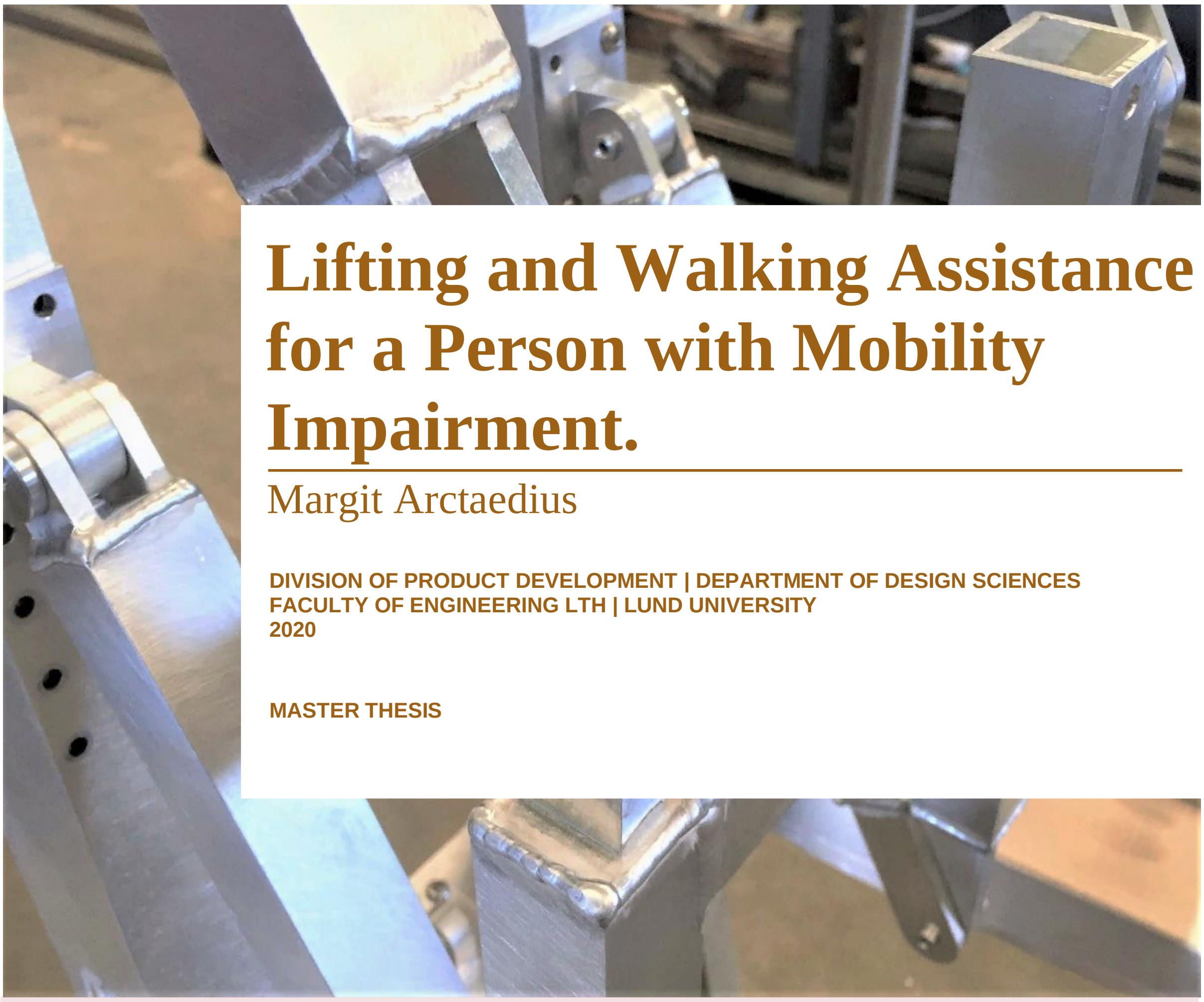

# Lifting and Walking Assistance for a Person with Mobility Impairment.

Margit Arctaedius

DIVISION OF PRODUCT DEVELOPMENT | DEPARTMENT OF DESIGN SCIENCES
FACULTY OF ENGINEERING LTH | LUND UNIVERSITY
2020

MASTER THESIS

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*Published by*
Department of Design Sciences
Faculty of Engineering LTH, Lund University
P.O. Box 118, SE-221 00 Lund, Sweden

Subject: Technical Design (MMKM10)
Division: Division of Product Development, Department of Design Sciences, Faculty of Engineering LTH, Lund University
Supervisor: Damien Motte
Examiner: Per Kristav

# Abstract

There exist many different designs of lifting aids and walking aids, but barely any solutions that can do both. This thesis is based on a person with mobility impairment with specific needs for which there were yet no adapted solution.

The goal was to design a product that can lift the user from sitting to standing position and then be a walking aid by supporting the user by the armpits, all this without needing the help from another person. The purpose is to enhance the user life quality, by being able to stand and walk independently, together with reducing the work load for assistants and family.

The design development process included establishing target specifications through user interviews and tests, concept generation and then evaluation of the concepts. Calculations were performed to dimension the structure and to meet the target specifications, and a CAD model and drawings were created. The designed parts were sent for manufacture and ordered to be assembled into a finished product.

The result is a complete operative product that the user will have within one year from the start of this thesis. The product will lift the user to standing position, where the structure locks, and the user can walk with the product supporting the user by the armpits. The solution uses a linear actuator together with a unique linkage lift design that generates the perfect lift velocity and distance. It is safe to use and includes an operational hand control, practical support tubes, phone case, and is designed to be stable and easy maneuverable.

**Keywords:** Product development, Walking aid, Lifting aid, Linkage lift, Manufacturing, Technical design.

# Sammanfattning

Det finns många olika utformningar av lyfthjälpmedel och hjälpmedel för att gå, så som patient lyftar och rullatorer, men det finns inte många lösningar som kan göra båda. Detta examensarete är baserat på en person med fysisk funktionsnedsättning som har specifika behov för vilka det inte fanns någon anpassad lösning.

Målet var att utveckla en produkt som kan lyfta användaren från sittandes till stående position och sedan fungera som ett gånghjälpmedel genom att stödja användaren vid armhålorna,. Syftet är att förbättra användarnas livskvalitet, genom att kunna stå och gå utan att behöva någon hjälp från andra, och också att minska arbetsbelastningen för assistenter och familj.

Designutvecklingsprocessen inkluderade att fastställa målspecifikationer genom användarintervjuer och test, konceptgenerering och efter det utvärdering av koncepten. Beräkningar utfördes för att dimensionera strukturen och för att uppfylla målspecifikationerna, och en CAD-modell och konstruktionsritningar gjordes. De designade delarna skickades för tillverkning och en linjär aktuator beställdes för att slutligen monteras ihop till en färdig produkt.

Den slutgiltiga designen lyfter användaren till stående position, där strukturen sedan låses och stödjer användaren så att hon kan gå. Lösningen är designad med en unik lyftkonstruktion som genererar en perfekt lyfthastigheten och lyftsträcka. Lösningen är säker att använda och inkluderar en handkontroll, praktiska stödhandtag, mobilhållare och är utformad för att vara stabil och lättmanövrerbar. Resultatet är en färdig produkt som användaren kommer att ha hos sig inom ett år från början av detta exjobbet.

**Nyckelord:** Produktutveckling, Rullator, Lyfthjälpmedel, Lyftkonstruktion, Tillverkning, Teknisk design.

# Acknowledgments

Firstly, I would like to thank my supervisor Dominique Harribey for helping and guiding me all the way through this project. The final result would not have been possible without his ideas, knowledge and motivation.

I also want to thank Véronique Roig for pushing and making this project possible, to Clement Nadal and Per-Erik Andersson for their technical expertise and to Damien Motte for the guidance and help with this report.

Lastly, I want to give a big thanks to the person in focus and her family for being so open and welcoming during the interviews and for letting us carry out the user tests without any hesitation. Without all their great input the result would not have been the same.

This project has been both exciting and challenging and I'm very grateful for the opportunity to carry out this project.

Toulouse, June 2020

Margit Arctaedius

# Table of contents

# Introduction

*This chapter presents the master thesis by explaining the problem description, the project goals and the project delimitations.*

## 1.1 Problem description

This master thesis is supported and conducted by the engineering school ENSEEIHT from INPT University in Toulouse, France, who received a request from a person with a mobility impairment with and a specific need, for which there were no existing solution.

The person, which this master thesis is based on, can walk with the help of a personalized walker, which supports her by the armpits. The problem is that she cannot position herself onto the walker. She needs the help of two or three persons to lift her up and from a sitting to a standing position and to position her right on the walker. This results in several problems; there needs to be minimum two assistants with her when normally there is only one, the assistants needs to be strong enough to lift her and hold her, and it can cause injuries to both the assistants and to the person with disabilities since there is no safety or help during the lift.

The problem and user's initial situation is further explained in chapter 3.2.

## 1.2 Project goal

The overall goal of this project is to develop a solution for a person with mobility impairments (hereafter called the user) that enables the possibility for her to stand up and walk around her house. The aims are to give the user the pleasure of standing and being able to walk on her own, to give the user independence, and a way for the user to build and maintain muscles. Further, an aim is to reduce the workload for assistants and family.

It differs from already existing solutions both since it is a specific and individual case but also since the goal is that the solution will be autonomous. Meaning that the user can stand up and walk only with the help of this thesis final product and without the need of help from another person.

One contribution will be to persons with similar impairments, but the main contribution will be to the development and innovation of health lifting systems. Other companies can gain knowledge from this thesis and apply the given concept when developing new products. This could potentially lead to more companies developing and improving their lifting systems. A goal and hope is that the solution is both very user friendly and cost effective, which would mean that it can contribute to a higher living standard for future users.

## 1.3 Delimitations

The first and biggest delimitation is that it was decided that within one year from the start of the project the user should have a fully functioning product in her home. This created many sub-limitations which had a great importance during the product development. All parts of the product had to be either made in the laboratory (for example with 3D-printer) or they had to be available for purchase in the region. It had to be ensured that the manufacturing parts that could not be done in the laboratory could be done by companies in the region. The one-year limit made it necessary to prioritize what was most important in the project which meant that some aspects could not get as much time to be done and refined as in an ideal situation. This thesis is the starting point of the project and includes product development activities but not the final steps, such as final realization and user adjustments after manufacturing. Finally, another important limitation was to stay on the project budget; 8000 euro funded by the university which should include all material, prototype and manufacturing costs.

# 2 Methodology

*This chapter presents the thesis design process and the outline of the thesis.*

## 2.1 Approach and Design Process

The thesis started by following the product development process presented by Ulrich & Eppinger in the book Product Design and Development (2012). But it was quickly realized that this process didn't fit perfectly to this thesis problem and therefore the process was modified with an own approach to solve the problem. This own approach includes first the concept development phase, which is where many ideas are explored and concepts are generated and evaluated into one final concept. Then it includes the detail design phase, which is where the complete specification of the geometry, materials and drawings of all parts are defined. It results in a complete description of all parts of the product, which is complete and ready for manufacture.

The first step in the concept development phase was to identify the user needs, which was done by interviews with the person, her father and her assistants. A few user tests were performed to specify some of the target specifications.

Before the concept generation, external research was done. It was divided in three categories. The first one was benchmarking of similar health care solutions that already exist on the market, the second one was research of what similar ongoing projects exists and the third one was a research of lifts and what lift solutions exist. The last one was done to broaden the knowledge about lifts and also to take a step away from health care products to be innovative and find new possible solutions.

The found information was then used, together with searching internally, for generating concepts, as suggested by Ulrich & Eppinger's method (2012). Ten concepts were generated and these where evaluated towards the target specifications. This was found to be difficult since the technical specifications are very precise and technical and needed further study and calculations. Therefore, four finalist were chosen for further investigation.

In the first concept generation and evaluation step, the concepts were designed as a whole. In the subsequent concept generation and evaluation step, the original problem was divided into subproblems where each subsolution from the prior concepts was further developed. The best solutions to each subproblem were then selected. This was possible since the subproblems were relatively independent from each other and could therefore be evaluated separately. This method was chosen both since it was too complex and time-consuming to compare the concepts as a whole and also to be able to combine the best subsolutions from the different concepts.

When the final concept was developed, a second user test was carried out. This was to get the user's opinion and comments on whether something should be changed or added before starting the detail design phase.

In the detail design phase, the complete specifications of the solution were designed, such as deciding dimensions, materials, the linear actuator, etc. This was done by calculations, FEM analysis, talking to experts, and research. The initial plan was to create and use prototypes for testing these factors, but due to COVID-19 it was not possible and the other methods had to suffice. This step was made in several iterations since many choices was depending on others (for example; if one part was changed due to the FEM analysis, the dimensions of other parts had to be changed).

After this the design development was finished and the manufacturing, assembly and product testing were the only things left for having the final product ready to use.

## 2.2 Outline of Thesis

The steps explained above follows the same order in this thesis.

- Chapter 1 – Introduction
- Chapter 2 – Methodology
- Chapter 3 – Identify User Needs and Technical Specifications
- Chapter 4 – External Research
- Chapter 5 – Internal Concept Generation and Evaluation
- Chapter 6 – Further Concept Development
- Chapter 7 – Detail design
- Chapter 8 – Result, Final Design
- Chapter 9 – Discussion

# 3 Identify User Needs and Technical Specifications

*This chapter starts with explaining the user's initial situation in detail. Then it presents the user needs and technical specifications that were identified by interviews, a home visit and user tests.*

## 3.1 Method

Two user interviews were made, the first over skype to understand the bigger picture and the second one was a visit in the user's home to fully understand every detail of the situation and the user's needs. In the home visit both the user, her father and her physiotherapist were there to answer the questions. Chapters 3.2 and 3.3 are a summary of the information collected during the two interviews and user test. The full interview questions and answers can be found in Appendix B.1 and the user test in Appendix B.2.

Since it is a technical project not much time was spent on analyzing and prioritizing the user needs. Instead the user needs, together with the information from the tests and measured dimensions were directly translated into technical specifications.

## 3.2 Initial situation/Starting point

### 3.2.1 **Overview of the user's initial situation**

The user has mobility impairments since birth which reduces the mobility in her back, legs, arms and hands. But it doesn't stop her from having a full-time job and living on her own. Inside her home she moves around by pushing an office chair with her feet, see Figure 3.1, and on the outside she uses a traditional wheelchair. For smaller movements and actions she uses her mouth and head.

The user has assistants who come one at a time a few times a day to help her with the things she can’t do alone, like cooking, going to the bathroom, getting dressed etc.

The user owns a personalized walker with which she can walk with. It supports her by the armpits and when on it she can move around by pushing herself forward with her feet. This walker is shown to the right in Figure 3.1 and also in Figure 3.2. The user doesn’t have enough strength and movement in her legs so she can’t stand up on her own and therefore she can’t position herself onto the walker. She needs lifting help of two or even three persons, hence her situation is far from optimal.

**Figure 3.1 The user’s office chair on the left and the users personalized walker on the right.**

**Figure 3.2 The personalized walker.**

### 3.2.2 User impairments

The user has little mobility in her legs and cannot support herself on them but she has no problem with moving her feet. She can lean her upper body forward and backwards approximately 30 degrees without problem but she can’t lean at all to the sides. The user’s arms are bent and she has no mobility in the lower arms and hands. She can lift her left shoulder approximately 90 degrees and the right shoulder approximately 45 degrees.

### 3.2.3 Using the existing walker

In relation to using the walker, her full weight is supported by her armpits and she can press her arms inward towards her body to hold herself up. When on it she has no problems with keeping her balance. She moves and steers by pushing with her feet on the ground in the wanted direction. She can move in all directions and she can stop on her own. To get on it she needs two persons to lift her up by the armpits (one person for each armpit) and for them to position her on the middle of walker’s armrests. While she is being positioned on the walker there needs to be someone or something to block it so that it doesn’t move around. The size and dimensions of the existing walker are good according to both the user and her physiotherapist. Figure 3.3 and Figure 3.4 illustrates the use of the existing walker from a side and front view.

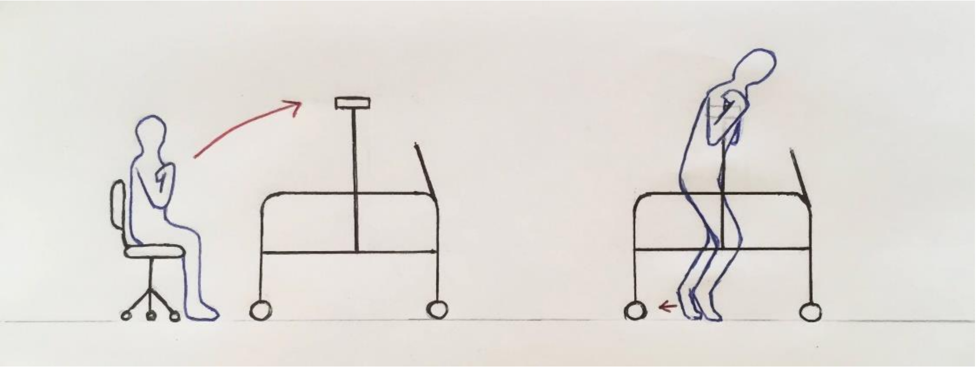


**Figure 3.3 Side view of using the existing walker, from sitting position to standing and walking position.**

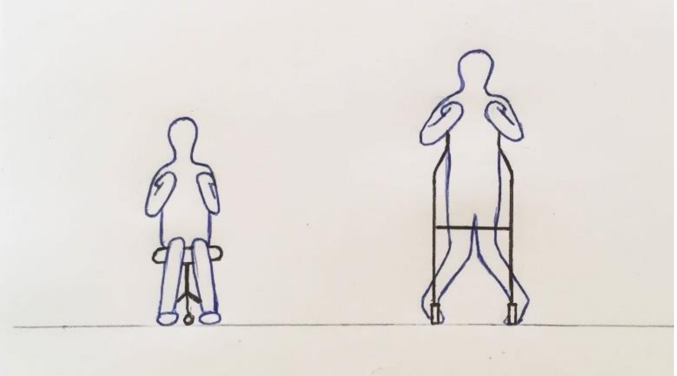


**Figure 3.4 Front view of using the existing walker, from sitting position to standing and walking position.**

## 3.3 Identification of the user needs

### 3.3.1 Purpose and usage of a new developed product

The main purpose for using the walker is to be able to walk small distances inside her house to be more independent and for the pleasure and feeling of being able to walk and stand up alone. For example it could be to walk from the living room to the bedroom or the bathroom. She wants to use it a couple times a day and approximately around 5 min each time. The other application is to help the user build and maintain muscles by walking and keeping a standing position. Further, an aim is to reduce the work load for assistants and family.

### 3.3.2 User needs

The user has a few specific wishes and needs for a new solution:

- She clearly states that she wants the solution to be adapted for both her chair and the toilet. Since currently, getting positioned to the toilet is a complicated task, and it would ease the work of her assistants.
- She would like the armrests to be more bent in a curve than how they are on her exiting walker, for further comfort and security reasons. Together with the user and physiotherapist a curve of min 15 degree was estimated.
- She does not want a security belt or other things holding her because she needs and wants to move freely.
- She states that it would be good with a handle for the assistant to be able to help her move the walker if necessary.

### 3.3.3 Security needs

The physiotherapist answered some questions regarding the ergonomic and security aspects with creating a new product. She said that it would not be a problem to lift the user either vertically or diagonally. She also stated that the user has good enough mobility that she would not need additional support or security while lifting and holding her. Since the existing walker is rather simple and works for the user she says that it doesn't need to be more complicated to lift her automatically. But she also states that it probably always would need to be anyone there with her while she is using it if there should be an emergency situation, no matter how secure our solution is made.

### 3.3.4 List of the needs

Table 3.1 below shows a list of the user needs. The formalism of functional analysis is used to express the needs in primary and secondary needs. This was done to understand and separate between the set demands and the user wishes.

**Table 3.1 Identified user needs.**

| *Identified user needs* | |
|---|---|
| **Get from sitting position to standing position and reverse** | **Main function** |
| Lift the user at a suitable velocity that won't hurt her | primary |

| | |
|---|---|
| The walker is fixed/blocked when the user is lifted up to it | primary |
| Flexible lifting system that can work both with the user's chair and the toilet | primary |
| Supports user's full weight (with a safety factor x2) | primary |
| To turn it on by herself (using mouth) | secondary |
| **Be able to push it alone in standing position** | **Main function** |
| Be light enough to be able to push it | primary |
| The dimensions fits user | primary |
| The walker is easy to move around the house | primary |
| There is enough space for the user to push it with her feet | primary |
| There is enough space for the user to move her upper body while pushing | primary |
| Can support the user while walking | primary |
| Allow the user to move as freely as possible (prefers to avoid a security belt or harness) | primary |
| It is secure for the user to use | primary |
| Having bent armrests for comfortability and safety | primary |
| Having fixed armrests for easier movement | primary |
| Assistant can easily move and control the walker | secondary |
| Possibility to adjust the dimensions of the walker | secondary |

## 3.4 Establishment of the target specifications

### 3.4.1 **User tests**

Five user tests were made during the home visit.

#### *3.4.1.1 How heavy can the walker be?*

The existing walker is 12 kg. To find out the max weight a test was made by adding weights to the walker until the user found it too difficult to move around with. It was found that with 6 kg extra the user could move and use the walker without problems. The max total weight was set to 18 kg.

Note: a more optimized mass distribution as well as more suitable wheels could raise this limit.

*3.4.1.2 How long is the lifting time?*

A lift from the chair to the existing walker was filmed and timed to 6.35 s. After discussion with user, father and physiotherapist it was decided that the goal lifting time should be within 5-10 sec.

*3.4.1.3 How big can the walker be?*

The exiting walker, the chair, the doors inside the house and the toilet was measured. The doors had a width of 770 mm, see Figure 3.5 and Figure 3.6 for the walker's and toilet's dimensions.

