Making Stairs Accessible

Joel Lindström

DIVISION OF PRODUCT DEVELOPMENT | DEPARTMENT OF DESIGN SCIENCES
FACULTY OF ENGINEERING LTH | LUND UNIVERSITY
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MASTER THESIS

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Development of a stair-climber for wheelchairs

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Department of Design Sciences
Faculty of Engineering LTH, Lund University
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Supervisor: Damien Motte
Co-supervisor: Per-Erik Andersson, Håkan Eftring
Examiner: Olaf Diegel

Abstract

Sweden is making big strides towards making its society accessible, however in spite of these efforts there are still many problems related to accessibility for the 130,000 wheelchair users in the Swedish society that need solving. Because of cultural historic preservation laws, there are places that are not allowed to be altered in order to make them more accessible for wheelchair users. In addition, there are about 75,000 apartment buildings without elevator service. These are two of many problems that wheelchair users face in their everyday life today. This leads to transportations services having to perform thousands of stair-climbing operations every year.

One solution to problems related to wheelchair user accessibility would be an invention that could enable wheelchair users to climb stairs, which is what this project tried to accomplish. The product that has been developed within this project is a device that can be mounted on once own wheelchair and give it stair climbing capabilities.

Research and interviews were conducted to get a grasp of problems related to wheelchair user accessibility. With the help of Altran's product development process, wheelchair user's needs were defined and were used as a basis for concept and product development.

The product developed uses a belt driven system to make it possible for the user to climb stairs. The system is split into two parts that are mounted in the wheelchair's wheel mounting points. This to make it easier to carry each unit separately and it also makes it simple to mount. In addition to stairclimbing, the device provides some help drive when not climbing stairs, so that the user doesn't have to worry that the extra weight gained will be a disadvantage.

Keywords: Wheelchair, accessible, stair climber, concept, product, innovation

Sammanfattning

Sverige gör stora framsteg mot att göra samhället mer tillgängligt, men trots dessa framsteg finns det fortfarande många problem relaterade till tillgänglighet för Sveriges 130 000 rullstols användare, som behöver lösas. På grund av lagar och bestämmelser kring kulturhistorisk bevaring finns det platser och byggnader som inte får lov att handikappanpassas. Utöver det finns det 75 000 trapphus som helt saknar hiss även fast de borde ha det. Detta är bara två av många problem som rullstolsburna får möta i sitt vardagliga liv. Denna situation leder till att färdtjänst behöver utföra tusentals trappklättringsoperationer varje år.

En lösning till problemen relaterade till rullstolstillgängligheten skulle kunna vara en anordning som gav rullstolen klättrande egenskaper, vilket är vad detta projekt försöker uppnå. Produkten som har blivit utvecklad under detta projekt är en anordning som kan monteras på en rullstol och förser den med trappklättrande egenskaper.

Undersökningar och intervjuer gjordes för att få en helhetsbild av problemet relaterat till tillgänglighetsproblem för rullstolsburna. Med hjälp av Altrans produktutvecklingsmetodik togs användarbehov fram som sedan användes som bas för koncept och produktutveckling för att få fram denna produkt.

Den utvecklade produkten använder sig av ett bältdrivet system som gör det möjligt för användaren att klättra i trappor. Produkten är uppdelad i två delar som är fästa i rullstolens hjulinfästningspunkter. Detta för att förenkla processen att bära de olika enheterna separat samt göra det enkelt att montera. Produkten bidrar också med hjälpdrift när trappor inte klättras i, för att kompensera för den adderade vikten, och därtill underlätta för användaren.

Nyckelord: Rullstol, tillgänglighet, trappklättrare, koncept, produkt, innovation

Acknowledgments

During the work with this project, I have had to solve many problems related to the development of this product. This has of course lead to me acquiring new knowledge and improving my problem-solving capabilities, all within a company environment.

I would like thank Pontus Eklund and Mårten Fornander who gave me the great opportunity to do my master's project at Altran. They gave me constructive feedback, good ideas and ways to approach and solve problems. I also want to give my thanks to my supervisors Damien Motte, Håkan Eftring and Per-Erik Andersson for all their help and support during this project.

I would also like to thank all the interviewees for taking their time helping me with this project.

Lund, May 2018

Joel Lindström

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1 Introduction

1.1 Background

Even though many efforts have been made to make our society more wheelchair accessible there still are places which are not well suited for this group of people, especially staircases. Staircases are a trivial part of most people's everyday lives, however for someone in a wheelchair, stairs can be an obstacle difficult to overcome even with the help of others. Using a lift or a ramp can also be an inconvenience and be difficult to use, especially if the person has impaired mobility in arms and hands.

I have carried out this project at Altran which is a world leading company in engineering and R&D-services. Altran is involved in many different industries and projects all over the world, ranging from automotive-, aerospace- and energy industry to life science, finance and more. Altran has provided these services for over 30 years and has above 45,000 employees in 30 countries with a yearly revenue of 2.9 billion euros. [1]

1.2 The goal of the project

The goal with this master's project was to develop a wheelchair/add-on to a wheelchair that enables wheelchair users to move up and down staircases without the help of others. The product will be developed both conceptually and tested with prototypes.

1.3 Report process

The specific layout of the report and project is made to follow Altran's product development process [2]. The process is as follows:

- **Research study:** when gathering of information, data and interviews are conducted to be able to get a good grasp of the problem.
- **Defining of requirements and needs:** where the information found during the research process is used to determine for what kind of user this product will be made and also to set up requirements for the product so it will fulfill the user's needs.
- **Concept study:** potential solutions are found and concepts are made based on these possible solutions.
- **Design refinement:** the concepts are evaluated and iterated upon to be able to find the best possible solutions. Also small tests are conducted in order to see if the concepts will function as intended. This will eventually result in one final concept.
- **Product definition:** where the final concept will be thoroughly defined with calculations and dimensioning. Also, the necessary components will be decided in detail in combination with construction of a prototype to further validate and test the concept.

1.4 Report Layout

- **Chapter 2:** contains research study and defining of requirements and needs
- **Chapter** 3**:** contains concept study and design refinement
- **Chapter** 4**:** contains product definition

2 Preliminary Research

Chapter 2.1 is about the research made during this project, chapter 2.2 is the research conclusion and chapter 2.3 is where the product requirements are defined.

2.1 Research

2.1.1 General statistics

In Sweden there are about 130,000 wheelchairs users, which is ≈1.3 percent of the country's total population [3]. In most countries the number of wheelchair users are ≈1-1.4 percent [4].

In Sweden, every year 100-150 persons get a spinal cord injury because of accidents and about as many because of infections and diseases that results in impaired mobility in the legs or more [3].

About 70 percent of all people in manual wheelchairs are over 60 years old. Roughly 50 percent of those using wheelchairs do so because of neurological diseases or injuries and only 10 percent use so called active wheelchairs[1] in Sweden [5].

[1]Active wheelchairs are lighter and easier to maneuver than regular wheelchairs for people with a higher level of mobility.

2.1.2 **Wheelchairs**

Wheelchair users have different types of impairments and therefore different needs that require wheelchairs to suit those needs. Because of this there are different types of wheelchairs that has different sizes, weight, camber angles and functions. Needless to say, it is very important for a person in need of a wheelchair to get a wheelchair that suits the persons needs since the wheelchair will be used all day, every day. If something with the wheelchair does not fit the person in question, it can result in health problems like worn out shoulders, wrist problems and bedsores. The weight of the wheelchair is the biggest factor for why many people in wheelchairs suffer from health problems related to shoulders, hands and wrists, which for example arise from loading the wheelchair into a car and from rolling it up a hill or ramp [5].

The accessibility needs also differ a lot between different people depending on their disability and hand arm capabilities. While some athletic people are able to climb up and down shorter stairs on their own with the help of the handrail this ability is not that common in most regular wheelchair users [6].

Figure 1 Example on different kinds of wheelchairs

2.1.3 Accessibility

In Sweden there is a law called *Diskrimineringslagen 2008:567* which is supposed to prevent discrimination and give equal opportunities regardless of gender, ethnicity, religion, disabilities, sexual orientation and age [7]. This is why it is required for buildings to be accessible for people with physical disabilities. There are buildings that are exempted from this law on the grounds of for example cultural and historical heritage [8].

Despite of *Diskrimineringslagen* there still exist buildings and places that have not been made wheelchair accessible. As an example, according to a small study made in northern Sweden only 51 out of 180 grocery stores managed to fulfill the accessibility requirements demanded by law [9]. In addition to this example there are also about 75,000 apartment buildings without elevator service [6] and in order to access restaurants and bars it is not unusual to encounter stairs which of course is a problem for wheelchair users. Certain towns in Sweden also have a high percentage of buildings and places that are protected by cultural preservation laws which prevents these from being made wheelchair accessible [10-12].

This shows that there are buildings and places that according to law should be wheelchair accessible but in fact are not, and that there are buildings and places that cannot be made accessible because of cultural preservation law. Because of this, other solutions can be helpful and necessary for wheelchair users in these situations.

There are also instances where ramps are made too steep which makes it difficult to get up if the wheelchair user has impaired mobility in hands and/or arms; this also increases the risk of tipping backwards [13].

Current usage of stair climbers and related problems:

To remediate some of these accessibility issues that still exist the Swedish transportations service offer wheelchair users access to a so called “stair-climber”. The stair-climber can be connected to a wheelchair which gives it stair-climbing capabilities [14]. However, insufficient education of the transportation-service staff has led to incorrect usage of the climbers which has resulted in severe accidents [15]. These accidents have led to the stair climbers being removed from use in a couple of areas in the country, which has negatively affected the people that need/benefit from this service [16].

Skånetrafiken (the company in charge over Skåne’s transportation service) conducted 6,200 stairclimbing missions last year, but they try to limit the use of this service because of the risks involved in using the equipment. This service is for the time being only available for a period of six months for the user and during this time the user is expected to either move to a more accessible housing or have their home made accessible. This service is in addition not used in private houses, outdoor stairs, curved stairs and is only used were the user actually lives. Problems obviously starts to accumulate if the person wants to visit someone or go somewhere which isn't wheelchair accessible [17].

The stair-climbers used by the transportations service can be mounted on the user's own wheelchair. However, it is not self-stabilizing which means that the operator needs to hold it or else it will fall over (these stair-climbers are cheaper and lighter than the self-stabilizing ones) [17].

2.1.4 Existing stair-climbing products

There are a couple of solutions already on the market that give wheelchairs stair-climbing capabilities. However most of them cannot be operated by the wheelchair user alone and the ones that are self-operated are so heavy that they are not easy to move and therefore only convenient for usage in the perimeters of a home.

S-Max:

S-Max is an assisted stair-climber that can be connected to most regular wheelchairs and uses two wheel-pairs as seen in Figure 2. It uses one of these wheel pairs to push the wheelchair up a step and the other wheel pair to drive the wheelchair. S-Max is the stair-climber which is most regularly used by the transportation service in Sweden. It takes up comparatively little space and has low weight in comparison to other solutions (17 kg). It is also able to handle curved stairs. The main problem with this product is that it is not self-stabilizing which, if the assistant doesn't know how to use the device correctly, can jeopardize the safety of the climbing operation. It has a limited range of 26 floors and the price is not specified [18].

Figure 2 S-Max

Tryggve flex:

Tryggve flex is a self-stabilizing assisted stair climber that can be mounted on most regular wheelchairs as can be seen in Figure 3. It has a fixed angle that is adjusted beforehand for the staircase in question. The climbing mechanism is an electric driven belt system. It weighs 59 kg and has a limited range of 30 floors and costs 59 000 SEK not including tax [19].

Figure 3 Tryggve flex

Tryggve solo

Tryggve solo is similar to Tryggve flex but the user is able to operate the product by themselves as seen in Figure 4. It weighs 47 kg and costs 90,000 SEK not including tax. Because of its weight and that the wheelchair angle is fixed it is highly inconvenient to use anywhere but home [20].

Figure 4 Tryggve solo

Integrated stair climbers:

There are also some wheelchairs with built in stair-climbing capabilities (to a varying degree), but these are expensive and difficult to acquire.

IBOT

IBOT is a 4-wheeled wheelchair where the two wheel pairs are able to rotate around a common rotating axle as seen in Figure 5. It uses self-stabilizing technology which means that it can balance on two of the wheels which makes it able to raise to standing height and gives it some stair-climbing capabilities. It was discontinued in 2009 because of low demand and high price of 29,000 $ [21]. (253,043 SEK)

Figure 5 IBOT

TopChair-S

TopChair-S is an electric wheelchair that has a belt drive underneath which it can use to climb up and down stairs as seen in Figure 6. This wheelchair is bulky and expensive with a cost of 15,000 € (153,230 SEK), is not able to be loaded in to a regular car and has a range of 35 km [22].

Figure 6 TopChair-S

Scalevo/Scevo

Is a two-wheeled electric wheelchair that has self-stabilizing capabilities and has a belt driven system that it can deploy when climb stairs as seen in Figure 7.

Scalevo is not yet available on the market, it only exists as an unfinished prototype, which is why there is not much information available about this product as of now [23].

Figure 7 Scalevo Wheelchair

Market Conclusion:

The only solution that you can get on the market right now were you are able to climb stairs anywhere one want without help is TopChair-S. The other solutions mentioned above have either been removed from the market, are too heavy or bulky to actually use outside the perimeters of the house or cannot be used without assistance from another person (whom also are required to have the know-how in order to use it efficiently and with minimal risk).

2.1.5 Patent search

A patent search is also made to find potential inspiration and ideas but also to not unintentionally infringe on someone else’s patent. For the patent search Google patents were used were patents are indexed from 17 patent offices around the world. It was chosen to specifically look at patents with different solutions to the products to get as wide verity of solutions looked at as possible [24].

Patent 1, Stair climbing device

This patent depicts a stair climbing device adapted for a wheelchair, it uses a rotating element to be able to climb up to the next step as can be seen illustrated in Figure 8 [25].

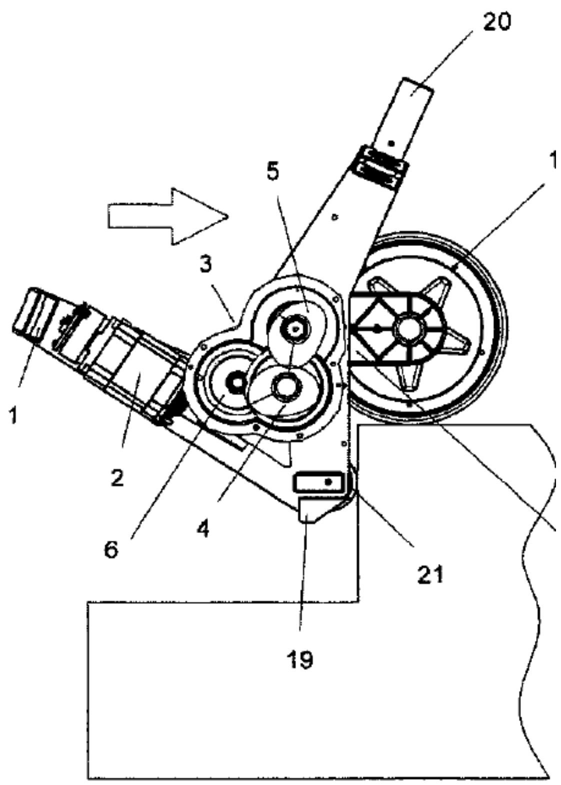


Figure 8 Stair climbing device

Patent 2, Battery powered stair climbing wheelchair

This patent is about a battery powered wheelchair that is supposed to replace a regular wheelchair and to give the user better access to their homes. This solution uses three wheels that can rotate around an axle to be able to climb stairs as can be seen in Figure 9 [26].

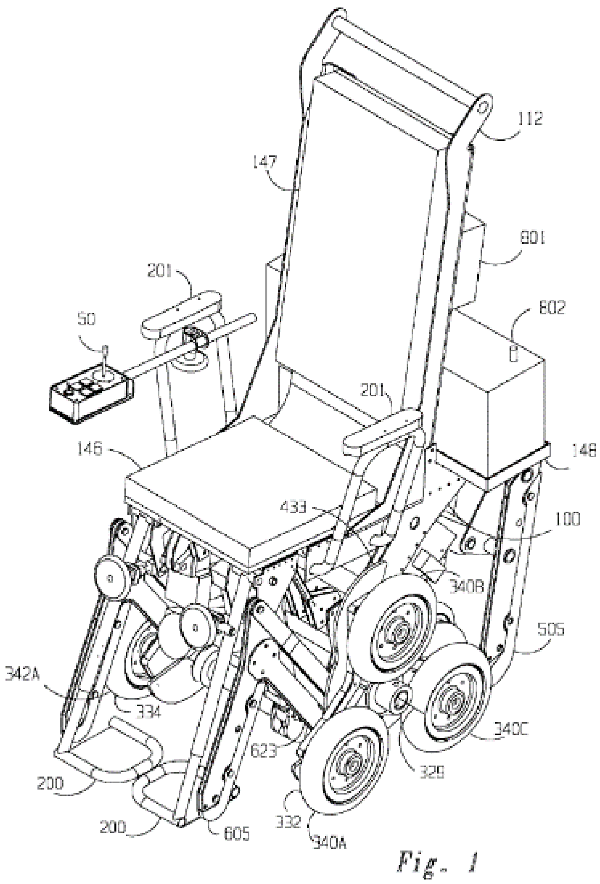


Figure 9 patent 2

Patent 3, Stair-climbing vehicle

This patent also uses the same kind of wheels as the previous patent but with an extra mechanism to keep the vehicle from becoming angled as seen in Figure 10 [27].

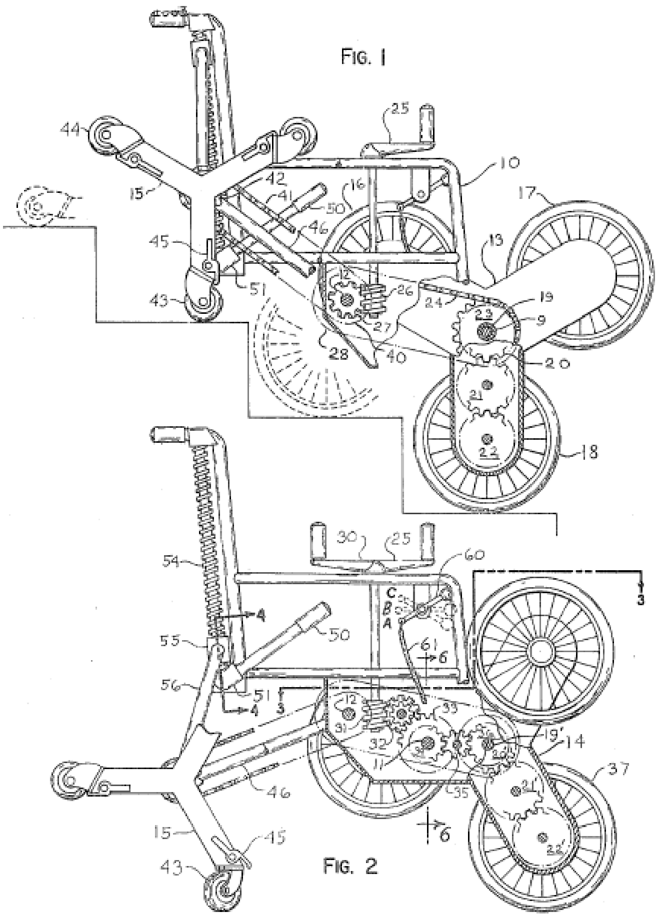


Figure 10 patent 3

Patent 4, Stair-climbing wheel chair

This patent describes a solution with the combinations of two wheels with feet and by rotating these wheels will walk the chair down the stairs as can be seen in Figure 11 [28].

