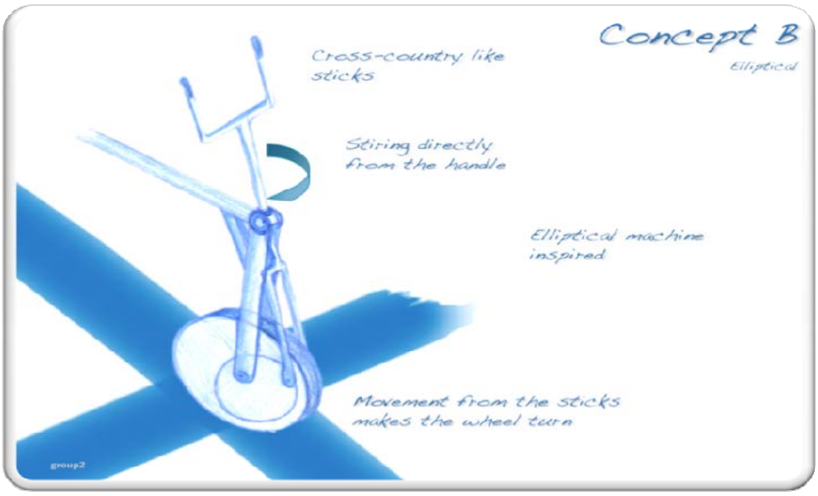


Concept B – Elliptical

It consisted of an Add-on inspired in the hand biking devices but with an approach to stick propulsion. The mechanism is a somehow complex, but the attachment and use are very simple. Another inspiration was the elliptical machine for exercise mechanism, which has an elliptic motion that can be used to propel this device. A handle that ends in sticks propels it.

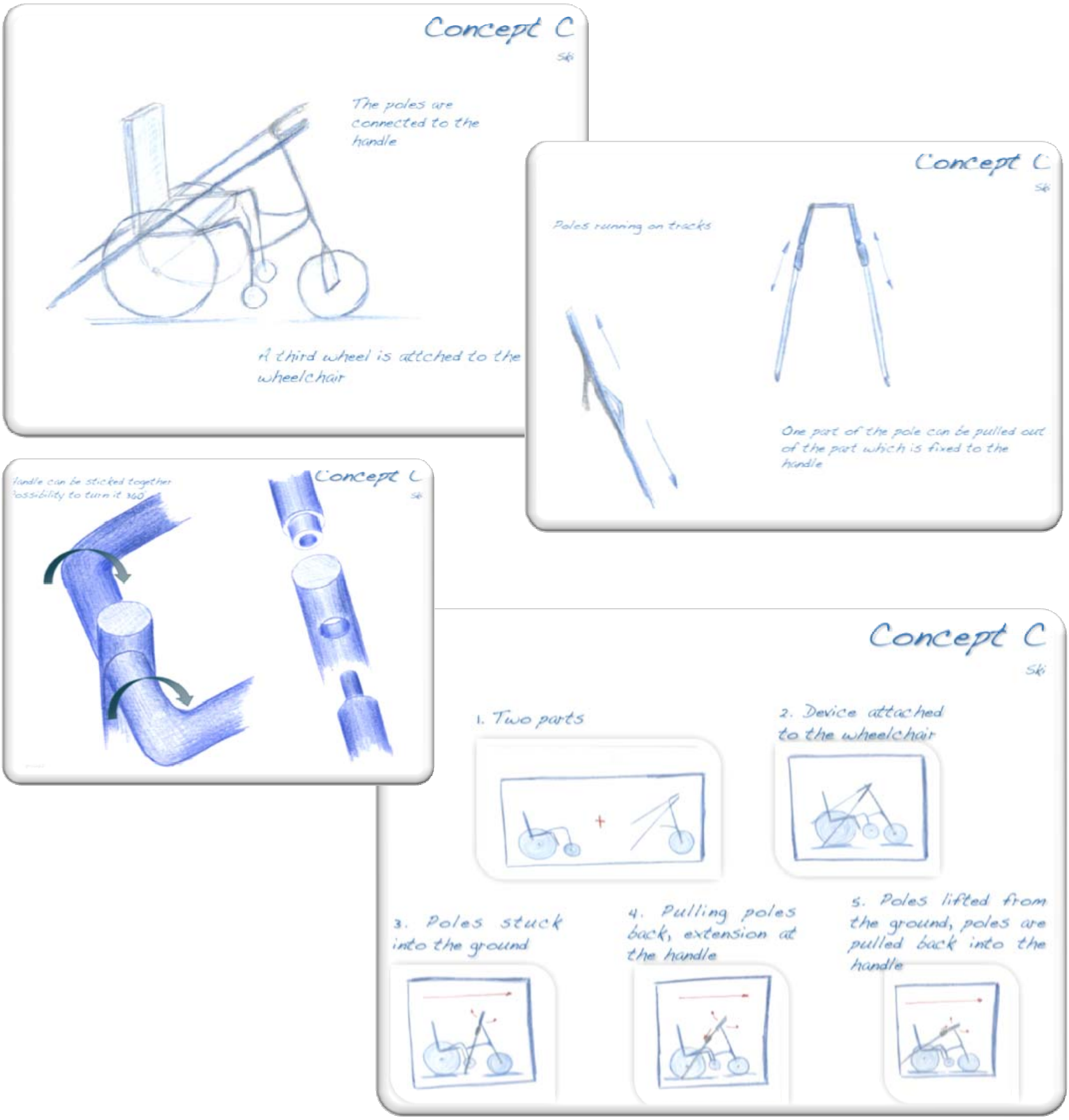


The movement is like that of cross-country skiing and is transmitted to the add-on wheel. The trajectory is elliptical. When the movement is like when pushing the ground, the gear makes contact with the wheel and transmits the energy. Stirring from the handle is possible by just turning it in the direction you want to go.



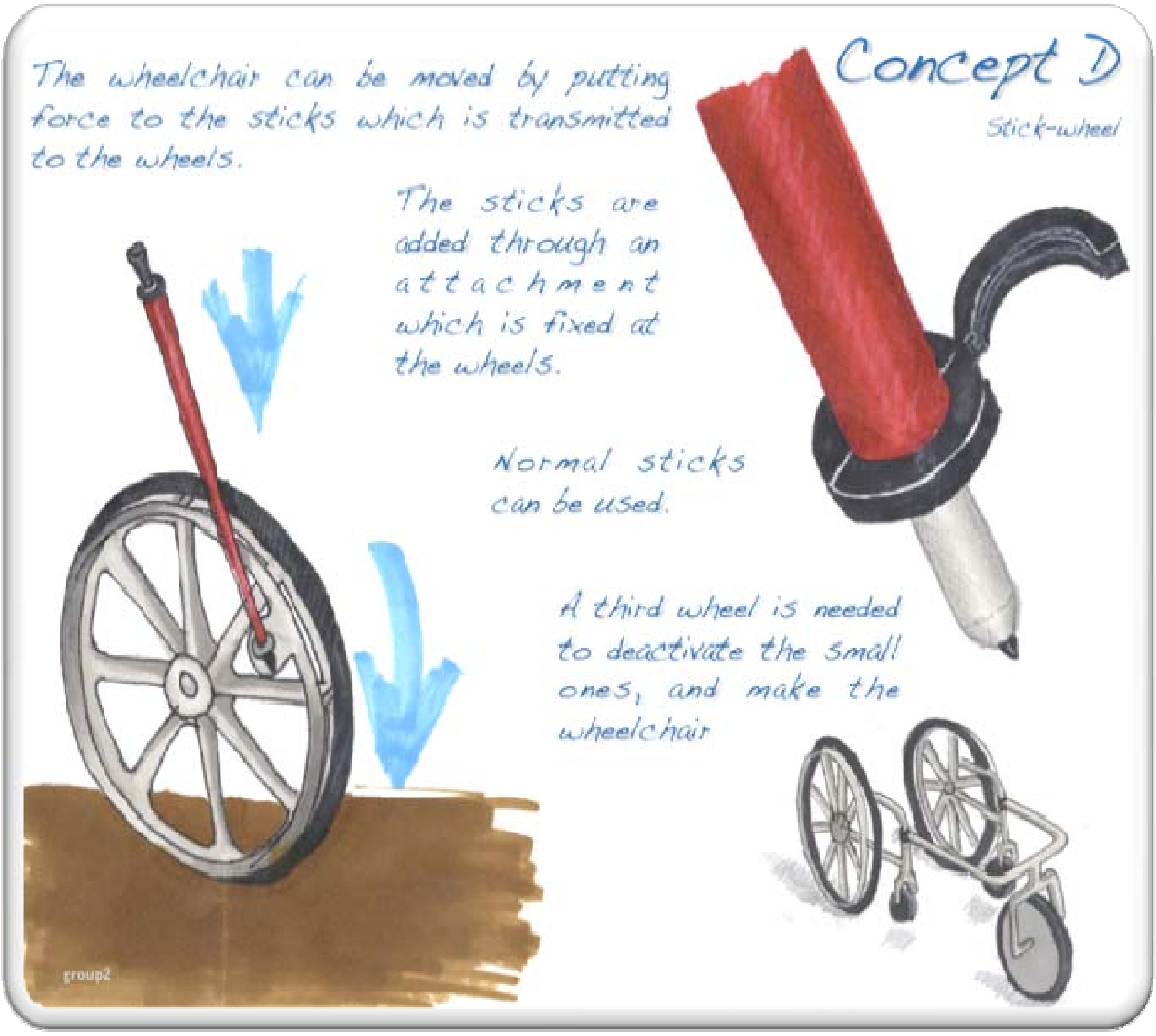
Concept C – Ski

This Add-on uses two sticks attached to it for propulsion. By making contact with the ground, the sticks make the wheelchair go forward. Both poles are connected to the handle, which enables an easier driving of the wheelchair. It consisted of only one piece to attach; the sticks could also be separated for easier carrying or pull out by a telescopic system.



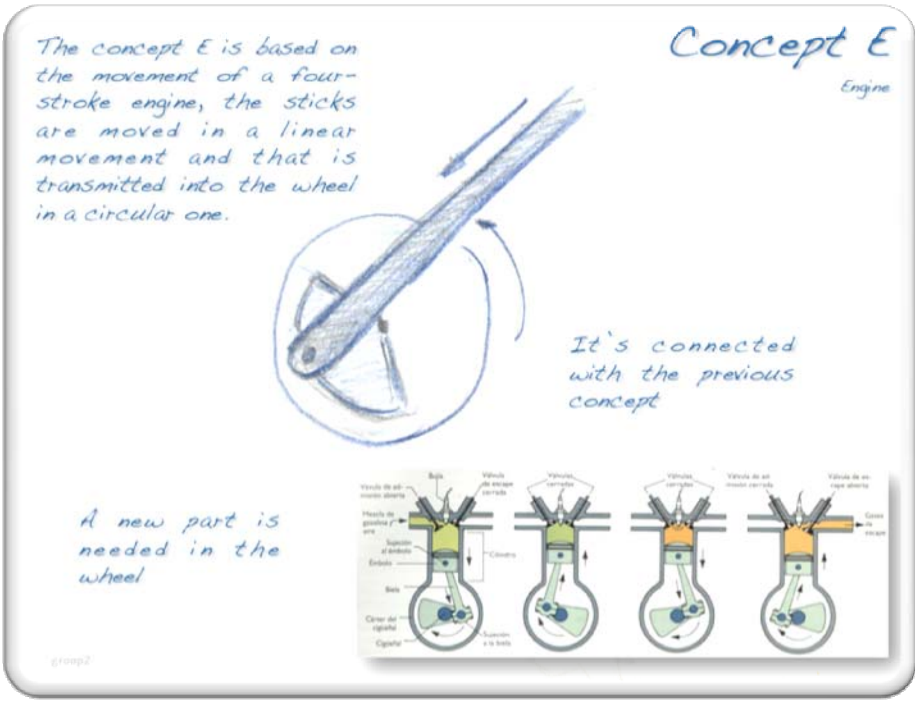
Concept D – Stick-wheel

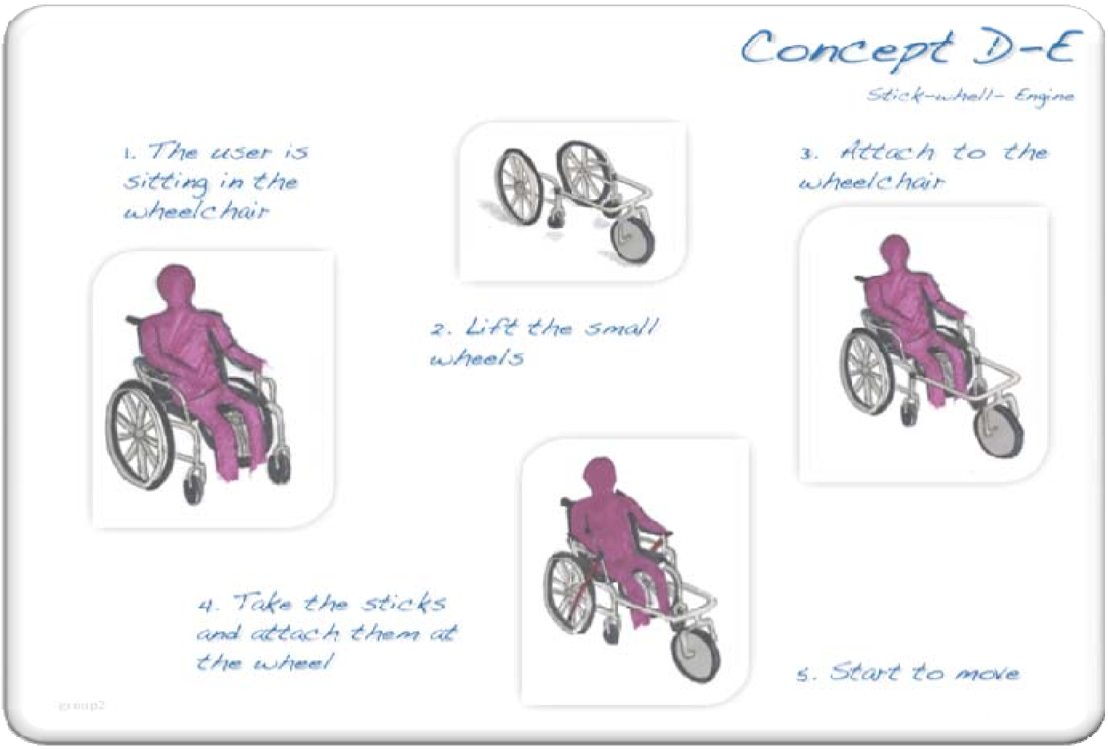
The main idea was to keep it as simple as possible. When attaching a stick onto the wheel frame it is possible to propel the wheelchair using them to turn the wheels. A simple attachment mechanism connects the stick and the frame. A third front wheel attached to the main frame will disable the small wheels to decrease the friction and change the weight to go faster. It is easy to transport and to manufacture, as the pieces are all low technology and the amount of material is small compared to other similar products.