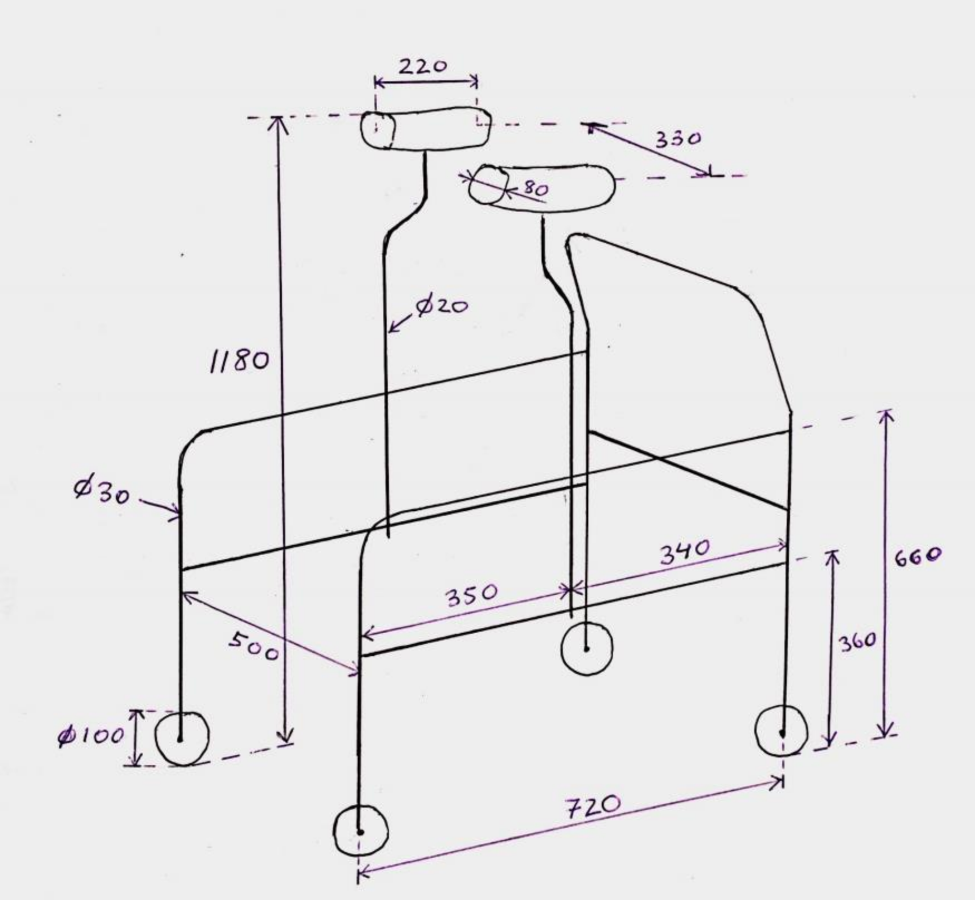


**Figure 3.5 Dimensions of the existing walker (mm).**

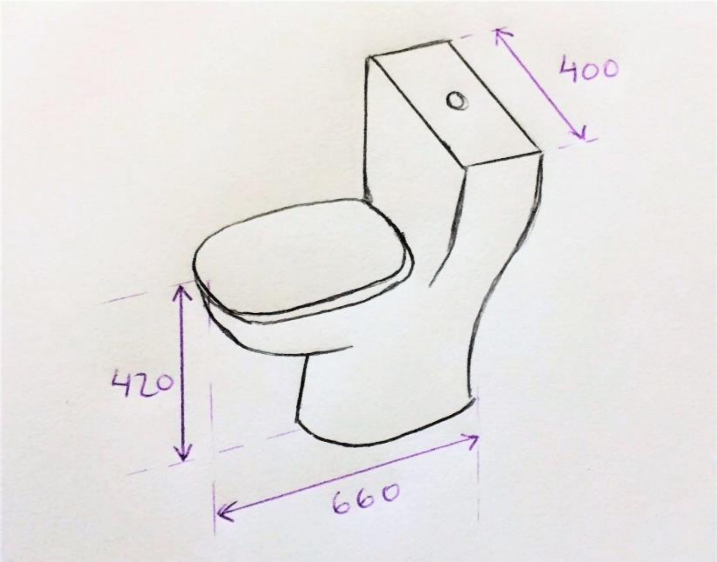


**Figure 3.6 Dimensions of the user's toilet (mm).**

#### *3.4.1.4 How much space is needed for her to move?*

During the visit it was noticed that the user needs more space for her feet than the width of the existing walker. A film was recorded when the user was walking to get the approximate dimensions needed for her to move freely. It was found that the width of the space needed for the feet is approximately 750 mm with a height of 360 mm. See Figure 3.7 for drawing. This is an estimated area and the user can adapt the movements for example when passing through a door frame.

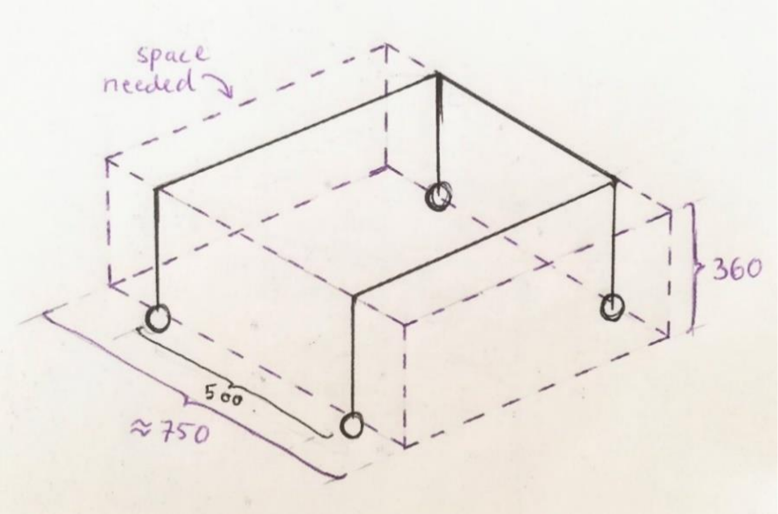


**Figure 3.7 Space needed for feet when walking (mm).**

#### *3.4.1.5 Should the armrests be movable or fixed?*

On the existing walker the armrests can turn 360 degrees horizontally and a test was made to see if this was needed or not. The armrests were taped until fixed and two films were recorded. One where the user walks with free moving armrests and one with fixed. The result was that the user said it felt easier with the fixed armrests and in the film with fixed armrests it looked like the movement was easier. Therefore, fixed armrests would be better.

### 3.4.2 **Target specifications**

After the interview and user tests the user needs were identified and established, see Table 3.2. Since almost all user needs were necessary requirements for a working solution, and therefore primary needs, no further analyze was made here and they were all directly transferred to technical specifications as shown to the right in Table 3.2. Some of the specifications shown had not yet been fully established but will be later on in the project.

ENSEEIHT also had specifications from their side. These were that the solution can be manufactured and ready for use within one year from the start of this master thesis, the project budget of 8000 euro and that the solution includes an electric motor. The last one since the laboratory where this thesis was conducted specializes on electrics motors.

**Table 3.2 Identified user needs and target specifications.**

| ***Identified user needs*** | ***Target specifications*** | *unit* | |
|---|---|---|---|
| **Get from sitting position to standing position and reverse** | Vertical lift distance ($B$) | mm | 400 |
| Lift the user at a suitable velocity that won’t hurt her | Lifting time ($t$) | sec | min 5, max 10 |
| The walker is fixed/blocked when the user is lifted up to it | Can be fixed/blocked | Yes/No | Yes |
| Flexible lifting system that can work both with the user’s chair and the toilet | Work with chair, toilet | Yes/No | Yes |
| Supports user's full weight (with a safety factor x2) | Possible lifting weight | kg | 50*2 |
| To turn it on by herself (using mouth) | Adapted for autonomous use | Yes/No | Yes |
| **Be able to push it alone in standing position** | | | |
| Be light enough to be able to push it | Weight | kg | max 18 |
| The dimensions fits user | Dimensions from existing walker and chair | mm | see Figure 3.5 |

|  |  |  |  |
|---|---|---|---|
| The walker is easy to move around the house | Dimensions of walker, suits user's home, suitable wheels | mm | see Figure 3.5 and Figure 3.6 |
| There is enough space for the user to push it with her feet | Design with space for feet | mm$^2$ | see Figure 3.7 |
| There is enough space for the user to move her upper body while pushing | Design with space for upper body to move | mm$^2$ | Will be established later on |
| Can support the user while walking | Stable system | Yes/No | Yes |
| Allow the user to move as freely as possible (prefers to avoid a security belt or harness) | Design for free movements | Yes/No | Yes |
| It is secure for the user to use | Can't tip over or fall | Yes/No | Yes |
|  | Foolproof with emergency design | Yes/No | Yes |
|  | Design with user protections | Yes/No | Yes |
| Having bent armrests for comfortability and safety | Bent armrests | deg. | min 15 |
| Having fixed armrests for easier movement | Fixed armrests | Yes/No | Yes |
| Assistant can easily move and control the walker | Handle for assistant | Yes/No | Yes |
| Possibility to adjust the dimensions of the walker | Design for adjustment | Yes/No | Yes |
| **University Specifications:** |  |  |  |
| Is possible to manufacture within one year | Complexity | Scale 1-5 | max 3 |
|  | Availability of parts and manufacturing | Yes/No | Yes |
| The funding | Respect budget | euro | 8000 |
| Includes electric motor | System with electric motor | Yes/No | Yes |

# 4 External Research

*This chapter shows what was found during the research and benchmarking, which later laid a base for the concept generation.*

An external research divided in three categories was done. The first one was benchmarking of similar health care solutions to see what solutions already exist on the market. The second category was research of what similar ongoing projects exists and to see what work has been done before. The last category was more general on different types of lift solutions and designs. This to broaden the knowledge about lifts and to see if a new innovative type of health lift could be designed.

## 4.1 Existing health care solutions

It already exists many different kinds of patient lifts, but most of them are made for persons with no mobility at all in their legs, see for example Figure 4.1 Patient lift "Maxi 500".Figure 4.1 and Figure 4.2.

**Figure 4.1 Patient lift "Maxi 500" (Arjo, 2020).**

**Figure 4.2 Patient lift from ceiling (Handi-Move, 2020).**

There are also a kind of product used for moving persons in a standing position as the ones shown in Figure 4.3 and Figure 4.4. For these products the user must have some strength in their legs (Spinlife, 2020).

**Figure 4.3 Electric stand assist lift (Spinlife, 2020).**

**Figure 4.4 Stand assist lift (Handi-move, 2020).**

Arjo has one product which is both a standing and raising aid which solves similar problems as the ones in this thesis (Figure 4.5). Howeve, Arjo’s walker does not support the user’s full weight and does not have any support by the armpits (Arjo, 2020).

**Figure 4.5 Arjo's Walker (Arjo, 2020).**

There are also recovery aids made for people who learns to walk again after an accident, like the one in Figure 4.6. This is good since it supports the user’s full weight and would work for the user to recover leg muscles but it is not flexible and won’t give the user the feeling of being independent and being able to walk around her house on her own.

**Figure 4.6 Walking recovery aid (Mulhern, 2016).**

Robotic exoskeletons is a new technology that helps paralyzed persons to walk using sensors and small motors (Figure 4.7). These solutions are very expensive and not on the market for everyone yet (Aviv, 2018). In this case it is not a suitable solution both since the user wants to avoid a security belt or harness to feel that she can move freely in her own motions, and also since the technology is too expensive.

**Figure 4.7 Robotic Exoskeleton (Aviv, 2018).**

There is a walker solution that helps the user getting from sitting position to standing position called Urise Stand Up Walker (Figure 4.8). It folds easily so that the user can push himself up from sitting position and then directly use it as a standard walker (1800Wheelchair, 2020). For this the user needs to have the strength to lift herself up to a standing position and therefor it can’t work for this thesis user.

**Figure 4.8 Urise Stand Up Walker (1800Wheelchair, 2020).**

A walker created for both walking and toilet use was found, see Figure 4.9.

**Figure 4.9 Rollator with toilet seat (1800Wheelchair, 2020).**

## 4.2 Similar projects

A few interesting projects and products in development was also found. The following products are not yet on the market but are, as in the case of this thesis, solutions to different situations and mobility impairments.

A better walker (Figure 4.10) is a project to improve the standard walker with the goal to decrease pain (Kickstarter, 2020). This is good inspiration for creating a walker for standing position as needed in this project. It just lacks a lifting from sitting to standing position solution.

**Figure 4.10 A Better Walker (Kickstarter, 2020).**

Automatic Walker is a social project developed at the Tulancingo Technological University has developed an automatic walker for children with walking disabilities, see Figure 4.11 (Universidad Tecnológica de Tulancingo, 2017). This too, is good inspiration for a standing position walker but would also need a lifting solution for it to work with the specifications of this thesis.

**Figure 4.11 Tulancingo Technological Universitys walker for children (Universidad Tecnológica de Tulancingo, 2017).**

At the *International Conference on Intelligent Robots and Systems* a robotic walker with focusing on combining both standing assistance and walking assistance was developed into a prototype, see Figure 4.12 and Figure 4.13 (Daisuke Chugo, 2009). This walker is the found solution that matches this thesis specifications the most. It presents a suitable working principle about how to lift the user from sitting position with three linear actuators; it and also has four wheels so that it also works as a walker. The only thing that would need to be adjusted is that the supports needs to support the user by her armpits instead of by her chest and elbows. This is unfortunately only a prototype and not much information about it can be found, but it will serve as good inspiration for the concept generation.

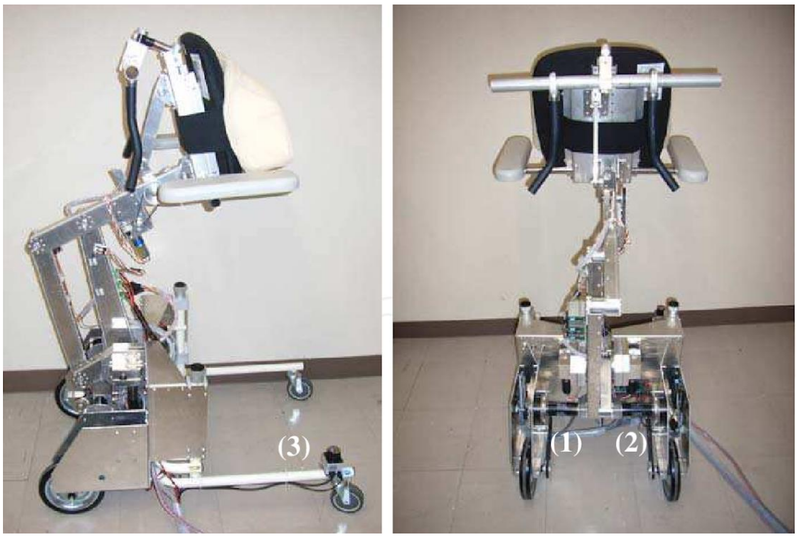


**Figure 4.12 Robotic walker prototype (Daisuke Chugo, 2009).**

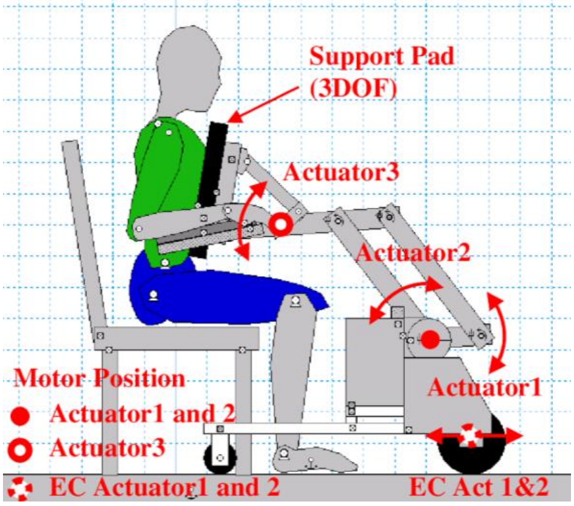


**Figure 4.13 Robotic walker explanation drawing (Daisuke Chugo, 2009).**

Figure 4.14 was found without explanations but serves as inspiration.

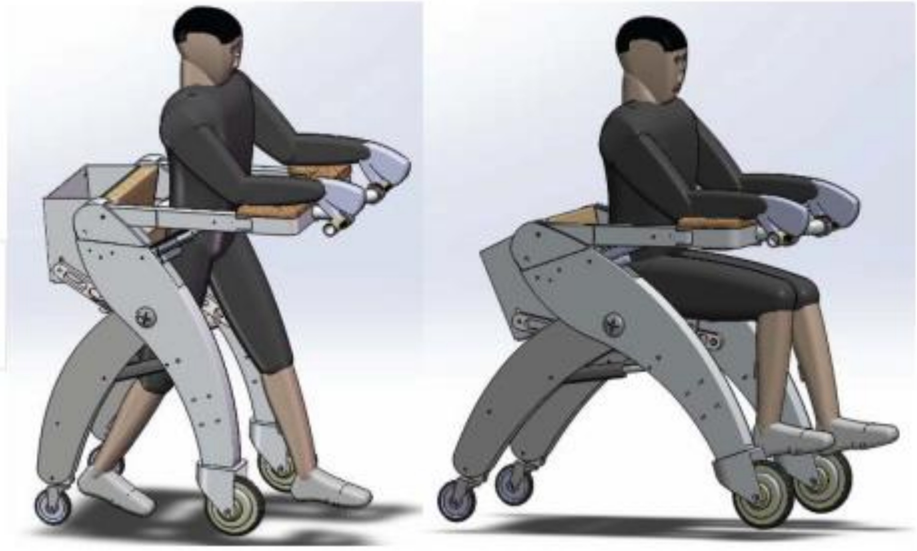


**Figure 4.14 Concept design of a rising and walking aid (Teamstudios, 2020).**

## 4.3 Lift solutions

There are many lift solutions not adapted for persons. A broad research was made to learn about different lifting techniques and designs.

There are three main types of lifts; pneumatic, hydraulic and mechanical lifts. Pneumatic lifts compresses air to create a lifting force while hydraulic lifts compresses a liquid instead. Both pneumatic and hydraulic lifts can produce very large forces but they are limited by their large actuator size. Mechanical lifts can either be hand operated or powered by an electrical motor. In the latter, the radial motion of the motor must be translated into linear motion, which is usually done with a linear actuator. The advantages of mechanical lifts are that they offer great control and accuracy. They are also quieter and more environmental friendly than pneumatic and hydraulic lifts. The disadvantage is that they are often the most expensive type of lift (Ronquillo, 2020).

To improve the lifts maneuverability there are different types lift designs. Articulating boom arm is a common design which allows a high degree of flexibility and for a large lift range, see Figure 4.15. (Ronquillo, 2020).

**Figure 4.15 Articulating boom arm lift (Liftexperten, 2020).**

Another common design is telescopic boom arm, which extends like a telescope, see Figure 4.16. These have a great extension range but there downside is that they cannot bend and they are not as flexible as other designs (Ronquillo, 2020).

**Figure 4.16 Telescopic boom arm lift (Ronquillo, 2020).**

Scissor lifts (Figure 4.17) can only lift vertically but they have very high capacities and can also have a bigger platform then most other lifts.

**Figure 4.17 Scissor lift, mechanical electric motor, max 300 kg (Transpalette Manuel, 2020).**

Forklifts are lift commonly used in warehouses and with pallet handling. They can both lift vertically and extend horizontally. They are often connected to a small truck like in Figure 4.18, but they don't have to be, see Figure 4.19.

**Figure 4.18 Forklift truck (E.I.C, 2020).**

**Figure 4.19 Genie Lift GL-4, mechanical with winch, max 227 kg (Genie Lift, 2020).**

Below (Figure 4.20- Figure 4.25) are images of other possible lifting solutions that were found during the research.

**Figure 4.20 TV lift, mechanical lift with electric motor, max 54 kg (Standsandmounts, 2020).**

Figure 4.21 Vehicle lift, hydro-pneumatic lift, max 2500kg (GYS, 2020).

Figure 4.22 Lift from above, hydraulic, max 3000 kg (Indiamart, 2020).

Figure 4.23 Example of rotating joint lift design (VEX Robotic Competition, 2020).

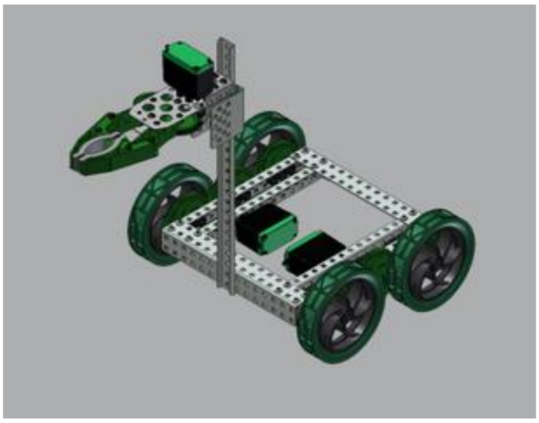


Figure 4.24 Example of elevator lift design (VEX Robotic Competition, 2020).

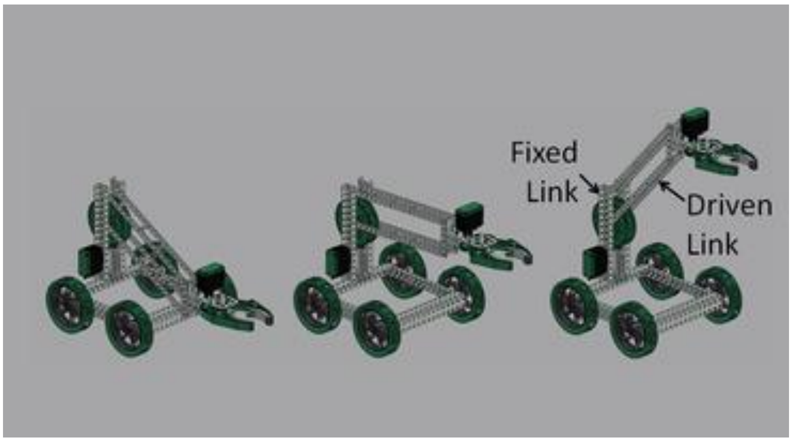


Figure 4.25 Example of linkage lift design (VEX Robotic Competition, 2020).

## 4.4 Conclusion after research

No product was found that would solve this thesis and user's problems. Several similar products and projects were found but they either focused on lifting the user from sitting to standing position, or on being a walking aid. This indicates that there is a gap in the market for a product that can do both. The fact that several projects in development was found also indicates that new solutions for all different types of mobility impairments are necessary and important.

Before the research it was already decided that an electric motor and therefore a mechanical lift should be used for this project. Research confirms that this would also be the best choice since a mechanical lift is smaller and thus lighter, it has the best accuracy and control, it is the quietest and most environmental friendly option and finally, since the max lifting weight acquired is only 100 kg, there is no need for the great force that hydraulic and pneumatic lifts offers.

# 5 Internal Concept Generation and Evaluation

*This chapter describes the concept generation process and illustrates and explains each generated concept. In the end of the chapter the concept evaluation is explained and four concepts are chosen for further development.*

## 5.1 Method

The concept generation was done by using Ulrich and Eppinger’s method. Their method is to generate ideas both by searching internally and externally and then combine the two into concepts. Searching internally refers to brainstorming and using your own creativity and searching externally refers to doing research and benchmarking (Ulrich & Eppinger, 2012). External search has been reported in the precedent chapter. By using this method the concepts in 5.2 were generated and then evaluated individually regarding to the set technical specifications. The first concept evaluation was done by evaluating the concepts against the more general specifications and then the remaining concepts were further developed in next chapter.