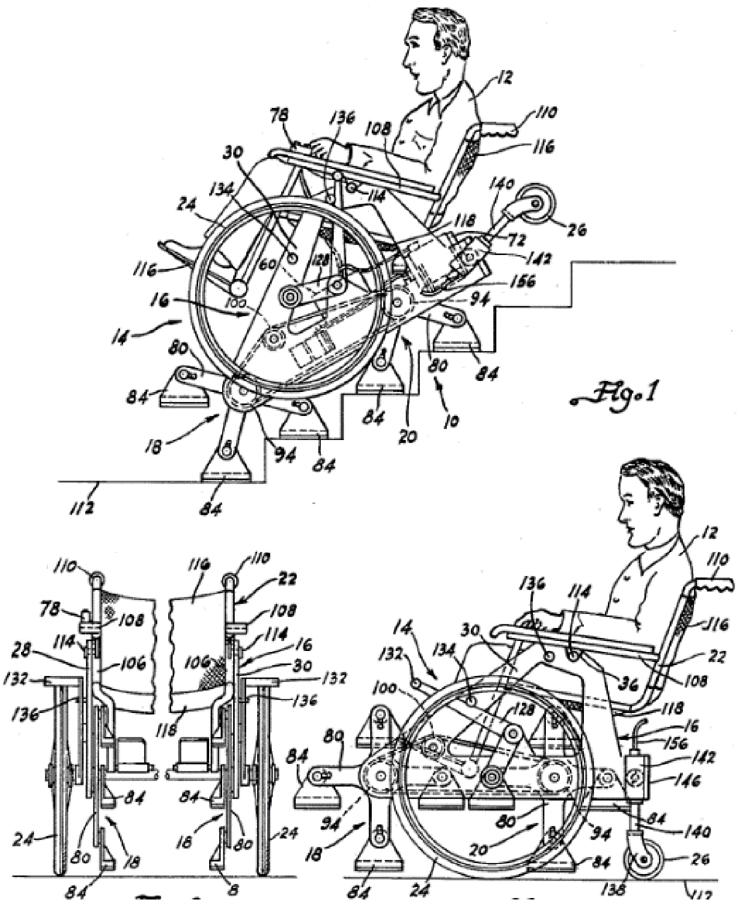


Figure 11 patent 4

2.1.6 ISO standard for Stair-Climbers

There is an ISO standard 7176-28 that defines what a stairclimbing device for wheelchairs should be able to handle to be perceived as safe and usable. The standard defines that a stair-climber is supposed to be able to handle a stair angle between 30-40 degrees with no event of brake failure, hazardous loss of traction and stability and any other hazardous situations [29].

2.1.7 **Interviews**

Interviews have been conducted with people who have different disabilities and abilities, all in order to get a good understanding of the problems related to accessibility for wheelchair users in our society and the general needs and requirements for these kinds of products.

Interviews (2018, February), Malmö, Sweden.

a. Larsson, H - Wheelchair user
b. Norsten, Å - Wheelchair user
c. Eftring, H – Assistant professor, Certec
d. Eklund, K - Wife is wheelchair user
e. Scholtz, A – Wheelchair user
f. Gripenhov, L – Wheelchair user
g. Karmaeus, T – Wheelchair user

In total seven persons have been interviewed, five of them are wheelchair users. The two people who are not wheelchair users have been interviewed because they have experiences and knowledge of the area in question. Eftring, H is a researcher who is working in the field of Rehabilitation technologies, and Eklund, K has used assisted stair-climbers to help his wife who is a wheelchair user.

All of the people who were interviewed agreed that there exists accessibility issues in Sweden and that there is definitively a need for a better solution of getting up and down stairs. The interviewees that were athletes (Larsson, H and Karmaeus, T) can, on their own, get up and down shorter stairs if there is a handrail accessible. However, if they encounter stairs that are without a handrail it is not possible to climb it without help, and this type of stairs is quite common at the entrance for example a store and usually have two to three steps. They said most people do not have the ability or do not want to take the risk to climb stairs by themselves. Also, the place where one lives matters, old cities with many historical buildings and old architecture complicate things considerably more for wheelchair users.

The other wheelchair users interviewed have substantially bigger problems with stairs and say that stairs are a fundamental problem in their everyday life and that there exists a need for a stair-climbing product that is convenient and easy to use.

Gripenhov, L says” There are stairs everywhere – both out- and indoors”. With this remark she adds that when she wants to go somewhere, she often uses Google Maps to assess whether it is possible for her to go and what obstacles she might face on her way.

Gripenhov, L says that when you do encounter problems you cannot be afraid to ask for help. She goes on to say that people are often very helpful, but you might face situations where there is no one to ask and that “To be able to manage on your own would be fantastic”

Eklund, K has used the assisted stair-climber Tryggve flex and Eklund explains that when his wife just started to use a wheelchair they lived a couple of floors above ground level with no elevator service in the building. Because of this difficult situation they were provided with an assisted stair climber from Tryggve to be able to get up and down the stairs. He says that he is content with this stair-climber and says that it felt stable and sturdy and that the self-stabilizing feature is a must. The problems that he experienced with this particular product was its size and weight, which made it difficult to handle the stair-climber when not climbing a stair.

When talking about what is desired in a stair-climber and what important factors it should focus on, Scholtz, A says “the stair-climber shouldn’t limit the regular functions and usability of the chair.” She goes on to say that the most important part of a stair-climbing product is that it should be safe. It should be stable so that it does not feel like it is about to fall while using it. The product has to be easy to use and with a customizable design, so it can be used by users with different disabilities. The product should also be small and light weight, preferably no more than 7 kg so that for example it is possible to lift it in to a car. The weight is also important to not damage shoulders and wrists of the user. The product should not protrude in front of the chair or on its sides. It is okay if it protrudes a bit behind the chair. Scholtz, A ends by saying “I wish for a portable stair-climber that is able to withstand wheather and wind and that I can use by myself – what freedom that would be!”

See detailed information from interviews in Appendix B.

2.2 Conclusion for the research

There are 130,000 wheelchair users in Sweden and many public places and buildings are not wheelchair accessible, some places that are not accessible should be and others are not allowed to be altered because of cultural preservation laws.

Wheelchairs tend to be specifically designed and adapted for the user in question and therefore wheelchairs can be very different. There are also differences in design between wheelchair brands.

Thousands of stair-climbing operations conducted every year and this despite the service being limited and that people are in need of a better service.

All interviewees agree on the fact that there exist issues related to accessibility in today’s society and that there are problems in this field that need solving.

2.3 Product requirements

The gathered data and analysis is used as a basis to decide which target audience this product is supposed to focus on and what requirements are supposed to be fulfilled, were it is looked at what kind of stairs wheelchair users have problems with and what ergonomic aspects regarding the wheelchair and the user that are important.

2.3.1 **Functionality**

The targeted users for this product are people who use manual wheelchairs regularly and who in their everyday life encounter obstacles such as curbs and stairs. These people also tend to handle their wheelchair on their own, for example lifting it into their car.

The problem that this product is supposed to solve is for wheelchair users getting up and down curbs and smaller stairs (two to five steps) by themselves, all in an easy safe and effective way. Also, the product should not compromise the wheelchairs weight or other important functions. The product should also be able to be used outdoors in different weather and climates. It should be able to be transported in a car where the user on their own would be able to get it inside with no more effort than it takes to get a wheelchair inside of a car.

If the solution can handle more than five steps would be a plus, however this is not a requirement that is aimed for if it would prove itself a lot more difficult than solving shorter stairs with compromises of other important aspects of the product.

2.3.2 **Technical constraints**

- The product should be an add-on to existing wheelchairs. *There are many different types of wheelchairs on the market and to avoid problems with adapting the stair-climber to all types of wheelchairs it has been decided that it will only be developed for a standardized wheelchair and to not develop an entire wheelchair.*

- The product will operate using either electricity or a combination of electric and manual power. *If a hybrid version of this product is developed, it will be important that the electrical power is sufficient to ensure that the wheelchair user is not damaging wrists and shoulders.*

- Unsafe and risky solutions will not be developed and used, even if they happen to perform well in other aspects. *Safety is extremely important to consider when a person is supposed to use a stair-climbing device on* *his/her own, sometimes without anyone in the proximity able to help the person in question if something goes wrong.*

- Focus is on developing a small and light solution (preferably no more than 7 kg). *The weight and size of this solution is very important because the user should be able to handle the product on their own, for example like lifting into a car.*

- The product will not be developed as a medical device, but instead as a usual consumer product. A *medical device generally takes a long time to develop because of the long list of requirements and specifications it has to fulfill. Therefor the choice was made to focus on a consumer product which can be developed faster, which is more feasible considering the timespan of the project.*

- The product will be designed in accordance with and strive to fulfill the requirements of ISO 7176-28 [29]. *which focus on a stair-climber's abilities and safety.*

2.3.3 **Safety**

- Low risk of tipping/falling
- Good safety features when something unexpected happens which is related to the technology *(empty battery during climbing or electrical failure)*
- Low sliding and slipping risk, for example on stairs that are wet
- Low/no risk of using the product in an incorrect way

2.3.4 **Usability**

- Easy use of the climbing function
- Good level of control for the user when climbing
- Small size and low weight
- Easy to pack into a car/foldable
- Good ergonomic properties
- Low strain on the user while having the device connected to the chair

2.3.5 **Good performance**

- High speed
- Comfortable climbing operation *(low/no level of bouncing)*
- Low energy consumption (*both system and user)*

- Large range of types of stairs it can handle
- Long climbing range

2.3.6 Easy assembly

- Short assembly time
- Low complexity of this operation
- Low number of components that need to be fastened to the chair

2.3.7 Accessibility and price (low)

- Good material choices (*strength and price*)
- Low construction complexity
- High level of manufacturability

3 Ideas and Concepts

In this chapter the product requirements specified during the research is used as a basis for generating ideas and concepts.

From the defined product requirements, the functionality and technical constraints will be used as overhanging targets while generating the concepts. The other five types of requirements (safety, usability, good performance, easy assembly, accessibility and price) will be used as criteria with which the concepts will be evaluated thereafter. This is in accordance with Altran's product development process [2].

3.1 Problem decomposition and solutions

The problem is broken down into smaller sub-problems in order to handle the process in a more structured fashion.

Sub-problems:

- **Climbing** *(what mechanism is getting the wheelchair up the stair?)*
- **Operation** *(how is the system controlled by the user?)*
- **Mounting** *(how is the product attached to the chair?)*
- **Climbing direction** (*the direction in which the person is facing)*
- **Weight reduction/ relieve systems** *(ways to lower the weight and strain on the user)*

Brainstorming and sketching was used to find as many solutions as possible for the individual sub-problems. The solutions are inspired by own ideas, existing products and patents.

- **Climbing solutions:**
  The different solutions can be seen illustrated in Figure 12. The solutions consist of a belt drive, three wheels with a common middle axle, wheels that can deform and take the shape of the stair, pneumatic or hydraulic pistons that can push the chair upwards, a foldable ramp, robot legs that can walk, rocket and aero propulsion.

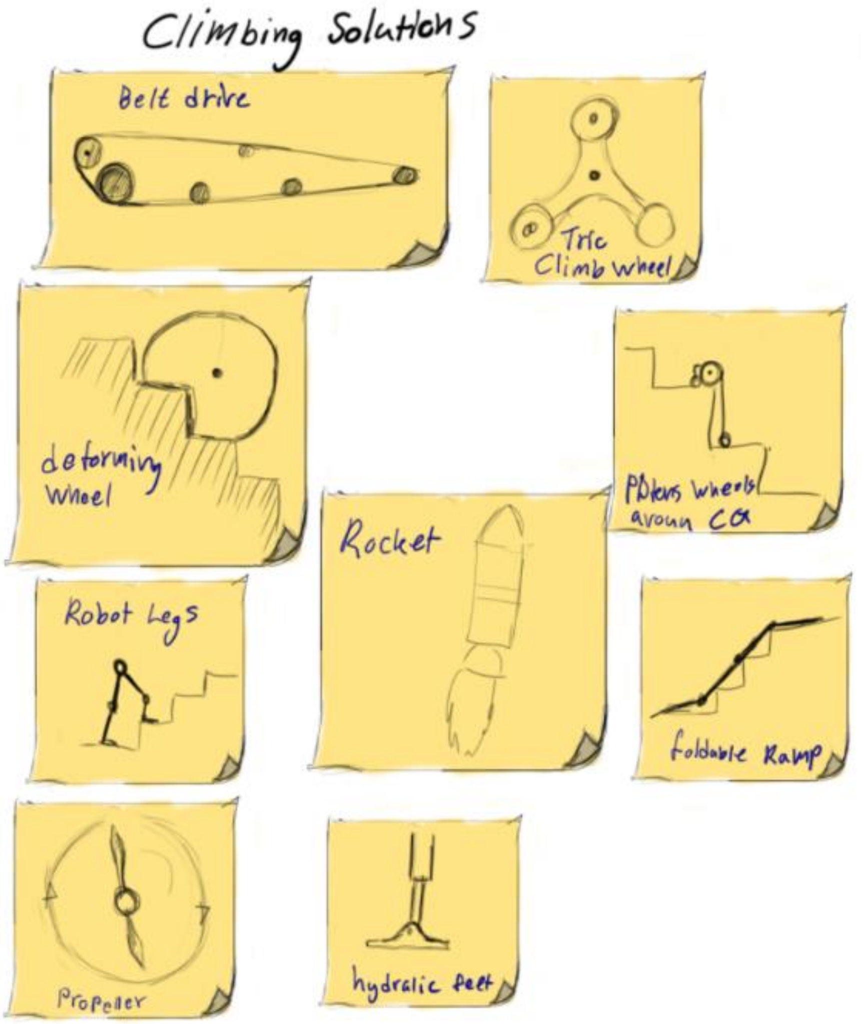


Figure 12 Climbing solutions

- **Operation solutions:**
  The different solutions can be seen illustrated in Figure 13. The solutions consist of a console mounted on the wheelchair, wireless wearable accessories, a solution where the climbing is connected to the movement of the wheels, small rim or leaver mounted on the wheel for operating and a autonomous ascent/descent system.

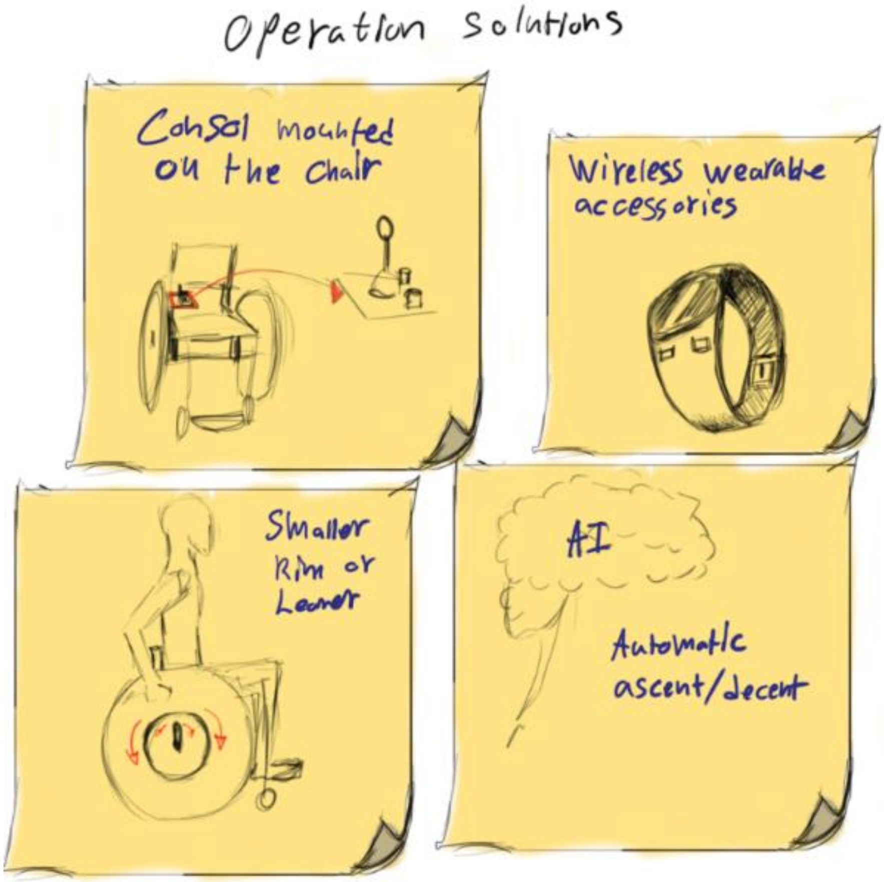


Figure 13 Operation solutions

- **Mounting solutions:**
  The different solutions can be seen illustrated in Figure 14 and they consist of a mounting system on the drive axle, backrest, wheel mount, integrated with the wheel, mountable bracket or attachment that the device can be mounted onto.