Concept E – Engine

Based on the movement of a four-stroke engine. The mechanics of the four-stroke engine could provide a way by which a smaller movement could be turned into a bigger one to make the wheel turn and therefore provide a more efficient mobility. As a concept it may work, but it would have to be further developed in detail to see how this movement could be adapted into a new mechanism for the wheelchair. A third front wheel would also be necessary to increase mobility.



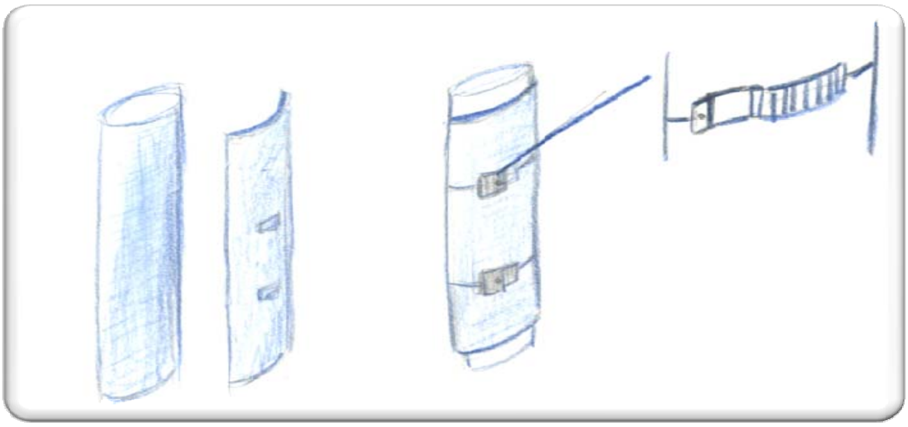


7.3.3 Attachments

All created concepts need a third wheel in front of the wheelchair to make it work. For this reason the group thought about a couple of possible attachments which made the connection to the wheelchair fast, safe and simple. Every device would be attached to the front tubes on both sides. In all cases the wheelchair's front is lifted up by the attachment wheel to disable the small front wheels.

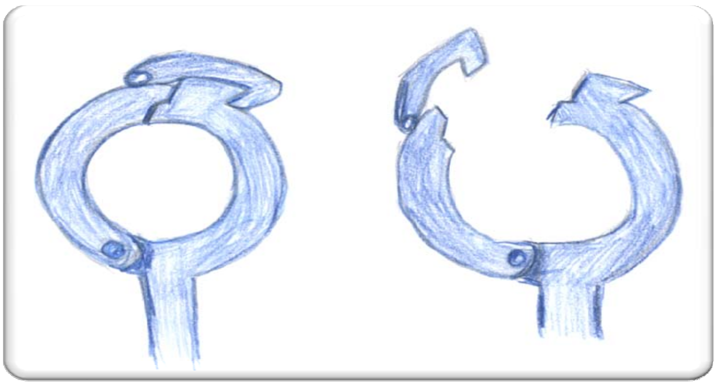
Attachment 1

Attachment 1 was inspired by a common ski binding. A splint with strings and clips, that is fixed to the Add-on, will be put to the front tubes of the wheelchair. Two strings, which are attached to the splint, go around the tube and are closed with the buckle. As the buckles have rills, the string can be put under tension and a stiff binding is made. A problem might be how to fix the splint to the Add-on and that the buckle might open accidentally.



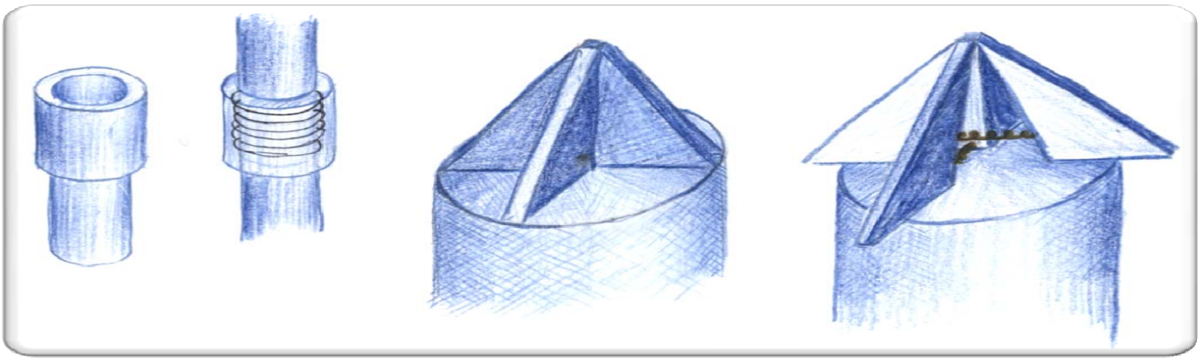
Attachment 2

A ring going along the Add-on can be closed and opened by a hinge. The ring goes around the front tubes and can be fixed by a hook. It had to be ensured that the hook does not open on its own under vibrancy.



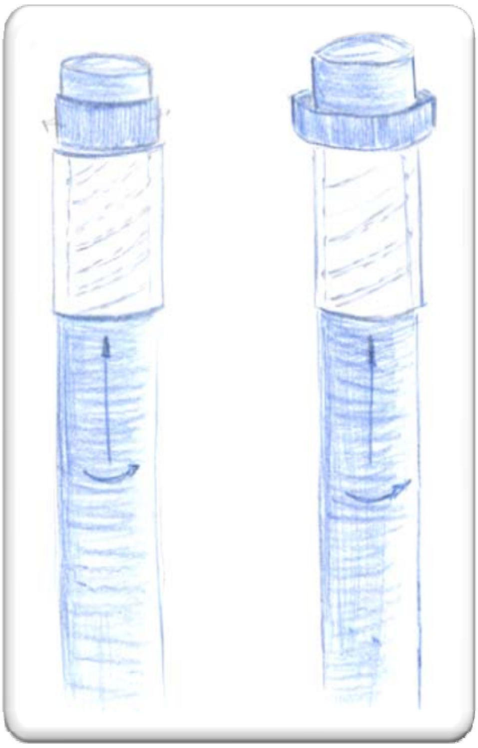
Attachment 3

Here at the tips of the Add-on the tube is provided with a pyramid-like top. When not using the Add-on, the pyramid is covered with a ring that can be pulled back. It is necessary that the front tubes of the wheelchair have a little device with a hole where the tube with the pyramid can be put through. Afterwards the whole attachment is pushed through and the ring is pushed back so the pyramid can straddle and fix the Add-on to the wheelchair. To release, the pyramid has to be pushed together to fit through the hole again.

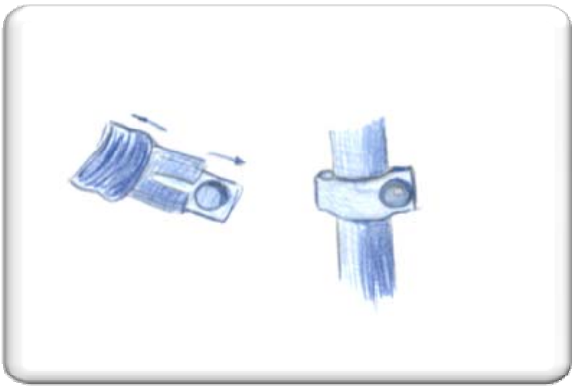


Attachment 4

Attachment 4 works in the same way the latter one does. Instead of the pyramid, a rubber ring sits on the top of the Add-on's tubes. It is also pushed through a hole. After that a screw-like unit is twisted and forces the rubber to spread. Therefore it cannot be removed again. To loosen the connection, the screw has to be turned in the opposite direction.



Attachment 5



For this attachment it is necessary to put a device on the front tubes of the wheelchair, which provides a ball on the outside. The device can stay all time and does not have to be removed after every use. The counterpart has a hole where the ball fits in. By pulling back the spring-loaded cover, the hole is revealed and the ball can be put inside. After that the cover is moved back and prevents the ball from slipping out. This attachment would be the group's first choice, because it exists already, which ensures that it works. It covers all the needed aspects and the costs would be relatively low compared to the other attachments as there are no developing costs.

7.4 Concept Selection

To fulfill the given task different concepts have been developed, of which one or two will be the final choice. This was achieved by using a Concept Scoring Matrix, where the best concept got more important criteria.

			CONCEPT									
			a – gear		b – elliptical		c – ski		d – stick/wheel		e – engine	
Selection Criteria	Relative Weight	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Scandinavian attractive	40	2	3	0.95	3	0.95	3	0.95	3	0.95	3	0.95
Clean Materials	50	2	2	0.80	2	0.80	2	0.80	2	0.80	2	0.80
Clean Manufacturing	60	2	2	0.95	2	0.95	2	0.95	3	1.43	2	0.95
Long-Lasting	90	4	3	2.15	3	2.15	3	2.15	2	1.43	4	2.86
Comfortable	160	6	3	3.82	2	2.54	2	2.54	3	3.82	3	3.82
Sport/Everyday	190	8	3	4.53	3	4.53	3	4.53	3	4.53	3	4.53
Safety	100	4	3	2.39	3	2.39	3	2.39	3	2.39	3	2.39
Cost	150	6	2	2.39	3	3.58	3	3.58	5	5.96	3	3.58
Cool look	80	3	2	1.27	2	1.27	2	1.27	2	1.27	2	1.27
Easy to transport	140	6	2	2.23	3	3.34	3	3.34	4	4.45	3	3.34
Stability	130	5	3	3.10	3	3.10	2	2.07	1	1.03	3	3.10
Turning	120	5	2	1.91	4	3.82	4	3.82	2	1.91	2	1.91
Braking	110	4	4	3.50	4	3.50	4	3.50	2	1.75	4	3.50
Mobility	200	8	4	6.36	4	6.36	2	3.18	2	3.18	4	6.36
Easy assembly	180	7	2	2.86	5	7.16	5	7.16	5	7.16	2	2.86
NordicWalking-CrossCountry	170	7	4	5.41	3	4.06	3	4.06	3	4.06	3	4.06

Weight	155	6	3	3.70	3	3.70	3	3.70	4	4.93	3	3.70
Adaptable to wheelchairs	150	6	2	2.39	4	4.77	4	4.77	4	4.77	2	2.39
Innovation	50	2	3	1.19	3	1.19	3	1.19	2	0.80	3	1.19
Interface	100	4	3	2.39	3	2.39	3	2.39	3	2.39	3	2.39
Part Replacement	90	4	2	1.43	3	2.15	3	2.15	3	2.15	2	1.43
		100										
	Total score			51.89		60.16		55.94		56.62		53.56
	Rank											
	Continue?											

Table 7.4 Concept scoring matrix

The team weighted the relative importance of the selection criteria. The concept's scores were determined by the weighted sum of the rating. All concepts showed fairly equal scores. Nevertheless the focus was put on the first concept, because it seemed to be the best one to enable the Nordic Walking motion. The work on concept B was discontinued because, although the elliptical movement in the front wheel seemed a good idea, the problem was how to transfer this movement to the Nordic Walking.

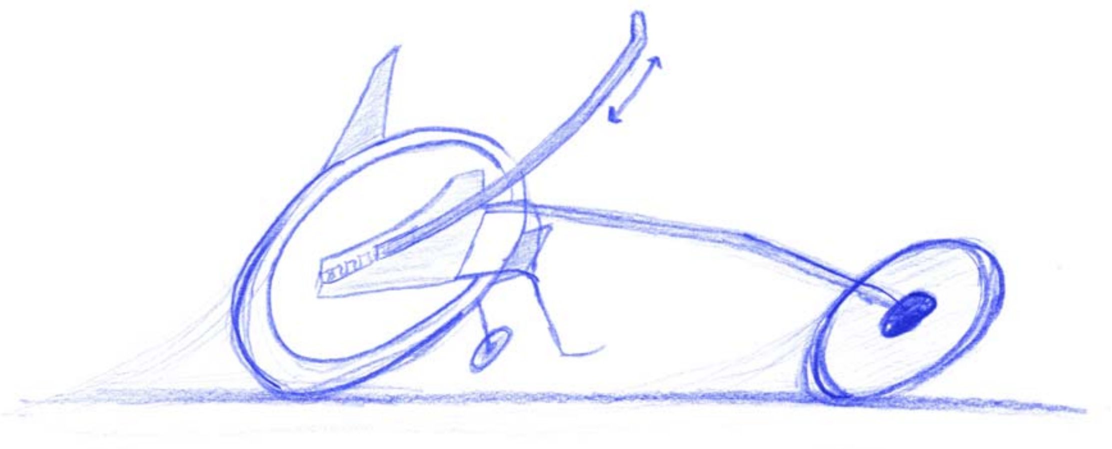
7.5 Concept Testing

The concept can be communicated to possible users to identify flaws or aspects to work on in different ways such as:

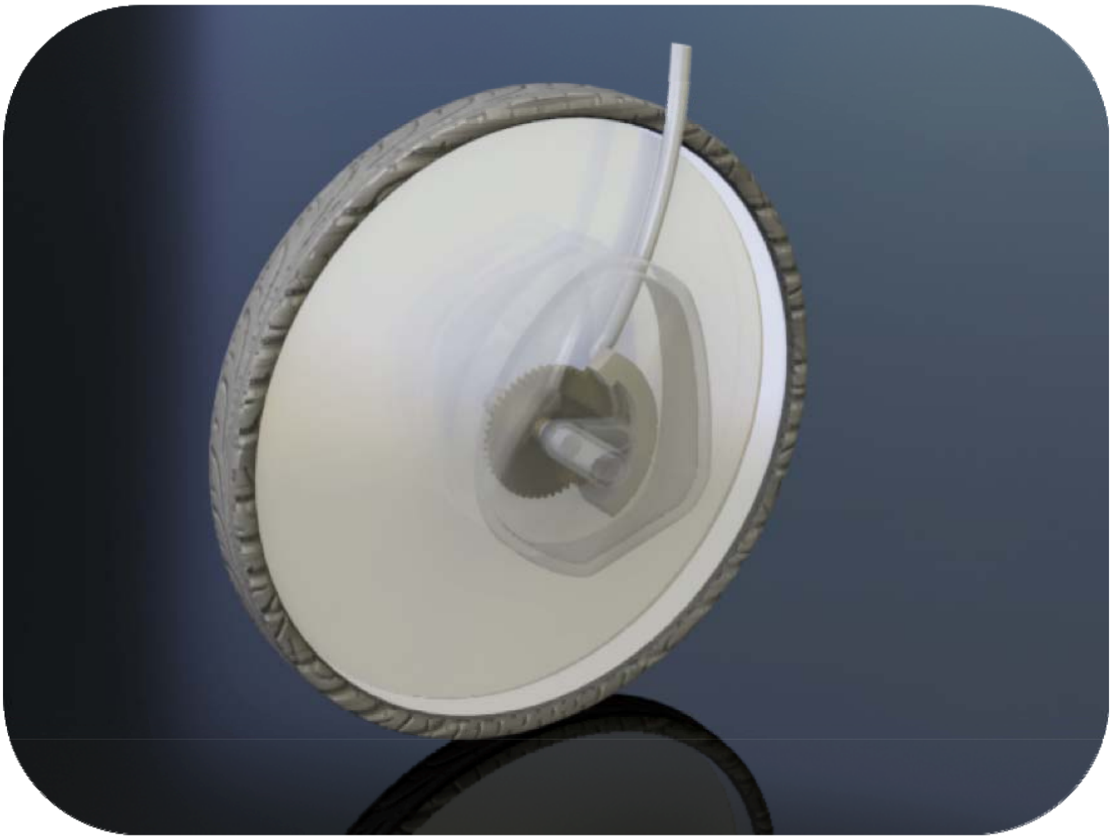
Verbal Description:

The new product is an Add-on for a wheelchair that can be easily attached and upgrades the moving of a wheelchair with poles. The device consists on a third wheel that deactivates the small wheels on the wheelchair and ensures better mobility. On each wheel sits a gear mechanism that transmits the movement from the poles to the wheels. The Add-on weights about 6 kg. And its size is 22 x 20 x 10 cm. The sales price will be around 1000 to 1500 EUR. Moreover it has a brake in the extra wheel.

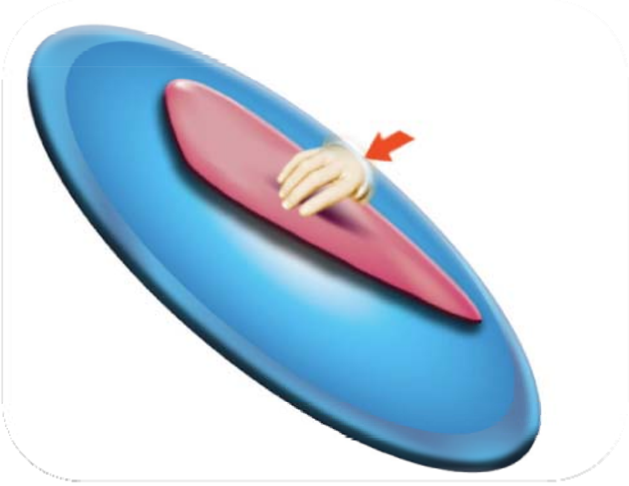
Sketch:



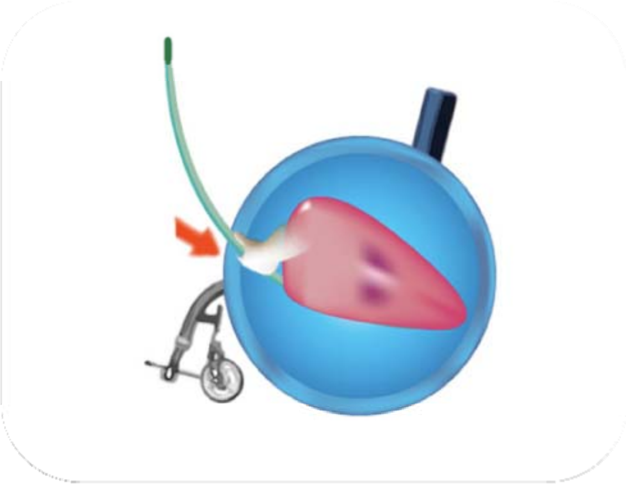
Photos and renderings:



Story-Board:



1. Attach the device.



2. Put the poles in.

3. Start moving!

Phase 2
System-Level Design

8 Product Architecture

The Product Architecture was a part of the concept development and system-level design.

8.1 Definition of Product Architecture

It is a description of the way(s) in which functional elements of a product or system are assigned to its constituent sections or subsystems, and of the way(s) in which they interact.[31] In other words product architecture defines the functional requirements within a product system, maps these requirements to physical elements or subsystems, and describes the interaction between these physical elements.

8.2 Importance and purpose of Product Architecture

For most products, especially for complex systems, it is essential to simplify and break down the product into smaller blocks. This can help reduce product development complexity and to further understood the item. This also means that the user/worker can clearly see how all elements have to be put together. The decisions felt during Product Architecture are highly affecting such things like product change, product variety, component standardization, and product performance, manufacturability and product development management. Not all of these subjects were mentioned in the following part as the focus was put on architecture itself.

A big advantage can be the enabling of postponement, the delayed differentiation of the product, which offers substantial potential cost savings.[32]

[31] http://www.businessdictionary.com/definition/product-architecture.html
[32] Ulrich, Product Design and Development

8.3 Establishing the architecture

As already mentioned in the definition, product architecture is defined as the scheme by which the function of a product is allocated to physical components. There are three distinct aspects mentioned:

1. All functions like overall function, subfunctions and functional elements are arranged in the *structure of functionality.* This usually is expressed by a verb and a noun, like in “reduce speed” or “increase pressure”, which describe what the product does. It is characterized by the fact that the higher level its level of details, the more assumptions about how the product physically works are embodied.
2. All physical parts of the product and their organization into subassemblies (also called chunks) need to be done. This is called *structure of physical components.* All components realize the functions of the product. Unlike the structure of functionality that shows what the product does, the structure of physical components shows how it is done.
3. Finally functional and physical characteristics are mapped and their interaction is clarified. There can be *one-to-one, one-to-many or many-to-one* mapping, which depends on the type of product architecture.[33]

The following chart sums up the aspects mentioned above:

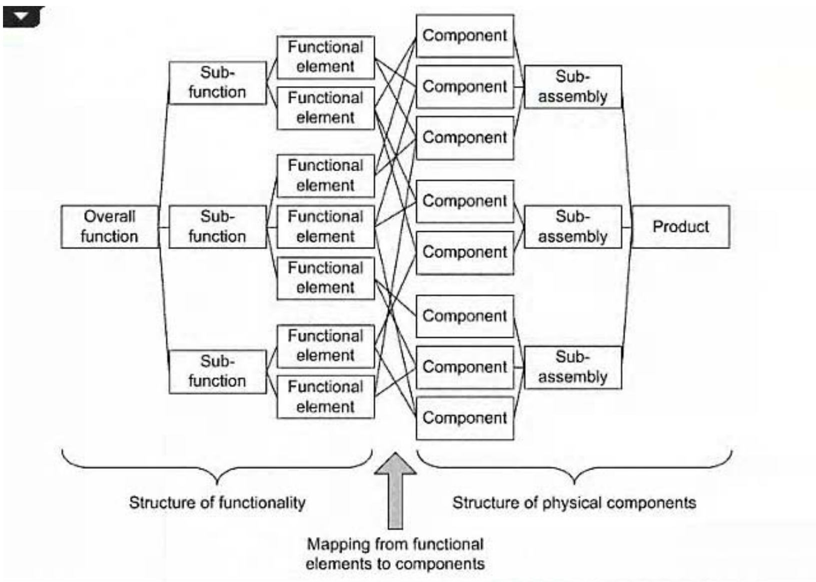


Figure 8.1 Schematic product architecture.[34]

33 http://books.google.com/books?id=Ds1wQEueHUsC&pg=PA39&dq=ulrich+product+architecture&hl=de&cd=5#v=onepage&q=ulrich%20product%20architecture&f=false

Translated for the wheelchair and the add-on the chart looks like this:

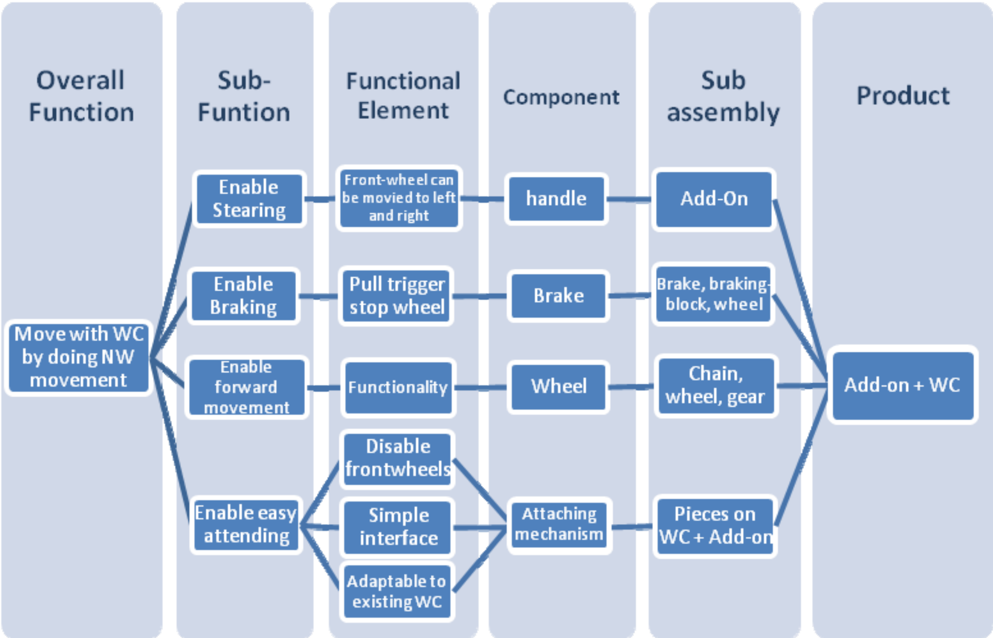


Figure 8.2 Wheelchair add-on product architecture

Product Architecture can be clarified in many different ways, but its most important characteristic is its modularity. Roughly speaking there are two kinds of modularity. One is modular and the other integral. The former is where rules have been established and the mapping relationship and interfaces are both simple. The latter one in which rules have not been established and the mapping relationship and the interfaces are both complex. There can be no clear line drawn to distinguish between both, it rather is a matter of degree. [35]

The wheelchair add-on was also an example for a mixed modularity. To show more clearly in what way both systems relate to each other, the following picture is shown. The physical independence of the components was very high, which meant all parts were physically separable.

[34]http://books.google.com/books?id=Ds1wQEueHUsC&pg=PA39&dq=ulrich+product+architecture&hl=de&cd=5#v=onepage&q=ulrich%20product%20architecture&f=false
[35] http://research.nii.ac.jp/TechReports/02-002E.pdf

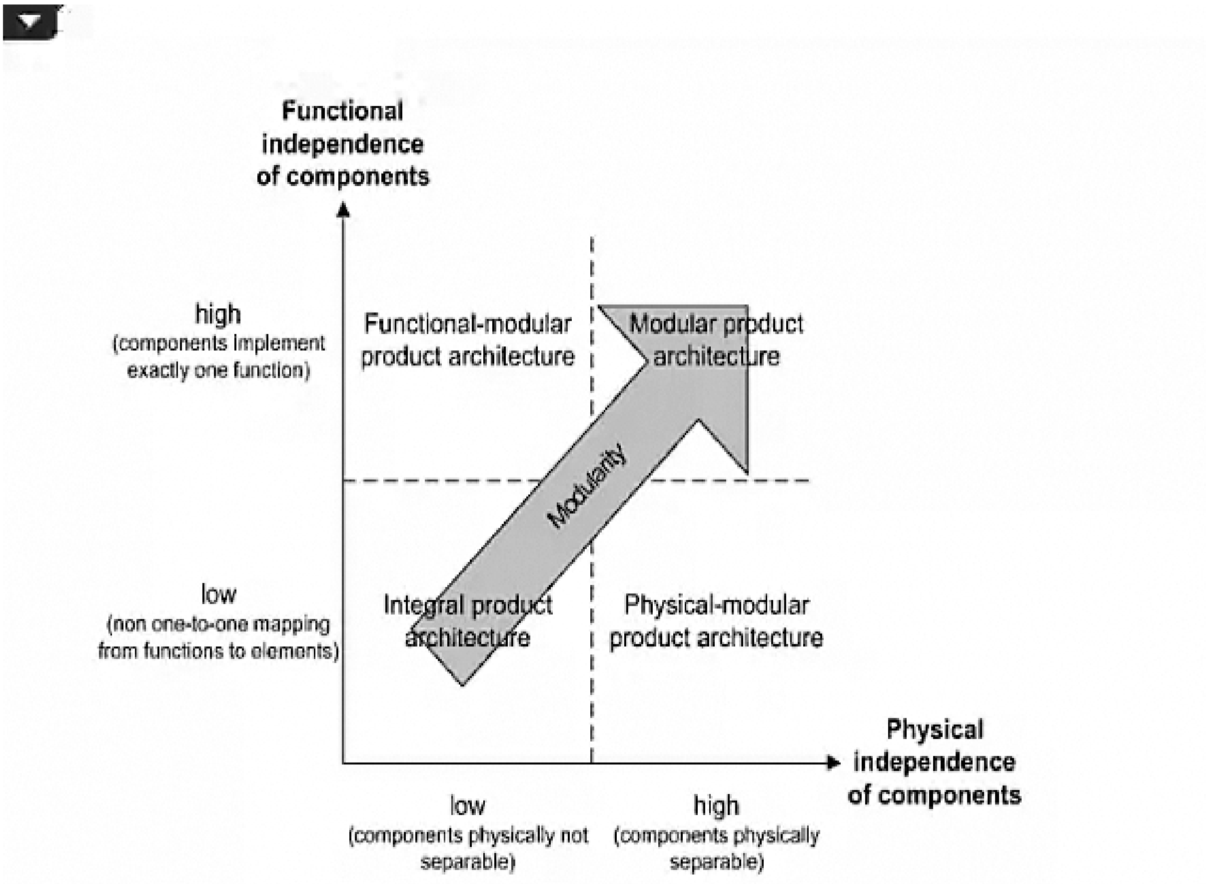


Figure 8.3 Classification of product architecture based on Göpfert (1998, p.107)[36]

If all aspects work together as a unit product performance – how well a product implements its intended functions – the functionality will be met to its best.