## 5.2 Concept generation

### 5.2.1 **Concept A, Articulating boom arm lift**

Concept A was inspired by the articulating boom arm lift. It is meant to be a fixed lift which can lift the user from her chair to the existing walker, as shown in Figure 5.1.

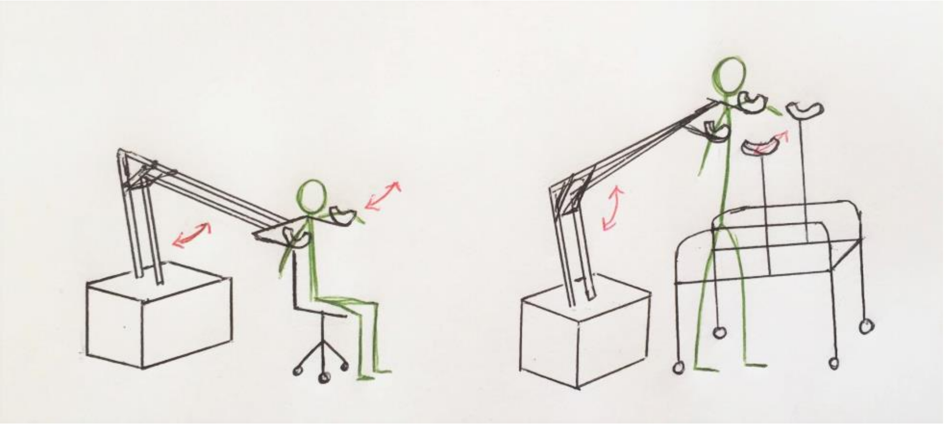


Figure 5.1 Concept A, Articulating boom arm lift.

### 5.2.2 Concept B, Fixed motor with coupling solution

The thought behind concept B (Figure 5.2) was to have a fix station with the motor to avoid having the motor on the walker. From the fixed station a customized walker can be coupled and through that the armrests can be raised. When they have been raised to the highest position, the walker can easily be decoupled and the user can walk with the walker. To sit again the user must return to the fixed station so the armrests can be lowered.

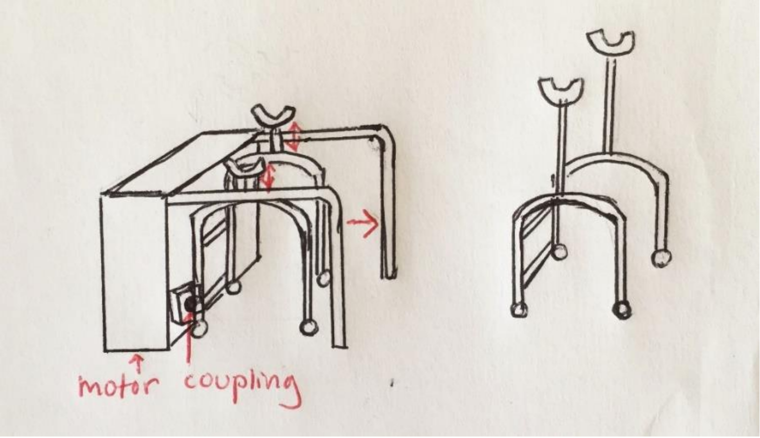


Figure 5.2 Concept B, Fixed motor with coupling solution.

### 5.2.3 Concept C, Fixed lift from above

Concept C was inspired both by Arjo’s patient lift “Maxi 500” (Figure 4.1) and the lift from above (Figure 4.22). It is meant to be able to raise the user from above by using straps that are placed around the user's armpits. It can move horizontally to position the user from her chair to the existing walker as shown in (Figure 5.3).

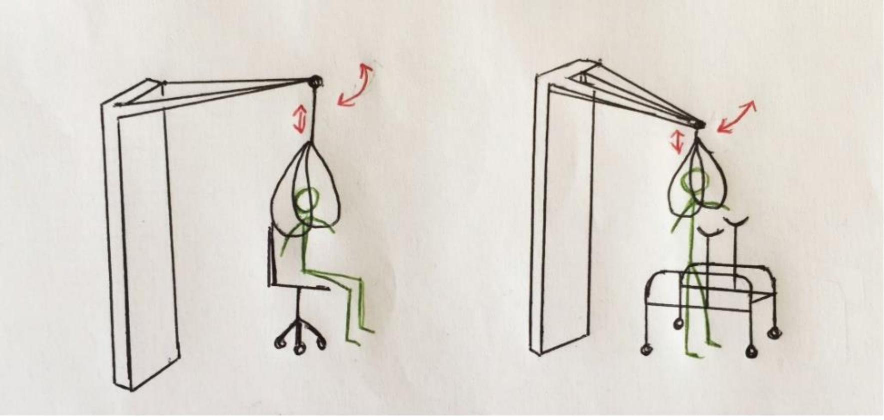


**Figure 5.3 Concept C, Fixed lift from above.**

### 5.2.4 Concept D, Movable lift from above

Concept D (Figure 5.4) is similar to concept C but the difference is that there is no fixed station. Here the motor is placed on the walker and it lifts the user from above. After the user has been lifted she can just continue to walk and there is no need for her existing walker. Another difference is that the part that are being raised must be solid in this concept to increase stability.

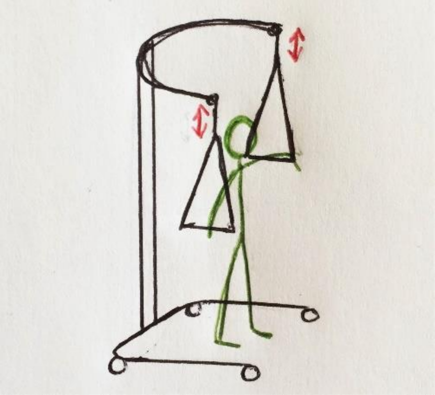


**Figure 5.4 Concept D, Movable lift from above.**

### 5.2.5 Concept E, Telescopic boom arm lift

This concept uses a telescopic boom arm and is also supposed to be movable with the motor included (Figure 5.5). It can lift the user from sitting to standing position and then when user has been lifted she can just continue to walk.

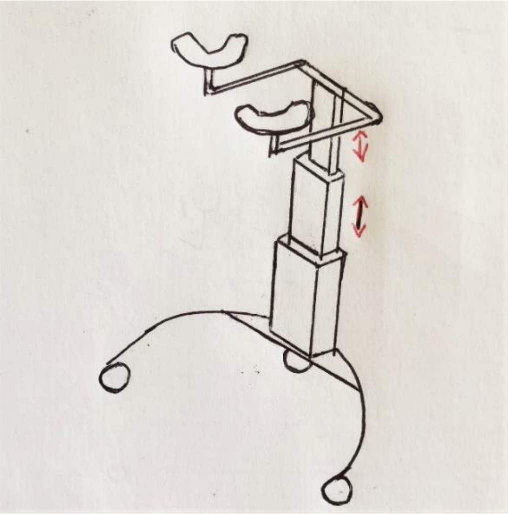


**Figure 5.5 Concept E, Telescopic boom arm lift.**

### 5.2.6 Concept F, Vertical lift with circular lower part

Concept F is inspired by the GL-4 forklift (Figure 4.19) and the TV lift (Figure 4.20). It is movable and includes a linear actuator which creates a vertical lifting movement as shown in Figure 5.6.

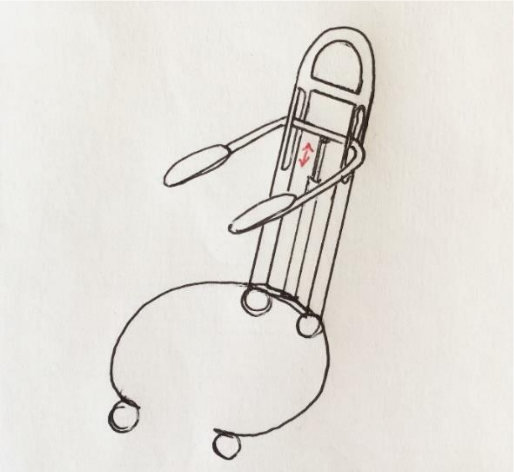


Figure 5.6 Concept F, Vertical lift with circular lower part.

### 5.2.7 Concept G, Vertical lift with surrounding frame

Concept G are divided in two versions which both are very similar to concept F regarding the lift design. The difference lies in the design of the frame which here will surround the user in two possible variations as shown in Figure 5.7.

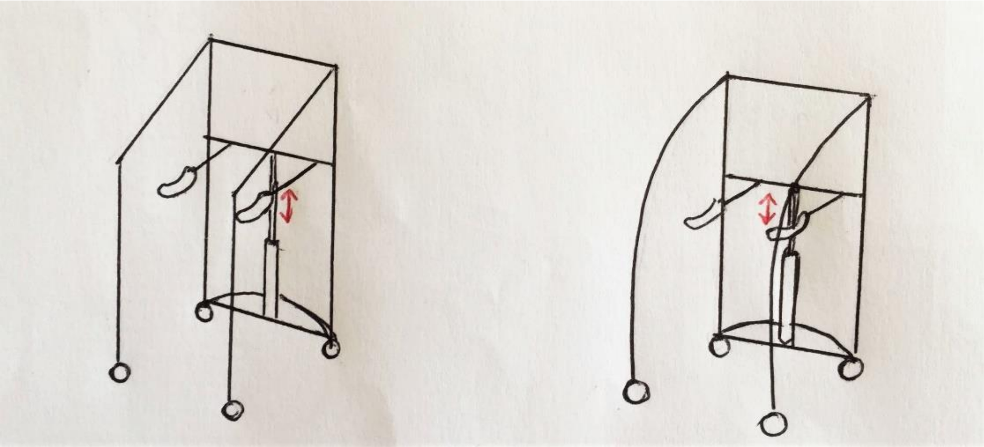


Figure 5.7 Concept G, Vertical lift with surrounding frame.

### 5.2.8 Concept H, Lift with parallelogram

Concept H is using a linkage lift design, the same as used in both the robotic walker (Figure 4.12 and Figure 4.25) and the articulation boom arm. Here it is designed as a parallelogram so that the left side with the armrests always stays parallel to the frame, see Figure 5.8. Here too, a linear actuator is used.

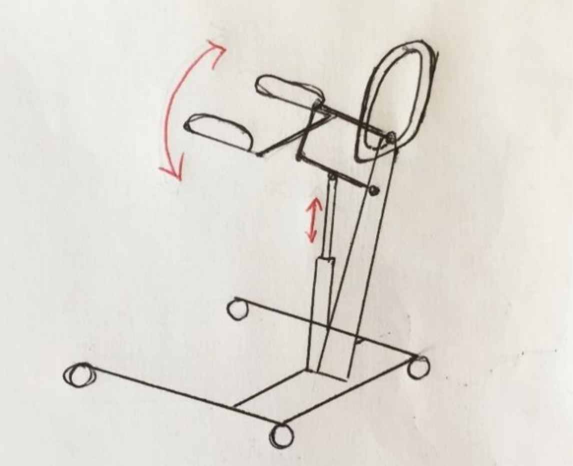


**Figure 5.8 Concept H, Lift with parallelogram**

### 5.2.9 Concept I, Double linkage lift

Concept I is somewhat similar to concept H, the difference is the structure of the frame which here is double and longer vertically, but it still uses a linkage lift design and a linear actuator. Also the bottom part has a rounder shape. See Figure 5.9.

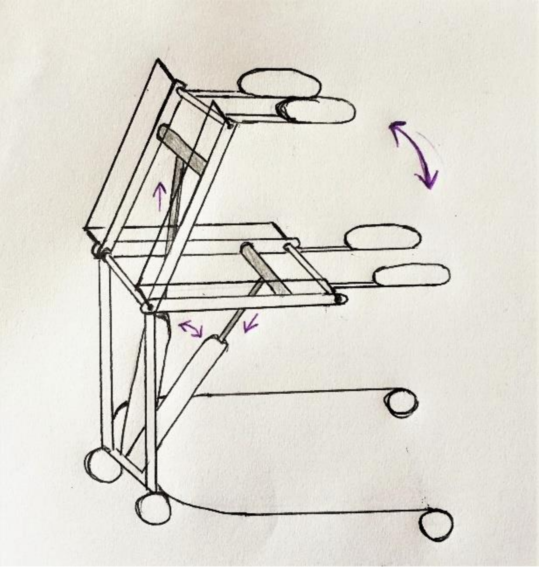


**Figure 5.9 Concept I, Double linkage lift.**

### 5.2.10 **Concept J, Scissor lift**

The last concept is inspired by the scissor lift. It is also movable and can both work as a lift from sitting to standing position and as a walker when in the highest position, see Figure 5.10.

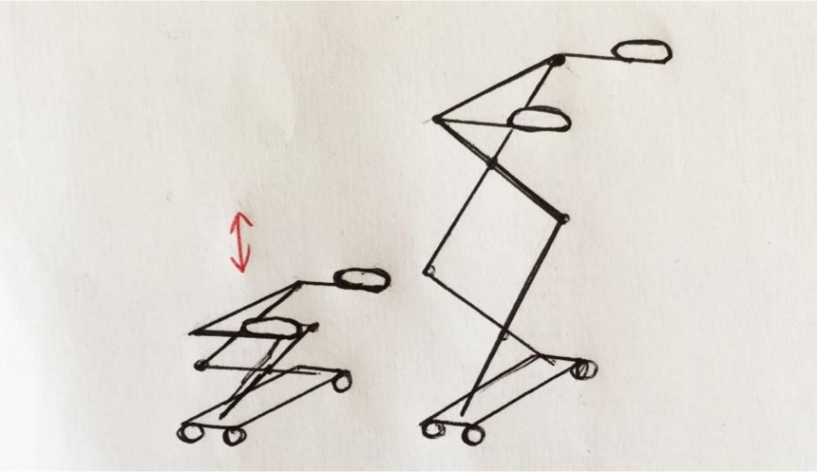


**Figure 5.10 Concept J, Scissor lift.**

## 5.3 Concept evaluations

The concepts were then evaluated with regard to the technical specifications in Table 3.2. The first decision was to discard concepts with a fixed base with a motor (i.e. Concepts A, B & C), since one specification was a flexible system which can work both with her chair and toilet. It would create unnecessary complexity to make several fixed stations and it would greatly decrease the flexibility of the solution. Concept D, the movable lift from above, was discarded since there was doubts if it could be made stable enough.

Since several of the technical specifications are very precise and technical (as the lifting time, max total weight, lifting weight etc.) it was hard to evaluate the concepts based on these criteria (since no calculations had been done yet). Therefore the following evaluation was mainly based on the complexity specification. The simpler the solution, the better. This also goes hand in hand with the respect budget-specification. With this in mind, Concept E, the telescopic boom arm lift and Concept J, the scissor lift were discarded.

After this, four concepts were left (Figure 5.11), where Concepts F and G are very similar in the lift construction design and Concepts H and I both use a linkage lift design. From here it was hard to do any further evaluating without doing more research and tests, therefore, it was decided to further develop and investigate all these four concepts to find the best possible solution. How this was done will be described in next chapter.

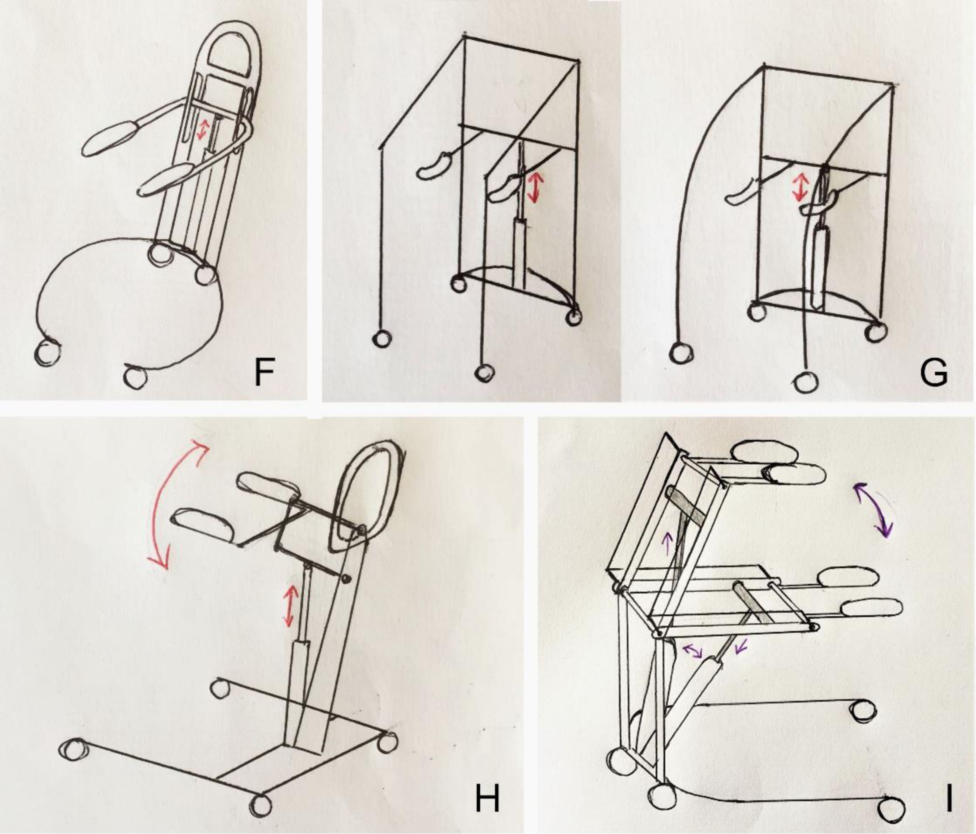


Figure 5.11 Chosen concepts to further develop.

# 6 Further Concept Development

*In this chapter the four chosen concepts were all divided into sub parts where each part was tested separately. When the best design for each sub part was identified, a final concept could be presented. This final concept was then shown to the user for a second user test.*

## 6.1 Problem decomposition

A problem decomposition was done to divide the whole concept into sub parts which will be explored individually. In this way the best individual parts can then be combined to optimize and create the best final concept possible.

The sub parts are:

1. Legs
2. Armrests
3. Linear actuator and motor
4. Mechanical solution (lift design)
5. Frame analysis (double or simple design)
6. Straight or leaning upright bar

### 6.1.1 **Legs**

The chosen concepts included five different leg shapes. To decide which shape to choose each shape was evaluated and the original shape from the existing walker was included. The limiting factor for the legs was the size; it needed to be small enough to fit through doors (770 mm) and to be flexible and easy to walk with. But it also needed to be big enough so that the user's chair can enter (a width of 580 mm) and for the user to be able to move her legs freely (Figure 3.7). With this, an estimation of the size needed for the different leg shape can be seen in Figure 6.1.

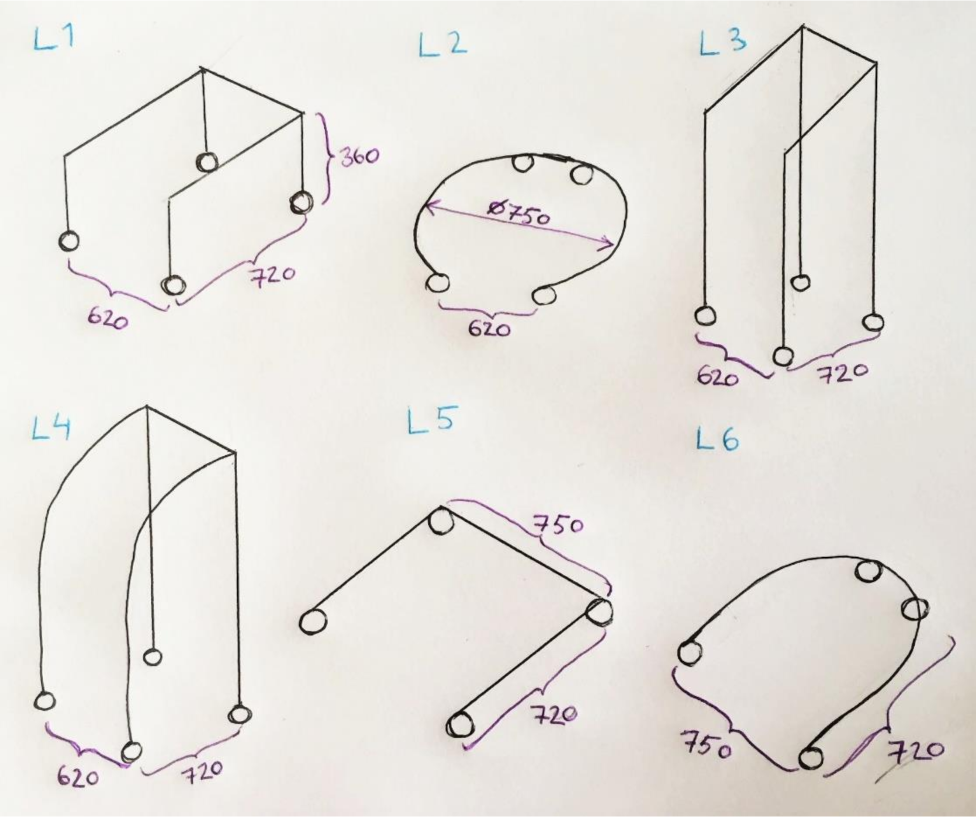


**Figure 6.1 Different leg shape possibilities (mm).**

After doing the drawings and estimation of the sizes for the different shapes the legs, L2, L5 and L6 were discarded due to their large width. L4 was discarded due to that it would be too complicated to manufacture. Lastly, L3 was discarded due to that it would need more material and therefore be heavier than L1. In addition, it was considered to be less esthetically pleasing.

So, L1 was chosen since it is the smallest version, it is simple to manufacture and it is ensured that it is stable and works in reality.

### 6.1.2 **Armrests**

For the armrests a few different shapes were investigated. All had bent armrests for comfortability and safety and fixed for easier movement, as the target specifications.

The other concern was the specification that the armrests that wouldn’t disturb the user while walking and that there is enough space for the user to move her upper body while pushing. Therefore A2 and A3 in Figure 6.2 were sketched, were there would be nothing for the users arms to bump into. But after showing these three alternatives for the user, she didn't think A1 would disturb her.

In a construction view A1 was also the best alternative since it is the simpler version which means it will be easier to construct, it needs less material which implies less weight and costs, and it also has the shortest way for the force transmission, which leads to the least possible deformation (Sundström, 2004).