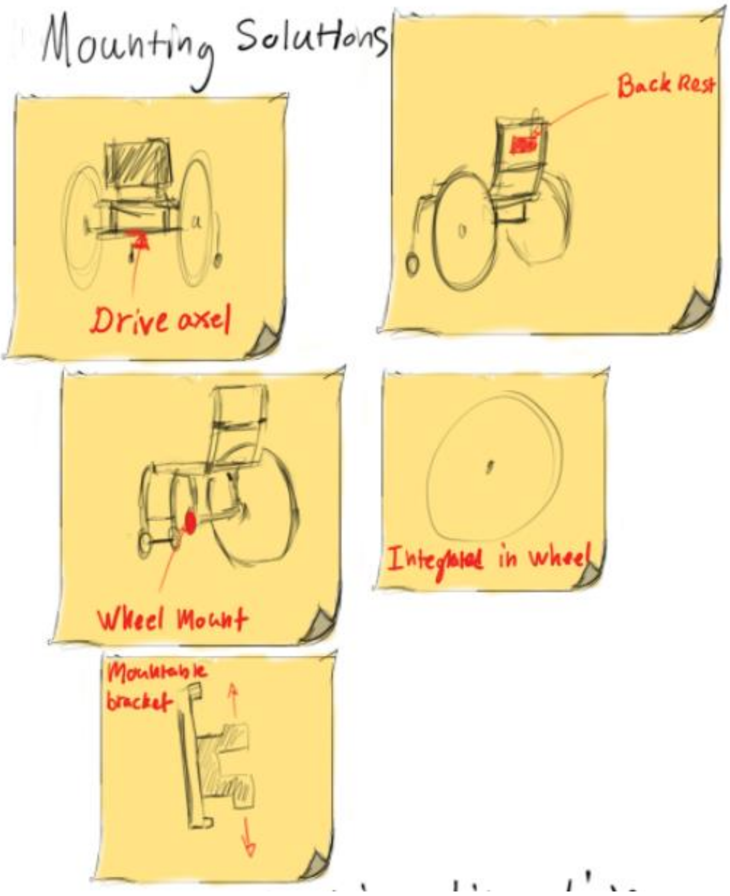


Figure 14 Mounting solutions

- **Climbing direction:**
  The different solutions can be seen illustrated in Figure 15 where the directions consist of facing down the stairs, facing up the stairs or facing in the climbing direction.

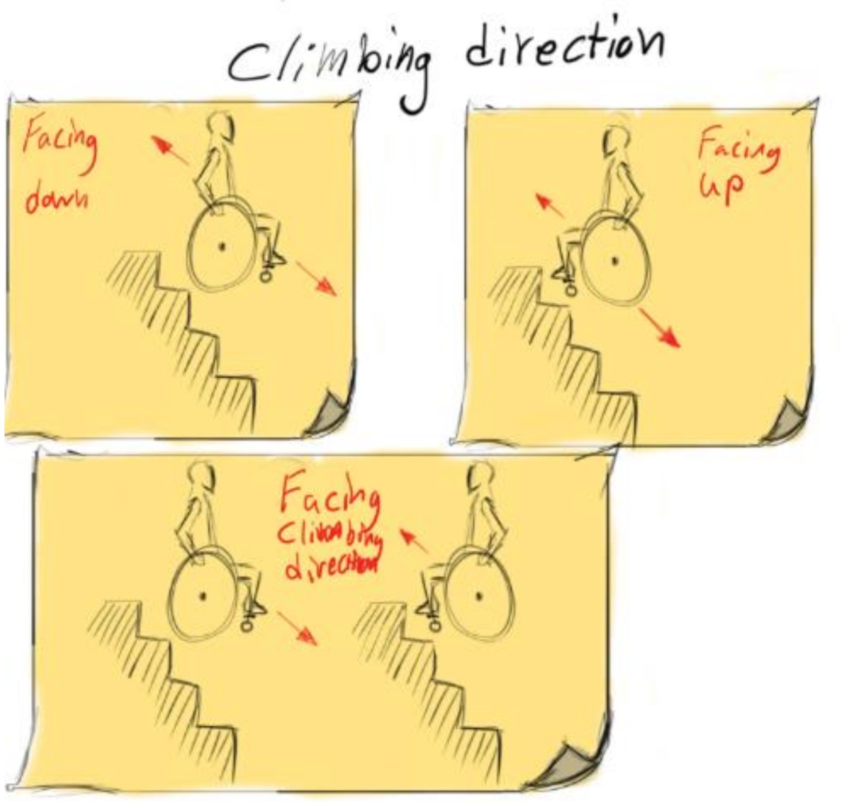


Figure 15 Climbing direction

- **Weight reduction/ relieve solutions:**
  The different solutions can be seen illustrated in Figure 16. The solutions consist of a device that help to push the wheelchair forward, to help lower the strain on the user’s wrists and shoulders when not climbing. The use of lightweight materials, small batteries in combination with manual power, a solution made in smaller and divided parts so that the whole device doesn’t need to be lifted at once (for example when getting it in to a car). A small and smart construction that can be stable without the need of being large and bulky.

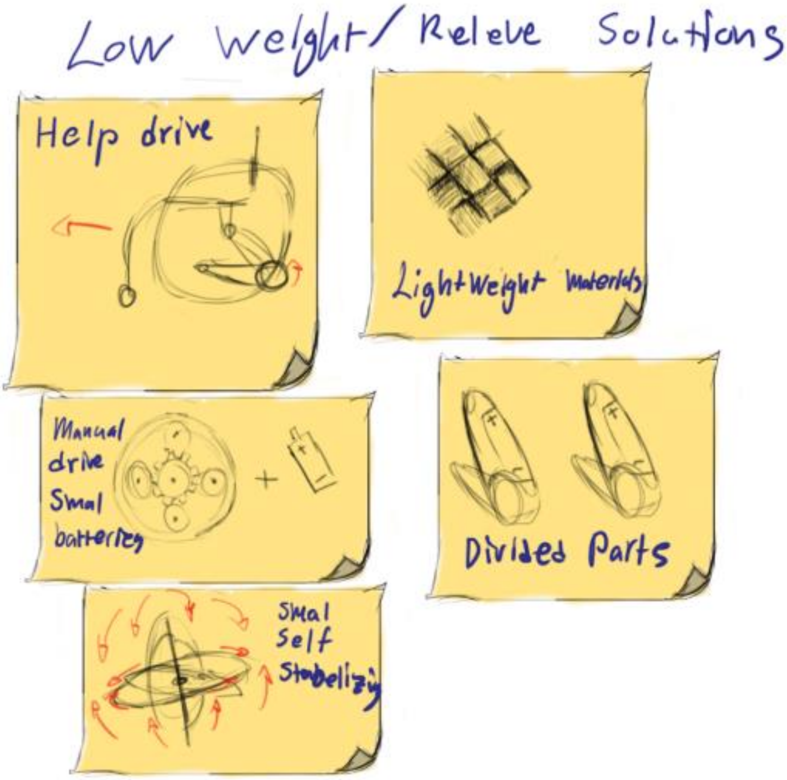


Figure 16 Low weight/ relive solutions

These sub solutions are then evaluated on the basis of how well they fulfill the criteria relevant to their specific area so that the solution which solves the problem in the best possible way is found. These sub solutions are more or less independent from each other which makes this evaluation possible. If each sub solution were more dependent on each other they would have been combined first before being evaluated. This evaluation is mostly to get an early indication on what system could result in the best product and will only be used as a general guide to find the best concept.

3.1.1 **Sub-solutions evaluation**

The sub solutions are given a score depending on how well they fulfill the criteria (1=does the job well 0=bad job 0,5=unknown or average).

Climbing solutions:

The criteria that the climbing solutions are evaluated after are the following:

Comfortability: how comfortable the ride is, if it is smooth or bouncy.
Fall/tipping risk: how stable the solution is, if it has any risk of falling.
Sliding risk: if there is a risk that it might slide while climbing.
Size: if the solution is small, it is considered better for manageability.
Weight: low weight is a good thing when considering many different aspects of the product.
Speed: a faster climbing speed is ranked better.
Stair variation: it is preferable that the climber can handle a large variety of different types of stairs.
Price: low price is good.
Construction difficulty: how easy it is to manufacture this product
Range: low level of energy consumption and long range is good

There are 10 criteria and a perfect score for one system is therefore 10 points.

Climbing solutions	Comfortability	Fall/tipping risk	Sliding risk	Size	Weight	Speed	Stair variation	Price	Construction difficulty	Range	summa
Belt Drive	1	1	1	0.5	0.5	1	0.5	0.5	0.5	0.5	6.5
Triple wheel	0	0	0.5	1	1	0.5	0	1	0.5	1	4.5
Deforming wheels	1	0.5	1	0.5	1	0.5	0	0	0	0	4.5
Wheel with push pistons	0	0.5	1	1	1	0	0	1	1	0.5	5.5
Robot legs	0.5	0	0	0	0	1	1	0	0	0	2.5
Rocket motor	0	0	1	0	0	1	1	0	0	0	3
Propellers	0	1	1	0	0	1	1	0	0	0	4
Pneumatic or hydrolic pistons	1	1	0	0	0	0.5	0	0	0.5	0	3
foldable ramp	0.5	0.5	0.5	0	0		0	1	1	0	3.5

Figure 17 Climbing solutions evaluation

In Figure 17 it is shown that the belt drive and the wheel with push pistons have best performance. The belt drive is a very comfortable and safe solution and has average performance in the other aspects, while the wheel with push pistons takes little space and weight in comparison to the belt drive.

Mounting solutions

The criteria the mounting solutions are evaluated after are the following:

Size: if the solution is small, it is considered better for managability.
Weight: low weight is always desired.
Mounting time: how long it takes to mount, and shorter mounting-time is better.
Mounting difficulty: how difficult it is to mount and the strain on the user.
Few components: number of components that need to be mounted.

There are five criteria and a perfect score for one system is therefore five points.

Mounting solutions	Size	Weight	Mounting time	Mounting difficulty	Few components	summa
Drive axle	1	1	0.5	0.5	1	4
Back rest	0	0	1	1	0	2
Wheel mounts	1	1	1	1	0	4
Integrated in the wheel	0.5	0.5	1	0.5	1	3.5
Adjustable mount	0.5	0.5	0.5	0	0	1.5

Figure 18 Mounting solutions evaluation

The solutions of mounting the product in the wheel mounts and on the drive axle are the once performs the best. The drive axle is close to the ground which means that the size of the solution can be reduced, and the number of components kept low. while attaching it in the wheel mounts are easier to reach which decrease the mounting time. Results in Figure 18.

Operation solutions:

The criteria that the operation solutions are evaluated after are the following:

Intuition: how easy it is to understand how the product functions and how it is supposed to be used.
Weight: low weight is desired since it has a good impact on many other aspects.
Mounting: how long it takes to mount, modifications to the wheelchair etc.
Low risk of errors: no risk of errors while operating/using the product.
Control: level of control the user have while operating the product.
Price: low price is good.

There are six criteria and a perfect score for one system is therefore six points

Operation solutions	intuity	Weight	Mounting	low risk for errors	Control	Price	summa
console mounted on the chair:	0.5	0.5	0	1	1	1	4
wireless wearable accessories:	0.5	1	1	0.5	1	0.5	4.5
connected to the movement of the wheels:	1	1	0.5	0.5	1	0.2	4.2
thing mounted on the wheel for operating:	1	0.5	1	1	1	0	4.5
automatic ascent/descent:	1	1	1	0	0	0	3

Figure 19 Operation solutions evaluation

For operating the system, the highest ranked solutions are wireless accessories and the smaller wheel/lever on the wheels. Wireless accessories don't need to be mounted on the wheelchair, have low weight and can be made so that it is clear how it should be operated. The problem that these solutions might face is that the batteries can run out. The solution with the smaller wheel/lever is combined/mounted on the wheel of the wheelchair, this will present a very intuitive motion and it doesn't need batteries to function but will add some weight and extra accessories to mount to the chair. The result is illustrated in Figure 19.

Climbing direction

The criteria that the climbing direction are evaluated after are the following:

Oversight: how well you perceive where you are going.
Safety: how safe it would be for the user to face the different directions if something happens.
Pleasantness: how it feels for the user to face a particular direction

There are 3 criteria and a perfect score for one system is therefore 3 points.

Climbing direction	Oversight	Safety	Pleasantness	summa
In the direction of the moment:	1	0.5	0.5	2
Face down the stairs:	0.5	1	1	2.5
Face up the stairs:	0.5	0	0	0.5

Figure 20 Climbing direction evaluation

For the climbing direction it is shown that the user should be facing down the stairs for a safer feeling rather than being able to see in the direction of the stairs when going up, as seen in Figure 20.

Low Weight solutions

The criteria that the low weights solutions are evaluated after are the following:

Price: Low price is better
Range: Long range is better
Size: Small is better
Manufacturability: Easier to manufacture is better
Strain on user: the stain on the user should be low
Carriable: how easy it is for example to get it into a car

There are 6 criteria and a perfect score for one system is therefore 6 points.

Low Weight solutions	Price	Range	size	manufacturability	Strain on user	Carriable	summa
eletric help drive (to lower increast wight strai	0	0.5	0.5	1	1	0	3
lättvikts material	0	1	1	0	1	1	4
små batterier i kombination maed manuell dri	1	1	1	1	0	1	5
uppdelad (för att lättare kunna lyfta)	0	1	1	0.5	1	1	4.5
eletrisk stabiliserad lösning (stabil utan att be	0	0	1	0	1	1	3

Figure 21 Low weight solutions evaluation

Low weight materials, small batteries in combination with manual drive and a split solution for lower weight while lifting are evaluated to be best. In addition, another interesting solution is the electric help drive. Even though it wasn't the highest ranked feature, it can still be a good solution to lower the strain on the user. Result illustrated in Figure 21.

3.2 Concepts generation and screening

To find complete solutions for the entire system the sub-system solutions are combined to form complete concepts. Different ways of using the solutions are experimented with in order to visualize how the shape and size of the product will affect the solutions functionality. Even sub solutions that were not highly evaluated is looked at to not exclude them to early in the project. The concepts can be seen in Figure 22.

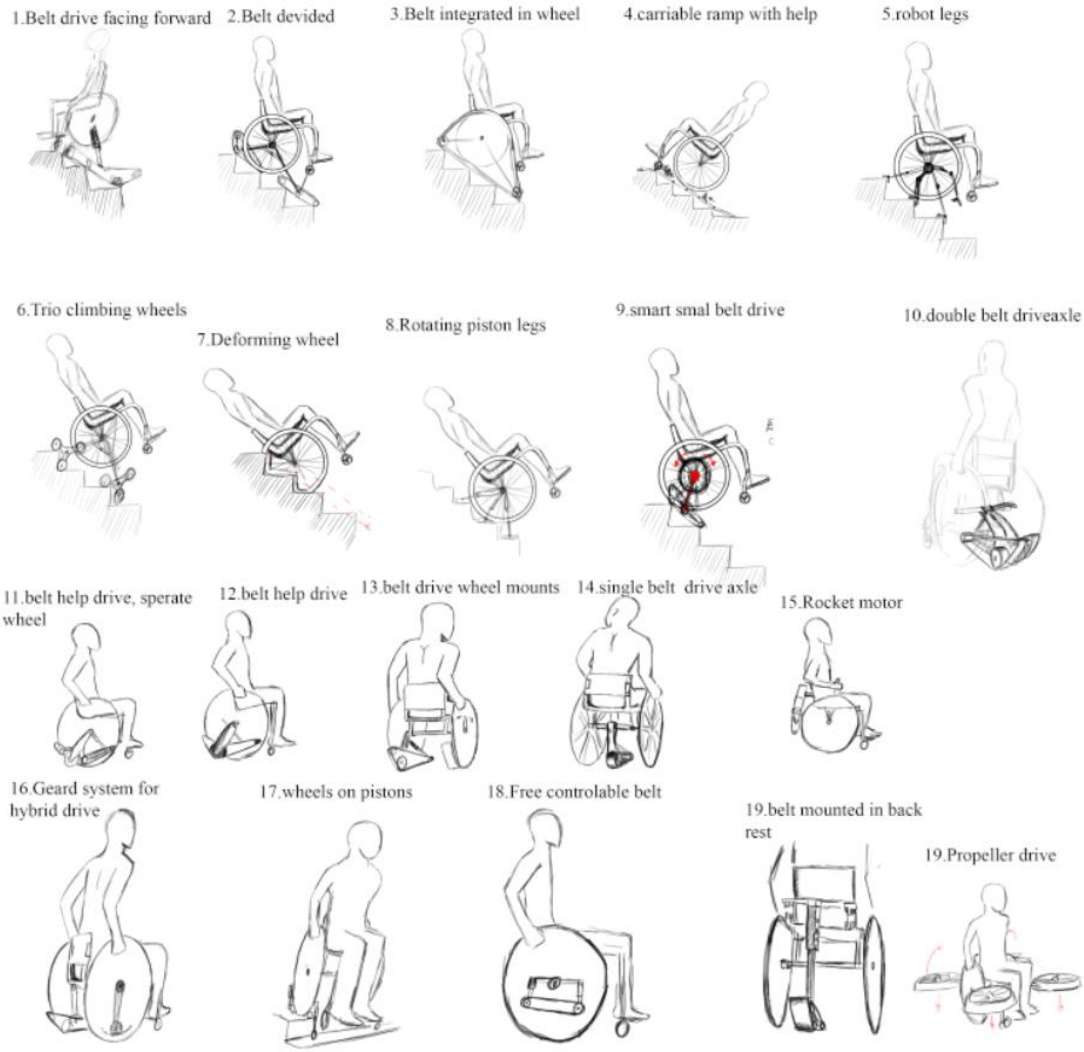


Figure 22 Compilation of concepts

3.2.1 **Heart and brain matrix**

Evaluation of the different concepts are made in a heart and brain matrix in accordance with Altran’s product development process. A heart and brain matrix have two axis, one heart axis and one brain axis. The brain axis depicts the technical function and feasibility of the idea/concept which in this case will be based on the sub solution evaluations. The heart axis depicts the feeling and interest for the concept. The concepts in the top right will be chosen for further development and evaluation and the concepts on the far right on the heart axis can also be of interest if the functionality of these solutions can be improved to a reasonably good level [2, p. 136].