36 http://books.google.com/books?id=Ds1wQEueHUsC&pg=PA39&dq=ulrich+product+architecture&hl=de&cd=5#v=onepage&q=ulrich%20product%20architecture&f=false

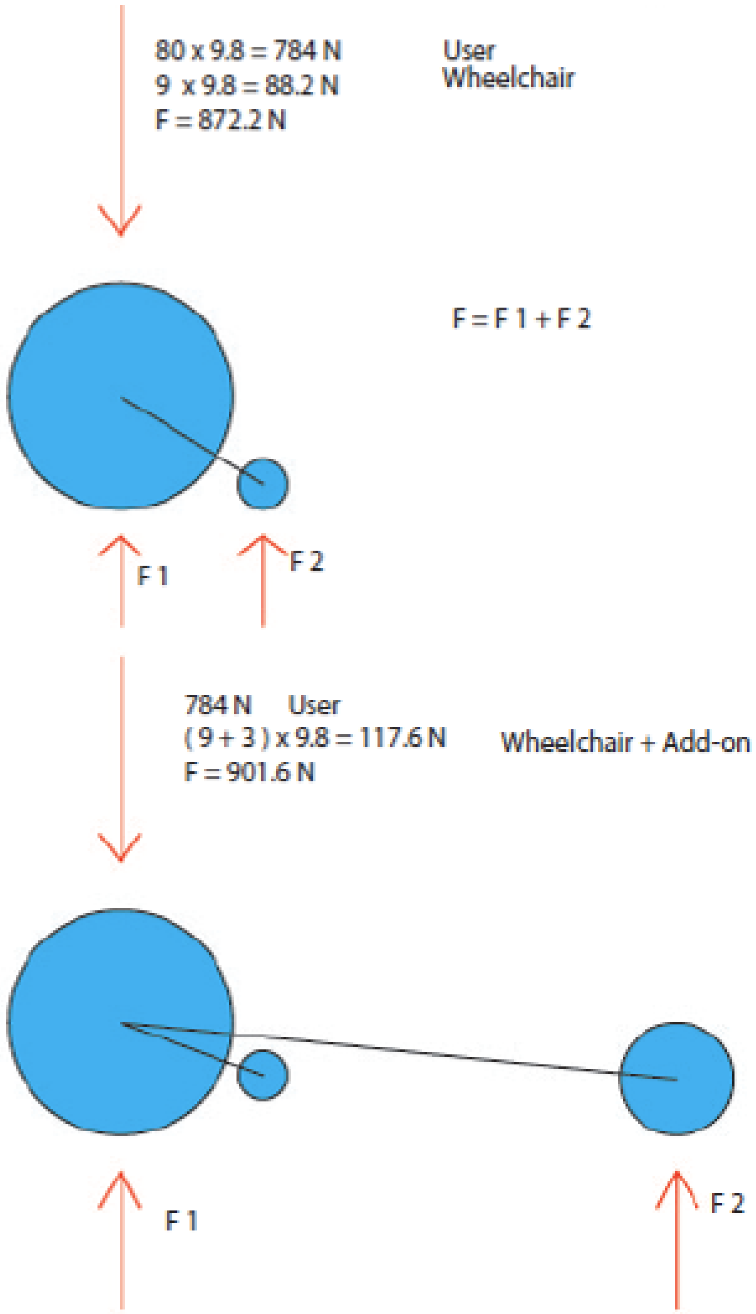
9 Industrial Design

Needs	Level of Importance	Explanation of Rating
Ergonomics Ease of use	High	It has to be used as easy as possible because the product would be most likely used frequently
Ease of maintenance	High	As the price of the product might be higher than planned, it is important to design it in a way that it can be maintained easily.
Quantity of user interactions	Medium	The situation is not critical, as there are only few interactions. But it is very important that these are fully understood by the user.
Novelty of user interactions	Medium	A similar Add-on might be known already so the customer feels familiar quickly. Otherwise all interactions can be understood fast.
Safety	High	It is important that the add-on allows safe use, so the user does not hurt himself or other people.
Aesthetics Product differentiation	Low	There are not many add-ons like this and with the same objective in the market. It is a very innovative product.
Pride of ownership, fashion, or image	High	The user has to be proud of using this product. Looks shouldn't reflect disability.
Team motivation	High	It is a product that is going to help make life better for the users.

Table 9.1 Assessing the importance of industrial design for the add-on.

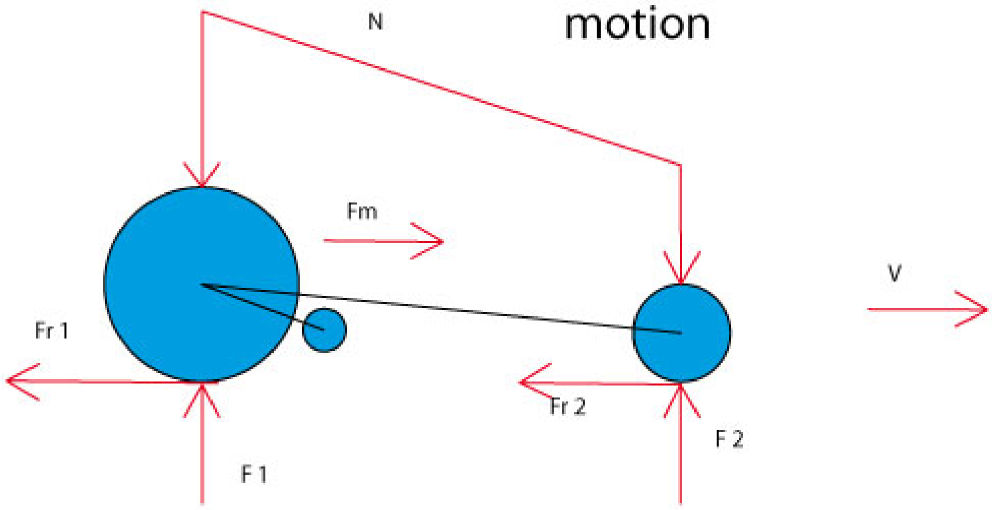
Ergonomics were very important for this product. Safety, easiness of use and maintenance had to be kept under consideration. On the other hand, aesthetics can help the user feel better by the emotional relation with the product and were also an important aspect to consider.

10 Forces Diagram



This is the diagram of static forces. There are no horizontal forces because the body is in static conditions.

Diagram of Forces and motion



General movement of the wheelchair:

Fo = m x a

Fo = Fm - (Fr1 + Fr2)

N = m x g = F1 + F2

Fr1 = F1 x η   Fr2 = F2 x η   η = Friction Coefficient

Fo = Fm - (N x η) asphalt friction with wheels = 0.75 aprox (with dry asphalt)

Fr = 901.6 N x 0.75 = 676.2 N this is the force that we need to apply to the wheelchair to start the movement.

This second diagram shows all the forces that would interact with the body in a dynamic situation. These equations express the calculations required to know how the force that the user needs to apply to the wheelchair to start moving it.

11 Solution

11.1 Add-on concept

The final concept developed came out after researching on various aspects that were considered important and were mentioned in the past chapters.

This add-on consists of three parts: two propulsion mechanisms that shift the ordinary drive to a stick-operated drive, one for each rear wheel, and a front sport wheel. Both propulsion mechanisms are easily connected onto a gear that has to be preinstalled onto the axe on both sides of the chair. This gearing doesn't interfere with any other function of the wheelchair. The stick mechanism is already preassembled and the user only requires making the connection between the gear and the add-ons by a simple click mechanism by pressure.

But there was the problem of transmitting the movement only in one direction. Because of that, the team decided that the mechanism should be based on the normal movement of a bicycle. That means if we apply a force in one direction, the wheel will move in the same way, but the wheel doesn't stop or move back when a force is applied in the other direction. Many different types of Coaster exist in the market depending on the required tasks. The piece needed for our design is a Freewheel/Flip Flop Coaster.

Figure 11.1 Freewheel/Flip Flop Coaster[37]

The Freewheel is very similar to a lead coaster, but it has small slots of different diameters to put the gear. Its advantages are: easy installation, big market, efficient and cheap.

http://www.btt.com.ar/nota/250/250636.shtml

The front wheel is an already-existing accessory for trekking. Any front wheel of this kind would do, making the speed of the wheelchair faster and making it more efficient for rough terrains. The user propels the system by pushing both poles at the same time as if they were skiing with a back and forth movement on an arc trajectory. For turning, the mechanism on the front wheel helps, but also using only the stick on one side would help to make smooth turns.

Based on the requirements the add-on had to fulfill from the product specifications, its main features are:

Scandinavian attractive

The Scandinavian market has very specific requirements for the gods they buy. High quality and personalized products are the only ones that can succeed within this market. For this matter the add-on offers a series of features that can relate to this need. Sustainability, durability, attractiveness, ergonomic, top technology, comfort, safety, fair cost, adapted to cites' infrastructure, modular and easy to use are some of this features. Scandinavian customers demand higher assets than the average. This add-on provides an unique opportunity to do a sport proper of this culture considering the characteristics of its people and infrastructure.

Clean materials and manufacturing

Most of the components the add-on is made of are used also on bikes. Denmark, as well as Norway, Sweden and Finland, are countries where bicycles are pretty common and unused parts or entire bicycles that people no longer use are easily found. These materials could be repurposed to provide parts for the add-on. It is important to keep waste at minimum and profit as much as possible of the resources available in order to compete with products in the market today. Research on this matter has to be further done.

Long-lasting product

The materials of which the wheelchair is made of are break resistant and can last for a long time without being damaged. Plus most parts can be upcycled or recycled within the biking sector, which besides helping to reduce waste of materials, is also a good source for part replacement and fixing. There are numerous establishments where bicycle parts are sold and repaired, which helps make the life of the product longer.

Comfortable for the user

Comfort is related to several other characteristics of the product. It refers to ergonomics, usability and emotional aspects.

The handles have a smooth grabbing surface of neoprene and are also ergonomically shaped so the users hands feel comfortable when using it.

The handle on the side mechanisms helps to make the attachment comfortable by not having to touch pointy or improper parts for the hands.

Users feel comfortable using it because of its intuitive use and easy driving. They also can feel related to the product, which makes it comfortable in an emotional level. It provides new experiences for the users that are meant to improve their life.

The materials are light so the user can feel comfortable carrying them. The user can use and carry them around without making it difficult to move.

Adaptable for sports/everyday life

The mobility this add-on provides can be used for both sport and everyday life. It was designed as an exercise and recreation device, not for competitions. People can enjoy a nice exercise routine or a get-together with friends. The user will have the opportunity to go out around the city or countryside with other people on bikes or similar devices.

It can also be used for everyday life as the city's bike infrastructure provides a safe way to get around the city. Using only a moderate force, the user can transport him from one place to another and not being completely fatigued. The space the add-on is not more than that of Christiania Bikes, which are the biggest vehicles that transit through the bike lanes. The sticks and the front wheel can be taken out and stored when going into a smaller place.

Increase safety

User's safety is considered on the device to avoid injuries according to ergonomics and safety restrictions in Europe. Internal mechanism is protected from the user so its hands don't touch the mechanism while on motion. Further testing has to be done on driving.

Minimize cost: selling price <1000€

Most similar products' prices on the market range between 500 and 1000 Euros. This add-on can be produced based on these standards. The material and manufacturing costs come up to ……., which is feasible to sell for a price within the established price margin.

Most pieces already exist in the market and their prices are not high, which makes the system less expensive to build. Even though a few parts have to be manufactured specifically for this add-on, like the PP carcass, the grip and some parts within the mechanisms, they are inexpensive to produce. The main mechanism can be installed at a very low cost due to the fact that it's the same mechanisms some bicycles have and every workshop or even the user can do.

Cool/fun look (personalized)

For wheelchair users personalization is an important aspect of their devices. The way wheelchair users are built are in most cases built to fit the user and not the other way around. Personalization is not only important on the ergonomics, but also on the looks of what they have. The plastic cover provides the possibility of personalizing the looks of the device by making it more appealing to the user. All exterior parts can be personalized in terms of colors. The looks of the whole device express the idea of speed and fun so that it doesn't look like a medical device or reflect awkwardness.

Easy transport and mobility (stability/turns)

When long distances have to be traveled, the front wheel helps the user get through it in a fast and efficient way. Due to the fact that is meant for bicycle paths, the user doesn't need to make extreme 90 degrees turns, but rather small and smooth turns as to go along the path or change onto a crossing lane.

Easy to use and assemble.

The use is intuitive, which makes it easily understandable. By having the mechanism in one piece, the use becomes simpler; users can use it immediately after installing it.

The attachment of all elements is very easy. The main mechanisms are connected with a click mechanism by pressure. Detachment is also easy by a release mechanism.

Cross-county Skiing / Nordic Walking

After a long research, it was considered that Nordic Walking was not the optimal exercise for a handicap person, due to the fact that it makes the muscles work less than when they are used for turning the wheels of a standard wheelchair. Instead, Cross-country skiing was a similar sport that provided a better opportunity for exercising the body. The double-poling technique works out the whole body, helping the user to build up muscle with a complete and fun exercise.

Less than 12kg

Mechanical parts are made with aluminum, light and strong material. The cover is made of polypropylene, which is also light and provides protection to the inner parts. The entire device has to be able to be carried around without complicating the user's mobility. The entire system, wheelchair included, weights less than 12 kg, which makes it bearable for the user to have.

Adaptable to existing wheelchairs types and sizes

The mechanism on the wheels is based on the way most wheelchairs are built and can be easily installed on any wheelchair, no matter the type or size. Poles are adapted to the size of the user, is the length of the tube that has to be adjusted. Front wheels are a common add-on for wheelchairs, plus most of them are built to fit most wheelchairs, so the user wont find it hard to find one that suits his.

Apply top technology

Top technology does not always relate to the amount of tech gadgets and digital devices some object has. For this add-on a manual drive had to be kept, as it is an exercise device, so the main aspects of its technology are related to energy proficiency.