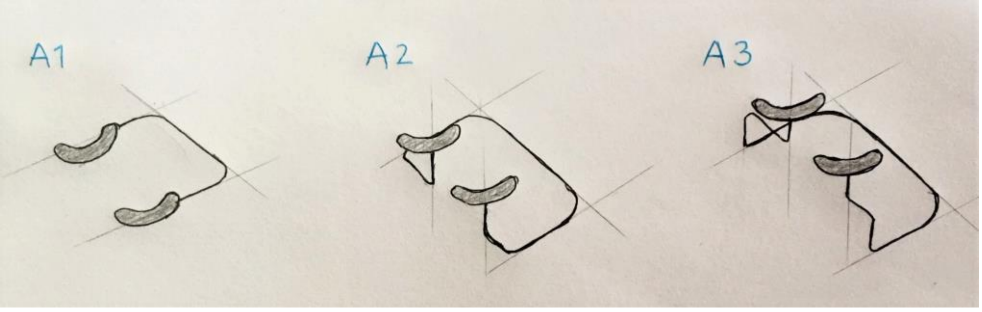


**Figure 6.2 Armrest design possibilities.**

### 6.1.3 Linear Actuator and motor

Since all chosen concepts includes a linear actuator, an initial research was done to see what options were available and to make sure that it could be a possible solution. By researching what actuators exists it was found that there are linear actuators in all different sizes, from actuators that can take up to 65 kN and weights 45 kg, see Figure 6.3 (Cetic, 2020), to small ones like the one in Figure 6.4, that can take max 450 N and weighs only 2 kg (CDR devices, 2020). It was found that the bigger and heavier actuator, the more load could be applied. It was also found that the velocity decreased with bigger possible loads.

**Figure 6.3 Example of a bigger linear actuator, max load 65 kN (Cetic, 2020).**

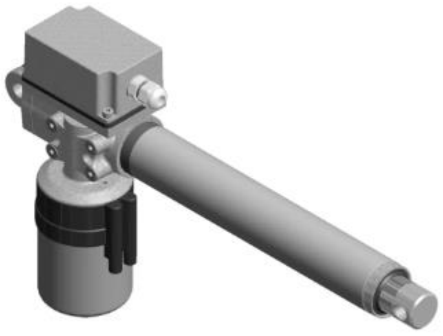


**Figure 6.4 Example of a smaller linear actuator, max load 450 N (CDR devices, 2020).**

After the research it was decided to buy a linear actuator with including electric motor to save time, reduce the complicity and since it was found that were actuators for prices that the budget would allow.

The max load, stroke length and mass did not seem to be an issue; the range in these aspects were large. The limiting aspect was the velocity. The lifting velocity specification was min 5 s and max 10 s and since the lifting distance was 400 mm, a min velocity of 40 mm/s would be needed, see Equation (6.1).

$$\boldsymbol{v} = \frac{\mathbf{400\ mm}}{\mathbf{10\ s}} = \mathbf{40}\ \mathrm{mm/}\mathbf{s} \tag{6.1}$$

The min load needed was set to 1000 N, see Equation (6.2).

$$\boldsymbol{F_{user}} = \boldsymbol{m_{user}} * \boldsymbol{g} * \boldsymbol{safety\ factor} = \mathbf{50}\ \mathrm{kg} * \mathbf{9.82}\ \mathrm{m}/\boldsymbol{s}^{\mathbf{2}} * \mathbf{2} = \mathbf{982}\ \mathrm{N}\ \approx \mathbf{1000}\ \mathrm{N} \tag{6.2}$$

No actuator with a min load of 1000 N was found with a velocity of 40 mm/s. Therefore a mechanical solution, like a linkage lift design would be needed to increase the velocity.

After this research it was also decided that a battery wouldn’t be needed since it would add on too much extra weight and since the usage is only for inside the house it was assumed that a AC wall plug would always be available nearby. So, for the lift and lowering actions the motor would be connected with a power cord to a wall plug by the assistant. This does affect the flexibility of the system, but it was decided to be less important than the target specification of the systems possible max weight. In a possible future second edition or upgrade of the system, this would be one of the first thing to investigate for improvements. However, for this thesis project a battery solution was discarded.

In conclusion, linear actuators exist in a wide range and can be bought for a reasonable price, and would therefore be a good choice. A direct vertical lift with the actuator, like an elevator lift design (Figure 4.24) and Concepts F and G, will not be possible since the actuator velocity would be to slow, but this can be resolved with a mechanical solution. This was therefore further explored as a next step.

### 6.1.4 **Mechanical solution (lift design)**

To increase the lifting velocity either a rotating joint lift design or a linkage lift design (Figure 4.23-Figure 4.25) can be applied, as found in the preliminary research. Why the rotation joint lift design isn't applied in any of the concepts is since it wouldn't keep the armrests horizontal as in the linkage lift design used in Concept H and I. They are designed as parallelograms are therefore the armrests will always stay parallel to the floor (i.e. horizontal). The difference is shown in Figure 6.5. Consequently, a linkage lift design formed as a parallelogram was found to be the best solution for this project.

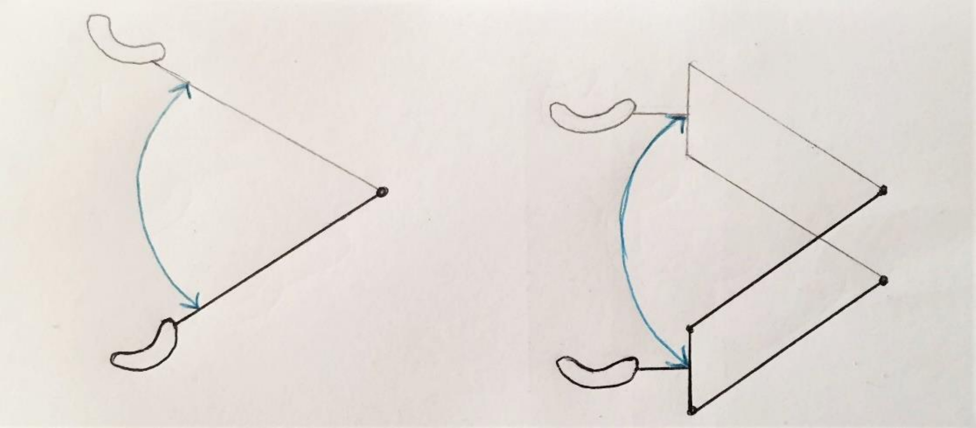


**Figure 6.5 Difference between a rotating joint lift (to the left) and a linkage lift design (to the right).**

### 6.1.5 **Frame analysis (double or single design)**

At this point one wanted to find out if it was necessary to have a double design like in Concept I or if it would suffice having a simple design as in Concept H. The design in concept H is clearly a simpler design, which is better in many aspects but there was a concern that the structure would be too fragile and unstable.

Therefore a frame analysis in Autodesk's Inventor was performed. Inventor's frame analysis is used to understand the structural integrity of a given frame regarding deformations and stresses, when subjected to various loading and constraints. It is a structural static analysis where the structure is simplified into linear beam elements. It was chosen as method since it is a simplified study and the goal here was to simply compare the two design options.

The two different versions were created as beams only, with the same dimensions and aluminum tube. The only difference was, as shown in Figure 6.6, that one version has a double linkage design.

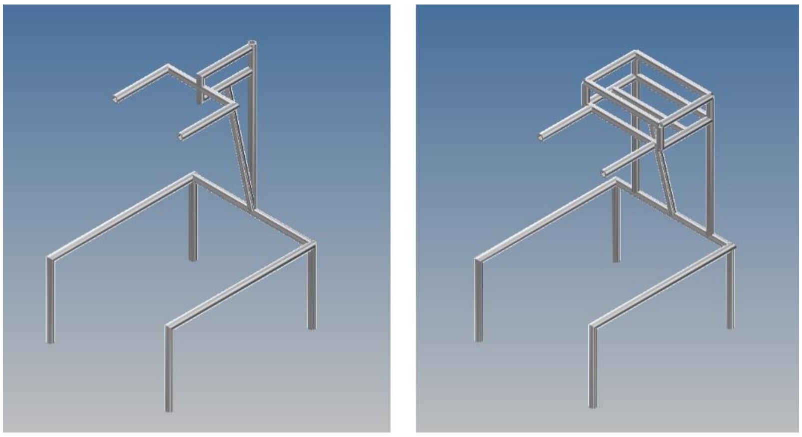


**Figure 6.6 Single linkage design to the left and double linkage design to the right.**

Nodes were set to connect each beam to each other and fixed constraints were set at each foot. The load of 1000 N was divided to each armrests where the user's weight would apply and the simulation was performed.

Deformation, $S_{max}$ and mass were the three parameters used to compare the designs. The deformation parameter shows how much the beam will deform under the force of 1000N. $S_{max}$ is the maximal von Mises stress that will occur in the beams. The von Mises criteria calculates the stress of a material that is under load, and if this stress is bigger than the materials yield strength, the material will yield (Continuum Mechanics, 2020). The mass depends on the density of the chosen aluminum tube.

### *6.1.5.1 Results of frame analysis*

The results are shown in Table 6.1, Figure 6.7 and Figure 6.8. It is important to keep in mind that these are not accurate values and can only be analyzed in comparison with each other (since the dimensions had not yet been decided).

**Table 6.1 Frame analysis results of single and double linkage design.**

| | **Single** | **Double** |
|---|---|---|
| **Max deformation (mm)** | 43 | 25 |
| **$S_{max}$ (MPa)** | 87 | 83 |
| **Mass (kg)** | 8,3 | 11.9 |

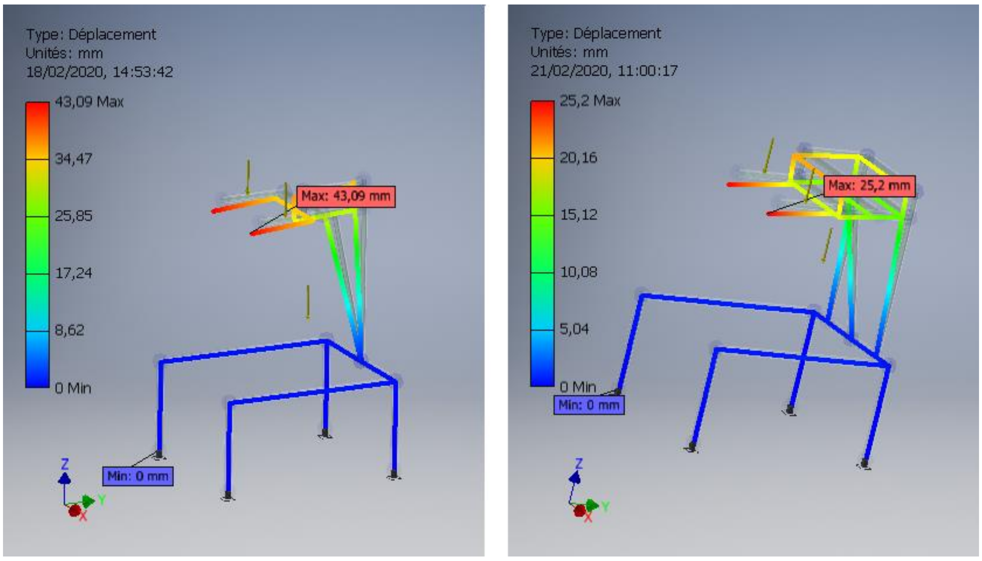


**Figure 6.7 Deformation results in the single (left) and double (right) linkage design.**

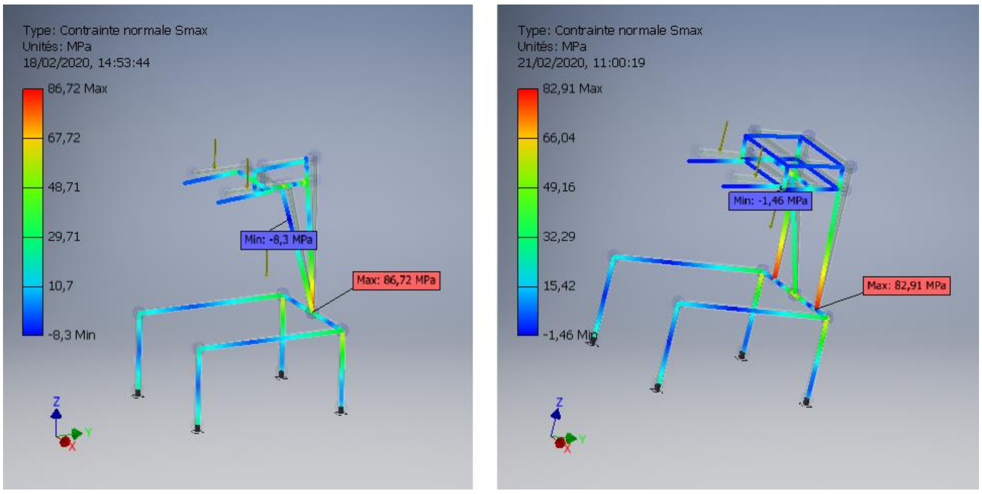


**Figure 6.8 Stress results in the single (left) and double (right) linkage design.**

In summary; the deformation decreases by almost half in the double design, the max stress barely changes and the mass increases with 50 % in the double design.

### *6.1.5.2 Evaluation of results*

The large increase of the mass, and the fact that the max stress barley changes concluded that the single design was the best choice. The big deformation was believed to be adjustable later on by changing the tube profile and dimension.

### 6.1.6 **Straight or leaning upright bar**

The last decision to make for the final concept was whether the upright bar should be straight or leaning. See the difference in Figure 6.9. In the drawing the parallelogram is assumed to have the same dimensions ($r_1$). L is the length from the base where the actuator is connected, to where the user is positioned (where the load $F$ is applied).

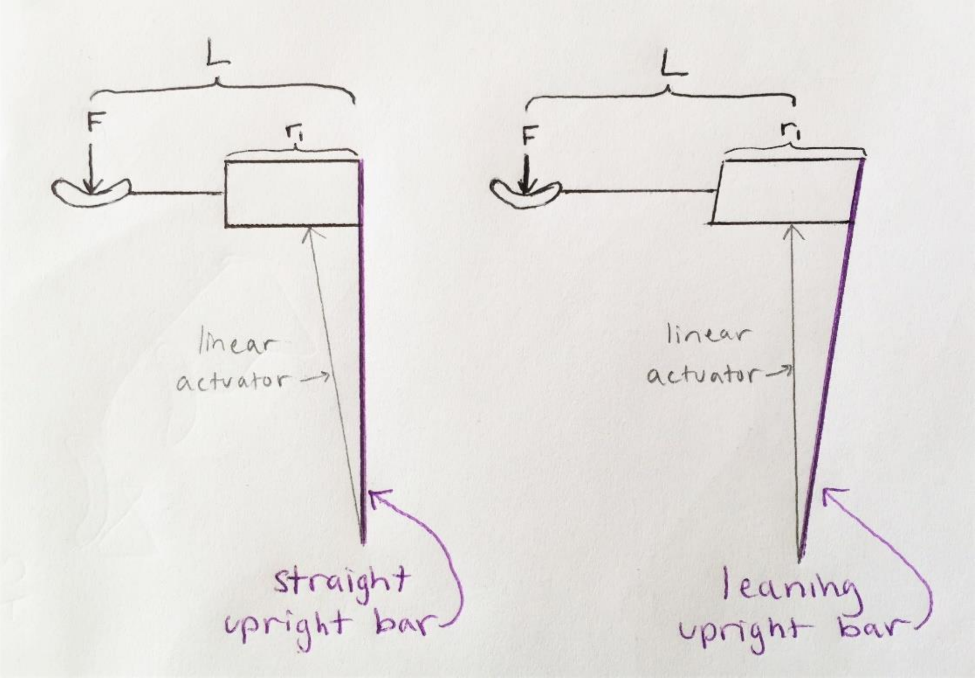


**Figure 6.9 Drawing of design with a straight upright bar (left) and a leaning upright bar (right).**

With the drawing it could be seen that with the leaning upright bar, the distance between the parallelogram and the user is bigger, which is preferable since it increases the free space for the user. When leaning, it also creates a counter balance to the load F, which will reduce stress in the beams. Furthermore, the system will be more stable since the center of gravity will be closer to the base point where the actuator is connected. The only disadvantage with the leaning bar is that the torque where the actuator connects to the parallelogram will be bigger than with the straight bar since the distance between this connection point and $F$ is bigger and $torque = force * distance$. Overall, the leaning upright bar has more advantages and was therefore chosen for the final concept.

## 6.2 Final concept

The final concept is a combination of the best solution principles found when investigating each sub problem. It consist of legs raised from the floor in a rectangular shape, a linear actuator including an electric motor, connected to a parallel shaped linkage lift which then raises and lowers the bent armrests.

The user will position herself inside the frame and with her armpits over the armrests. Then the motor will be turned on and linear actuator will push the linkage lift and the armrests upwards and lift the user to a standing position. In the right position the linear actuator will be locked and the user can start walking around whilst having the needed support from the walker. When the user wants to sit down again she either has to walk back to the chair or have an assistant position it inside the frame again, and the linear actuator will be lowered back to the starting position. See Figure 6.10.

**Figure 6.10 Final concept design. The starting position is shown on the left and the standing and walking position is shown on the right.**

## 6.3 Second user test

This final concept was shown and explained to the user and her father to get their valuable comments and opinions on it before starting with the detail design. Overall they liked the concept and were positive to it, they only had a few concerns and suggestions of changes which are presented in Table 6.2 below.

**Table 6.2 Concerns and suggestions form second user test.**

| | Concern | Suggestion |
|---|---|---|
| **Space for legs** | There isn't enough space for her legs when walking | Making the frame longer |
| **Flexibility** | Can it be lowered to different heights, such as to the toilet? | - |
| **Support for assistants** | There is no good way for the assistants to help steering or moving the walker | Adding handles on the sides |
| **Stability concern** | Is it going to be stable enough? | - |
| **Safety** | There is a possibility to be pinched in the linkage | Cover it in a safe fabric material |

It was considered that these concerns and suggestions did not require a significant change of the final concept and they were therefore addressed in the next step, the detail design.

# 7 Detail design

*In this chapter the details of the system are defined. Starting with explaining how the linear actuator was chosen and then with the calculations for deciding the dimensions in a way that they agrees with the target specifications. After, material choices, joint design, reinforcement design are explained, partly with the help of FEM analysis. Lastly, the final added parts and the structure drawings are presented.*

## 7.1 Choosing the linear actuator

### 7.1.1 **Criteria for the linear actuator**

The following criteria's were considered when choosing the linear actuator:

- The min load
- The mass
- The velocity
- The stroke length
- The price
- Availability; possible for the university to buy
- The power supply; 240 V AC
- Plus if integrated system

Some calculations and assumptions were made for each criteria.

#### *7.1.1.1 The min load*

As mentioned above, the min load for the actuator was set to 1000 N, see Equation (6.2).

#### *7.1.1.2 The mass*

Since the target specification of total product mass was set to 18 kg, the max mass criteria for the linear actuator was set to 5 kg. With this the frame and rest would still be able to weigh 12 kg, which is the same weight as the existing walker.

### *7.1.1.3 The velocity*

To understand how the velocity correlates in the parallel linkage, some calculations were performed. In Figure 7.1 the parallelogram is drawn and point U is where the armrests are going to be placed and therefore also the user, and point A is where the linear actuator is connected to the parallelogram.

The angular velocity is the linear velocity divided by the radius:

$$\boldsymbol{\omega} = \frac{\boldsymbol{v}}{\boldsymbol{r}} \tag{7.1}$$

The two horizontal bars have the same velocity ($v_u$) and the same radius ($r_1$) at point U, this gives

$$\boldsymbol{\omega_1} = \boldsymbol{\omega_2} \tag{7.2}$$

At point U Equation (7.1) gives

$$\boldsymbol{\omega_1} = \frac{\boldsymbol{v_u}}{\boldsymbol{r_1}} \tag{7.3}$$

And at point A Equation (7.1) gives

$$\boldsymbol{\omega_2} = \frac{\boldsymbol{v_a}}{\boldsymbol{r_2}} \tag{7.4}$$

Equation (7.2-7.4) gives

$$\frac{\boldsymbol{r_1}}{\boldsymbol{r_2}} = \frac{\boldsymbol{v_u}}{\boldsymbol{v_a}} \tag{7.5}$$

This means that the velocity depends on where on the parallelogram the linear actuator is connected; the greater the difference between $r_1$ and $r_2$ - the greater difference between $v_a$ and $v_u$.

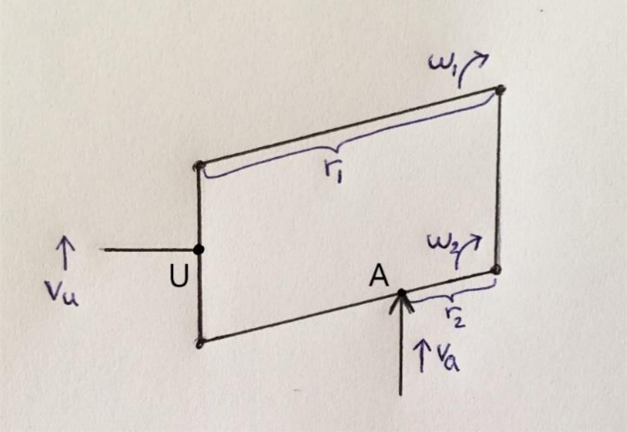


**Figure 7.1 Drawing of the velocities of the parallelogram.**

From the target specifications, the lifting velocity specification is min 5 s and max 10 s and the lifting distance is 400 mm. This means that the min user velocity is 40 mm/s and the max user velocity is 80 mm/s, see Equation (7.6).

$$\boldsymbol{v_u} = \frac{\mathbf{400}\ \text{mm}}{[\mathbf{5};\mathbf{10}]\ \text{s}} = [\mathbf{40}\ ;\mathbf{80}]\ \mathbf{mm}/\text{s} \tag{7.6}$$

The ratio ($R$) between were the linear actuator could be connected (point A) was assumed to be between 2 and 3. If too large ratio, the actuator will be too close to the upright bar and the needed torque will increase greatly, and if too small ratio, the advantages with the linkage will be insignificant (i.e. the increasing velocity and range).

$$\boldsymbol{R} = \frac{\boldsymbol{r_1}}{\boldsymbol{r_2}} = [\mathbf{2}\ ;\mathbf{3}] \tag{7.7}$$

This means that the min actuator velocity is 13.3 mm/s and the max actuator velocity is 40.0 mm/s:

$$\boldsymbol{v_a} = \frac{\boldsymbol{v_u r_1}}{\boldsymbol{r_2}} = \boldsymbol{v_u} * \frac{\mathbf{1}}{\boldsymbol{R}} = [\mathbf{13.3}\ ;\mathbf{40.0}]\ \mathbf{mm}/\text{s} \tag{7.8}$$

#### *7.1.1.4 The stroke length*

The stroke length is how long the linear actuator can extend. To understand what stroke length was needed some further calculations were performed. In Figure 7.2 only the lower part of the parallelogram is drawn and point A is where the linear actuator is connected to the parallelogram. The circular arc ($b$) is the actuators stroke length.