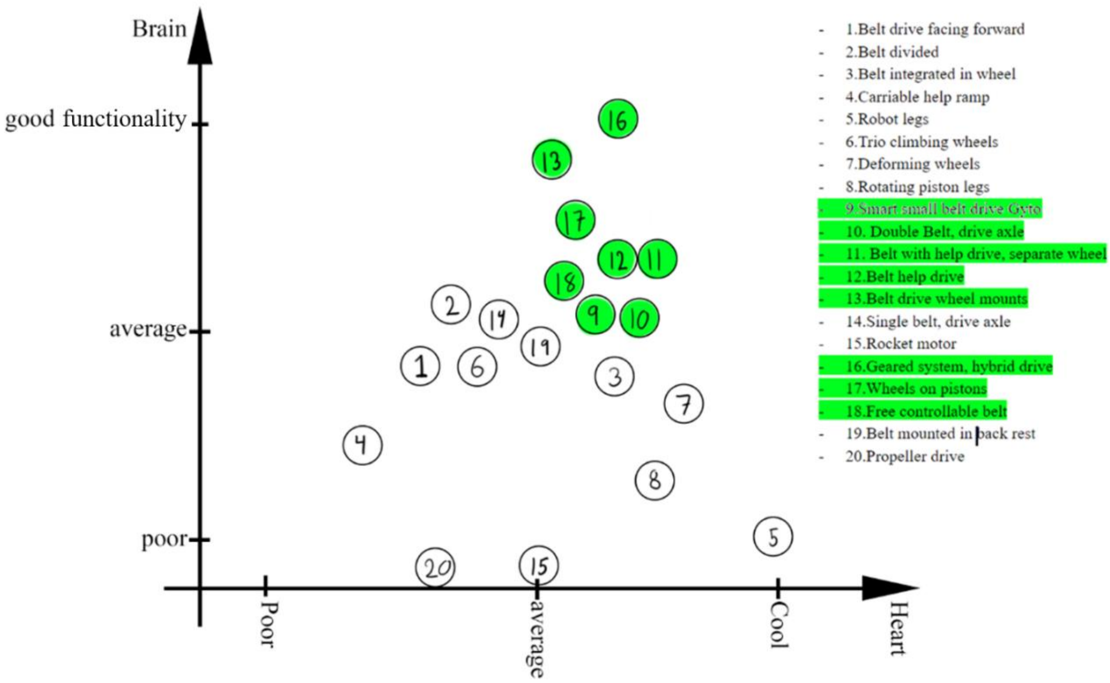


Figure 23 Heart and brain matrix

The result of the heart and brain matrix can be seen in Figure 23. Eight concepts were chosen for further development and evaluation because of their technical feasibility and interesting aspects. Concept 5 is not considered since robot legs are not expected to be possible to be improved to a reasonable product, this because of technical difficulties and questionable safety aspects.

3.2.2 **Chosen concept ideas**

List and description of the eight chosen concepts from the heart and brain matrix

The different aspects of these concepts can be mixed later if it provides a better overall concept.

- **Concept 9:**
  This concept utilize a small belt drive with a built-in gyroscope which gives it the ability to move and rotate in all directions so it can stabilize the wheelchair. This has the positive effect that the device can be made small and light and still manage to operate in an effective and stable way. One problem with this solution is that it is dependant on battery power to keep it stable and should not be operated on low battery levels which can present a potential safety risk.

Figure 24 Concept 9

- **Concept 10:**
  This concept has a double belt driven system to give it a wider and more stable base. It is mounted on the drive axle to be close to the ground and to minimize the weight. This makes it easier to mount the product and it will also be easier to build the pushrod/piston in-between the two tracks.

Figure 25 Concept 10

- **Concept 11:**
  This concept has three systems with two separate belt drives and one wheel. The wheel has contact with the ground and will provide extra power when the person is not climbing stairs. this will lead to lower strain on wrists and shoulders and the ability to travel longer distances without getting tired (batteries can also be recharged when traveling downhill). The rear track is supposed to help climb the first step and will still have contact with the stair when the front belt is folded down to provide for a longer contact path and stability.

Figure 26 Concept 11

- **Concept 12:**
  This concept also has a help drive system but instead of separate systems it has only one long belt. The small rear wheel is fixed to the device, this means that when the front part is lowered gives a longer contact patch with the stair to heighten the friction and stability of the device illustrated in Figure 28. It is supposed to be mounted on the axle so that it can move freely and follow the ground to be able to handle uneven surfaces while driving.

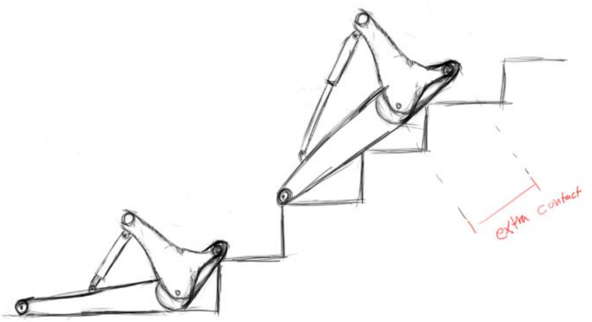


Figure 28 Climbing illustration

Figure 27 Concept 12

- **Concept 13:**
  This concept is supposed to be mounted together with the wheel of the chair in the wheel mounts. Because the contact patch with the stair has been spaced out gives the system more stability in the sideways direction, also the weight and size for each individual unit can be kept low so that it will be easier to lift in to a car even if you have reduced arm strength.

Figure 29 Concept 13

- **Concept 16:**
  This concept is similar to Concept 13 but where the wheels are mechanically connected to the drive system so that it can be manually driven by the user which lowers the need for big batteries. This lowers the weight of the entire system and the possibility to climb stairs even when the batteries are empty and also the ability to charge the batteries when in downhill.

Figure 30 Concept 16

- **Concept 17:**

  Small wheels on pistons to push the chair up the stair/ climb down. It is mounted in the wheel mounts where the wheels come in two pairs on each side of the mass center to be able to get up and down stairs in a stable manner.

Figure 31 Concept 17

- **Concept 18:**

  Belt drive that has moving and bending capabilities for absolute control over the climbing operation for a smooth and safe ride both up and down and for the initiation and end of the climb.

Figure 32 Concept 18

3.2.3 **3D-print tests**

A small 3D print test was conducted before continuing with the concept evaluations, to get a better insight on stability and capabilities of systems like these. For the ability to do a better analyzation of the systems instead of guessing how they will perform.

A miniature wheelchair with user and a standard a stair was printed. This 3D print has the shape of Concept 10 with the belt angling system from Concept 12.

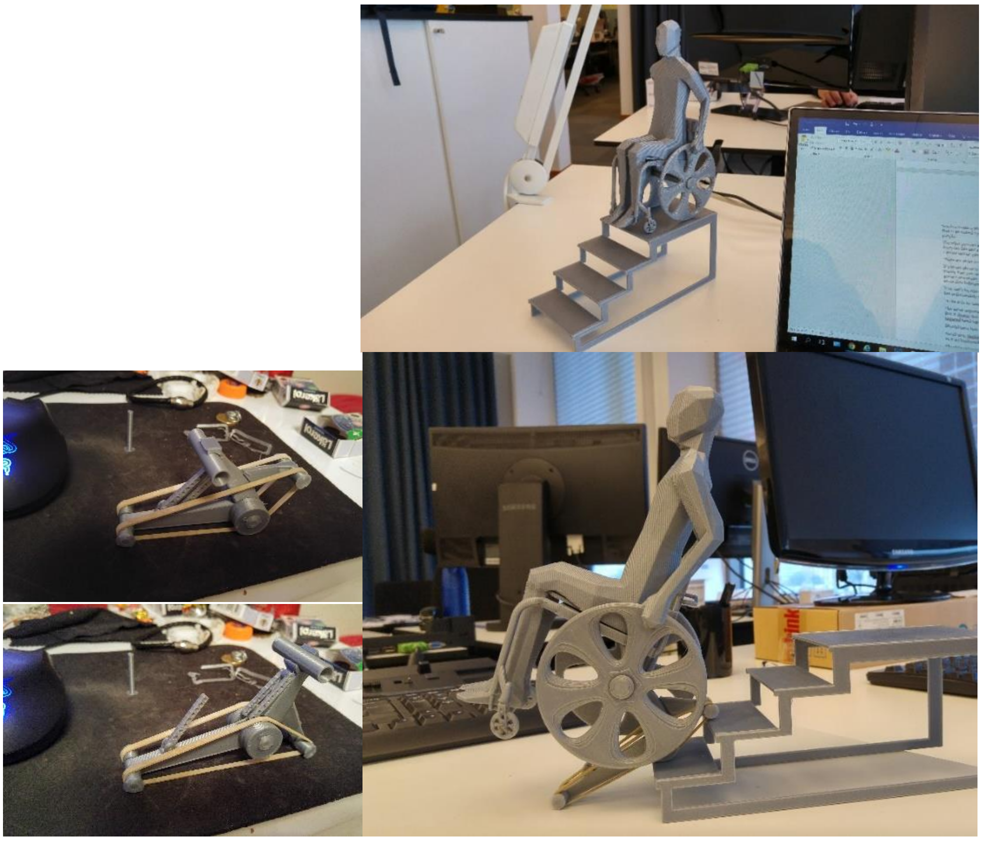


Figure 33 compilation of 3D printed prototypes

From these tests it was found that the length of the belt is sufficient to give stability back and forward, but the side to side stability it is quite unstable (belts needs to be spaced further apart) this means that concept with belts in the middle will have lower scores on safety. Even though the unstable concepts will score lower in safety they might have other important aspects that are important to look in to. If they have good aspects these could be implemented in the safer concepts.

3.2.4 **User feedback**

The concepts were also sent to the interviewees for feedback. The feedback was mostly positive for the various concepts. In particular, the concepts that featured help drive in combination with the stair climbing capability were well received. This extra feature was perceived to provide useful extra functionality for people.

3.3 Concept continuation

Before any further developments are made the concepts that are chosen are further evaluated to narrow down the number of concepts that will be tested and further developed. The evaluation will be based on the tests of the 3D-print, user feedback and criteria.

3.3.1 **Basic concept evaluations**

To be able to do a more detailed evaluation all the concepts will be evaluated and scored with the criteria's that the product should fulfill. To get a more accurate depiction of witch concept is the best, the criteria themselves should get evaluated to see witch criteria is the most important. To find which criteria are the most important a pairwise comparison is made were the criteria are evaluated against each

Safety:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	sum
1 Low tip/falling risk		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20
2good safety features when something happen (like empty battery or similar)	0		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19
3 low slipping risk towards the stairs (even on wet stairs)	0	0			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	17
4low/no risk to use the product in an improper way	0	0	0		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	17
Usability:																						
5 easy use of the climbing operation	0	0	0	0		1	0	0	1	0	1	1	1	1	0	1	1	1	1	1	1	12
6 level of controllability from the user when climbing	0	0	0	0	0		0	0	0	0	1	1	0	0	0	1	1	1	1	1	1	8
7 small size and weight	0	0	0	0	1	1		1	0	0	1	1	0	1	1	1	1	1	1	1	1	13
8 easy to pack in to a car/foldable	0	0	0	0	1	1	0		0	0	1	0	0	0	0	1	0	0	1	1	1	7
9 good ergonomic properties	0	0	0	0	0	1	1	1		0	1	1	0	0	1	1	1	1	1	1	1	12
10low strain and load of the user while having the device connected to the chair	0	0	0	0	1	1	1	1	1		1	1	0	1	1	1	1	1	1	1	1	15
Good performance:																						
11 high speed	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0
12comfortable climbing operation (low/no level of bouncing)	0	0	0	0	0	0	0	1	0	0	1		0	0	0	1	1	1	1	1	1	8
13 low energy need (both system and user)	0	0	0	0	0	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	15
14 big range of stairs it can handle.	0	0	0	0	0	1	0	1	1	0	1	1	0		0	1	0	1	1	1	1	10
15Long range	0	0	0	0	1	1	0	1	0	0	1	1	0	1		1	1	1	1	1	1	12
Easy assembly:																						
16 Short assembly time	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0		0	1	1	1	1	5
17 Low complexity of this operation	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1		0	1	1	1	7
18Low number of components that needs to be fasten to the chair	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1		1	1	1	6
Design and price:																						
19 Good material choice (strength and price)	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0		0	1	2
20 Low construction complexity	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1		1	3
21 High level of manufacturability	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0		1

Figure 34 Pairwise comparison matrix

other two at a time as seen in Figure 34. These scores are then used to calculate the weighted score of the main criteria categories (safety, usability, good performance, easy assembly and design and price) where the score is computed with the category's theoretical maximum score (100%) as a basis [2, p. 113].

The weighted score:

- Safety 91%
- Usability 56%
- Good performance 45%
- Easy Assembly 30%
- Design and price 10%

The evaluation matrix is made so that each of the concepts are evaluated on how well they fulfill the criteria where they are scored from 1-5 where 5 is perfect and 1 is not fulfilled at all. The different criteria are multiplied with the weight factor to give a final score. This score is supposed to be more representative of the concepts abilities.

The scores are based on tests made with the 3D printed prototype, user feedback and engineering knowledge.

It is also important to note that the concept scoring of the best isn't always the best concept in every regard, so the rest of the concepts shouldn't be dismissed after the evaluation without thought.

Concept Evaluation Matrix [2, p. 135]:

Wheelchair Stairclimber idees		Small belt gyro		double belt, drive axel conection		Belt help drive, seperate whee		belt help drive		belt drive ,wheel mount		geard hybrid		wheel on pistons		ree controllable be	
Selection criterium	Weight factor	R	WR	R	WR	R	WR	R	WR	R	WR	R	WR	R	WR	R	WR
Safety	0.91	3	2.73	3	2.73	2.6	2.366	2.7	2.457	4.3	3.913	4.3	3.913	3	2.73	4.3	3.913
Usability	0.56	3	1.68	3	1.68	4.5	2.52	4	2.24	3.5	1.96	3.5	1.96	2.3	1.288	2.5	1.4
Good performance	0.45	2	0.9	3	1.35	3.3	1.485	4	1.8	3.5	1.575	3.2	1.44	2.5	1.125	3.5	1.575
Easy assembly	0.3	3.7	1.11	3	0.9	3	0.9	3	0.9	4	1.2	3.7	1.11	3	0.9	2.5	0.75
design and price	0.1	3	0.3	4	0.4	3.2	0.32	3.5	0.35	3	0.3	3	0.3	3.7	0.37	3	0.3
Sum:	2.32		6.72		7.06		7.591		7.747		8.948		8.723		6.413		7.938
Relative to best:			0,75		0.79		0.85		0.87		1.00		0.97		0.72		0.89

Figure 35 Concept evaluation matrix

In the bottom the three best scoring concepts are selected which are: belt drive wheel mounts (Concept13), geared hybrid (Concept 16) and free controllable belt (Concept 18). Also, the scores that where the highest where selected in each category to be able to have an overview of the aspects from all concepts that are the best as seen in Figure 35. The good aspects from different concepts can be mixed and added together to make an even better concept.

3.3.2 Concept further development and analysis

Some new iterations are made on the concepts based on the best performing aspects and concepts from the concept evaluation above. These iterations will be thoroughly analyzed with the help of small 3D printed prototypes and a scenario analysis of the climbing movement to be able to find the best concept to develop the product after.

From the evaluation it is decided that the concepts that will be developed will have a system making it possible to climb stairs even when the batteries are depleted, also a help drive system will be implemented to lower the strain on the user. The belts will also be spaced as far as possible to increase the stability of the product. These solutions will provide safe and multi-functional properties to the product that are useful for the user.

Iterated Concepts:

1. **Full belt help drive wheel mounts**

   This concept is basically the same as Concept 16 from before. With separate units mounted in the wheel mounts to split the weight of the system for easier transportability, help drive and manual drive capabilities.

Figure 36 Iterated concept 1

2. **Help drive separate wheels in wheel mounts:**

This concept is a combination of Concept 13 and Concept 11. The concept is divided in three systems with a drive wheel that helps to push the wheelchair when not climbing in a stair and two belts one in front and one in the rear, the rear one is there to help get up on the first step.

The concept is also split into two separate units that are mounted in the wheel mounts.

Figure 37 Iterated concept 2

3. **Flexible belt.**

This concept is similar to Concept 18 but with the major difference that it is a split system mounted in the wheel mounts. This concept has the ability to move and bend freely to give it better control over the climbing operation.

Figure 38 Iterated concept 3

In-depth motion Analysis:

In the motion analysis the concepts are looked at and analyzed on how they handle the different aspects of the climbing operation. The climbing operation is divided in three stages which are named initiation (when it starts on the first step), climbing (in the middle of the stair) and the "landing" (on the top of the stair).

1. **Concept 1**
   For the first system motion analysis it is found that there could be a problem with the landing stage of the climbing operation. There is a point where the chair will tip which result in a risk that the momentum could cause the user to fall backwards at the top of the stair as seen in Figure 41.

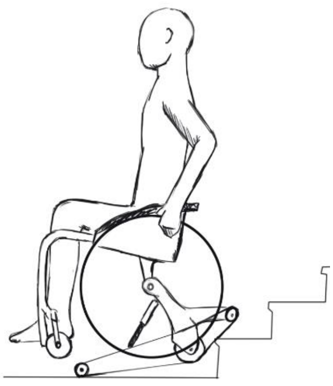


Figure 40 Initiation

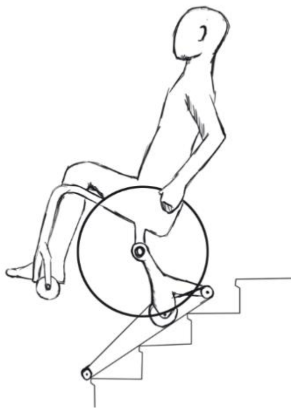


Figure 39 Climbing

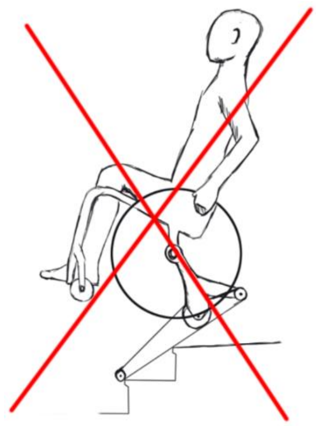


Figure 41 Landing

To solve this problem two possible solutions are introduced one solution where a small wheel on an axle is folded down to catch the chair giving it a stable descent (Figure 42). And the other is a solution were the entire rear belt drive is able to fold down for the same effect (Figure 43).

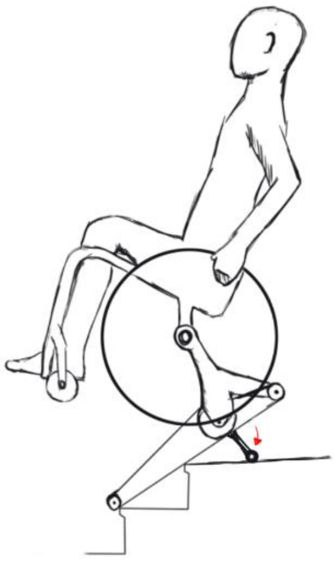


Figure 42 Solution 1

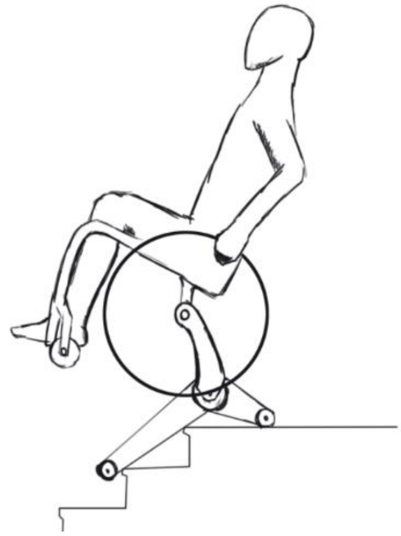


Figure 43 Solution 2

2. **Concept 2:**
   This solution provides the most energy efficient way for the help drive where the system only has to drive the wheel that has contact with the ground. Unfortunately, this introduces some problems where it needs more components which results higher complexity with more parts that can introduce problems. This solution also has less belt in contact with the stair with a big contact patch removed because of the wheel which can reduce grip and stability.