The Freewheel mechanism is the best energy proficient for this kind of movement so that the relation between the user's force and the propulsion is the best for its purpose. Also, the mechanism developed profits most of the user's energy in comparison with other poling devices for wheelchairs that do a similar exercise.

11.2 Design for manufacturing

11.2.1 Materials

The materials chosen for most of the parts in the system are Cast Aluminum-alloys. These materials contain 5-22% of silicon, that make the material more fluid so that they fill the mold and take up fine detail. This feature makes the manufacturing costs lower than other processes.

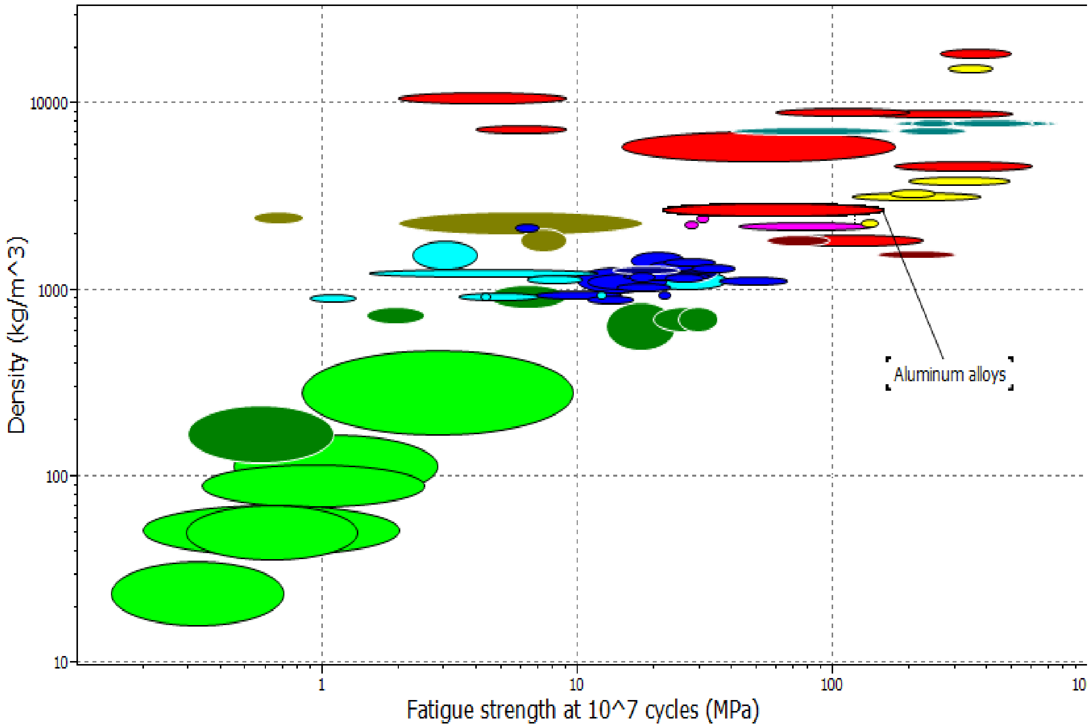


Figure 11.2 Density vs. Fatigue Strength

The price of this material goes from 1.7 to 1.87 USD/kg, which is very reasonable price for a material with these properties (weight, strength, hardness) that allow it for the use in our product. In the other hand the manufacturing process is cheap and easy, all the processes and materials for the different pieces are explain on the next chart:

Piece	Material	Price	Process
Main Piece	Cast Al-alloys	1.25– 1.39 EUR/KG	Casting
Guide	Cast Al-alloys	1.25– 1.39 EUR/KG	Casting
Axis	Cast Al-alloys	1.25– 1.39 EUR/KG	Casting
Pole	Aluminum alloys	1.17 – 1.29 EUR/KG	Bending
Cover	PP	0.87 - 0.96 EUR/KG	Injection molding
Grasp	Polyisoprene	2.22 – 2.45 EUR/KG	Injection molding

Table 11.1 Material Prices/ Process

(In the Appendix 1 there is all the information about the processes and materials)

11.2.2 Recycling and sustainability

Most of the components the add-on is made of are used also on bikes. Denmark is a country where bicycles are pretty common and unused parts or entire bicycles that people no longer use are easily found. These materials could be repurposed to provide parts for the add-on. It is important to keep waste at minimum and profit as much as possible of the resources available in order to compete with products in the market today. Research on this matter has to be further done.

11.2.3 General Cost Calculation

This Add-on has a front wheel that is made by a company and the sale price is 774 EUR.

The other part of the Add-on has a weight of 1 kg and has been design by this group, and has different parts which are described above. This add-on will need about 5 - 7 EUR in materials, and then the cost will be really increase by the manufacturing process that will be around 150 EUR for the gear system and around 20 EUR for the poles, and around 10 EUR for the rest of the pieces and 10 EUR more for the assembly.

With this calculations the final Add-on will have a production cost from 300 to 400 EUR. And the sale price will be around 1000 to 1500 EUR.

12 Conclusions

Nordic Walking is not a sport that can be done on a wheelchair. This sport is intended for people who want to do a more complete exercise when going out for a walk, they do not use only their legs, but their arms too. Wheelchair users evidently cannot do major workouts on their legs, instead they mainly use their upper limbs. There is no point for them to do Nordic Walking, the exercise done for the arms is too little, it is not even as much as the one done when propelling the wheelchair as usual.

Cross-country skiing is a better exercise for this purpose. The force used in the arms when doing this exercise is much bigger and can make the wheelchair travel more. Also, a parallel movement is required so that the wheelchair can follow a straight path with more stability. Most muscles on the upper part of the body are worked out with this exercise, which is a major benefit for the user.

It is important to enable people to have new experiences and as much opportunities as possible. Everyone always looking for different things to do that are far away from ordinary, new experiences are important to fulfill the human curiosity and challenge their mind and body. People with physical disabilities are often disregarded in our society because they are part of a minority. It is crucial to provide them with new tools for having a better life quality.
It is necessary to profit the resources, infrastructure and materials available, to make a product successful. This project was intended for a specific Scandinavian market, so all the infrastructure and cultural aspects had to be considered for developing the product. In this case, the bicycle culture in these cities provides a good opportunity for wheelchair users.

Every market has its own requirements. Scandinavians have high standards for their products and by making them more specifically for them, the product would be more likely to succeed.

Testing on an actual prototype has still to be done in order to make it better. As a concept for a new product this idea can work, but it is necessary to make some tests before developing this product so that the mechanisms work in a proper way and the device is really adapted to a wheelchair user. Unfortunately timing, equipment and resources available were not available for the team to make this kind of testing.

This product provides an innovative way to exercise and do a different activity for wheelchair users. There are many products like these on the market, but none of them is adaptable for actual use on the streets as a vehicle. These features, along with the ones mentioned before, make of this device a product that is not only useful, but also fun. It really has the opportunity to succeed on making life better for a minority that is often disregarded: wheelchair users.

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Appendix 1

1. Responsibility Matrix

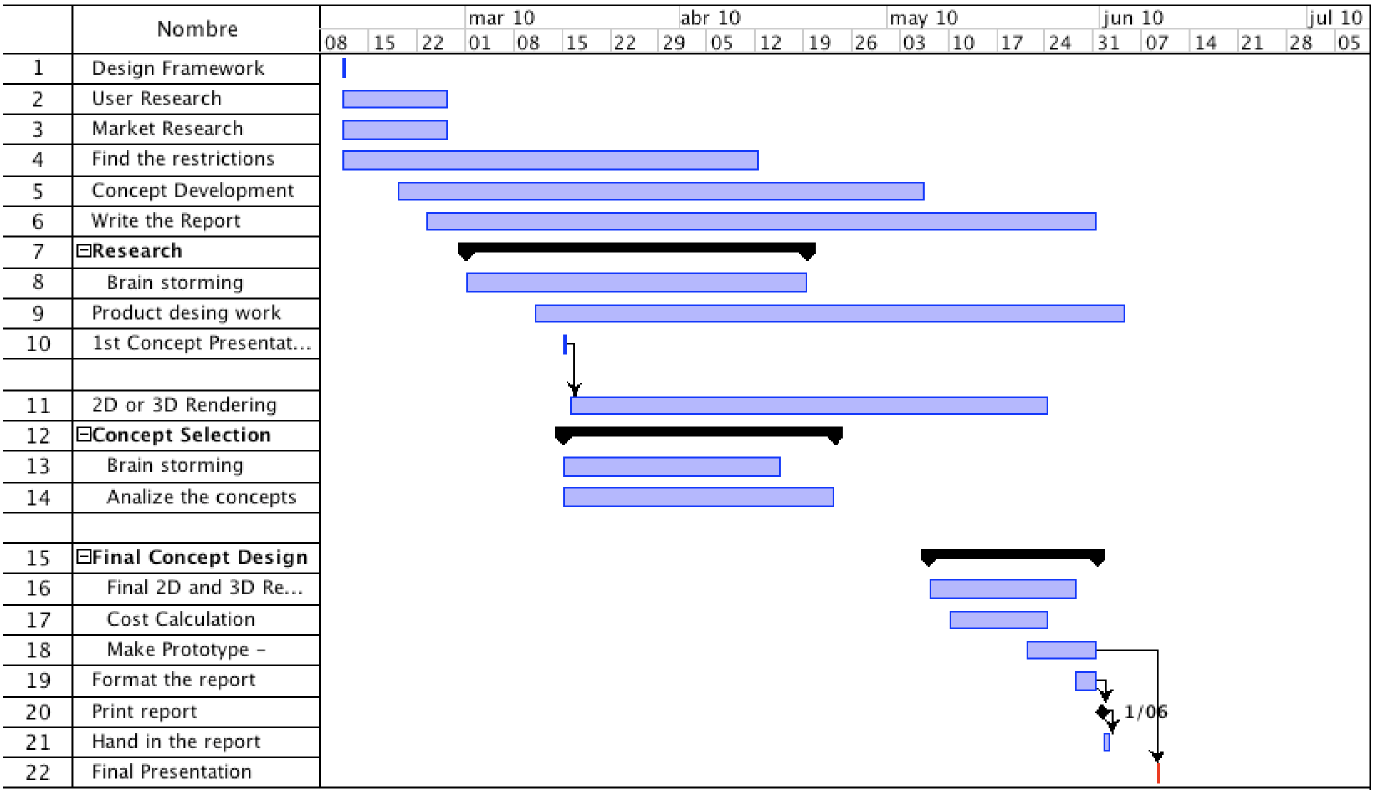
					Phase 0						
					Background information						
	Preparative research	Creating first concepts	Abstract	Introduction	Wheelchair	Nordic Walking	Cross Country	Methodology	Market Research	Ergonomics	Restrictions/ Norms
Belén	Orange	Orange				Orange					Orange
Julia	Orange	Orange	Orange		Orange			Orange		Orange	
Ignacio	Orange	Orange							Orange		
Rafael	Orange	Orange		Orange			Orange				

	Phase 1					Phase 2					
	Concept development								Solution		
	Identifying Customer Needs	Product Specifications	Concept Generation	Concept Selection	Concept Testing	Product Architecture	Industrial Design	Force Diagram	Add-on Concept	Design for Manufacturing	Conclusion
Belén	Orange	Orange	Orange	Blue	Orange						
Julia	Orange		Orange	Blue		Orange	Blue				
Ignacio	Orange		Orange	Blue			Orange	Orange		Orange	
Rafael	Orange		Orange	Orange					Orange		Orange

	Additional work						
	Gantt-Chart	Sketches	Technical drawings	Modeling	References	Proof-reading	Layout
Belén		Orange	Orange	Orange			
Julia		Blue			Orange	Blue	
Ignacio	Orange	Blue					Orange
Rafael		Orange				Orange	

Orange: Responsible
Blue: Support

2. Gantt Chart



3. E-mail from "Dansk Handicap Forbund"

-------- Original-Nachricht --------
Datum: Fri, 26 Feb 2010 13:09:57 +0100
Von: DHF - Dansk Handicap Forbund <dhf@dhf-net.dk>
An: Julia Voigt <voigts_julia@gmx.de>
Betreff: Re: wheelchair

Hello
Unfortunately we can not help you as it is not allowed to register such
information (or religion, colored people etc.)
regards
Marianne Fly
2010/2/22 Julia Voigt <voigts_julia@gmx.de>

> Hej,
>
> I was wondering if there is an official number of how many people in
> Denmark are using a wheelchair? I couldn't find any information about that.
>
> Looking forward to hearing from you.
>
> Mange tak.
>
> Julia Voigt
> --

4. Wheelchair ergonomics[38]

ADJUSTMENT	WHEELCHAIR	BODY	Pay attention to...
HIGHER SEAT HEIGHT FRONT PART & BACKWARD TILT **Bigger castors** **Longer forks** **Smaller drivewheels in same position** **Drivewheels moved up on frame**	• Front of wheelchair frame is higher. Backward seat slope increases. • Backrest is reclined. • Drive-wheels move forward in relation to user's trunk. • Fork attach-ments on frame need to be re-adjusted.	• Seat slope increases pelvis' tendency to tilt back and thighs are lifted up. Pelvis is backward stabilized. • Trunk's pressure against backrest increases. If backrest is high and contoured, truck be-comes more stable. Seating unit is tilted-in-space. • If seat pressure against thighs is high, pressure against backrest increases, increasing tendency to slide. • Manoeuvrability with arms is improved, and with feet impaired.	• Backrest pres-sure against pelvis' upper parts may increase. • Stable pelvis can make it difficult to lean forwards. • Foot propulsion: may become difficult to reach floor comfortably. • Risk of tipping backwards in-creases! Protections may be needed.
LOWER SEAT HEIGHT REAR PART & FORWARD TILT **Smaller castors** **Shorter forks** **Bigger drivewheels in same position** **Drivewheels moved down on frame**	• Front of wheelchair frame is lowered. Backward seat slope decreases. Slope may be horizontal or even forward. • If backrest becomes forward angled, needs to be readjusted. • Drive-wheels move rearwards and weight on castors increases.	• Seat slope tilts pelvis forward and thighs become more horizontal, or may slope forwards. The pelvis becomes less back-ward stable making it easier to tilt it forward. • Moving trunk forward requires less energy. • Manoeuvrability with feet is improved. Due to more efficient floor pressure and reach. • Leaning forwards and stand-ing up is easier.	• Pelvis' and thoracic spine's pressure against backrest decreases. • Too much trunk freedom forwards may give user sense of instability. • Wheelchiar stability increases. Risk of tipping backward decreases. Much weight on castors makes arm propulsion harder.
WIDTH **Wider seat**	• Frame width increases, and also backrest width*.	• Pressure against hips often leads to asymmetric seating. Wider seat decreases pressure.	• Too wide seat decreases stability.
Narrower seat	• Frame narrows. Backrest narrows*.	• Narrow seat is more stable.	• Too narrow seat leads to hip pressure.
SEAT DEPTH Shorter seat	• Short seat may shorten frame*.	• Shorter, not too deep seat, lets backrest stabilize pelvis.	• Too short seats are poor in distributing pressure and stability.
Deeper seat	• A deeper seat often makes frame longer*.	• Longer, well contoured seat, improves pressure distribution and makes legs more stable.	Too long seats most often lead to sliding and slouching.