The vertical lifting distance ($B$) is 400 mm, but for having surplus and for having extra space under the armpits when in the lowest position, the vertical lifting distance was set to 500 mm. The possible movement angle ($\alpha$) was assumed to be 100 °. The bigger degree the better, since when the angle is the largest possible, the linkage design is fully utilized and more efficient.

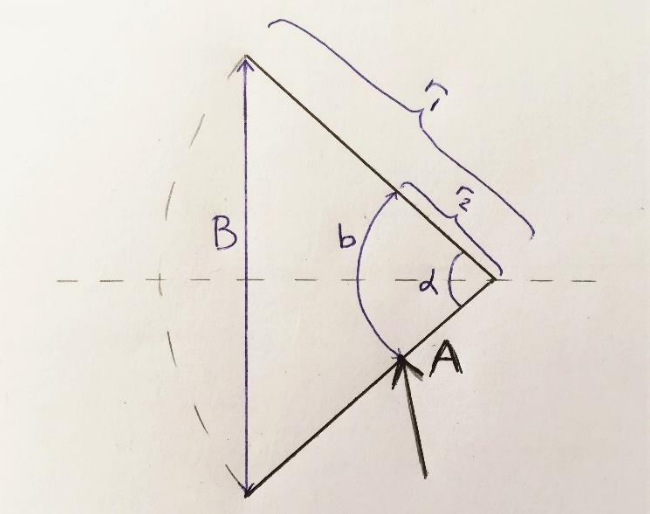


**Figure 7.2 Drawing of lower part of the parallelogram.**

From geometry Equation (7.9) and (7.10) are found:

$$\boldsymbol{B = 2 * r_1 * \sin\left(\frac{\alpha}{2}\right)} \tag{7.9}$$

$$\boldsymbol{b = \frac{\alpha}{360} * \pi * 2 * r_2} \tag{7.10}$$

These two equations with Equation (7.7) gives:

$$\boldsymbol{b = \frac{\pi*\alpha*B}{360*R*\sin\left(\frac{\alpha}{2}\right)} = \frac{\pi*100*500}{360*[2\ ;\ 3]*\sin\left(\frac{100}{2}\right)} = [189.8\,;284.8]\ \mathrm{mm}} \tag{7.11}$$

Which means that the min stroke length is 189.8 mm.

*7.1.1.5 The price*

The max price was set to 800 euro, which is 10 % in relation to the total budget.

### 7.1.2 The chosen linear actuator

A linear actuator was found that fulfilled all of the criteria. It is Ewellix's Matrix 7, shown in Figure 7.3. Its technical data is shown in Table 7.1 in correlation to the set criteria.

**Figure 7.3 Chosen linear actuator (Ewellix, 2020).**

**Table 7.1 How the chosen linear actuator correlates to the set criteria (Ewellix, 2020).**

| | Criteria | Ewellix Matrix 7 |
|---|---|---|
| **Load (N)** | > 1000 | 3000 |
| **Mass (kg)** | < 5 | 4.2 |
| **Velocity (mm/s)** | 13.3 – 40.0 | 13 – 18 |
| **Stroke length (mm)** | > 189.8 | 50 – 700 (250 was chosen) |
| **Price (€)** | < 800 | 490 |
| **Availability** | | yes |
| **Power supply** | 240 V AC | 240 V AC |
| **Integrated system** | | yes* |

* The Ewellix Matrix 7 has an alrealdy integrated system which means that you can choose which of their operational swithces to connect to the actator. The chosen one is a hand switch with one “up”-and one “down”-button, shown in Figure 7.4.

**Figure 7.4 Hand switch to operate the linear actuator (Ewellix, 2020).**

## 7.2 Dimensioning

This was one of the thesis biggest and complicated step. During the time of the thesis, many different embodiments arose that lead to that changes and modifications in the design were needed. The dimension and overall dimensions of the frame were made in several different iterations and if all those steps and changes would be presented, this thesis would be very long. Therefore, below is a list of the conditions that the design must meet and that arose from the different calculations, tests and second user interview. The calculations that led to the final dimensions and design are presented next.

- The actuator must be positioned in a way that the motor part is placed towards the outside of the frame. This since otherwise there is no space for the user’s knees when in sitting position. Figure 6.10 can help understand this issue.
- A double parallelogram and design must be used, due to both the previous point and to avoid sheer stresses and torque bending that can arise from the user’s movements.
- The actuator must be connected to the top part of the parallelogram due to the length of the actuator and the wanted height at the standing position.
- Regarding the armrests, the placement criteria’s (parallel to the floor and where the load is located) should be fulfilled in the top position, since when the user is walking is the critical situation.
- A manually added stop (a limit switch) for highest and lowest position is needed due to that it was not possible to dimension the frame in a way that the physical max and min stop of the actuator matches the target positions, due to the target dimension specifications.

### 7.2.1 **The legs and frame**

The tube dimension for the legs and frame were chosen to be 40x40 mm with a thickness of 3 mm to create a stable base. The tube to the left in Figure 7.5 has the dimensions 80x40 mm since the actuator and the upright bars are installed on it. The width was set to 700 mm so that the inside dimension is 620 mm to fit the chair. The height was set to the same as in the existing walker; 360 mm. The length needed to be longer than the existing one to make sure that the user's feet would have enough space when the linkage was applied.

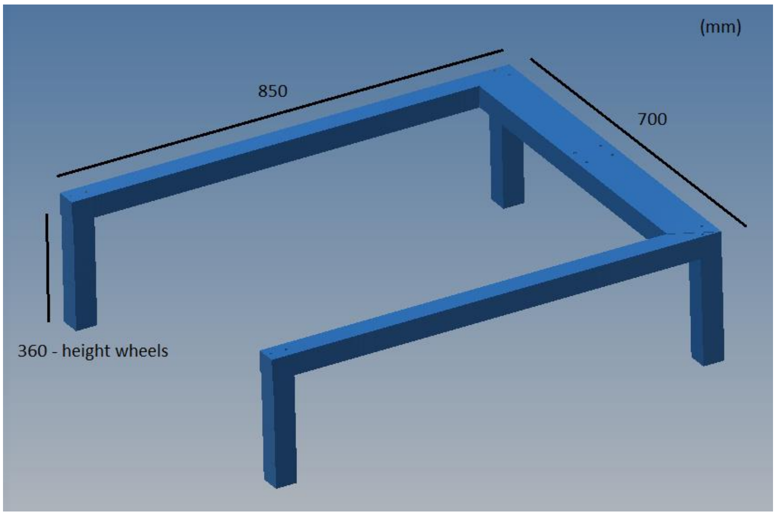


**Figure 7.5 Dimensions of the legs and frame.**

### 7.2.2 **The linkage**

There were three criteria that the dimensioning of the linkage was based on; the lift time (*t*), the vertical lift distance (*B*) and that the upright bar should be leaning with a certain angle ($\mu$), which all are dependent of the other. The limiting factors were that that the length of the parallelogram ($r_1$) and the possible movement angle ($\alpha$) could not be too large. Further, the distance at which the actuator is connected to the parallelogram ($r_2$) was also a depending factor. See Figure 7.6 for a sketch with the variables.

Therefore, equations for each criteria were set up in Matlab where tests were made by changing each variable separately to find the optimal values for the length and angle that matches all three criteria.

The equations are explained and presented in Appendix C.1.

The results are presented in Table 7.2 below.

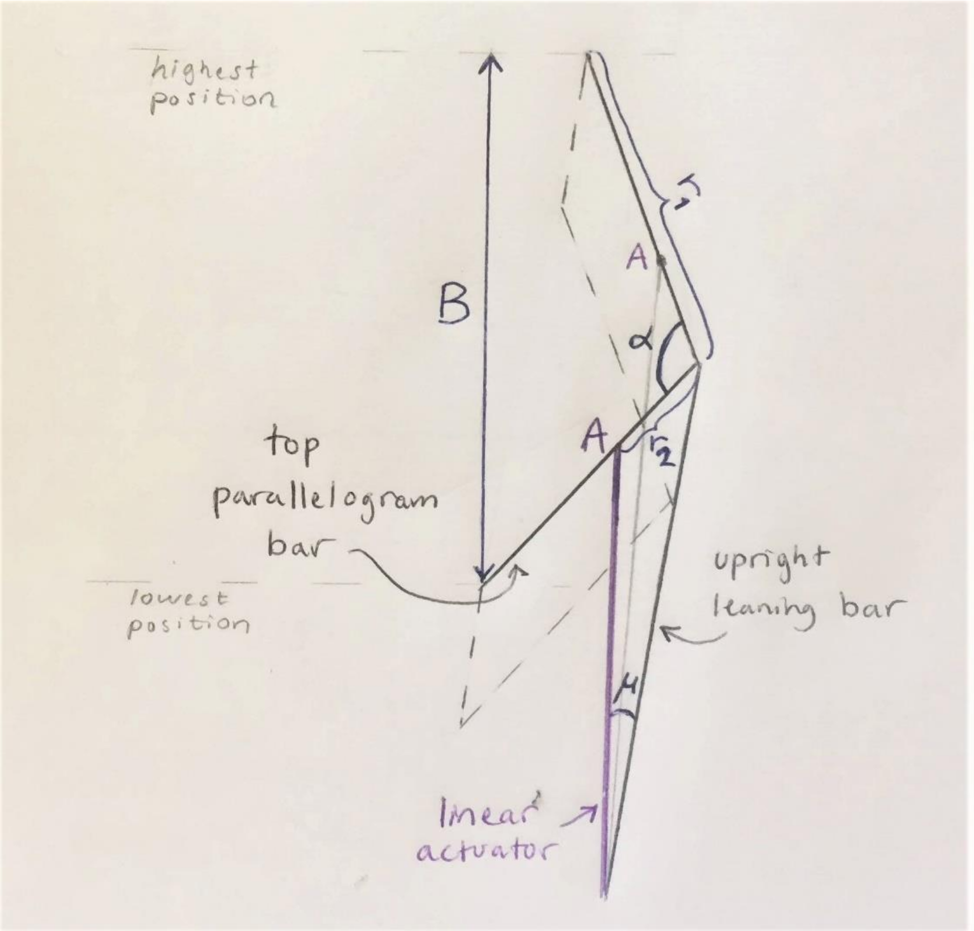


**Figure 7.6 Sketch of the highest and lowest position of the linkage design showing the variables used when dimensioning.**

**Table 7.2 Results of linkage dimension calculations.**

| Variable | Explanation | | Criteria | Results (final chosen values) |
|---|---|---|---|---|
| **t** | user lift time | (s) | 5-10 | 8,97 |
| ***B*** | lifting distance | (mm) | > 400 | 500 |
| **μ** | leaning angle of upright bar | (deg) | > 0 | 5 |
| **$r_1$** | length parallelogram | (mm) | | 306,3 |
| ***α*** | possible movement angle | (deg) | | 110 |
| **$r_2$** | distance to where the actuator is connected to the parallelogram | (mm) | | 103 |

### 7.2.3 **Height**

The design height was calculated based on the specification for the needed armrests height in walking position (1180 mm). In previous step it was ensured that the linear actuators length would fit in the lowest position. In this step a drawing and some geometrical calculations were made to decide the length of the upright leaning bar and where to attach the linkage. This drawing and calculations are explained and presented in Appendix C.2.

It was found that the linkage should be attached to the upright leaning bar at a distance of 537 mm to match the target specifications.

## 7.3 Joints

Revolute joints needed to be designed for the linkage. The critical factor was to avoid play as much as possible since the linkage will endure shear torque when the user is walking and shifting her weight from side to side.  To do so, big contact areas was preferred and tight tolerances were set for the manufacturing (see the drawings in Appendix D.2 for tolerances).

Another important factor was that aluminum parts cannot slide directly against other aluminum parts. Therefore plain bearings were used between the parts. The plain bearings in Figure 7.7, made in polymer material and with a collar, was bought.

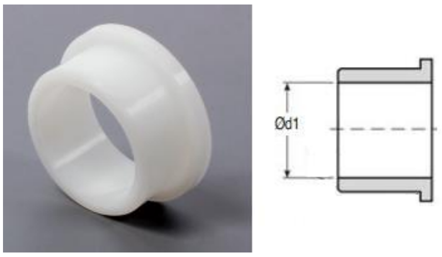


**Figure 7.7 Chosen plain bearing with an inner diameter (d1) of 8 mm (HPC, 2020).**

In Figure 7.8 and Figure 7.9, the designed revolute joint is shown.

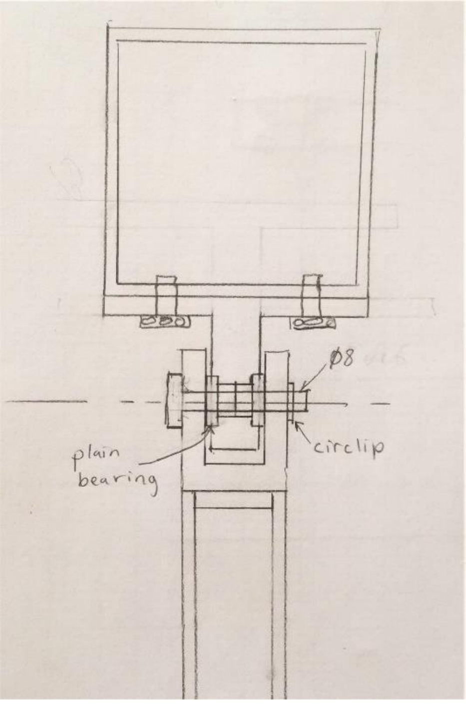


**Figure 7.8 Sketch of joint design from above.**

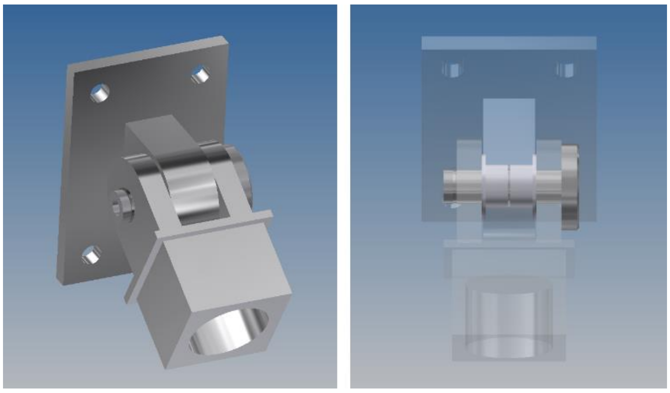


**Figure 7.9 Revolute joint that attaches the linkage to the upright bar.**

As seen an axis is designed, and it has a lathered groove where a circlip is placed to fix the axis.

The joint is fixed to the upright leaning bar with standard M5 screws. This choice was made since if it is removable, the height of the linkage can be adjustable (one of the target specifications). To be so, additional alternative mounting holes were added to the upright bar.

The joints between the horizontal and vertical parallelogram bar were designed in the same way, the only difference is that both sides are designed to fit inside the bars and the joint arms were made longer so that the bars won't touch when the linkage is in the highest and lowest position, see Figure 7.10.

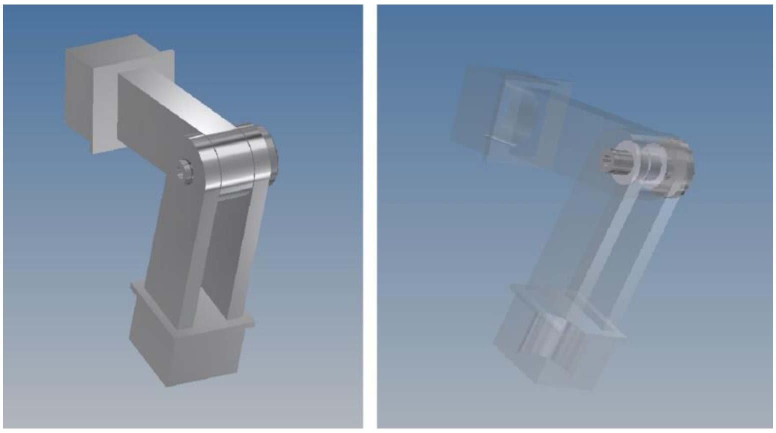


Figure 7.10 Revolute joint that connects the parallelograms bars to each other.

The whole linkage design (in the highest position) with the linear actuator is shown in Figure 7.11.

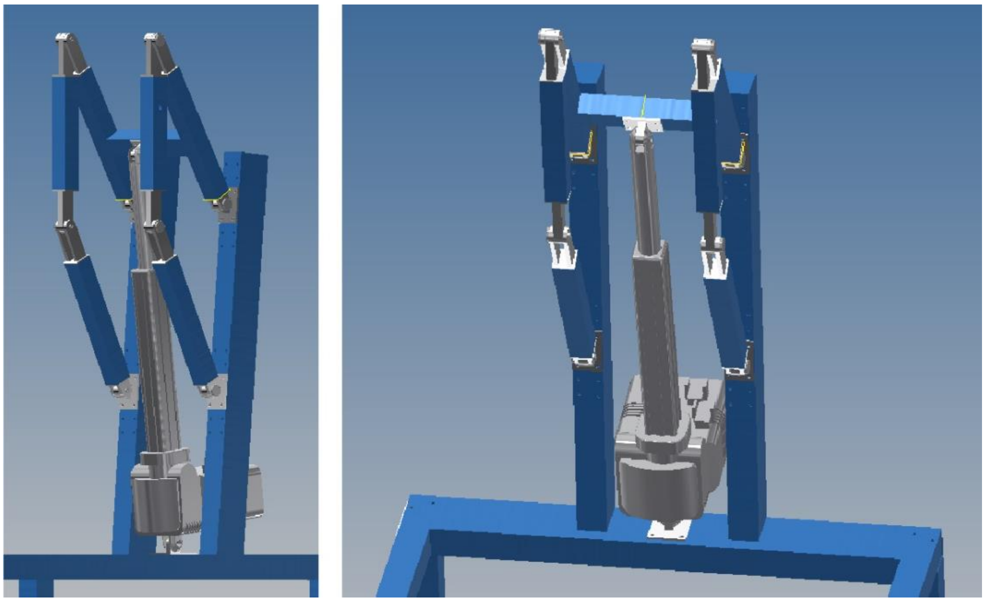


Figure 7.11 Linkage design with joints (in highest position).

## 7.4 Fixation and final design of the armrests

In the further concept development the armrest design was chosen, in this step it was investigated how the armrests could be attached to the linkage.

After designing the linkage, it was realized that the armrests needed to be placed on the same level, or higher than, the top joints. This was since there could not be any possibility that the users head or hands could touch or come in contact with the joints, both since it could bother the user and be dangerous. Some concepts were sketched, shown in Figure 7.12.

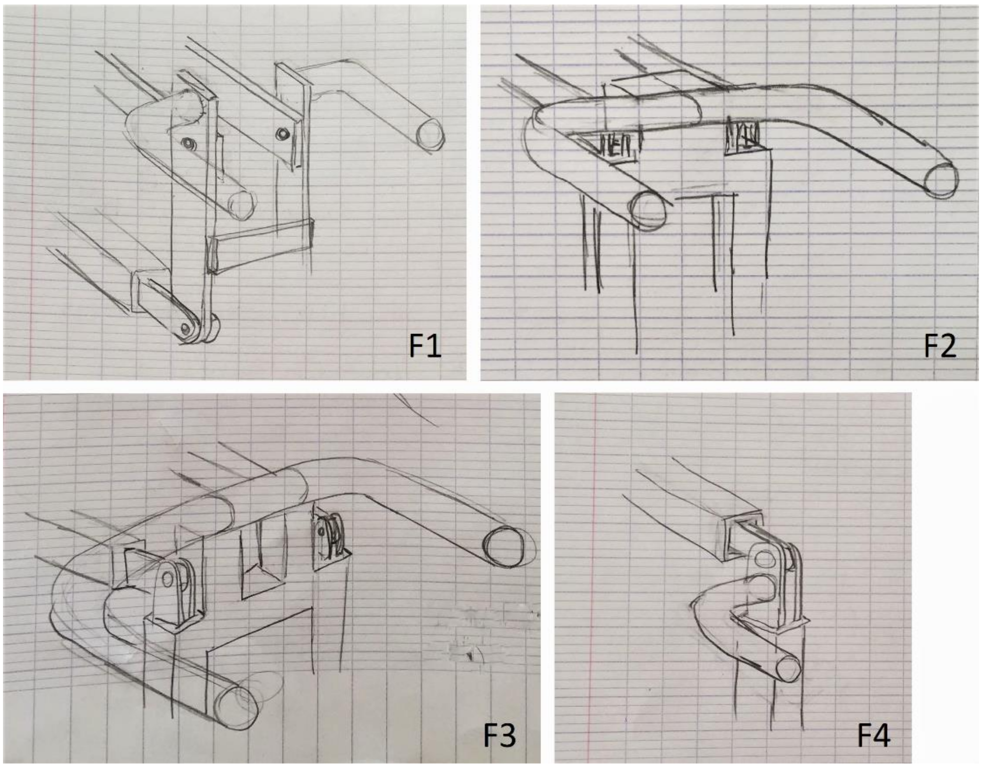


**Figure 7.12 Possible armrest fixation solutions.**

When testing in Inventor, it was found that F3 would not work when the linkage is in its lowest position and therefore a mixture of F2 and F3 was chosen. To fixate the armrest a solution with curved attachments was designed with the same diameter as the armrest (30 mm) and with M5 threads to be fixed with M5 nuts. To avoid the possibility of rotation, reinforcements on the sides were needed. As a first concept they were designed as angled parts to be welded to the armrest and fixed by screws onto the vertical bar, but note that this was changed later on. The chosen armrests solution is shown in Figure 7.13.

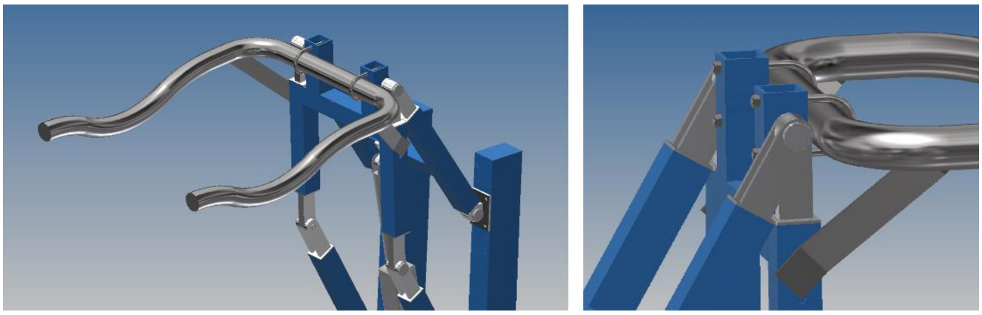


**Figure 7.13 Final fixation solution for armrests.**

For comfortability, a plastic foam was designed to cover the armrests and for safety and aesthetics, buttons for the tube ends were designed. See Figure 7.14.