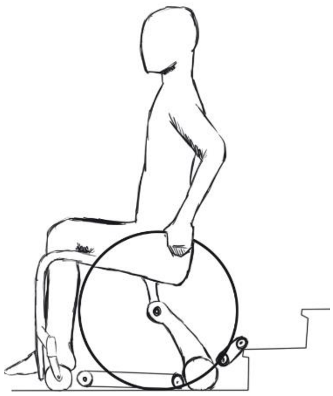


Figure 43 Initiation

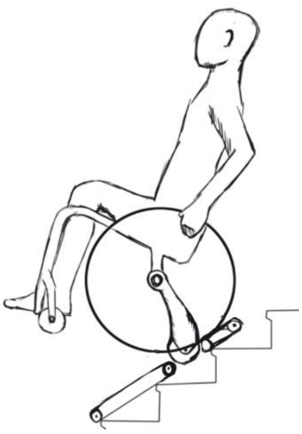


Figure 41 Climbing

Figure 42 Landing

3. **Concept 3:**
   This concept have a good climbing system with good control in the most situations but is more complex with more pistons that will add weight and doesn't support help drive to the same extent as the other concepts which is a quite essential part. The climbing benefits from this system isn't that much better than for the other two concepts in comparison to its draw backs.

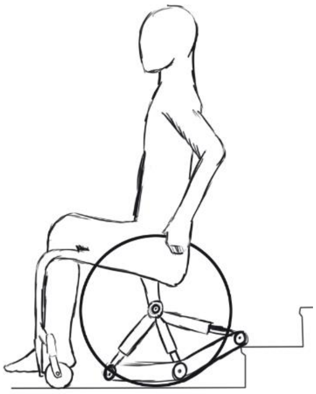


Figure 46 Initiation

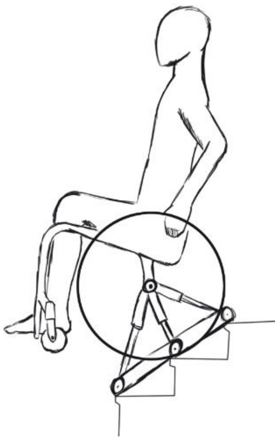


Figure 45 Climbing

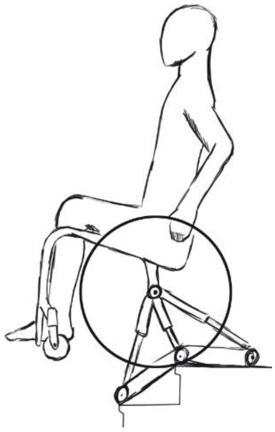


Figure 44 Landing

3.3.3 3D print and testing

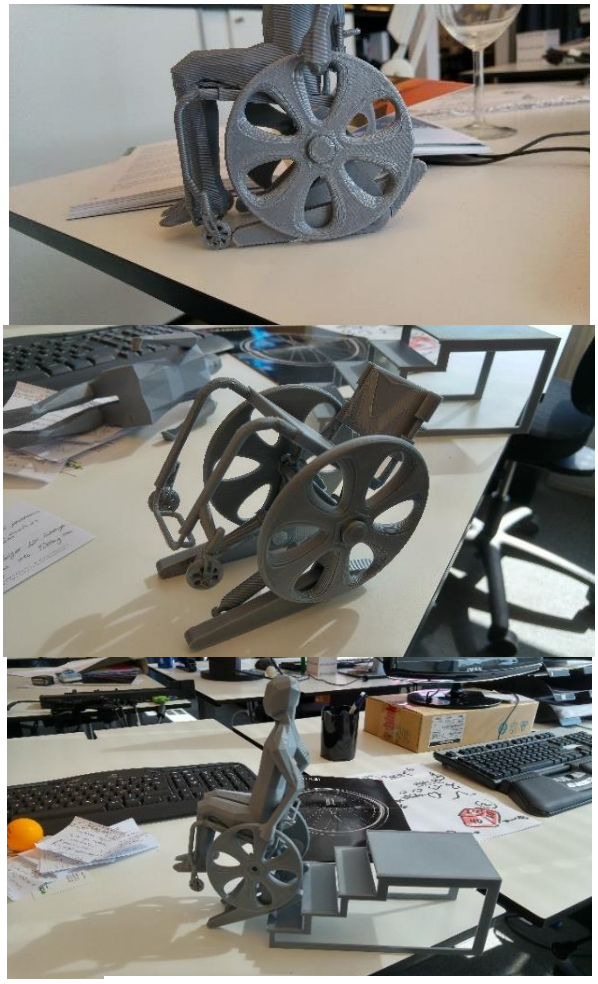


Figure 47 3D-print analysis collage 2

A new 3D printed model were made were it this time were mounted in the wheel mountings to test the side stability and to better visualize the concept as seen in Figure 50. The pistons were made with screws to be able to set the angle for faster testing. The 3D printed surface was a bit slippery which complicated the testing of the model, but with some rubber bands glued to the bottom made it possible to test. Then the model was perceived as stable both back/forward and in the sideways direction.

3.4 Chosen concept

The information found from the motion analysis and the 3D print is used to decide on which concept to continue with.

The concept that was chosen to be further developed is the first concept with the rear part being able to angle down in the top of the stair to prevent it from falling backwards seen in Figure 52. This was chosen because it handles all the problem in the most efficient way with allot of contact with the stair making it safe. It also gives the benefit of a help drive so that the user won’t get tired while having it connected to the wheelchair. It’s not overly complicated so that both weight and price can be kept as low as possible to optimize the product for the users needs.

Figure 49 Chosen concept

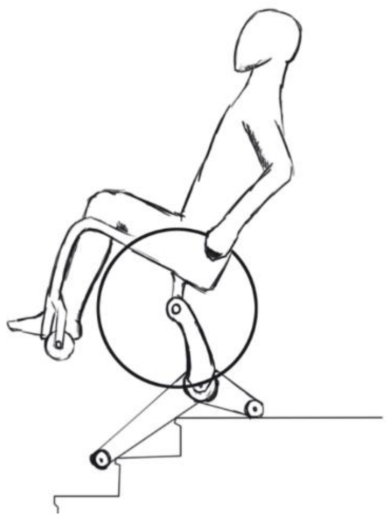


Figure 48 Chosen concept function

4 Detailed design and development

Now when the concept has been chosen and all the sub systems have been defined it is time to make the detailed design of the product, not just schematic sketches and arbitrary prototypes, but something useful and concrete that can be used for the construction of a real product.

Target numbers such as system mass, maximum user weight, system price, reference stairs with angle, step height and shape, also which wheelchair the product will be designed for needs to be defined. These numbers are important both for calculations and design and will be based on data gathered during the research process and ISO standards.

The important calculations that are necessary to define the design to achieve the sought-after functions of the product are:

- **System stability**, how length and positioning of the belts affects stability and how the mass centrum is different between individuals.
- **Friction,** friction towards the stair, contact path, belt groves and pattern are also important safety aspect so that the product doesn't slip.
- **Motor and piston powers** that are necessary to drive the system for the maximum load cases.

These different aspects also need some safety margins when designing so that the product never runs on its outmost limits.

4.1 Numbers and basis

Concrete values are set for the product as goals references from market standards, conducted research, ISO standards and interviews.

The wheelchair that was chosen as a base for the calculations is Panthera S3. This is a popular manual wheelchair, also this exact model was available on site for this project (landed by one of the interviews) to get hands-on experience and measurements of it. See Appendix C.1.2 for more information about the chair [30].

- *Weight = preferably no more than 7 kg that is to be lifted at once (from interviews)*
- *Maximum user weight = 100 kg (limitation for the specific wheelchair [30])*

- *Price = no more than 50,000 SEK. for a well-functioning and safe product (to be able to be competitive and a realistic choice for the user)*

ISO 7176-28 (ISO standard for stair climbers safety and ability), this standard defines what angles of a stair a stair climber should be able to handle which are 30-40 degrees [29]. This is combined with ISO 14122-3 (criteria for steps, stairways and ladders) to define step height and step lengths [31].

From ISO 14122-3 the following is given:

Step height maximum: 250 mm

Step length maximum: 270 mm

See more information from ISO 14122-3 in Appendix C.1.3.

The data for the center of gravity of a sitting person is taken from a study made by Matthew P. Reed for the University of Michigan Transportation Research Institute. In this study, data is gathered from 447 women and 315 men of their seated center of gravity [32]. From this study it is possible to extrapolate the center of gravity (CG) for a person of a mass of 40 kg (lowest of the test subjects) and for a person of 100 kg which are considered to be the extremes for this product. Data Points can be found in Appendix C.1.1.

Center of mass for a 40 kg person:

CGx = 17cm

CGy = 19cm

Center of mass for a 100 kg person:

CGx = 27cm

CGy = 27cm

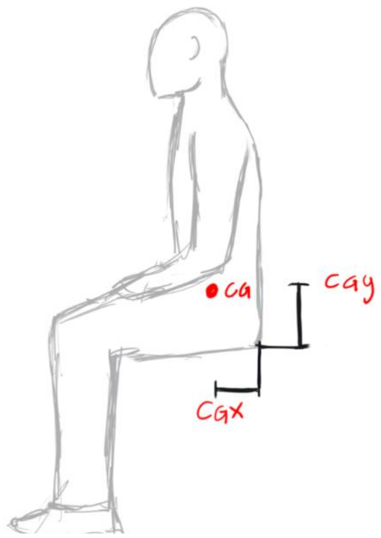


Figure 50 Illustration on center of gravity

Wheelchair data:

Data taken from Panteras data sheet [30]. Some data was missing which has been measured on the wheelchair that was available for this project (find full data sheet in appendix C.1.2). The point P in Figure 54 is where the climber will have contact with the ground to help push it forward. The seat height is set to the average height were the angle E is neglected, this angle will be accounted for when the entire wheelchair is angled in the calculations instead.

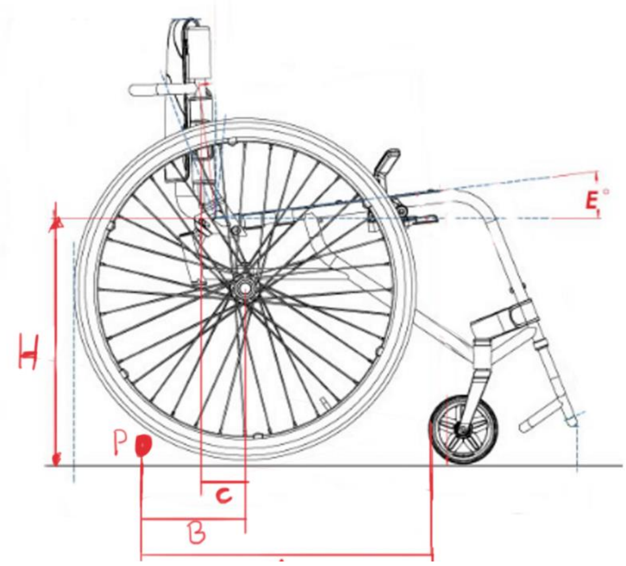


Figure 51 Measurements of the chair

H = 45 cm (Average seat height)

C = 10 cm (Distance between wheel axle and back rest)

B = 18 cm (Distance between wheel axle and P)

A = 51 cm (Distance between P and front wheel)

Wheel diameter = 60.96 cm (24 inches)

During the climbing the person will be slightly angled backwards to avoid slipping out of the seat and for the benefit of moving the CG backwards, which means the length of the belt can be shorter. This angle will be no more than 15 degrees to maintain a comfortable climbing experience.

4.2 Calculations

When doing the calculations, it is important to look at different scenarios and look at the extreme points to be able to design the product so that it can handle all worst-case scenarios.

4.2.1 Stability Calculations

The stability during the climbing operation is dependent on a couple of different factors where the most important are stair angle V, belt lengths L1 and L2, wheelchair angle alpha and CG position.

For the chair to be stable during the climbing, the distance between the CGLX and the endpoints needs to be longer than one step length so that the center of mass always have contact points around it to prevent tipping (illustrated as the x and y distances in Figure 55).

Position P is where the product has contact with the ground and is where L1, L2 and the chair is rotated around.

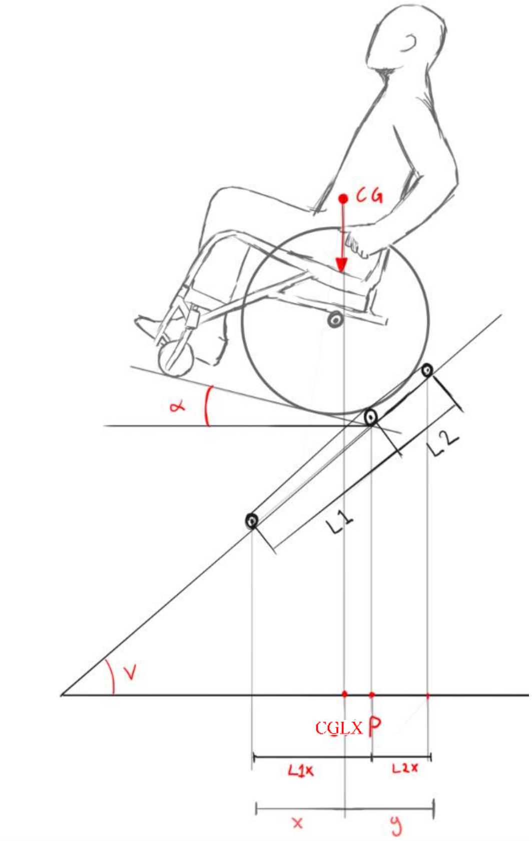
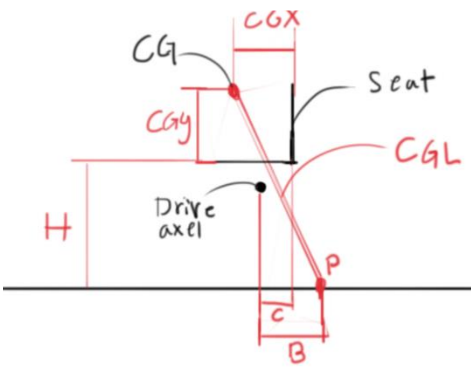


Figure 52 Illustrative image for stability

To be able to find the distance x and y from Figure 55 (distance from CG to endpoints), the geometry of the situation needs to be solved. The first thing that is calculated is the distance between P and CG called CGL in Figure 56. This is made by combining the wheelchair data and the center of gravity data.



$$CGL = \sqrt{(B - C + CGX)^2 + (H + CGY)^2}$$

Figure 53 Illustration of distance from P to CG

The angle $\propto$ represents the wheelchair angle while γ represents the angle between the ground and CGL while the chair is not climbing. These two angles need to be combined to be able to project CG's position on the X-axis. The angles are represented in Figure 57.

$$\gamma = \arcsin(\frac{H + CGY}{CGL})$$

$$L1X = Cos(V) * L1$$

$$L2X = Cos(V) * L2$$

$$CGLX = Cos(\gamma{+}\propto) * CGL$$

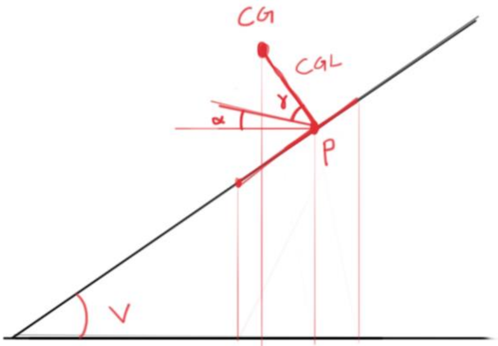


Figure 54 Illustration on geometry

$$CGLX = (avstånd\ från\ P\ till\ CG\ på\ x\ axeln)$$

Now the distances X and Y can be calculated as represented in Figure 58.

$$X = L1X - CGLX$$

$$Y = L2X + CGLX$$

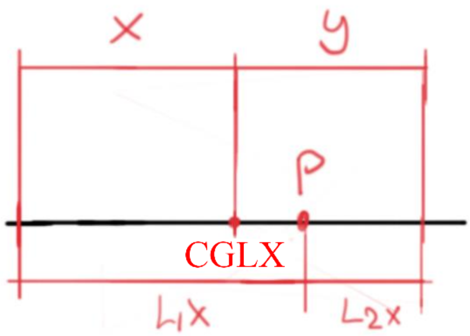


Figure 55 Illustration on projection on the X-axis

Because the CG and chair dimensions are fixed, the necessary length L1 and L2 are plotted in a 40-degree stair depending on the angle alpha, with a safety margin of 3 cm to allow the person to move and shift their CG without falling. X and Y needs to be longer than 30 cm because the maximum step length is 27 cm with the safety margin of 3 cm.

Length L1:

$$L1 = \frac{X + Cos(\gamma{+}\propto) * CGL}{Cos(V)}$$

From the graph in Figure 59 it can be observed that the necessary length L1 gets shorter when the wheelchair angle alpha gets higher which is a result of moving the center of mass backwards.

The 40 kg person needs a minimum L1 of 49 cm with a wheelchair angle of 15 degrees.

The 100 kg person needs a L1 of 59 cm with a wheelchair angle of 15 degrees, unfortunately this is not possible in accordance to the wheelchair geometry where only a maximum L1 length of 51 cm is possible. Here is a difference of 8 cm from what is possible and what is needed, this problem needs to be resolved for the product to function.

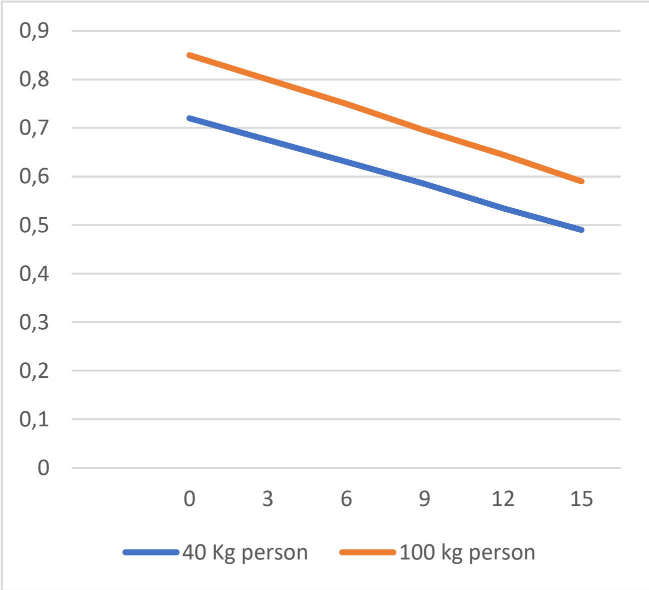


Figure 56 Length L1 depending on alpha

Length L2:

$$L2 = \frac{X - Cos(\gamma + \propto) * CGL}{Cos(V)}$$

In Figure 60 it can be observed that L2 behave the opposite from L1 where the necessary length gets longer when the wheelchair angel is higher because the CG is moved backwards.