* Can be avoided by using special back and seat solutions.

38 http://www.engstromconcept.com/pdf/beskrivnengbok.pdf

ADJUSTMENT	WHEELCHAIR	BODY	Pay attention to...
ANGLE **Reclining (backward angle)** **High backrest**	• Drive-wheels move forward in relation to user's trunk. (Tip protection?!) • More weight on drive-wheels. • Easier to manoeuver wheelchair. Rolling resistance decreases due to less weight on castors.	• Backrest reclined backward tilts pelvis. Pelvis is stabilized. • Entire trunk stabilized against high backrest only if backrest recline is big enough. • Anatomically contoured backrest can be reclined less, without trunk losing stability against backrest surface.	• Leaning the trunk forwards requires more energy when pelvis is backward stabilized. • Reclining planar backrest makes trunk' tend to collapse more. Pressure against the pelvis increases. • Flexion of spine together with pelvic tilt influences pelvis to slide forwards on seat.
Forward angle **Medium height**	• Drive-wheels move rearwards in relation to trunk. • Less weight on drive-wheels. • More weight on castors. • Higher rolling resistances. Much more difficult to arm propel wheelchair.	• Forward angulation tilts pelvis forwards. Combined with seat sloping backwards, pelvis and trunk stabilized against backrest. • Trunk can be kept upright when backrest is a little forward unless back is too high, restricting extension of spine. • Anatomically contoured backrest does not need to be angled forward as much as planar backrest, to make the pelvis stable and functionally positioned.	• Backrest's pressure against trunk increases. Pelvis is pushed forwards. • Pelvis stabilized against short back-rest, improves upper trunk activity. • Forward tilted pelvis on horizontal seat increase trunk's tendency to fall forwards.
HEIGHT **Higher backrest**	• Wheelchair much more difficult to manoeuver when backrest height restrictings arms freedom of move-ment.	• A high, reclined backrest increases the trunk's stability against the backrest surface. • If anatomically contoured, equal stability is acheived in a better position, using less recline.	• Planar, high backrest pushes trunk forwards. Needs to be reclined for pushing force to go away.
Lower backrest	• More room for extension of trunk. Risk of tipping increases. (Tip protection!?)	• Trunk´s freedom of movement is improved when backrest is lowered, if combined with a seat surface stabilizing legs, pelvis and low back.	• Short backrest needs to be well con-toured to sufficiently stabilize pelvis and low back.

5. Restrictions and norms[39]

Reference	Title
ISO 10542-1:2001	Technical systems and aids for disabled or handicapped persons -- Wheelchair tie down and occupant-restraint systems -- Part 1: Requirements and test methods for all systems
ISO 10542-2:2001	Technical systems and aids for disabled or handicapped persons -- Wheelchair tie down and occupant-restraint systems -- Part 2: Four-point strap-type tie down systems
ISO 10542-3:2005	Technical systems and aids for disabled or handicapped persons -- Wheelchair tie down and occupant-restraint systems -- Part 3: Docking-type tie down systems
ISO 10542-4:2004	Technical systems and aids for disabled or handicapped persons -- Wheelchair tie down and occupant-restraint systems -- Part 4: Clamp-type tie down systems
ISO 10542-5:2004	Technical systems and aids for disabled or handicapped persons -- Wheelchair tie down and occupant-restraint systems -- Part 5: Systems for specific wheelchairs
ISO 16840-1:2006	Wheelchair seating -- Part 1: Vocabulary, reference axis convention and measures for body segments, posture and postural support surfaces
ISO 16840-2:2007	Wheelchair seating -- Part 2: Determination of physical and mechanical characteristics of devices intended to manage tissue integrity -- Seat cushions
ISO 16840-3:2006	Wheelchair seating -- Part 3: Determination of static, impact and repetitive load strengths for postural support devices
ISO 16840-4:2009	Wheelchair seating -- Part 4: Seating systems for use in motor vehicles
ISO 7176-1:1999	Wheelchairs -- Part 1: Determination of static stability
ISO 7176-2:2001	Wheelchairs -- Part 2: Determination of dynamic stability of electric wheelchairs
ISO 7176-3:2003	Wheelchairs -- Part 3: Determination of effectiveness of brakes
ISO 7176-4:2008	Wheelchairs -- Part 4: Energy consumption of electric wheelchairs and scooters for determination of theoretical distance range
ISO 7176-5:2008	Wheelchairs -- Part 5: Determination of dimensions, mass and maneuvering space
ISO 7176-6:2001	Wheelchairs -- Part 6: Determination of maximum speed, acceleration and deceleration of electric wheelchairs
ISO 7176-7:1998	Wheelchairs -- Part 7: Measurement of seating and wheel dimensions
ISO 7176-8:1998	Wheelchairs -- Part 8: Requirements and test methods for static, impact and fatigue strengths
ISO 7176-9:2009	Wheelchairs -- Part 9: Climatic tests for electric wheelchairs

[39] http://www.iso.org/iso/search.htm?qt=wheelchair&searchSubmit=Search&sort=rel&type=simple&published=on

ISO 7176-10:2008	Wheelchairs -- Part 10: Determination of obstacle-climbing ability of electrically powered wheelchairs
ISO 7176-11:1992	Wheelchairs -- Part 11: Test dummies
ISO 7176-13:1989	Wheelchairs -- Part 13: Determination of coefficient of friction of test surfaces
ISO 7176-14:2008	Wheelchairs -- Part 14: Power and control systems for electrically powered wheelchairs and scooters -- Requirements and test methods
ISO 7176-15:1996	Wheelchairs -- Part 15: Requirements for information disclosure, documentation and labeling
ISO 7176-16:1997	Wheelchairs -- Part 16: Resistance to ignition of upholstered parts -- Requirements and test methods
ISO 7176-19:2008	Wheelchairs -- Part 19: Wheeled mobility devices for use as seats in motor vehicles
ISO 7176-21:2009	Wheelchairs -- Part 21: Requirements and test methods for electromagnetic compatibility of electrically powered wheelchairs and scooters, and battery chargers
ISO 7176-22:2000	Wheelchairs -- Part 22: Set-up procedures
ISO 7176-23:2002	Wheelchairs -- Part 23: Requirements and test methods for attendant-operated stair-climbing devices
ISO 7176-24:2004	Wheelchairs -- Part 24: Requirements and test methods for user-operated stair-climbing devices
ISO 7176-26:2007	Wheelchairs -- Part 26: Vocabulary
ISO/TR 13570-1:2005	Wheelchairs -- Part 1: Guidelines for the application of the ISO 7176 series on wheelchairs
ISO 10542-1:2001	Technical systems and aids for disabled or handicapped persons -- Wheelchair tie down and occupant-restraint systems -- Part 1: Requirements and test methods for all systems
ISO 10542-2:2001	Technical systems and aids for disabled or handicapped persons -- Wheelchair tie down and occupant-restraint systems -- Part 2: Four-point strap-type tie down systems
ISO 10542-3:2005	Technical systems and aids for disabled or handicapped persons -- Wheelchair tie down and occupant-restraint systems -- Part 3: Docking-type tie down systems
ISO 10542-4:2004	Technical systems and aids for disabled or handicapped persons -- Wheelchair tie down and occupant-restraint systems -- Part 4: Clamp-type tie down systems
ISO 10542-5:2004	Technical systems and aids for disabled or handicapped persons -- Wheelchair tie down and occupant-restraint systems -- Part 5: Systems for specific wheelchairs

6. Materials and processes

Cast Al-alloys

Description The material Almost all aluminum alloys for casting contain 5 - 22% silicon (Si) -- the silicon makes the alloys more fluid so that they fill the mold and take up fine detail, even in thin sections. Further additions of copper (Cu) or magnesium (Mg) give age-hardening alloys. The plain Al-Si alloys are used for marine components and hardware and for cooking utensils because of their good resistance to corrosion in salt water; and they are used for pistons and cylinder liners because of their good thermal conductivity and low expansion. As a general rule the casting alloys have lower ductility and strength than the wrought age-hardening alloys -- few have tensile strengths above 350 MPa.

Composition (summary) Al + 5 - 22% Si, sometimes with some Cu, Mg or Zn to allow age-hardening.

General properties				
Density	2.5e3	-	2.9e3	kg/m^3
Price	* 1.7	-	1.87	USD/kg
Mechanical properties				
Young's modulus	72	-	89	GPa
Shear modulus	25	-	34	GPa
Bulk modulus	66	-	72	GPa
Poisson's ratio	0.32	-	0.36	
Yield strength (elastic limit)	50	-	330	MPa
Tensile strength	65	-	386	MPa
Compressive strength	50	-	330	MPa
Elongation	0.4	-	10	%
Hardness - Vickers	60	-	150	HV
Fatigue strength at 10^7 cycles	32	-	157	MPa
Fracture toughness	18	-	35	MPa.m^1/2
Mechanical loss coefficient (tan delta)	1e-4	-	0.002	

Polyisoprene rubber (IIR)

Description The material Isoprene (or Polyisoprene) is synthetic natural rubber, and is processed in the same way as natural rubber. It has low hysteresis and high tear resistance, making it bouncy and tough.

Composition (summary) (CH2-C(CH3)-CH-CH2)n

General properties				
Density	930	-	940	kg/m^3
Price	* 2.22	-	2.45	EUR/kg
Mechanical properties				
Young's modulus	0.0014	-	0.004	GPa
Shear modulus	4e-4	-	6e-4	GPa
Bulk modulus	1.45	-	1.55	GPa
Poisson's ratio	0.499	-	0.5	
Yield strength (elastic limit)	20	-	25	MPa
Tensile strength	20	-	25	MPa
Compressive strength	23	-	25	MPa
Elongation	500	-	550	%
Fatigue strength at 10^7 cycles	* 3.45	-	7	MPa
Fracture toughness	0.07	-	0.1	MPa.m^1/2
Mechanical loss coefficient (tan delta)	* 0.82	-	2	

Aluminum alloys

Description The material Aluminum was once so rare and precious that the Emperor Napoleon III of France had a set of cutlery made from it that cost him more than silver. But that was 1860; today, nearly 150 years later, aluminum spoons are things you throw away - a testament to our ability to be both technically creative and wasteful. Aluminum, the first of the 'light alloys' (with magnesium and titanium), is the third most abundant metal in the earth's crust (after iron and silicon) but extracting it costs much energy. It has grown to be the second most important metal in the economy (steel comes first), and the mainstay of the aerospace industry.

Composition (summary) Al + alloying elements, e.g. Mg, Mn, Cr, Cu, Zn, Zr, Li

General properties

Density	2.5e3	-	2.9e3	kg/m^3
Price	* 1.17	-	1.29	EUR/kg

Mechanical properties

Young's modulus	68	-	82	GPa
Shear modulus	25	-	31	GPa
Bulk modulus	64	-	71	GPa
Poisson's ratio	0.32	-	0.36	
Yield strength (elastic limit)	30	-	500	MPa
Tensile strength	58	-	550	MPa
Compressive strength	30	-	500	MPa
Elongation	1	-	44	%
Hardness - Vickers	12	-	151	HV
Fatigue strength at 10^7 cycles	21.6	-	157	MPa
Fracture toughness	22	-	35	MPa.m^1/2
Mechanical loss coefficient (tan delta)	1e-4	-	0.002	

olypropylene (PP)

Description The material Polypropylene, PP, first produced commercially in 1958, is the younger brother of polyethylene - a very similar molecule with similar price, processing methods and application. Like PE it is produced in very large quantities (more than 30 million tons per year in 2000), growing at nearly 10% per year, and like PE its molecule-lengths and side-branches can be tailored by clever catalysis, giving precise control of impact strength, and of the properties that influence molding and drawing. In its pure form polypropylene is flammable and degrades in sunlight. Fire retardants make it slow to burn and stabilizers give it extreme stability, both to UV radiation and to fresh and salt water and most aqueous solutions.