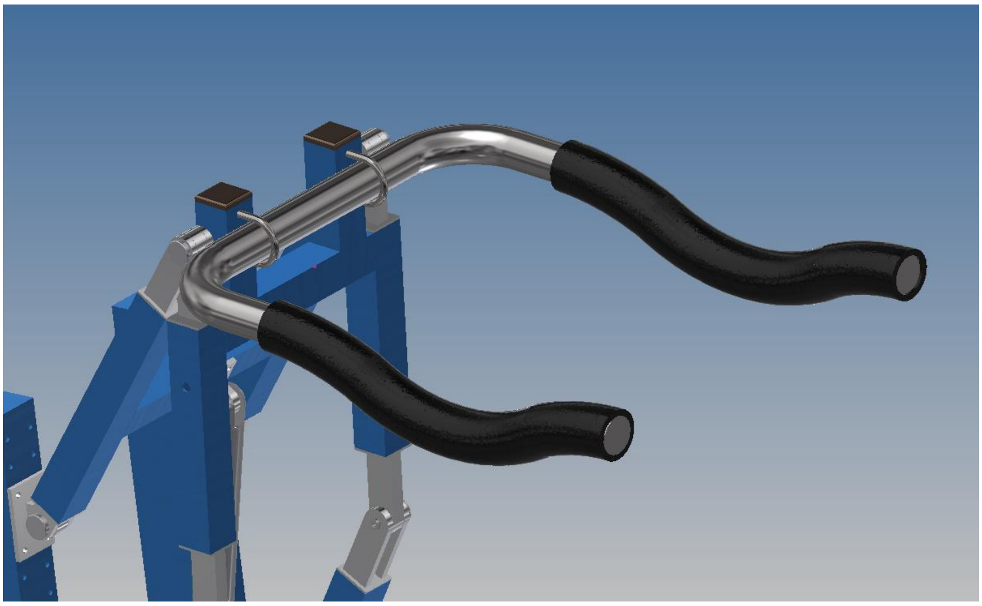


**Figure 7.14 Final armrests design (without the reinforcements).**

## 7.5 Material

Aluminum was chosen to all parts that could be made in aluminum. This since aluminum has many advantages; it has a low density compared to other metal and despite this it has a very high strength, it can be processed in many different ways where one of them is welding, it is cheap and, it is environmental friendly since it can be completely recycled (Zarges, 2020).

The alloy Aluminum 6060 was chosen since that is what the chosen welder company worked with. Aluminum 6060 has a yield strength of approximately 170-190 MPa (Aluminco, 2020).

The parts that could not be manufactured in aluminum were the bent parts; the armrests and the support tubes (explained in Section 7.9.2). It is not possible to bend aluminum in these ways and therefore stainless steel where used for these parts. Stainless steel has a yield strength from 250 MPa to 450MPa depending on different steel families (Azom, 2005).

The reinforcements and the curved attachments for the armrest were chosen to be made in steel, which have a greater yield strength than aluminum. This was confirmed to be a good choice in the FEM analysis (Section 7.6) where it could be seen that these parts absorb great forces and the largest values of Von Mises stress.

Lastly, the smaller detail parts, like the buttons for the tube ends and the phone case (Section 7.9.4) were 3D-printed in plastic.

## 7.6 FEM Analysis

A FEM (Finite Element Method) analysis was conducted in Autodesk's Inventor. At first, the thought was to do the FEM analysis in ANSYS which is a software specialized in doing simulation, but due to COVID-19 the laboratory computers and ANSYS were inaccessible.

FEM is a numerical mathematic technique which uses partial differential equations to a high degree. It can be used to understand and simulate structures in order to solve mechanical problems or to optimize designs. To perform a FEM analysis a mesh is created. This contains millions of small elements in which each one is a mathematical point and in this way the 3D-structure can be analyzed. This means that the smaller mesh elements, the more precise simulations (Interesting Engineering, 2019). It is also needed to define the constraints and loads that the structure is affected by, to perform an analysis. For example, some surfaces or points might be unable to move, then a fixed constraint should be added (Machine Design, 2004).

This project static stress analysis was made when the linkage is in its highest position since this is the position which will be under load the most time (when the user is standing up and walking). At first, the thought was to do a second analysis when the linkage is horizontal too (during the lift) since this is a critical position where the load is the furthest from the actuator, but there was not enough time for this. So, it was assumed that if the stress analysis in the highest position was acceptable, the horizontal position would be acceptable too.

### 7.6.1 Attachment constraints

The legs and actuator were removed to simplify the calculation. A fixed constraint was set where the actuator connects to the top part of the linkage. This was because the actuator has a very high force of 3000 N. Also the two upright bars were attached with fixed constraints. These fixed constraints can be seen in Figure 7.15.

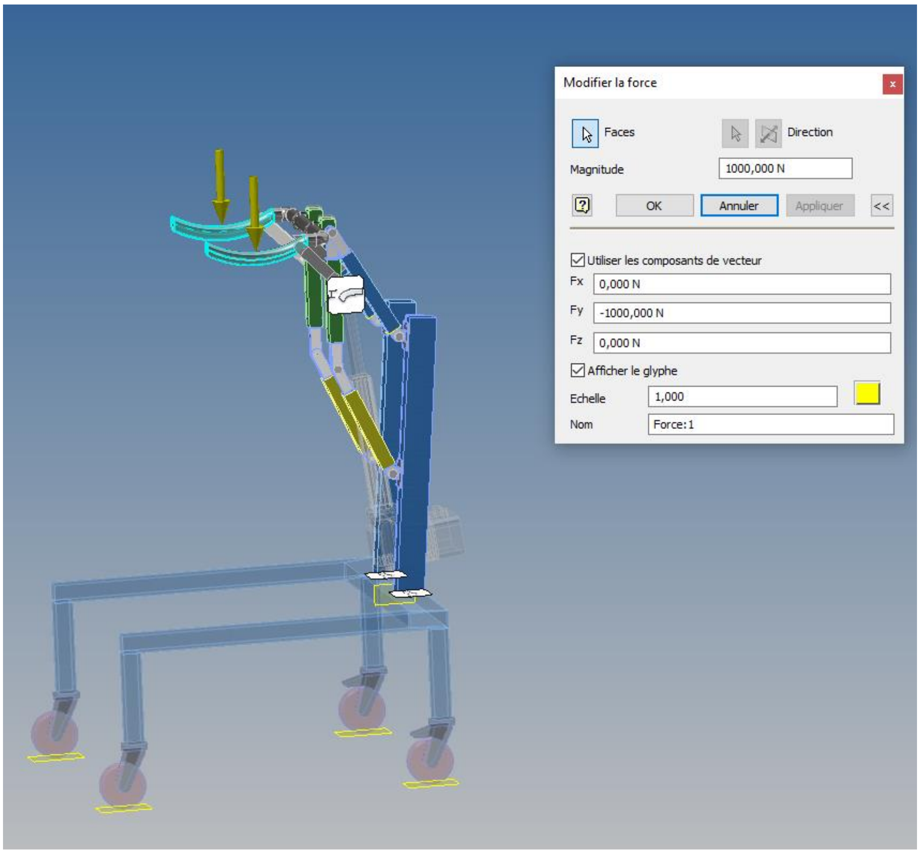
### 7.6.2 Contact constraints between parts:

One of the limitations with Inventor’s Stress Analysis tool is that a welded contact cannot be chosen. Instead welded parts were set to Bonded contacts. The Bonded contact simulates rigid bonding of faces to each other, like weld or glue joints between two parts. All contacts except for the ones in the joints were set to bonded contacts.

In the joints the axes and the plain bearings were set to Sliding / No Separation contacts, which allows relative sliding between contact faces, but prohibits separation.

### 7.6.3 Forces

The load of 1000 N was divided equally on the armrests where the users armpits will be positioned, see Figure 7.15.



Magnitude 1000,000 N

☑ Utiliser les composants de vecteur

Fx 0,000 N

Fy -1000,000 N

Fz 0,000 N

☑ Afficher le glyphe

Echelle 1,000

Nom Force:1

**Figure 7.15 Picture showing where the forces were applied (the two yellow arrows) and where the fixed constrains where attached (the three white rectangles).**

### 7.6.4 **Meshing**

The overall element size was set to 10 mm. This since the computer available couldn’t handle a finer overall mesh of a structure this size.

### 7.6.5 **Results**

The structure had a maximum displacement of 1.96 mm in the outer part of the armrests, see Figure 7.16.

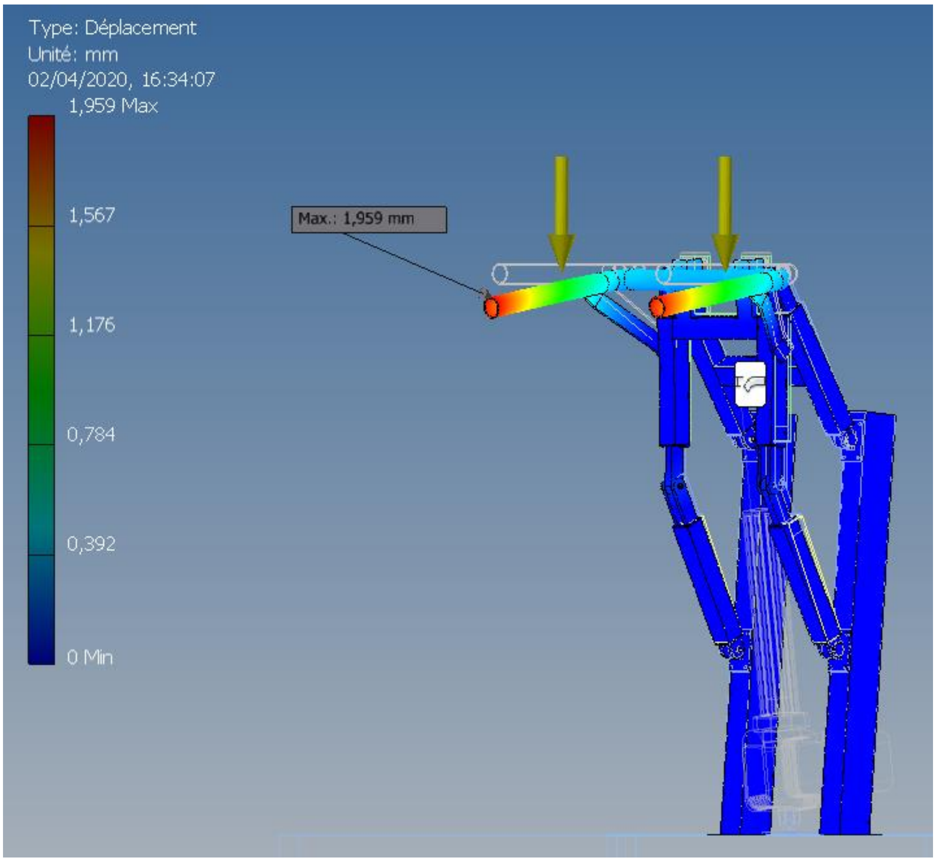


Figure 7.16 Total displacement of the structure.

The biggest Von Mises stress the structure seen was 115.9 MPa (Figure 7.17 and Figure 7.18) in the contact between the armrest and the reinforcement, and the second biggest evolved in the curved attachments. 115.9 MPa corresponds to 46% of the lowest yield strength of the material (250 MPa). This is considered a very good safety margin, given that the load is already set with a factor 2. But since the overall mesh size was set to 10 mm (quite large) a new simulation was made were a local mesh was created to obtain more definite results.

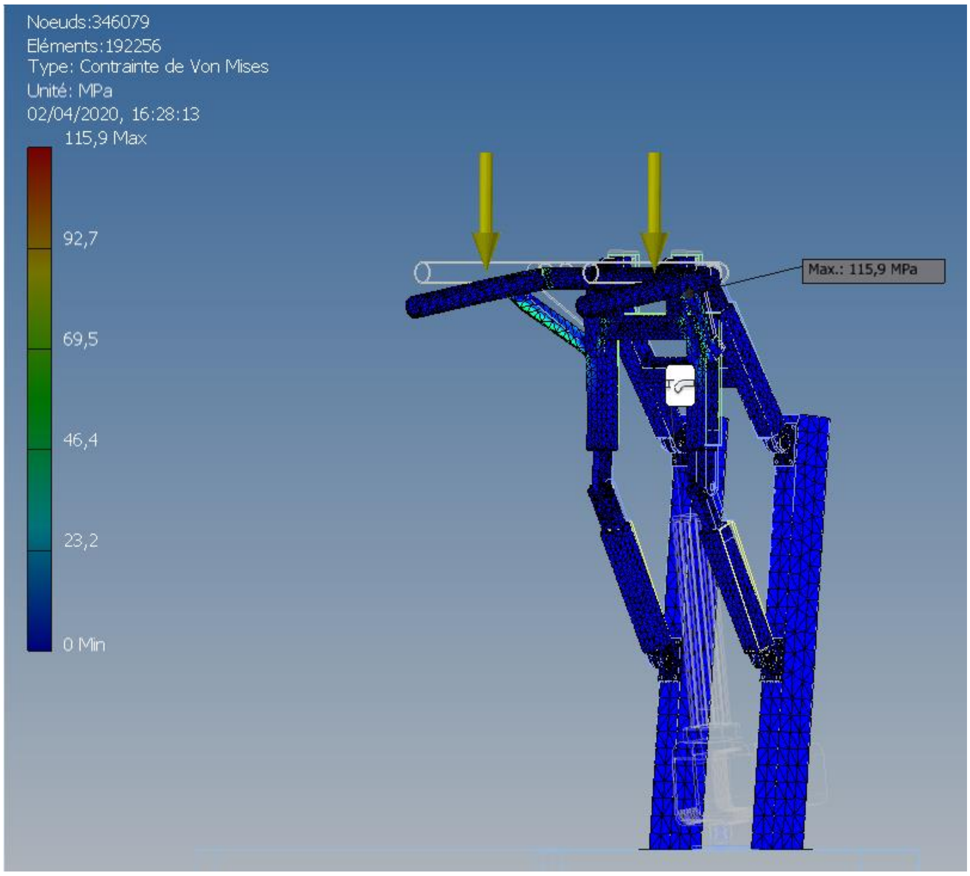


**Figure 7.17 Von Mises Stress results in the structure. Critical stress concentrations evolving at the contact between the armrest and the reinforcements.**

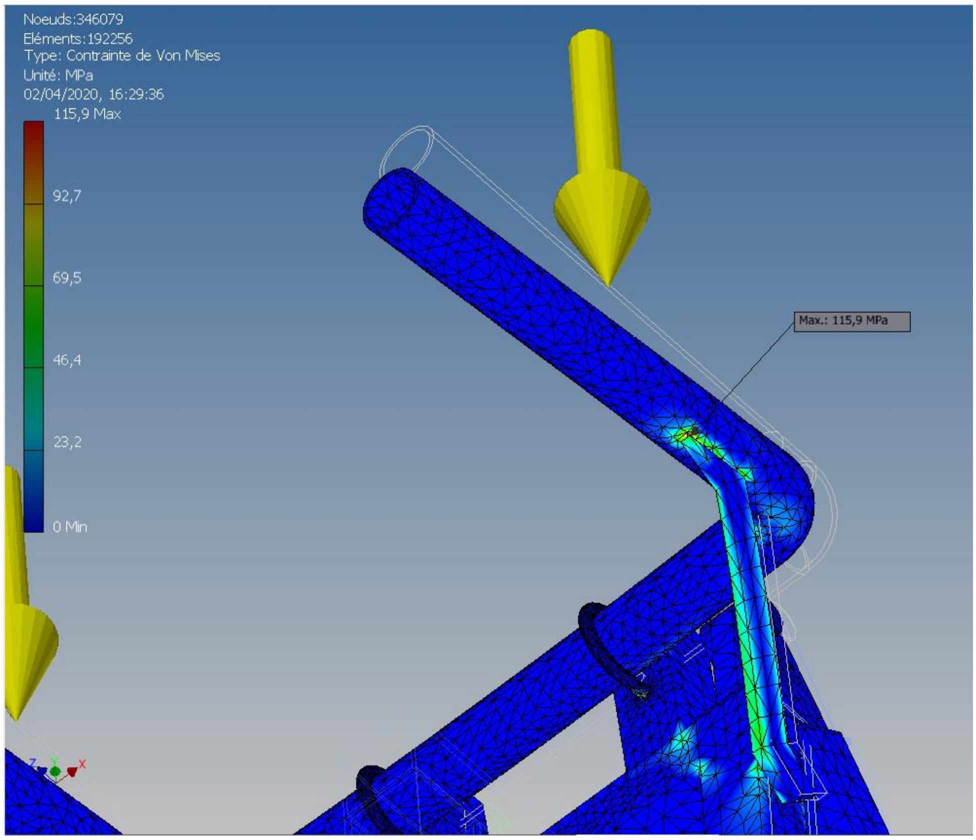


**Figure 7.18 Zoomed in picture of where the maximal Von Mises stress arose.**

## 7.6.6 **Second simulation with local mesh**

### *7.6.6.1 Local mesh*

A local mesh of 0.5 mm was added to the reinforcements and the outer parts of the armrests, see Figure 7.19.

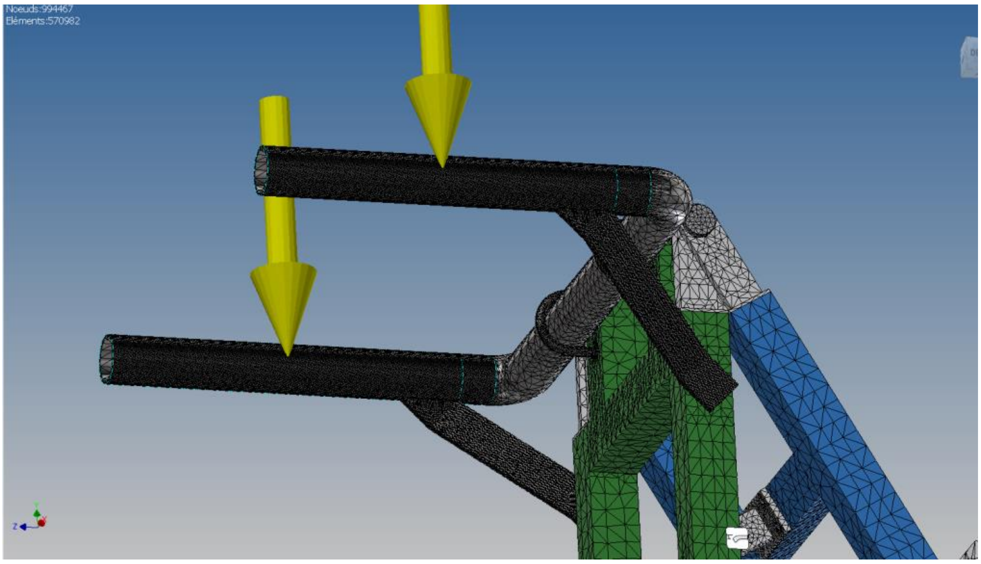


**Figure 7.19 Picture showing where the local mesh of 0,5 mm was added.**

### *7.6.6.2 Results with local mesh*

With the local mesh the biggest Von Mises stress the structure sees was now 295 MPa. When looking closer it was found that the critical area is on the armrest exactly where the reinforcement is welded to the armrest, see Figure 7.20.

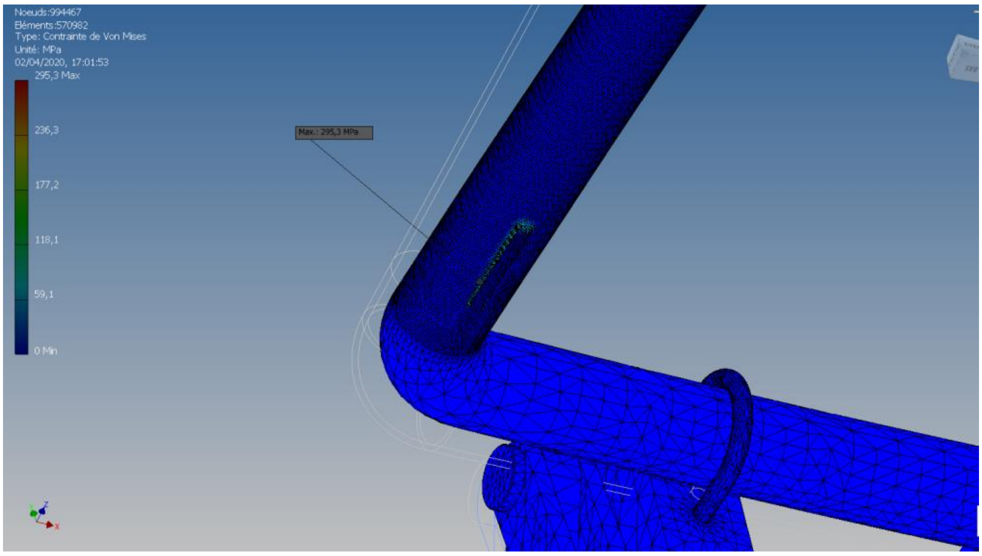


**Figure 7.20 The maximal Von Mises stress found with added local mesh.**

### 7.6.7 **Third simulation with larger reinforcement**

A new simulation was made where the reinforcement was enlarged to create a bigger contact area between the reinforcement and the armrest as a way of reducing the stress. The local mesh of 0,5 mm was kept and the result was a max Von Mises stress of 345 MPa, see Figure 7.21.