For a 40 kg person the necessary length of L2 at 15 degrees is 29.5 cm and for a 100 kg person its 19.5 cm.

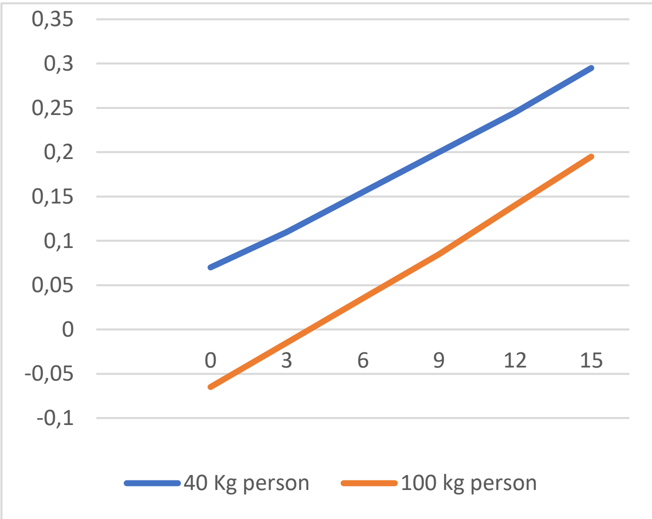


Figure 57 Length L2 depending on alpha

L2's length is also limited by the stair height where it must be able to get the chair up on the first step, with a maximum step height of 25 cm. The belt L2 cannot be behind the wheel because then the wheel will hit the step before the belt. The minimum length L2 can be determined from Figure 61.

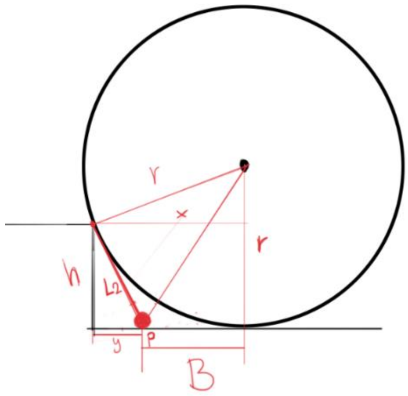


Figure 58 Necessary L2 length depending on step height

$x = \sqrt{r^2 - (r-h)^2}$

$y = \mathrm{x} - \mathrm{B}$

$L2 = \sqrt{y^2 + h^2}$

$L2 = 27.72\ cm$

From these calculations the minimum L2 needed is 27.72 cm but from the stability calculations it needs to be a minimum of 29.5 cm which means it needs to be made longer than 29.5 cm.

4.2.2 **Torque Calculations**

The torque calculations look at the necessary force that the pistons need to supply to the system to be able to lift the chair for the climbing operation.

Front Belt:

The rotational force for the front belt is calculated at the initiation of the climbing (momentum around P). V is the stair angle and ∝ is the angle of the front belt. L1 is set to the maximum length that the wheelchair allows (48 cm). Illustrated in Figure 62

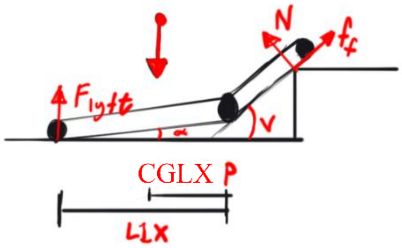


Figure 59 Illustration of forces in the initiation stage

Equilibrium equations for forces and momentum:

(↑) $Flyft + N * \cos(V) + Ff * \sin(v) - mg = 0$

(←) $N * \sin(V) - Ff * \cos(v) = 0$

$(moment\ around\ P)\ Flyft * L1x - mg * CGLX - N * (\sqrt{}(0{,}25^2 + 0{,}27^2) = 0$

$L1X = \cos(\propto * L1)$

Necessary torque = Flyft*L1x

The necessary torque is then plotted for the angle alpha between 0-40 degrees as seen in Figure 63. The necessary torque gets lower because the Center of mass is moved backwards. The maximum torque required for a 100 kg person is 392.6 Nm

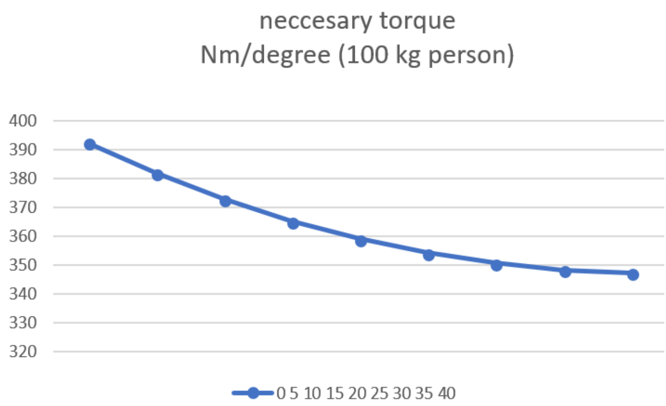


Figure 60 Torque plot for front belt

Rear Belt:

The second torque calculation looks at the necessary torque for the rear belt at the top of the stair. Where V is the angle between the front belt and the ground and ∝ is the angle between the rear belt and the ground.

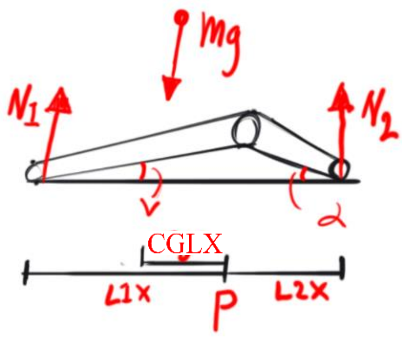


Figure 61 Illustration of forces in the landing stage

Equilibrium equations:

$(\uparrow)\ N1 + N2 - mg = 0$

$(moment\ around\ N1)\ N2 * (L1x + L2x) - mg * (L1x - CGLX) = 0$

Connection between alpha and V:

$L1 * sin(v) = L2 * \sin(\propto)$

$L1x = cos(v) * L1$

$L2x = cos(\propto) * L2$

$$N2 = mg * \frac{L1x - CGLX}{L1x + L2x}$$

Torque = N2*L2x

The torque is plotted dependent on the angle alpha as seen in Figure 65. The torque gets lower because the lever towards the point of momentum gets shorter when alpha gets larger. The maximum torque required for a 100 kg person is 129 Nm.

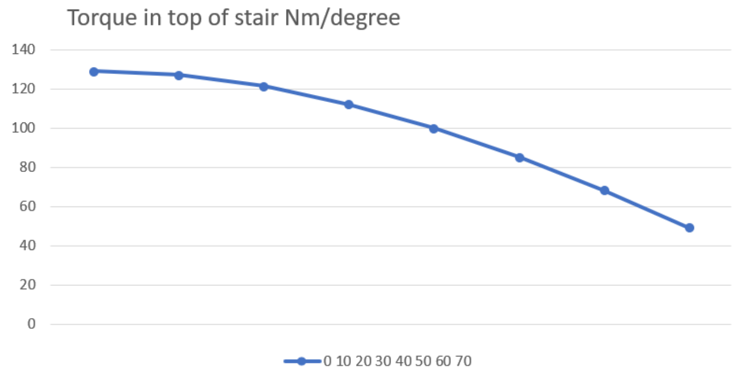


Figure 62 torque on rear belt depending on alpha

4.2.3 **Friction Calculations**

The necessary friction needed to keep the system from slipping is calculated according to Figure 66.

$(\uparrow)\ N * \cos(V) + Ff * \sin(V) - mg = 0$

$(\leftarrow)\ N * \sin(V) - Ff * \cos(V) = 0$

$$N = \frac{mg}{\cos^2(V) + \frac{\sin^2(V)}{\cos(V)}}$$

$$Ff = \frac{N * \sin(V)}{\cos(V)}$$

$$friction\ coefficient\ \mu = \frac{Ff}{N}$$

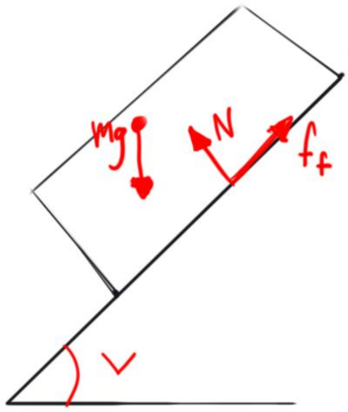


Figure 63 Friction illustration

The necessary friction is then plotted as a function of the stair angle as can be seen in Figure 67 describe the necessary friction coefficient between the stair and the belt to avoid the belt from slipping dependent on stair angle.

The maximum necessary friction coefficient in a 40-degree stair is 0.84. The friction coefficient are dependent on what materials are in contact.

Friction coefficient values are looked up between different surfaces, data taken from engineeringtoolbox.com [33].

Rubber on dry concrete (0.60-0.85)[33]

Rubber on wet concrete (0.45-0.75)[34]

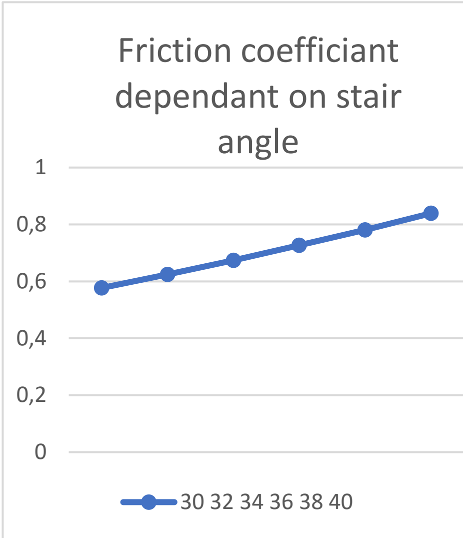


Figure 64 Plot friction depending on angle

This is possible to alter by introducing patterns and grooves in to the belts that will change the contact angle between the materials which will lower the necessary friction coefficient between the materials.

4.2.4 **Driving Calculations**

The torque required from the driving "wheel" is dependent upon its radiuses and the angle of the stair. R is the radius of the drive wheel

Motor torque needed $= \frac{Ff}{R}$ = T (Nm)

This gives the minimum driving torque from the driving motor to be 31,6 Nm for a 100 kg person in a 40-degree stair with a wheel radius of 5 cm with no friction losses. The climbing speed also needs to be defined to be able to define the correct motor for the task. The speed that the system should be able to handle is about 2-4 km/h which is slightly slower than regular walking speeds [35], but is considered sufficient for this task (no slower than 2 km/h).

Equations:

Wanted speed = Vs (m/s)

RPM needed $= \frac{Vs}{2 * \pi * R} * 60$

Motor effect needed $= T * 2 * \pi * \frac{RPM}{60}$ (W)

This results in a minimum motor speed of 106 rpm. With this speed and torque results in a required motor effect of 351 W to be able to climb in 2 km/h.

4.3 Design

The calculations made will be used to define the design and find the necessary components for the product to function as intended in reference to the concept.

Figure 65 Finished design render

Finished Design:

The product consists of two units that are mounted in the wheel mounts with only a small additional fastening point needing to be added to the chair. It has the ability to function as a help drive and climb stairs in an effective manner for people up to 100 kg. It has a well-integrated and ergonomic design to help the user to a more accessible life. It will have the ability to regenerate power when climbing down stairs or by manual power. The front belt wheels are made smaller to be able to get the contact patch of the belt further forward without too much loss of efficiency in driving the belt.

Figure 67 product components **Figure 66 unit exploded view**

1. **Front push piston:** (DLA-24-40-A-200-POT-IP65) A compact electronic piston that can handle a maximum force of 1200 N with a stroke length of 200 mm. The piston is positioned so that it can handle the forces applied to it and are also able to angle the belt 65 degrees which accounts for the stair angle and wheelchair angle. It has a force margin of 568 N for the maximum load. It costs 2,500 SEK and weighs 1,5 kg [36].

2. **Rear push piston: (**DLA-24-30-A-100-IP65) A compact electronic piston that can handle a maximum force of 800 N with a stroke length of 100 mm. Positioned for the appropriate angling of the rear belt. It costs 1,875 SEK and weighs 1.13 kg [37].

3. **Drive motor: (**DOGA 319H) Compact motor with worm gear with high torque 40 Nm and 100 RPM gives max effect of 419W which is more than the 351W required. This motor is perfect for this application where it can be geared for a maximum climbing speed of 2.4 km/h and easily geared for a help driving speed of 5-10 km/h. The worm gear is self-locking which will prevent the system from rolling if the battery is depleted in a stair. It cost 3,316 SEK and weighs 1 kg [38].

4. **Battery cells:** The battery cells used are LGs LG HG2 18650 cells with 3 Ah. In total both units fit 36 cells which deliver 400 Wh which results in a climbing height of 1,464.93 meters with 100% efficiency for the maximum load, this height might differ with regen power. One cell weighs 45 grams and costs 56.93 SEK, makes the total battery mass 1.62 kg and the total cost of 2,049 SEK. With 400w motor gives depleted battery after 1 hour if run at full effect [39].

5. **Angling mechanism:** This is the part connected to the wheel mount where a small motor with a worm gear is used to be able to angle the entire unit forward the necessary 8 cm for it to be stable for all possible users. This unit is by own design and is approximated to cost around 1,000 SEK and have a mass of 200 grams. Also with a small generator implemented in the middle that can convert the movement of the wheels to charge the batteries.

6. **Handle bar:** This handle bar has two functionalities, both to be able to angle up the unit so it's not in contact with the ground (utilize the angling mechanism) and easier handleability when its disconnected from the chair.

7. **Control wheel:** This is a smaller hand rail that is used to control the device, when the user angles it to drive forward and backwards.

8. **Control/gear lever:** gear lever for gear ratio between drive motor and drive system (for climbing mode and help drive mode for the assisted driving).

In Figure 71 the mounting system for the units are depicted where only a small part with four rods around the hole for the wheel mount needs to be added to the wheelchair to securely fasten the stair climber. This is in order to not make it difficult for the user to attach it to the chair and also to not disturb the mounting of the wheels.

Figure 68 Mounting

Here are some renders on the climbing operation for the product for all the stages of the climbing depicted in Figure 72, 73 and 74.

Figure 69 Climbing initiation

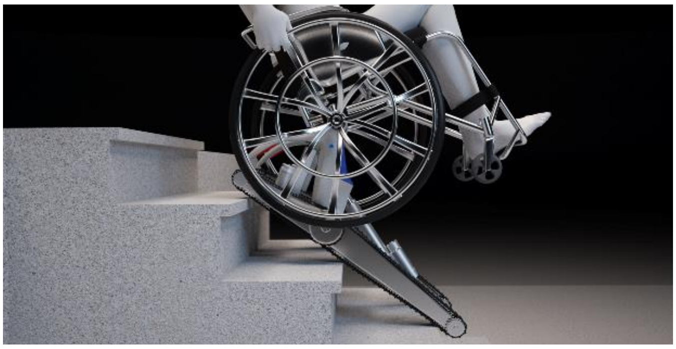


Figure 70 Climbing

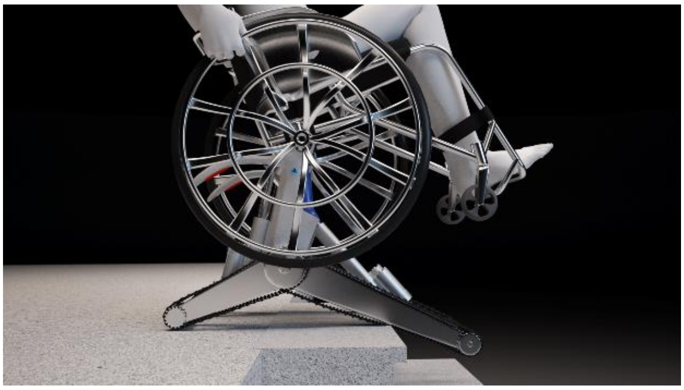


Figure 71 Landing

4.3.1 **Piston and battery calculations**

Battery:

$$\text{Battery energy content} = \text{Cells} * \text{Ah} * \text{V} = 36 * 3 * 3.7 = 399.6\ (\text{Wh})$$

$$Maximum\ climb\ hight = \left(\frac{\text{Battery energy}}{\text{motor power}}\right) * \text{speed} * \sin(\text{v})$$

$$= \left(\frac{399.6}{419}\right) * 2{,}4 * \text{Sin}(40) = 1\,471.26\ \text{m}$$

$$\text{Mass} = \text{CellMass} * \text{cells} = 0.045 * 35 = 1.62\ \text{kg}$$

Pistons:

The position of the pistons is made with the help of SolidWorks where it was easy to measure angles possible depending on the positions and stroke lengths of the pistons. Then the pistons where chosen depending on the forces they needed to be able to handle for the given position. Piston position seen in Figure 75.

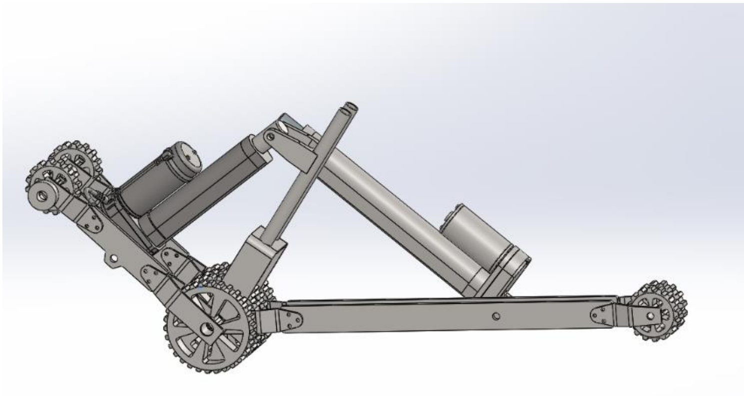


Figure 72 Piston positioning model

Front:

Pistion angle $= Pv = 45^0$ in the point of highest torque needed

Pistion position on belt arm $=$ $\text{S} = 0{,}3$ m as seen in Figure 76

From the calculations that were conducted in chapter 4.2.2 it was found that the maximum torque necessary was 392.6 Nm

With two pistons at 1,200N =>2,400N

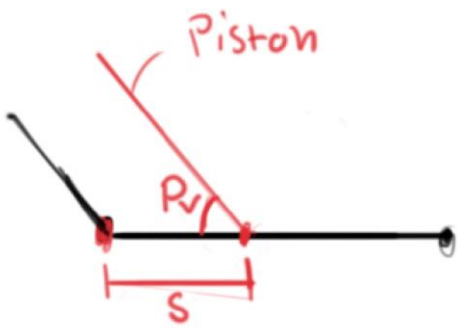


Figure 73 Front piston situation

Gives maximum torque power possible $= \sin(45) * 2400 * 0.3 = 509.11$ Nm

This results in a difference of 116 Nm

This means that a theoretical maximum user weight of 129.7 kg before this difference is zero.