Composition (summary) (CH2-CH(CH3))n

General properties

Density	890	-	910	kg/m^3
Price	* 0.879	-	0.967	EUR/kg

Mechanical properties

Young's modulus	0.896	-	1.55	GPa
Shear modulus	0.316	-	0.548	GPa
Bulk modulus	2.5	-	2.6	GPa
Poisson's ratio	0.405	-	0.427	
Yield strength (elastic limit)	20.7	-	37.2	MPa
Tensile strength	27.6	-	41.4	MPa
Compressive strength	25.1	-	55.2	MPa
Elongation	100	-	600	%
Hardness - Vickers	6.2	-	11.2	HV
Fatigue strength at 10^7 cycles	11	-	16.6	MPa
Fracture toughness	3	-	4.5	MPa.m^1/2
Mechanical loss coefficient (tan delta)	0.0258	-	0.0446	

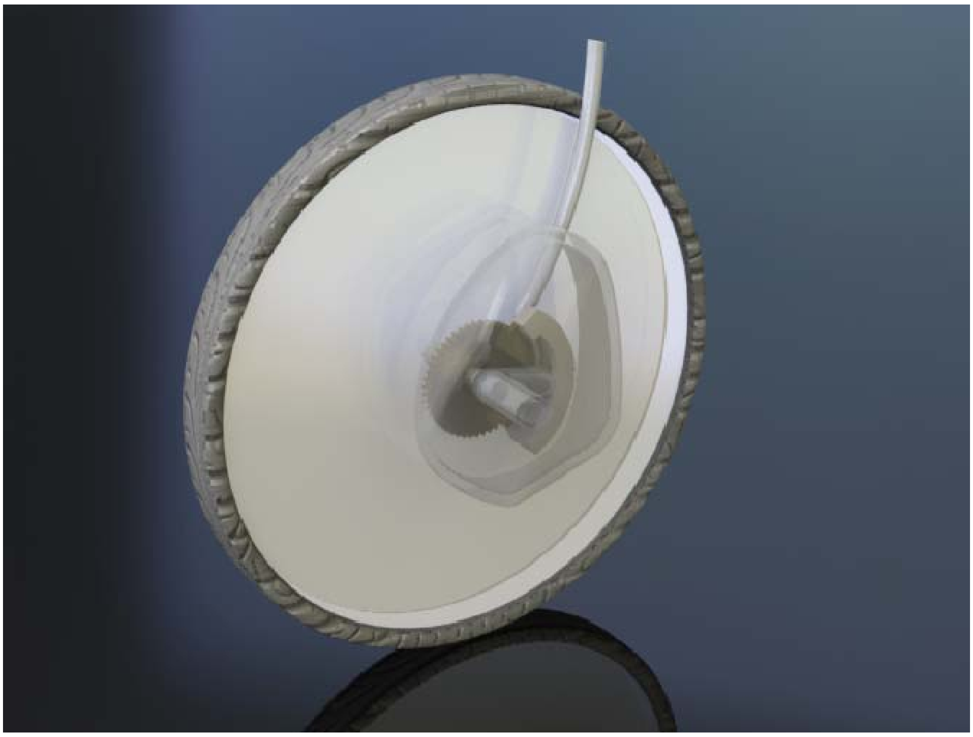
Injection molding

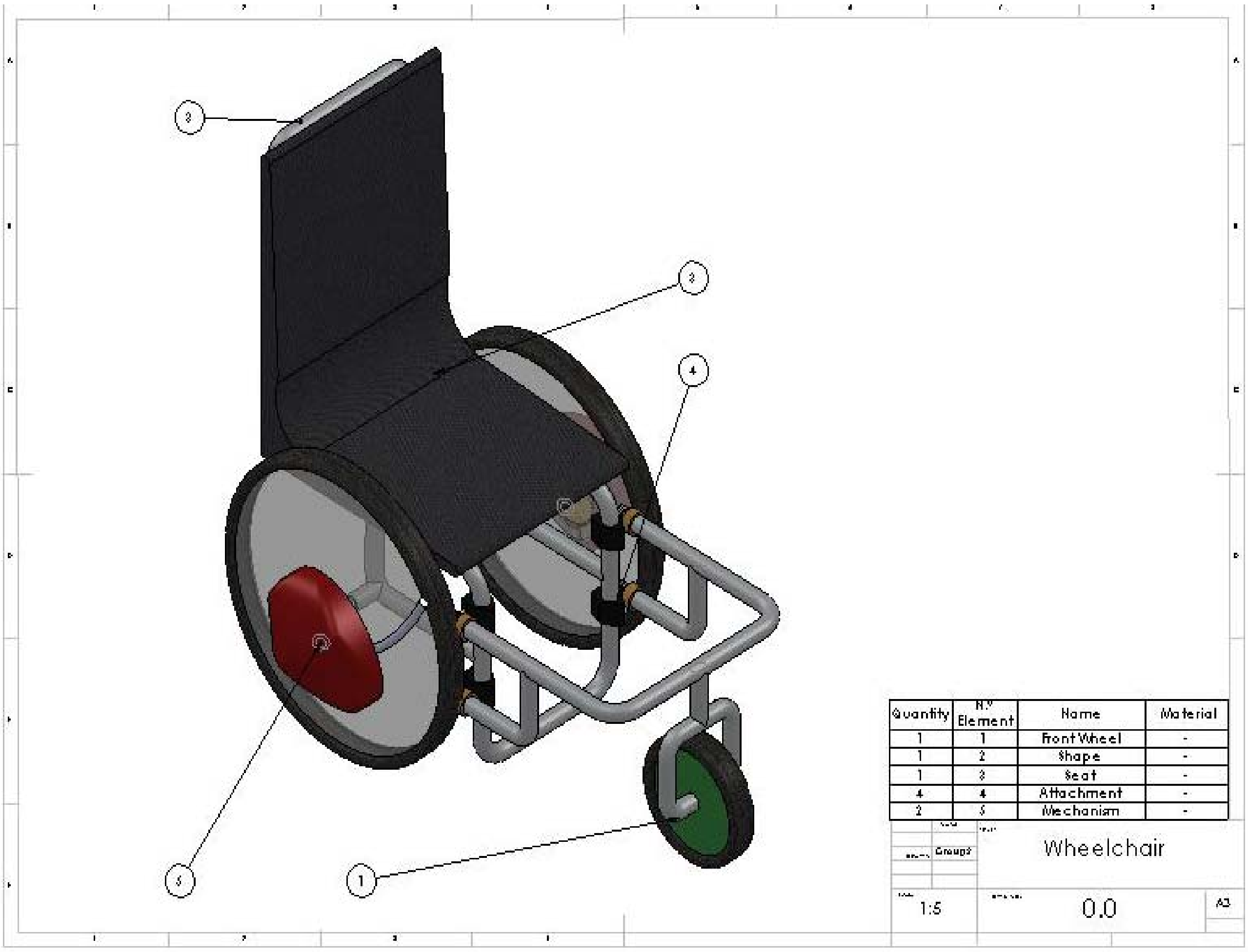
Description The process No other process has changed product design more than INJECTION MOLDING. Injection molded products appear in every sector of product design: consumer products, business, industrial, computers, communication, medical and research products, toys, cosmetic packaging and sports equipment. The most common equipment for molding thermoplastics is the reciprocating screw machine, shown schematically in the figure. Polymer granules are fed into a spiral press where they mix and soften to a dough-like consistency that can be forced through one or more channels ('sprues') into the die. The polymer solidifies under pressure and the component is then ejected. Thermoplastics, thermosets and elastomers can all be injection molded. Co-injection allows molding of components with different materials, colors and features. Injection foam molding allows economical production of large molded components by using inert gas or chemical blowing agents to make components that have a solid skin and a cellular inner structure.

Sand casting

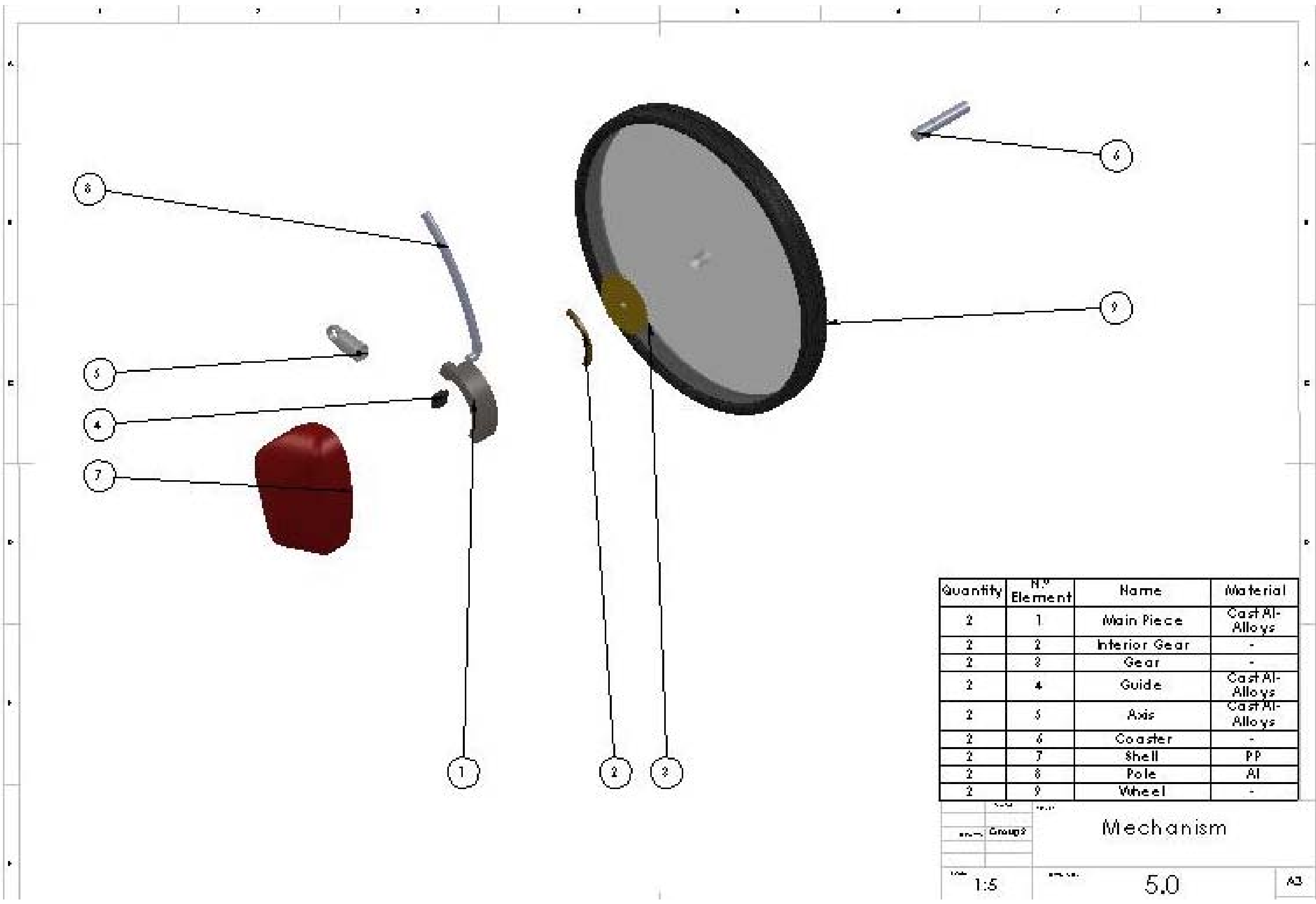
Description The process SAND CASTING probably started on beaches -- every child knows how easy it is to make sand castles. Add a binder and much more complex shapes become possible. And sand is a refractory; even iron can be cast in it. In GREEN SAND CASTING, a mixture of sand and clay is compacted in the split mold around a pattern that has the shape of the desired casting. The pattern is removed to leave the cavity in which the metal is poured. Cheap wooden patterns, with gates and risers attached, are used when the batch size is small and the process is manual, but this is slow and labor intensive. Automated systems use aluminum patterns and automated compaction. The sand mold is referred to as 'green' when it is used in a moist condition. Dry sand molds are stronger and more rigid, and thus are used in making large heavy castings. In CO2 /SILICATE SAND CASTING, a mixture of sand and sodium silicate binder is packed around a pattern as before and flooded with CO2 to seal the sodium silicate gel. The mold is, in principle, reusable, but deteriorates quickly. In EVAPORATIVE SAND CASTING, the pattern is made from polystyrene foam, and is first coated with a refractory coating and then embedded in dry, unbounded sand. When molten metal is poured into the mold, the polystyrene pattern vaporizes. Very complex shapes of undercuts at re-entrant angles are feasible without the use of cores. In SHELL CASTING, a mixture of fine-grained sand and thermosetting resin is applied to a heated metal pattern (aluminum or cast iron) and cured to form a shell. Two matching shells are then joined to form a complete mold that is then placed in a frame packed with sand. The process gives good surface finish and better dimensionality than conventional sand casting.

Appendix 2





Quantity	N.º Element	Name	Material
1	1	Front Wheel	-
1	2	Shape	-
1	3	Seat	-
4	4	Attachment	-
2	5	Mechanism	-