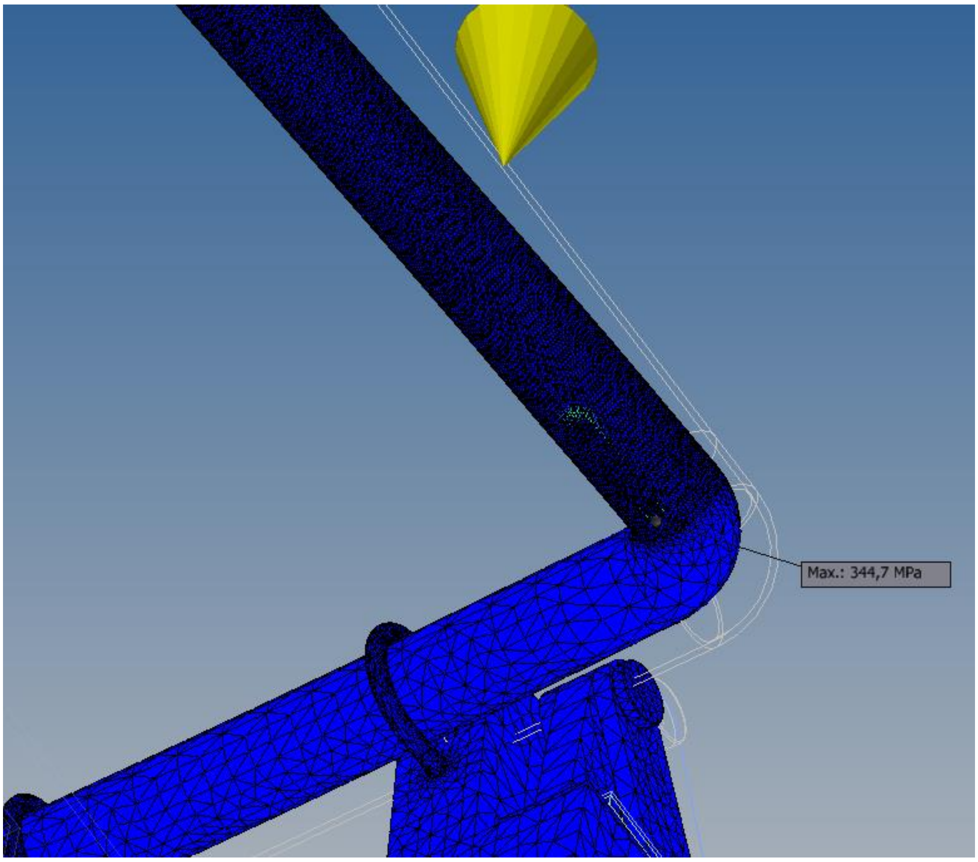


**Figure 7.21 Maximal Von Mises stress when a larger reinforcement was added.**

### 7.6.8 **Evaluation of FEM simulations**

In all simulations the structures maximum displacement was 1.96 mm. In regard to the overall size of the structure this is a small and acceptable displacement.

The local mesh results gave very high unacceptable stress concentrations which suggests the necessity of further reinforcement or changing the reinforcement. The fact that the critical stress is exactly where the reinforcement is connected to the armrest and that the stress increases when the reinforcement is enlarged implies that there is a problem with the contact between them. It can depend on two factors; that the contact is between a cylinder and a flat area or that Inventor cannot distinguish and process a welded contact. It was therefore decided to change the design of the reinforcement to avoid this type of contact (which also, after investigating the reinforcements, was learned to be difficult to weld).

Normally, after changing the reinforcement, new stress analysis would be performed to evaluate the new design but at this point the time was limited and creating the drawings to send to the welder was prioritized so the manufacturing would be ready in time. With the new reinforcements, presented in next chapter, the stresses and deformation was assumed to be within the safety margin. Unfortunately, neither any prototypes could be created and tested, which is a limitation in this thesis.

## 7.7 Reinforcements

### 7.7.1 Reinforcements for armrest

New reinforcements were designed with the help of Per-Erik Andersson, lecturer and head of Lund University's product development division. The new reinforcements are designed with a pipe bracket to fit the tube to avoid welded parts. This pipe bracket is then connected to the linkage via an angled part with two joints. The reinforcement can be jointed at both ends thanks to its shape and the position of the joints, which prevents rotation. The pipe bracket is designed as two half circles, to be able to install it on the bend tube (the armrest). It connects with three M4 screws and nut on the top (which will be covered later on for the user's security) and with two M8 screws underneath and at the end towards the linkage. See Figure 7.22-Figure 7.24.

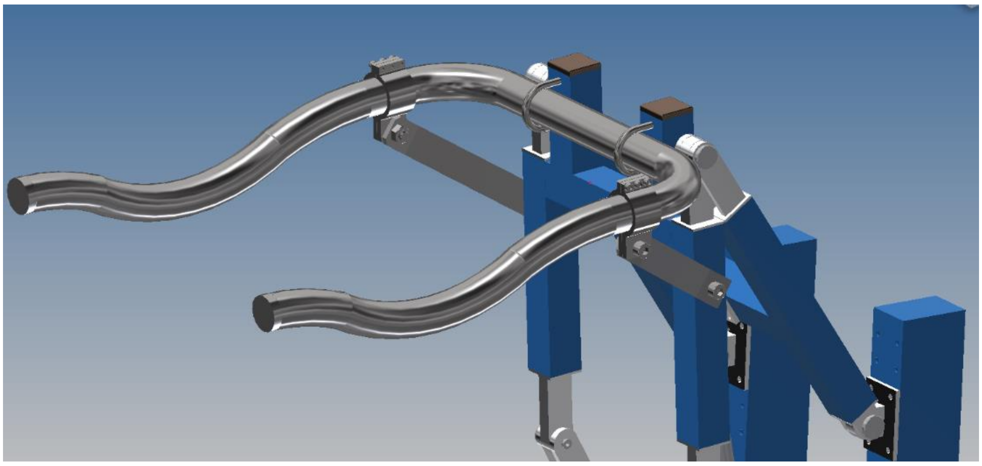


**Figure 7.22 Reinforcements for the armrests.**

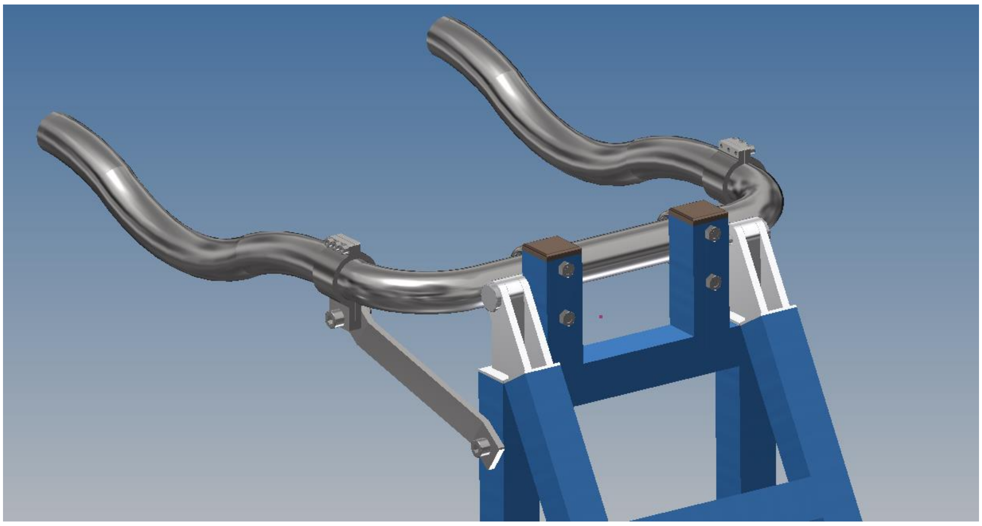


**Figure 7.23 Reinforcements for the armrests, shown from behind.**

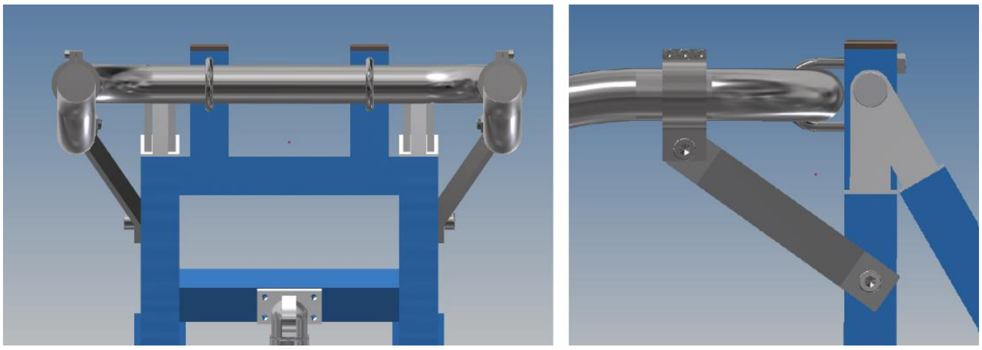


**Figure 7.24 Reinforcements for the armrests, shown in a front and side view.**

### 7.7.2 Frame reinforcements

Since time and possibilities for tests and simulations was limited, it was decided to design frame reinforcements to ensure structural strength. Reinforcements were designed for each place where a tube was welded to another, see Figure 7.25. They were designed as shown to improve the flow of force and thus reduce the stress concentration between the tubes.

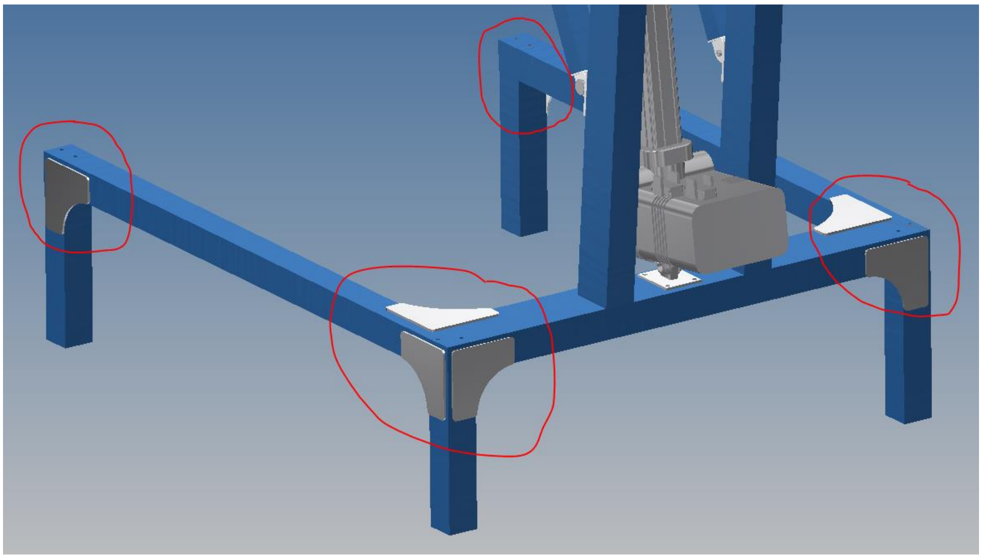


**Figure 7.25 Frame reinforcements (eight in total).**

### 7.7.3 Reinforcements for upright bars

Two reinforcements were also designed for the two upright bars to ensure strength. Since they are leaning with a five-degree angle, the same design could not be used. Instead a 20x20 mm tube with 45 degree angle was designed to reinforce them. At first they were designed with two plates at each end to avoid flat effect (that perpendicular forces occur in the upright bar and frame), see Figure 7.26. However, after sending the drawings for manufacturing, the welder decided that the end plates were not necessary.

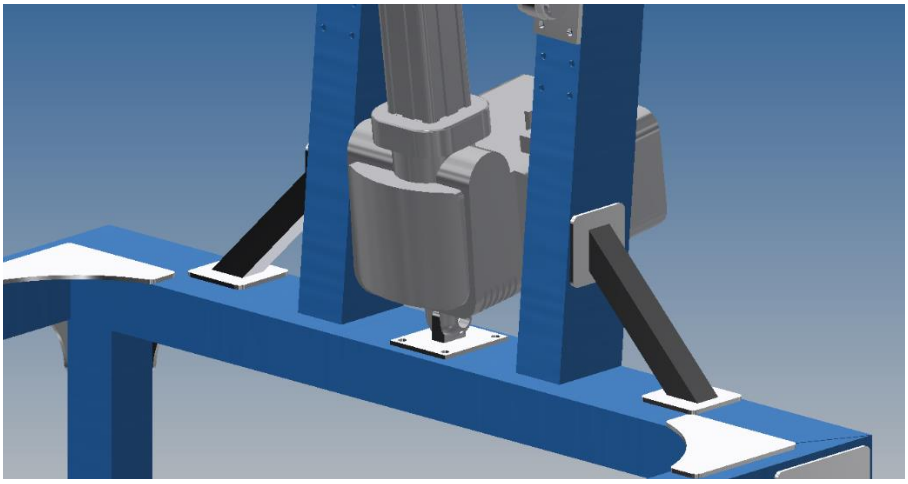


**Figure 7.26 Reinforcements for upright bars. (Note that the end plates were later on removed).**

## 7.8 Stability control

The stability of the structure was examined to make sure that it would not tip during use. To do so, the center of gravity was located. This since if the center of gravity passes outside the support base, the structure will tip (Royal Academy of Engineering, 2020). In this case, the support base is determined by drawing lines between the wheels contact point with the floor, see Figure 7.27. Inventor can automatically locate the center of gravity and it was found to always be inside of the support base with margin, see Figure 7.28. It was not possible to add the users center of gravity in Inventor, but since the user always is positioned within the frame, and therefore also within the support base, the structure cannot tip.

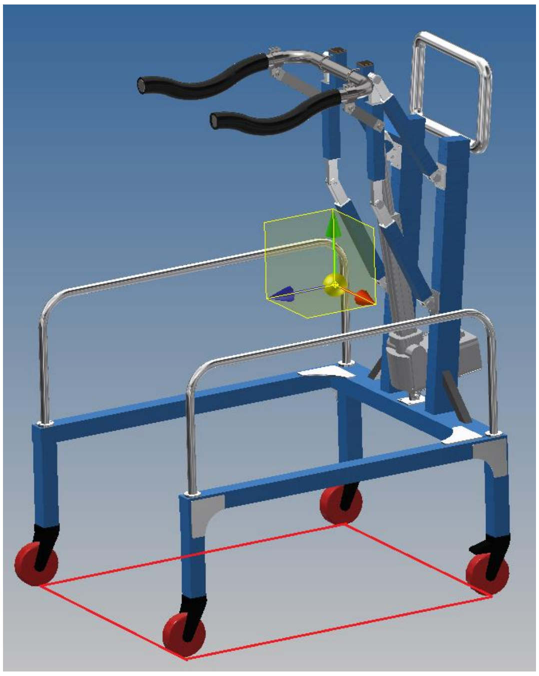


**Figure 7.27 Red lines indicating the structure's support base and the yellow dot shows the structure's center of gravity when the armrests are lifted and without the user weight.**

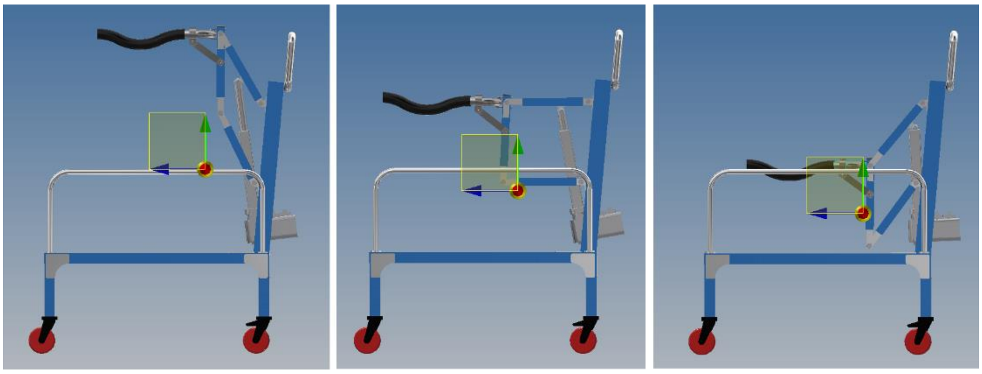


**Figure 7.28 Center of gravity in three different lift positions.**

# 7.9 Added parts

## 7.9.1 **Wheels**

### *7.9.1.1 Criteria when choosing wheels*

When choosing the wheels a few factors were taken into consideration.

- The weight of each wheel could not be too big. A limit was set to 400 g per wheel.
- The wheels needed to be able to be fixed with an axis.
- Thin wheels with a big diameter was wanted in order to reduce the contact area to the floor to reduce the friction and makes the structure easy to move around.
- The material had to work well with a linoleum floor.
- The front wheels should be rotational and the back wheels should be fixed, to facilitate the movements.
- The front wheels needs to include the breaks, so that they are accessible to the assistant.
- Acceptable price and availability.

### *7.9.1.2 The chosen wheels*

The best alternative fulfilled all criteria except that the back wheels are not fixed, but this was considered to be acceptable.

They are polypropylene wheels with thermoplastic rubber made for use inside hospitals, rehabilitation centers, collective kitchens and offices and similar. They have a diameter of 100 mm and a width of 32 mm. The front wheels weigh 0.389 kg and the back wheels 0.362 kg. See Figure 7.29 for image.

**Figure 7.29 Chosen wheels (front wheels to the left and back wheels to the right). (Guitel Hervieu, 2020).**

### 7.9.2 Support tubes

During the second user test, the assistant and father pointed out that there was not any good way for the assistants to help steering or moving the walker which can be important if the user gets tired or needs any kind of help. Therefore, support tubes with a diameter of 20 mm was added to the side of the frame. Their height was set to the same as the side tubes in the existing walker.

A rounded rectangular tube was also added to the two upright bars for support. It was designed as a closed rectangle to enhance the stability of the upright bars. See Figure 7.30.

**Figure 7.30 Image showing the three support tubes.**

### 7.9.3 **Security**

Some parts were added secure the use and protect the user.

#### *7.9.3.1 Protection tape*

A corner protection tape was added to soften the tube edges of the frame, see Figure 7.31.

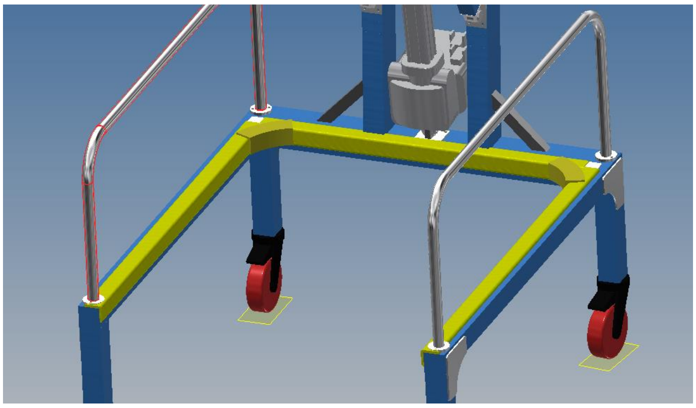


**Figure 7.31 Corner protection tape (in yellow).**

This will also be added to the sharp edges in the linkage and around the reinforcement.

#### *7.9.3.2 Plastic sheet*

Two plastic sheets were added so that the user can’t be pinched in the linkage joints, shown in Figure 7.32. At first the thought was to design more extensive protection for the linkage, but after testing and realizing that the actuators velocity is so slow that the possibility of being pinched is very low, the two plastic sheet was decided to be an appropriate solution.

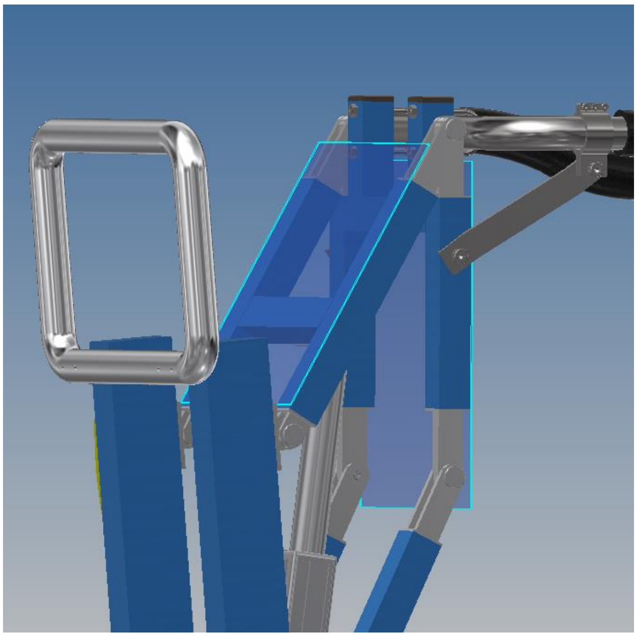


**Figure 7.32 Two plastic sheets for protection (the two outlined blue transparent rectangles).**

### *7.9.3.3 Emergency stop button*

The plan was to add an emergency stop button, but after testing the linear actuator with the hand switch it was realized that as soon as you let the button go the actuator stops without any delay. This, together with that the actuators velocity is very low, decided that an emergency button was unnecessary.

## 7.9.4 **Telephone case**

A phone case with an attachment to fit the armrest was designed (Figure 7.33). This part will be 3D-printed.

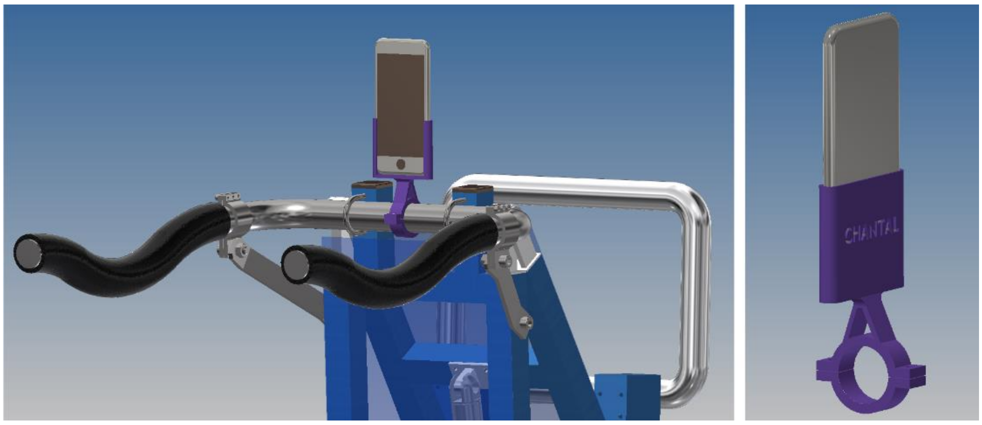


**Figure 7.33 Attachable phone case.**

### 7.9.5 Limit switch

A limit switch (a mechanical position switch) needed to be added since the physical max and min stop of the actuator didn't match the target positions. The limit switch can detect two possible states with the external roller, pressed or released. In this case, when the linkage is in the set highest position (standing/walking position), the switch will be pressed and this will send a signal to stop the actuator. The switch in Figure 7.34 was bought.

**Figure 7.34 Bascule double seuil à Levier, the chosen limit switch (RS Components, 2020).**

### 7.9.6 Electrical diagram

An electrical diagram, which shows the electrical circuit of the linear actuator, the hand switch (control box) and the limit switch, was designed and is shown in Appendix D.1.

## 7.10 Drawings

Drawings for all parts in aluminum, steel and stainless steel were made and sent to the chosen manufacturer. In these the most important tolerances and the welding were indicated. An exploded view was also made with a list of all parts. All drawings can be found in Appendix D.2.

Note that the tube thickness in the drawings are all 2 mm but this was changed to 3 mm by the manufacturer, since it was required for good welds.

## 7.11 Manufacturing and assembly

Figure 7.35-Figure 7.38 shows the manufactured parts and assembly process.