Rear:

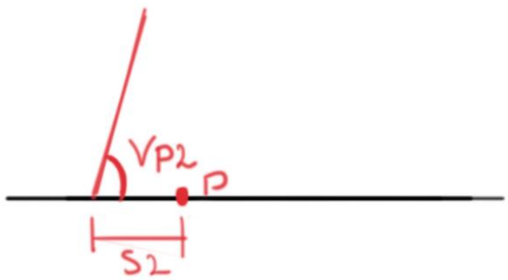


Figure 74 Rear piston situation

Pistion angle $= Vp2$ $(according\ to\ the\ picture) = 66^0$ in the point of highest torque needed

Piston position on belt arm $= S2 = 0{,}12$ m as seen in **F**igure 77

From the calculations that were conducted in chapter 4.2.2 it was found that the maximum torque necessary was 129 Nm.

With two pistons at 800N =>1,600N

Gives maximum torque power $= \sin(66) * 1{,}600 * 0{,}12 = 175.4$ Nm

This results in a difference of 46 Nm.

This means that a theoretical maximum user weight of 145 kg before this difference is zero.

4.3.2 **Dimensions and materials**

To be able get an estimation of the needed dimensions and materials for the product, a FEM analysis were conducted in SolidWorks as seen in Figure 78. The main part analyzed is the front belt structure which sees the biggest loads. The system is loaded with a vertical force in the end point of 408,95 N which is half of the biggest force from the torque calculations. It is half because only one unit is simulated. To simplify the system, it is only fixed in the wheel mount position so no forces affect the rear belt structure. In place of the pistons are only rigged rods. The materials that are considered for this product are materials with low weight and high strength. The kinds of materials that are well suited for this product with those specifications are carbon fiber and aluminum. Carbon fiber is a bit difficult to do calculations on because of its anisotropy material characteristics which is why the simulations are made on aluminum to save time and because of limitations with SolidWorks. In this instance aluminum 7075-T6 are used.

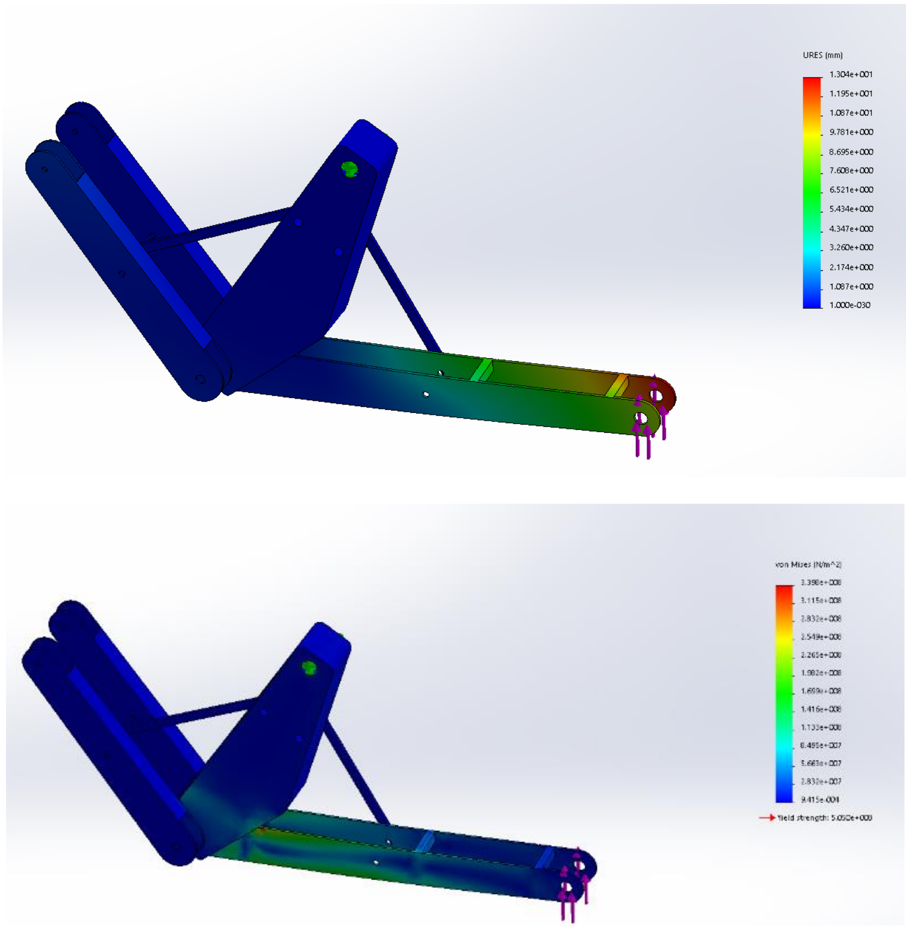


Figure 75 FEM analysis

No major time were spent on structural optimization, only enough to get a basic structure that can handle the loads.

The mesh quality is set to high, for high resolution answers. The biggest stress the structure sees is 3.4 N/m^2 which corresponds to 67% of the yield strength of the material. This is considered a good safety margin. The structure has a maximum displacement of 1.3 mm in the endpoint. The rest of the parts were then dimensioned in the same way with wall thickness and structure. Because these parts see lower loads they are assumed to handle it. This was done to be able to get a rough estimation for the mass and price calculations of the parts. The bigger parts were then replaced with carbon fiber for weight and price calculations. Because carbon fiber generally have higher yield strength than aluminum it is presumed to handle it.

4.3.3 Bill of materials and cost analysis

The weight, materials and manufacturing cost are based on rough estimations, found data and the simple FEM analysis. Se Figure 79 for parts and estimated mass and prices [40-42].

BOM:	st	Weight kg	Price kr	Material	
Estimations					
Rear belt	2	0,08	6,148	Rubber	
Front belt	1	0,24	18,444	Rubber	
Small belt drive wheels	4	0,076	14,8504	aluminium	
big belt drive wheels	4	0,204	50	aluminium	
Front structure	1	0,25	434,25	Carbon fibre	
Rear structure	2	0,1	173,7	Carbon fibre	
Piston Mount	3	0,07	112	aluminium	
Front axel	1	0,05	80	aluminium	
Rear axel	1	0,05	80	aluminium	
Drive shaft	1	0,1	160	aluminium	
Ballbarings	6	0,015	30	Bought	
mount bracket	1	0,1	350	aluminium	
Handle bar	1	0,05	10	plastic	
Angling mechanism	1	0,3	1000	aluminium	(kogs and worm gear)
Main body	1	0,2	1042,2	Carbon fibre	
Bought					
Battery cells (18650)	18	0,045	56,93		
Motor	1	1	3300		
Piston Front	1	1,5	2500		
Piston Rear	1	1,1	1800		
Small Dc motor for angelin	1	0,3	200		
sum (one unit):	33	7,83	13134,73		
Both units:	66	15,66	26269,46		

Figure 76 BOM

These costs are based on raw material value and estimated manufacturing cost based on EmachineShops sample prices for custom parts [41]. This means that the price estimation is made for outsourced manufacturing and small production volumes. This results in a production cost of 26,269.46 SEK as seen in Figure 79. Based on Fabregas, K's article on how to price a product [45], its stated that a reasonable approach to price a product is to double the manufacturing cost which results in an estimated retail value of 52,540 SEK for the consumer. This price is comparable to the other stair-climbers on the market.

If investors would get involved to make larger production volumes and in-house manufacturing, this could bring down this price by a substantial amount.

4.3.4 **Product specs**

The specifications for the final design of the product results in a unit mass of 7.83 kg which is the weight the user would have to lift. A total system mass of 15.86 kg that will be added to the chair. The estimated manufacturing cost for the product is 26,269.5 SEK and estimated retail price is 52,540 SEK. it will have a maximum climbing speed of 2.4 km/h and a help driving speed up to 10 km/h. The product can handle a maximum load of 100 kg and climb 300-400 stories on one charge if help drive is not used.

4.4 Proof of concept

In this chapter, a prototype will be made to better test the ideas and functions of the product, and to see whether the product could be used in a real-world situation.

4.4.1 **Design and building**

It was quickly decided that a full-scale prototype was not viable because of time and financial limitations.

An Arduino board and some servomotors were acquired that would be possible to use for the prototype building.

Design:

A design was then made to fit the Arduino and the motors which resulted in model with a scale 1:3 to the original. Because no pistons were found this was solved by making it like crank pistons for the rotating of the arms. Furthermore, a model of the chair was made to be able to replicate the real conditions for the prototype for a more accurate test result. The model was designed from the beginning with the intent to be 3D printed as seen in Figure 80.

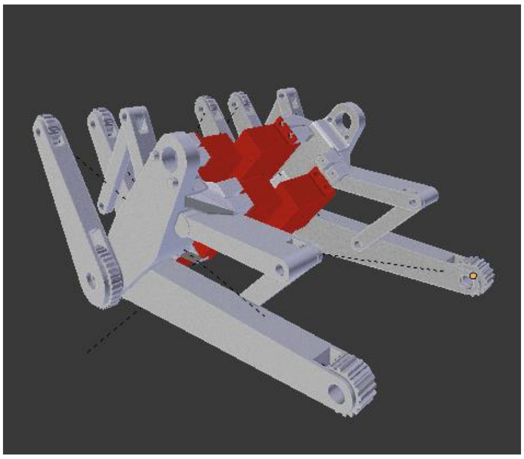



Figure 77 3D model of scale model

Printing:

The parts for the prototype was then printed on a Prusa i3 Mk2 [43] with no major problems, the drive shaft was the only thing needed to be re printed because it was made to small and weak and deformed under the weight of the motors.

Figure 78 Unit

Figure 79 Chair

Figure 80 3D printing Done

The belts were casted in 3D-printed molds with liquid rubber silicon as the casting material as seen in Figure 84-87 [44].

Figure 83 3D-printed molds

Figure 84 Molds filled

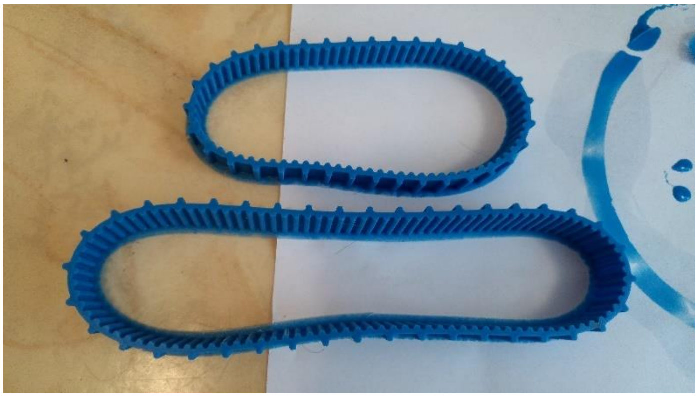


Figure 81 Casted belts

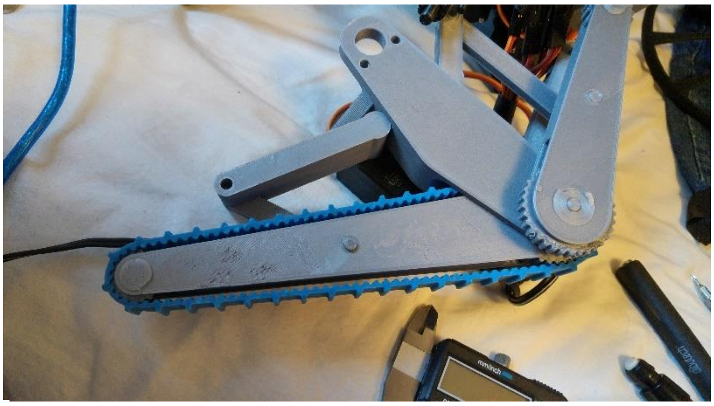


Figure 82 Belt installed in prototype

4.4.2 **Testing and results**

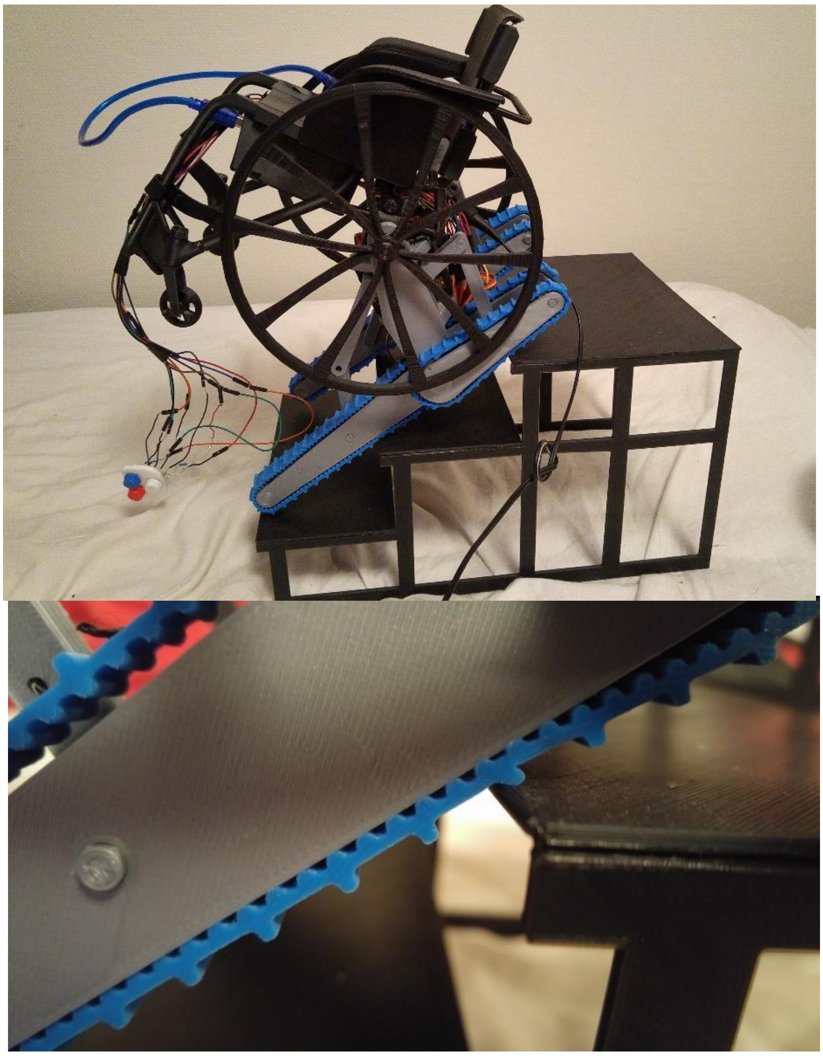


Figure 85 Prototype testing collage

From the testing of the prototype the grip and stability in the stair functions well were no slipping nor tipping has occurred even in the crucial areas as seen in Figure 88. Driving down the stair is no problem, but when the device tries to climb up there is a small problem with the flexibility of the belts where they stretch to much preventing them from turning. This is not a fault with the concept but with the material of the belts and could be prevented with some fiber inlays in the belts like carbon or glass fiber to make them stronger.

5 Reflections

This project has resulted in a design of a product that realistically could function in the real world and aid wheelchair users in their everyday life. This can be concluded from the successful prototype testing, with only some minor issues with the belts in the belt drive that could be resolved with more time.

Some more effort to get a more accurate representation of the center of mass would also have resulted in a more accurate test results for the prototype.

According to the calculations the unit mass will be 7.83 kg which is 0.83 kg more than the specifications. This mass can probably be reduced with some more structural optimization. However, it is still a high weight to carry for the user when getting it inside a car or similar. For example, this problem could maybe be resolved in another way more than just weight reduction.

A product price of 52,540 SEK is comparable with the current stair-climbers on the market and with the added functionality of this product this could prove to be a competitor to the other solutions. Needless to say, more work needs to be done, like structural optimization, better calculations and a full-scale prototype to test. With companies ready to invest in it, this product have the potential of becoming reality and greatly improve the living standards for wheelchair users.

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Appendix A Time plan

A.1 Time plan

In the beginning of this project a brief time plan was made were the "big" goals for the project were defined and planed. The planning was made with a couple of days in between the different tasks to give some buffer time for the project to account for unforeseeable events.

A.1.1 Research

1. *Gathering of basic information and analyzation of existing products on the market to get an overview of the problem and potential solutions.*
   (18-02-05 to 18-02-09)

2. *Get in contact with relevant people and conduct interviews to find out about the problems a wheelchair user face and the needs for this kind of product.*
   (18-02-11 to 18-02-21)

3. *Gathering and compilation of interviews. Generation of user needs, limiting factors and product criteria to fulfill the user needs. Compare the user needs to existing products on the market what they don't focus on that are important.*
   (18-02-28 to 18-03-02)

A.1.2 Ideas and Concepts

1. *Generate quick ideas and potential solutions for the problem with the criteria's and user need as a base. (all possible solutions on different sub-problems in the system).*
   (18-03-07 to 18-03-09)

2. *Evaluate the different solutions on how well they fulfill the different criteria to find the best solutions for the task.*

(18-03-11 to 18-03-12)

3. *These ideas used as a base to further develop to more well-developed concepts.*
   (18-03-19 to 18-03-25)

4. *Evaluate these concepts with evaluation matrixes and small function prototypes to test their abilities to be able to find the concept that solves the problem in the best way.*
   (18-04-06 to 18-04-15)

A.1.3 Design

1. *The concept that performed the best is the one that should be further developed with a finished design, dimensioning and components to be able to function properly. Physically biased calculations to be able to dimension the product.*
   (18-04-18 to 18-05-04)

2. *When the finished design is done a more finished and functioning prototype will be made and be used as proof of concept.*
   (18-05-06 to 18-05-17)

3. *Refining of report and presentation*
   (18-05-18 to 18-05-31)

4. *Presentation*
   (18-06-05)

A.2 Project plan and outcome

During the process of the work the time schedule was followed quite well with some areas that took more time than planned for example research and report writing consumed a lot of time. Also, some mistakes were made in the calculations that were found out about much later when big parts of the design were already made that needed to change because of this. But with the planned buffer time, the overall project planning wasn’t affect to much by these occurrences.