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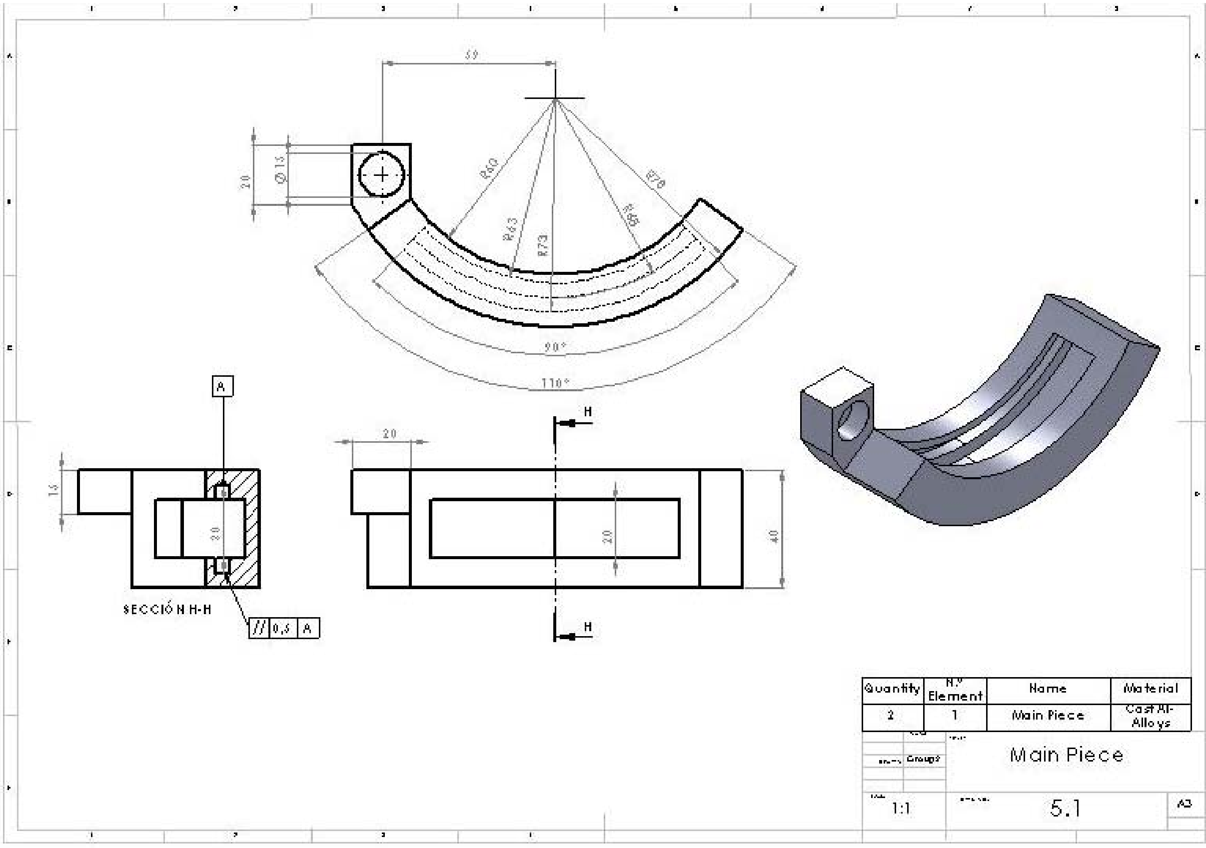
2	1	Main Piece	Cast Al-Alloys
2	2	Interior Gear	-
2	3	Gear	-
2	4	Guide	Cast Al-Alloys
2	5	Axis	Cast Al-Alloys
2	6	Coaster	-
2	7	Shell	PP
2	8	Pole	Al
2	9	Wheel	-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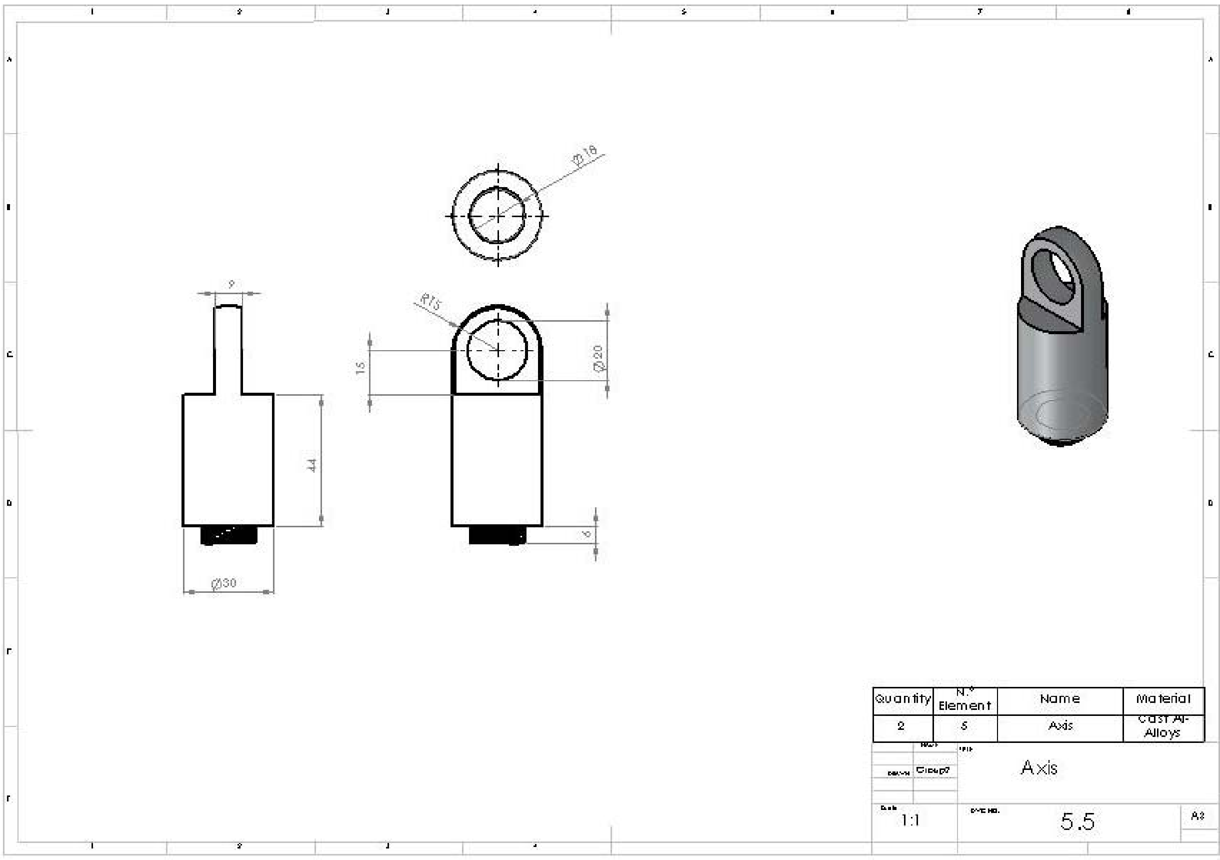
A3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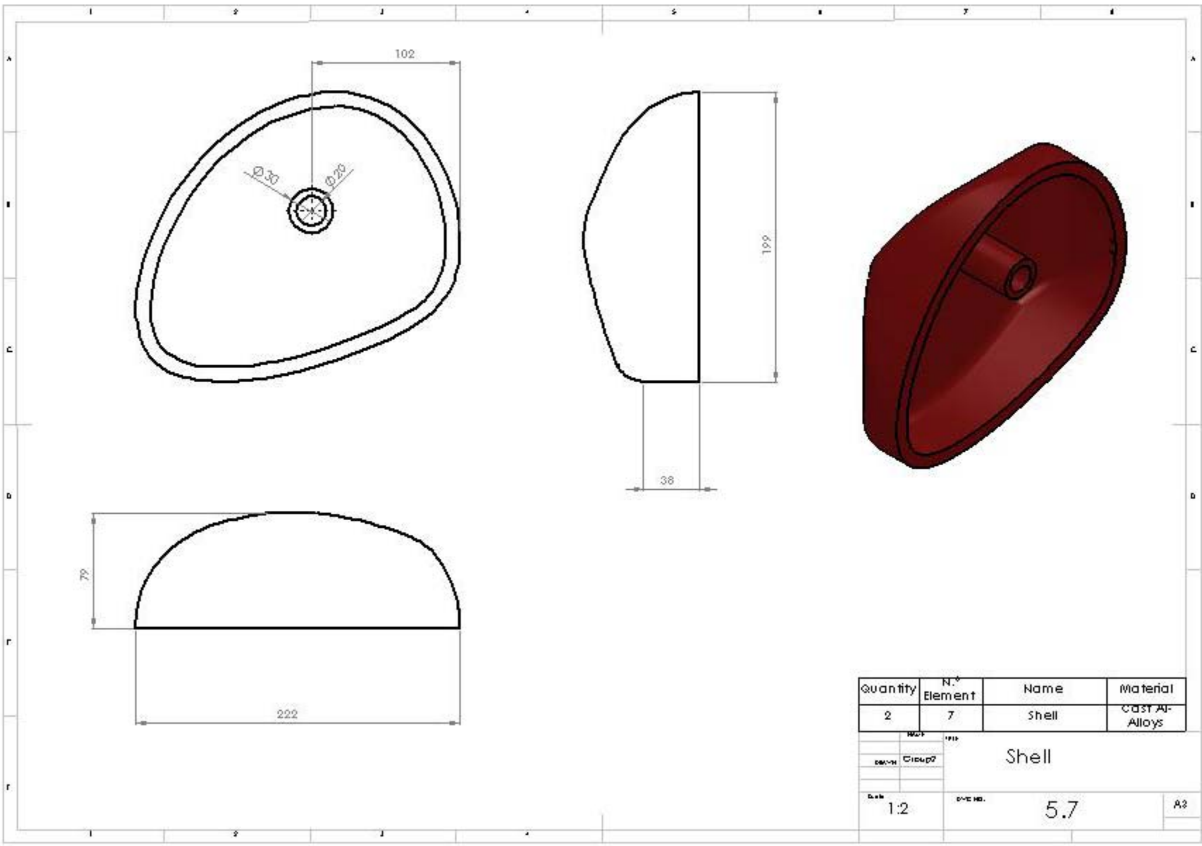
A3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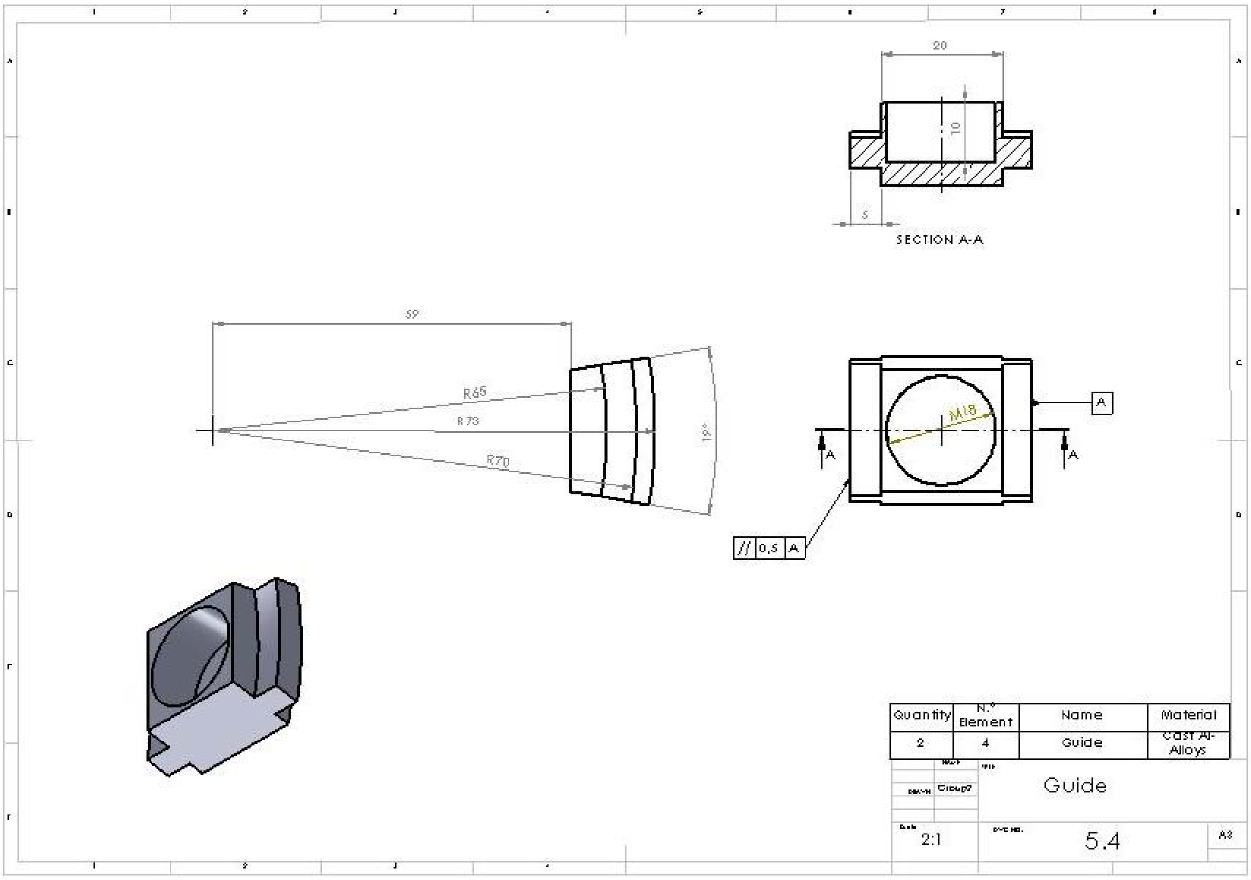
5.7
A3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Guide
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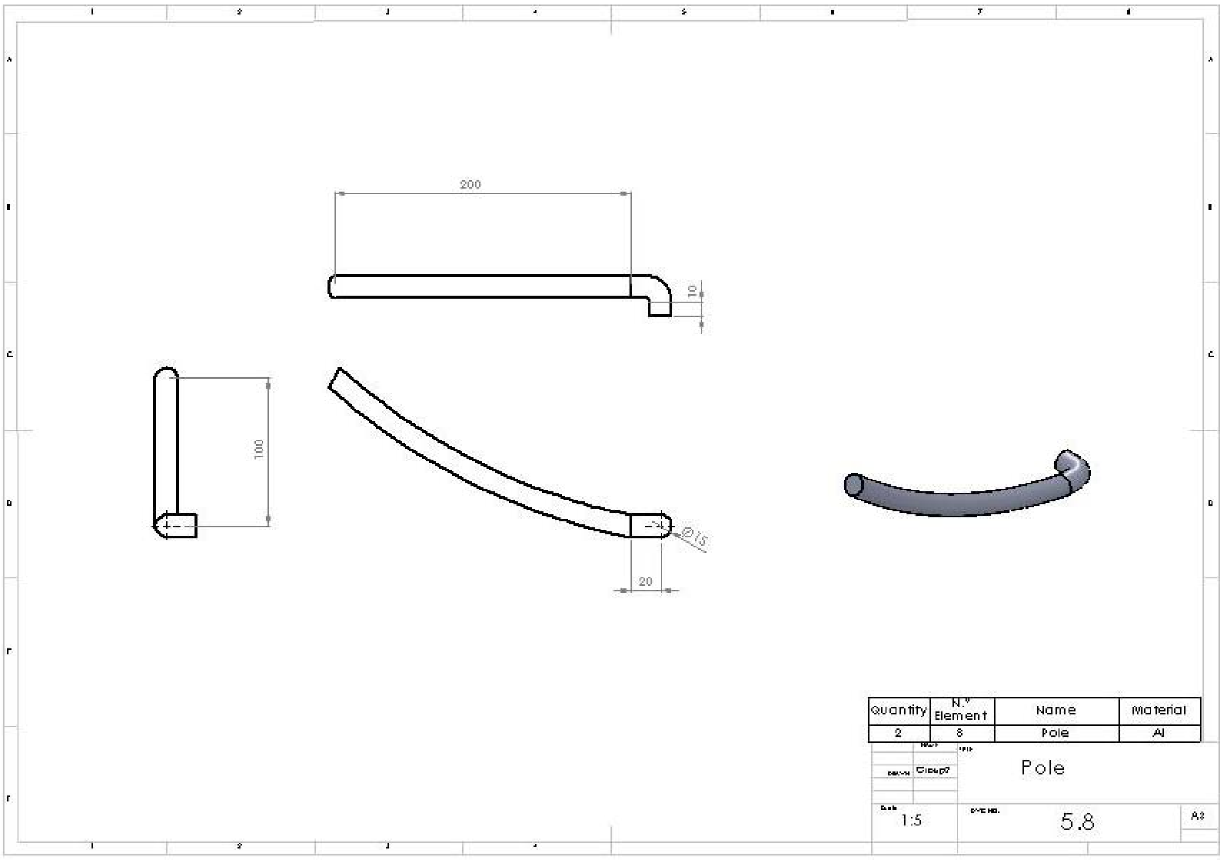
5.4
A3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Al
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