Appendix B Research

Here is the appendix information of the research.

B.1 Detailed Interviews

Larsson, H: (aktiv rullstolsanvändare)
Larsson säger att om det finns ett räcke tillgänglig vid en trappa så kan han klara att ta sig både upp och ned för den på egen hand men att alla inte har samma rörelseförmåga som honom vilket ger att dessa personers behov kommer att se något annorlunda ut.

Han säger också att samhället förändras och handikappanpassas allt mer (med diskrimineringslagar, osv.), så han märker inte själv så stora problem i sin vardag med vanliga trappor.

Dock finns det en del ställen (affärer, osv.) där det finns 2–3 trappsteg utan något räcke som inte går att ta sig uppför eller runt utan att få hjälp, han säger att detta är ett stort problem för alla rullstolsanvändare, och tycker att detta borde vara störst fokus på att lösa. (Eget förslag på lösning, någon slags ramp man kan ha med sig som ska vara extra lätt att ta sig upp för.)

Om Larsson skulle själv börja använda denna typen av produkt så får den inte kompromissa på rullstolens smidighet och rörlighet, där får inte heller vara någon avsevärd vikt ökning av stolen då detta kan leda till utslitning av axlar och leder vid användande och att det kommer försvåra processen att få in den i bilden vilket inte hade varit bra. För en permanent lösning som alltid sitter på stolen får den inte överstiga 2–3 kg och för en lösning som är avplockar 6–7 kg-

(vill gärna se vad som händer senare i projektet och beredd att ge feedback på alternativa lösningar från hans perspektiv)

Feedback på koncepten, Larsson säger att han gillar idén med hjälpdrift vilket gör att produkten får ett mycket bredare användningsområde och gör hela konceptet mycket bättre.

Norsten, Å: (professor)
Han menar på att det finns ett behov att göra det lättare för rullstolsanvändare att lättare kunna ta sig upp och ned för trappor, (osäker på hur stort det är), han menar också på att vikten hos en sådan produkt är viktig att hålla nere för en sådan lösning.

Eftring, H: (professor Certec (biträdande handledare på skolan))
Eftring säger att rullstolsanvändare har olika mycket rörlighet och styrka i armar och bålen vilket gör att behoven kan skilja sig mycket åt från person till person och att det är viktigt att ta kontakt med dessa personer för en bättre bild av problemet (bidrog med olika kontaktuppgifter till personer bland annat Larsson, H).

Feedback på koncept, Han gillar idéerna bakom koncepten och bidrog med tabeller för olika kroppsmått för män och kvinnor.

Eklund, K: (rullstolsburen fru)
Eklund har erfarenhet av en självstabiliserande trappklättrare och han tycker att den fungerade mycket bra och var inga funna problem med den, (förutom att vikten var aningen för hög vilket gjorde den svår att lyfta, när nu detta behövdes).

Tunga rullstolar kan ge mycket problem som förslitningar på tummar handleder och axlar så en manuell rullstol med tung utrustning är inte bra för användaren.

En lösning för att på egen hand kunna ta sig upp och ned för trappor och hinder på över 7cm skulle göra jättestor skillnad, bara möjligheten att på ett säkert sätt kunna ta sig ner för en kant eller ner för en trappa hade förbättrat möjligheterna stort för framkomligheten.

Många rullstolar specialanpassade vilket gör det svårt att göra en produkt som kan anpassas till denna variation, tips att göra en integrerad stol men som är byggd av standardkomponenter som finns på marknaden.

Tranström, P: (Skånetrafikens färdtjänst)
Tranström berättar om färdtjänstens riktlinjer och erfarenheter av deras trappklättrare där det finns stora säkerhetsrisker i att använda trappklättrare för både kund och förare, men om man är rullstolsburen har man rätt till trappklättring i 6 månader på den egna adressen (ingen annan stans). Ibland klättras det inte på hemadressen häller beroende på utseende och kvalitet på trappan.

Under 2017 utfördes 6 200 trappklätringsuppdrag från Skånetrafikens färdtjänst.

Det Finns affärer, vårdcentraler och andra publika ställen som saknar framkomlighet för en rullstolsburen där vi inte utför trapppklätringsuppdrag, så ett behov att på något annat sätt kunna ta sig upp för en trappa hade varit hjälpsamt.

Hade gjort störst nytta om produkten klarar av små korta trappor typ 2-5 trappsteg.

Scholtz, A: (rullstolsanvändare)
Om trappklättraren ska gå att ta med sig så måste den vara hyfsat lätt och antagligen hopfällbar. ”Larvfotstrappklättrare i USA är hysteriskt stora.”

De trappklättrare som inte är självstabiliserande är allt annat än lätta att jobba med, (enbart en chaufför i Lund som klarar av att använda dessa trappklättrare).

Scholtz säger att det spelar ingen roll om den är manuell eller eldriven egentligen men det kan vara svårt för handikappade med nedsatt handfunktion om den är manuell.

“Det finns trappor överallt - utomhus och inomhus. Om jag fick önska skulle jag vilja ha en portabel trappklättrare som tål lite väder och vind och som jag klarade av att hantera själv - vilken frihet det hade varit!”

Gripenhov, L: (rullstolsanvändare)
Behovet:
Enligt Gripenhov så finns det ett jättestort behov av en sådan här produkt, “det är trappor överallt”. “En del kan ta sig upp för trappor med hjälp av handkraft, jag kan inte det och det flesta kan inte det heller”. Om Gripenhov ska någonstans är hon ofta tveksam om det kommer fungera och kolla på Google-maps gatu-vy för att få klart för sig om området är tillgängligt eller inte innan hon åker dit.

“Att kunna klara sig själv skulle vara toppen”.

Hon har använt sig av existerande trappklättrare när hon bodde på 4e våningen utan hiss då använde hon en assisterad larvbands lösning.

När man är ute på stan kan man ibland stöta på problem, Gripenhov är inte rädd att fråga efter hjälp i såna fall, men det är Inte alltid det finns någon tillgängligt att fråga.

Utformning av produkten:
Det viktigast med produkten är att den är säker och står stadigt och stabilt (“superviktigt”), men den ska också vara enkel att använda även om man har dålig hand kapacitet, (“ska vara lätt att använda utan att behöva små komplicerade rörelser med händerna”). Det hade också varit fördelaktigt om den vore modulär och anpassningsbar för den specifika individens behov. “Ska inte ta våldsamt stor plats”.

Det är viktigare att produkten bidrar med en bra balans än att vikten är så låg som möjligt, “jag kan lyfta en kasse med 6 kg, så för att själv kunna hantera produkten så skulle 6 kg kunna vara lagom, kan kanske lyfta mer men helst inte.”

Lite extra elhjälp hade inte varit så dumt (beroende på behoven som man har).
“Extra hjälp i sega backar hade varit kanon, vissa vill inte ha det för dem vill klara allting själv. Men vanliga användare har inget emot att få lite el hjälp ibland”

Utrustningen får helst inte sticka ut framför stolen för annars kan det bli svårt att komma fram till saker, men att den sticker ut bakom stolen är inte så farligt. Ett problem som kan ske om det går för mycket back är när man ska upp för en trottoarkant så lyfter man upp framhjulen och då kan de som sticker ut där bak ta i marken.

Man vill helst inte ha något som sticker ut på sidorna, “ont om plats som det är redan på sidorna om stolen”. Många dörrar är ganska trånga.

“Jag vill ha ansiktet i nedåt riktningen för att det känns tryggare och (som en säkerhetsåtgärd ifall något händer.)”

Det är inte bara trappor som är problemet utan det finns också trottoarer som här så höga så att dem inte går att ta sig uppför.

Hur vill man operera produkten:
Man vill helst ha lite kontroll av klättringsoperationen så att den inte bara helt autonomt klättrar i trappor.

(snabb recap)
Ska vara lätt att sätta på, stabil, välbalanserad, lätt att använda, batterier är tungt, försök hålla den vikten nere. (Kan använda lägesenergi när man åker nedför en trappa för att ladda upp batterierna igen.)

Karmaeus, T: (rullstolsanvändare)
Karmaeus säger att han själv inte har så stora problem med trappor i sin vardag (iallafall inte vad han tänker på) och kanske inte kommer ha så stor nytta av en sådan produkt. Men om han skulle börja använda denna produkt så måste den vara enkel att använda själv (både montering och användande). Den för inte heller förhindra det vanliga användandet av stolen (förlusten får inte vara större än vinsten).

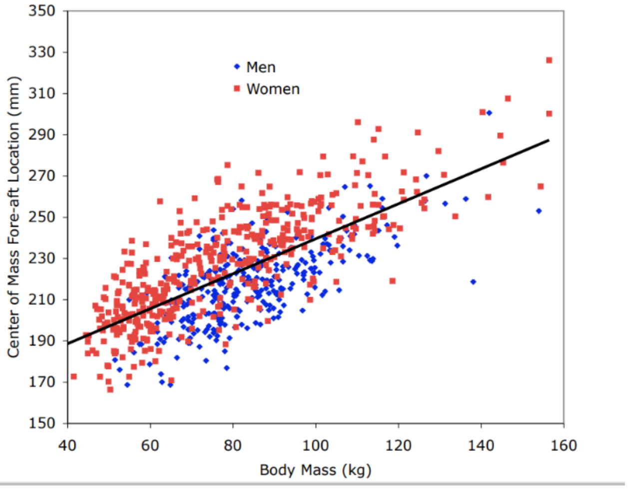
Appendix C Data values for detailed design and development

Here is the information about the data values for detailed design and development

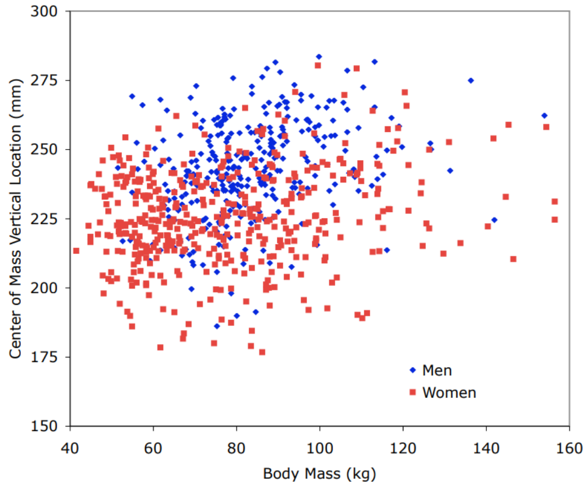
C.1 Data values

C.1.1 Normal distribution of CG

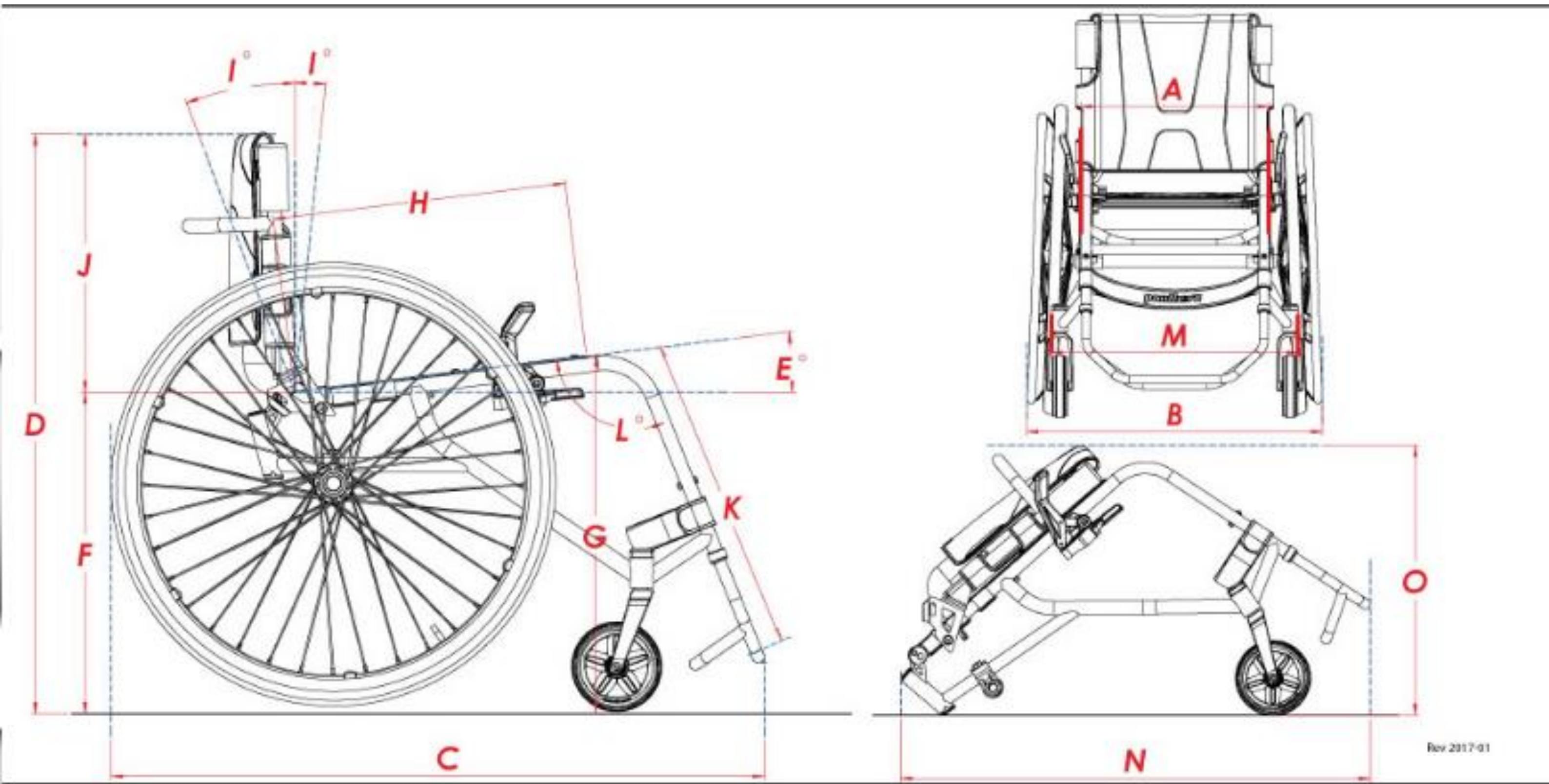
Normal distribution of CG for sitting people in the horizontal plane, in reference to the seat back.



Normal distribution of CG sitting people in the vertical plane, in reference to the seat.



C.1.2 Wheelchair data



	Modellkod	G548	G548	G548	G548	G548	G548
A	Sitsbredd cm	33	36	39	42	45	50
B	Total bredd	54	57	60	63	66	71
C	Total längd cm	78-90	78-90	78-90	78-90	78-90	78-90
D	Total höjd cm	64-84	64-84	64-84	64-84	64-84	64-84
E	Sits vinkel grader	7°	7°	7°	7°	7°	7°
F	Sits höjd bak cm	43	43	43	43	43	43
G	Sits höjd fram cm	47	47	47	47	47	47
H	Sits djup cm	40	40	40	40	40	40
I	Ryggvinkel bakåt - framåt	17,3°- (-5°)	17,3°- (-5°)	17,3°- (-5°)	17,3°- (-5°)	17,3°- (-5°)	17,3°- (-5°)
J	Rygghöjd cm	20 - 45	20 - 45	20 - 45	20 - 45	20 - 45	20 - 45
K	Benstödslängd i cm för benstödets olika lägen						
	Fotbåge standard	36,38,40,42,44	36,38,40,42,44	36,38,40,42,44	36,38,40,42,44	36,38,40,42,44	36,38,40,42,44
	Fotbåge förlängd	38,40,42,44,46	38,40,42,44,46	38,40,42,44,46	38,40,42,44,46	38,40,42,44,46	38,40,42,44,46
	Fällbara fotplattor	38,40,42,44,46	38,40,42,44,46	38,40,42,44,46	38,40,42,44,46	38,40,42,44,46	38,40,42,44,46
	Fällbara fotplattor förlängd	40,42,44,46,48	40,42,44,46,48	40,42,44,46,48	40,42,44,46,48	40,42,44,46,48	40,42,44,46,48
L	Benstödsvinkel grader	105°	105°	105°	105°	105°	105°
M	Bredd cm	46	49	52	55	58	63
N	Längd cm	78	78	78	78	78	78
O	Höjd cm	50	50	50	50	50	50
	Vikter						
	Total (g)	8200	8280	8360	8440	8690	8785
	Transport (g)	4650	4730	4810	4900	5130	5220
	Brukarvikt (kg)	100	100	100	100	150	150

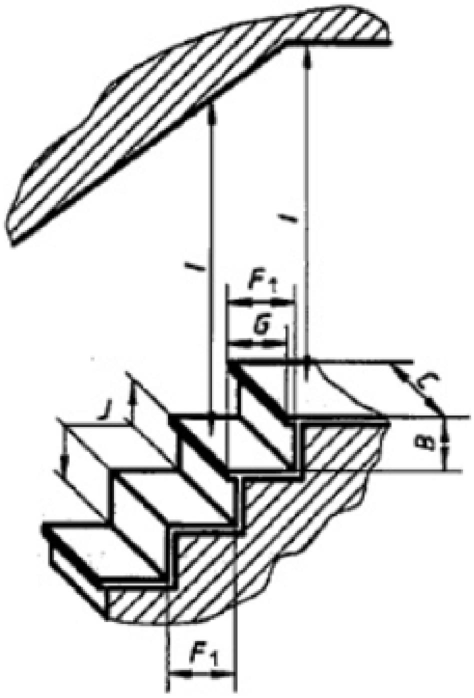
C.1.3 Stair data

Table 1 — Dimensions of steps, ladders and stairways

			Dimensions in millimetres
Symbol	**Description**	**Dimension**	
		min.	**max.**
A	Height of first step above ground or platform	—	600
B	Riser height		
	Rung ladders	230	400
	Steps (stepped ladders, stairs, etc.)	180	250
C	Step width		
	Ladders		
	for one foot	160	—
	for both feet	320	—
	Stairway	320	—
D	Rung tread — diameter or width	19	40
E	Instep clearance	150	—
F_1	Tread depth		
	Steps (stepped ladders, stairways, etc.)	240[1)]	400
F^2	Toe clearance (free space behind rungs)	150	—
G	Stride distance[2)]	130	270
H	Distance from top rung of ladder to platform level	—	150
I	Head clearance above step leading to walkway	2 000	—
J	Step placement (stair) (2B + G)	630	
R	Step placement from ladder	—	300

1) See 9.3; can be reduced to 130 when free space for toe clearance is provided.

2) The formula given for *J* shall always be satisfied.



Stairway