**Figure 7.35 Linear actuator and linkage parts.**

**Figure 7.36 Structure before assembly.**

**Figure 7.37 Linkage design assembled.**

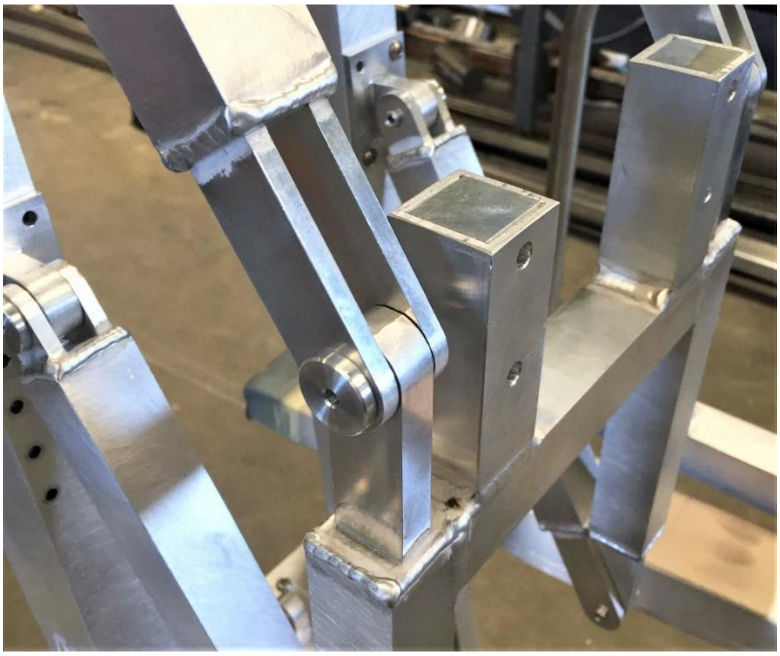


**Figure 7.38 Close-up of one of the revolute joints.**

**Figure 7.39 Painting of the structure.**

The paint color was decided by the user who wanted an as neutral expression as possible.

# 8 Result – Final Design

*This chapter presents the final design and its final mass and total cost.*

## 8.1 Final design

### 8.1.1 Final CAD design

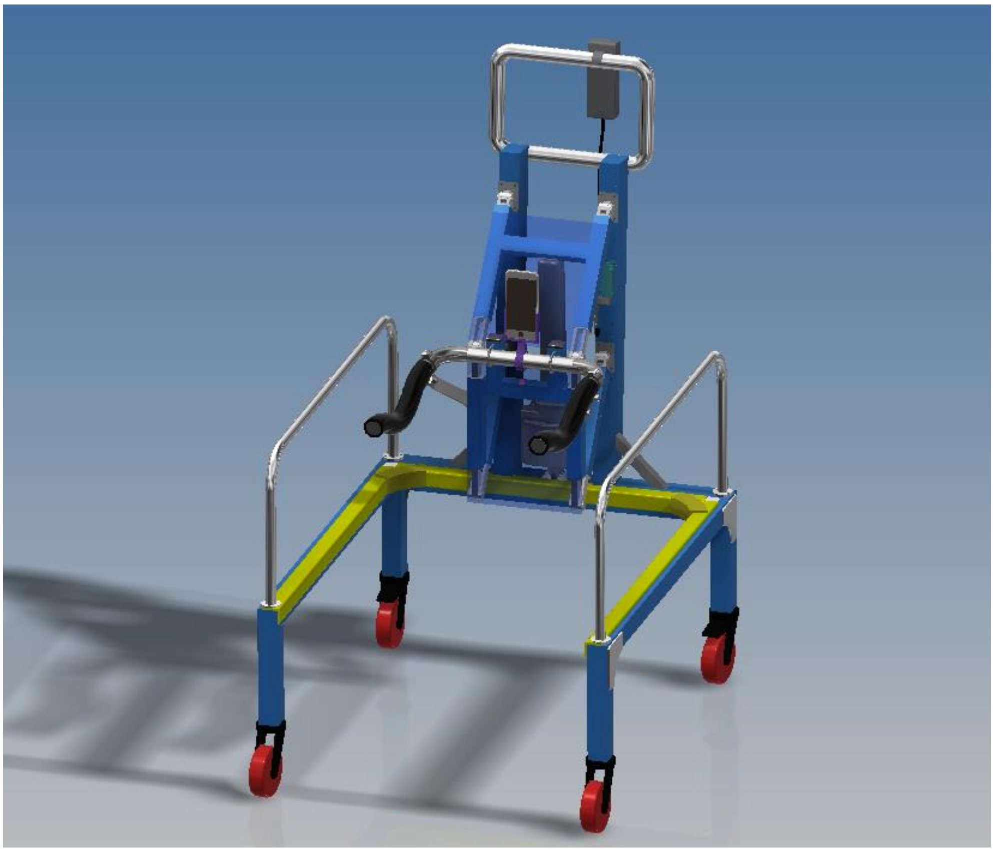


**Figure 8.1 Final CAD design, showing the structures lowest position.**

**Figure 8.2 Final CAD design, showing the structures highest position.**

**Figure 8.3 Final CAD design showing the usage in start and end position.**

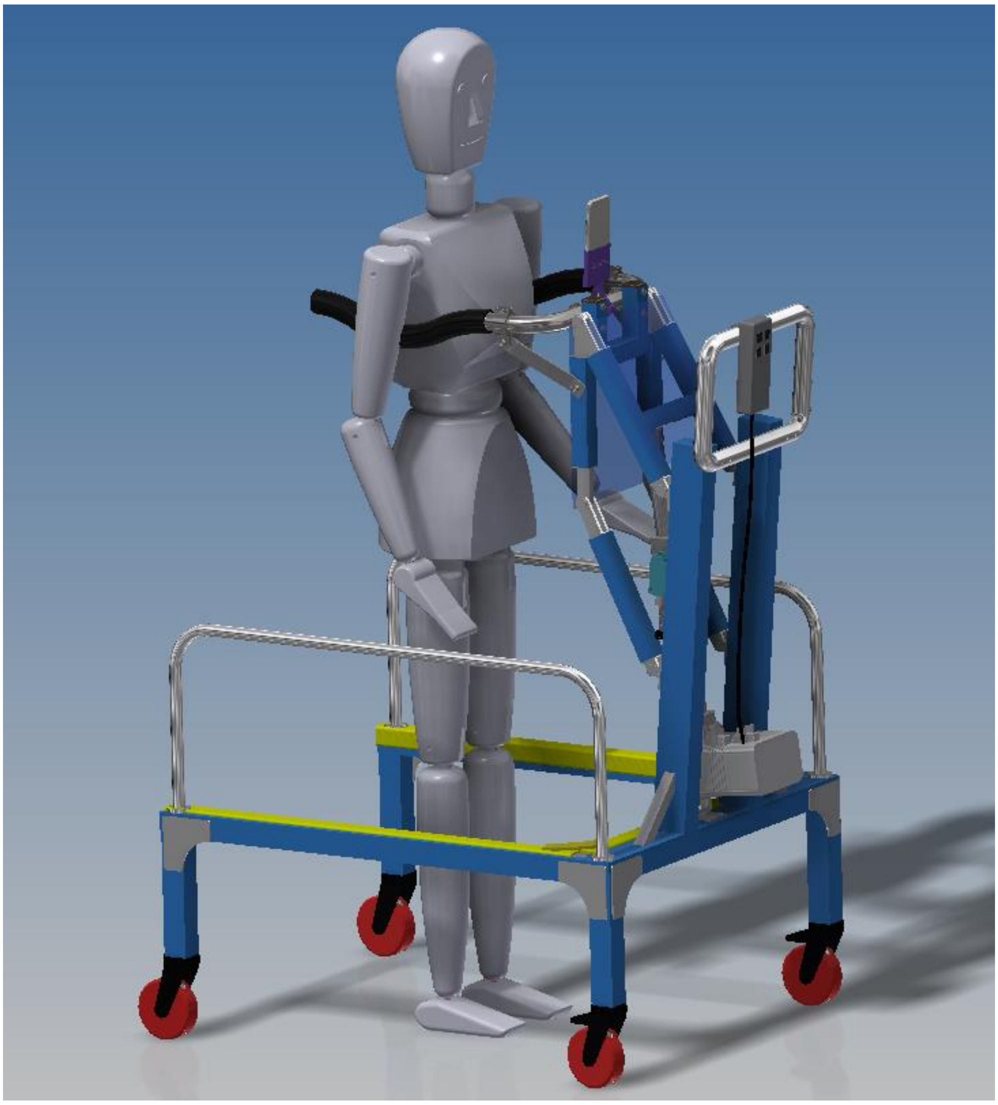


Figure 8.4 Final CAD design showing the usage in walking position.

### 8.1.2 **Final product**

**Figure 8.5 Final product.**

Figure 8.6 Close-up of the lift-design.

Figure 8.7 First test of the final product.

## 8.2 Final mass

The structure’s mass is shown in Table 8.1.

**Table 8.1 Structure's mass**

| Part | Mass (kg) |
|---|---|
| Linear actuator | 4.2 |
| Wheels | 1.5 |
| Metal parts | 11.3* |
| Additional parts (estimated) | ~1 |
| ***total*** | 18 |

* This value is from Inventor’s function to calculate the structure’s mass based on the materials density.

## 8.3 Final cost

The structure’s total costs are shown in Table 8.2.

**Table 8.2 Structure's cost**

| Part | Price (€) |
|---|---|
| Linear actuator | 490 |
| Manufacturing costs (metal parts) | 5575 |
| Wheels | 90 |
| Additional parts | ~200 |
| ***total*** | 6355 |

# 9 Discussion

*This chapter discusses the design process, both what turned out to be good decisions and which steps that could have been done differently or improved, and ends the report with a conclusion.*

## 9.1 The final concept

The final product meets nearly all the target specifications. The most dependent and limiting specifications turned out to be the lift distance and time, the weight and definitely the complexity. The target specification that could not be fulfilled was a total autonomous usage, due to security reasons. The other specification that is uncertain if it was fulfilled is the max system weight (this will be tested when the final product is assembled).

The mass was taken under consideration during the whole process but was unexpectedly affected in the manufacturing step of the metal parts. Both that the bended parts had to be changed from aluminum to stainless steel and that the thickness had to be altered. In a future product development, a large buffer will be counted from the beginning to prepare for unexpected changes. In this case, tests will be made with the user, and if in worst case scenario, the structure is too heavy, the support handles can be removed.

Another room for improvement is the aesthetic design. Unfortunately, since the focus landed on meeting the technical specifications the time for aesthetic design was deprioritized.

## 9.2 The process

The design process turned out to be an own particular process where much more focus was put on the detail design than initially thought. When looking back, the generated concepts where all fairly similar and this was probably due to that the technical specifications were as strict as they were.

If any step of the process could have been done differently or be improved it would be the further concept developments step. In retrospect, this structure and use of this step was somewhat unclear. It was a step to help moving forward and taking decisions but more time than necessary was spent on this step. The results found in the frame analysis was later on changed to the contrary, and finding the best solution for armrest and legs could probably have been included in the first concept generation to spend  more time on later steps instead.

Due to COVID-19 the projects content changed somewhat. The plan from the beginning was to create prototypes for tests and evaluations and also to execute more in-depth FEA simulations. This part had to be removed and instead the manufacturing was advanced, and with that the detail design was in focus instead. To somewhat compensate for the lost testing during the development, it has been decided to perform extra careful and numerous tests of the final assembled product before it is released. The positive side of this is that great knowledge about manufacturing, fabrication and reinforcement was gained, which was not expected from the start. The negative side is that the structure probably could have been designed in a lighter way, with less thick tubes if the in-depth tests could have been carried out.

## 9.3 Conclusion

This project has resulted in an actual manufactured product which enables the user to stand up and walk alone. This will give the user around her house independence as in the same time reduce the work load for assistants and family. When finalizing this report, the final test and evaluations of the final product still needs to be performed and potential improvements to be added, but counting this, the user will have a fully functioning product in her home within one year from the start of the project, which was the goal.

The user and her family are happy with the development so far and a possible patent application is currently under investigation.

In conclusion, the project and final product meets the overall goals and is seen as a success. This product has the potential to contribute to a higher living standard for persons with mobility impairments and it is certain that it will do it for at least one user.

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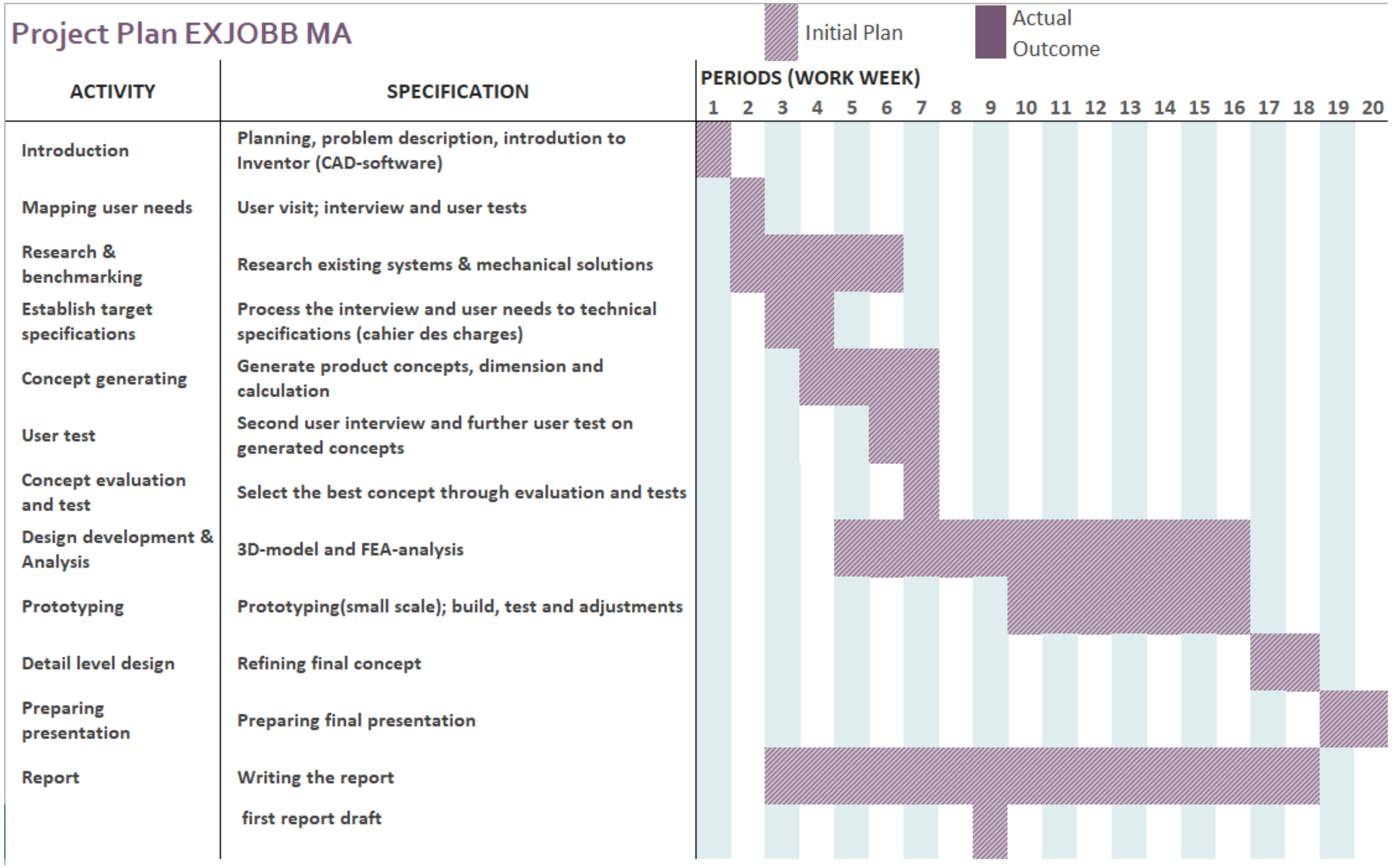
# Time plan and outcome

*A time plan and Gantt chart was created the first week of the project. This was then updated and changed in week four, when new insights and information had occurred. These two Gantt charts plus and the actual outcome is presented here.*

## A.1 Project plan

The Gantt chart created the first week of the project is shown below.



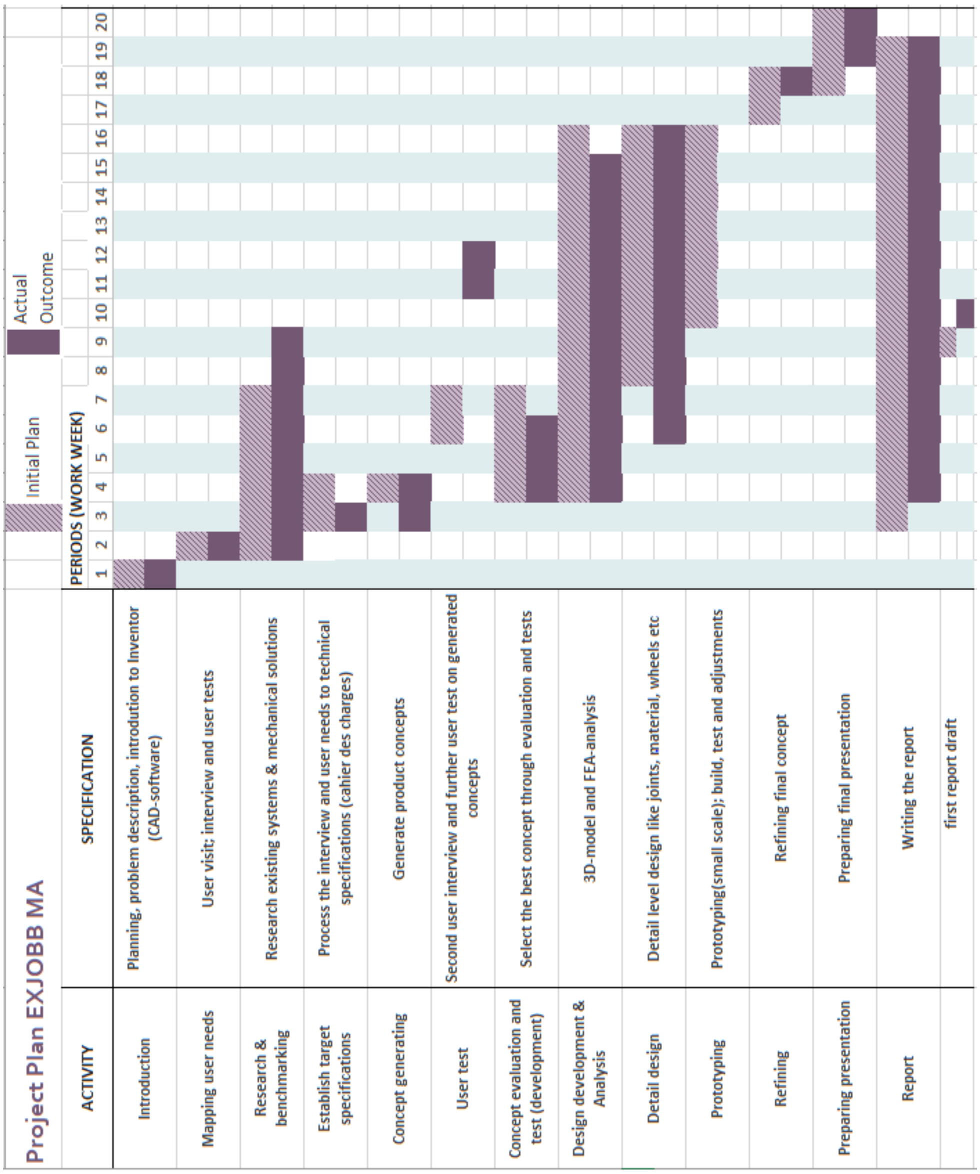
## Project Plan EXJOBB MA

▨ Initial Plan ■ Actual Outcome

| ACTIVITY | SPECIFICATION | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **PERIODS (WORK WEEK)** | | | | | | | | | | | | | | | | | | | |
| Introduction | Planning, problem description, introdution to Inventor (CAD-software) | ▨ | | | | | | | | | | | | | | | | | | | |
| Mapping user needs | User visit; interview and user tests | | ▨ | | | | | | | | | | | | | | | | | | |
| Research & benchmarking | Research existing systems & mechanical solutions | | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | | | | | | | | | | |
| Establish target specifications | Process the interview and user needs to technical specifications (cahier des charges) | | | ▨ | ▨ | | | | | | | | | | | | | | | | |
| Concept generating | Generate product concepts, dimension and calculation | | | | ▨ | ▨ | ▨ | ▨ | | | | | | | | | | | | | |
| User test | Second user interview and further user test on generated concepts | | | | | | ▨ | ▨ | | | | | | | | | | | | | |
| Concept evaluation and test | Select the best concept through evaluation and tests | | | | | | | ▨ | | | | | | | | | | | | | |
| Design development & Analysis | 3D-model and FEA-analysis | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | |
| Prototyping | Prototyping(small scale); build, test and adjustments | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | |
| Detail level design | Refining final concept | | | | | | | | | | | | | | | | | ▨ | ▨ | | |
| Preparing presentation | Preparing final presentation | | | | | | | | | | | | | | | | | | | ▨ | ▨ |
| Report | Writing the report | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | |
| | first report draft | | | | | | | | | ▨ | | | | | | | | | | | |

# A.2 Updated project plan and the actual outcome

The updated and changed Gantt chart (in week four) is shown below. The striped light purple areas shows the updated plan whereas the dark purple areas shows the actual outcome.



### A.2.1 Difference between first Gantt and the updated Gantt chart

The differences between the first plan and the changed one is that the *Generate product concept* is reduced to only one week but instead the *Select the best concept through evaluation and tests* is prolonged to four weeks. This was since it was realized that the evaluation and tests to find the best concept was more complicated. Another big difference is that *Detail level design* was added as it was realized that this would be one of the largest parts of the thesis. It was mainly because of this that the Gantt was updated.

### A.2.2 Difference between time plan and the actual outcome

Overall the project adhered well to the time schedule. One big delay was the timing of the second user interview and test. This was due to the availability of the concerning persons. Instead of showing the different concepts the user was shown the final concept (which she luckily was very positive to) and gave comments only to that one.

The other big difference was that the prototype step could not be performed at all. This was due to Covid-19 and that the laboratories equipment could not be accessed. Instead, more time was spend on the detail design, and designing reinforcements had a bigger part than planned. Also, sending drawings to the manufacturers the manufacturing step was advanced.

# Appendix B Interviews and user tests

## B.1 Interview with user, father and physiotherapist

### B.1.1 Understanding the usage

- For what and why will she use it?
  She wants to use it in the house, short walks between rooms, for the pleasure of standing and being able to walk alone. Never for the outside.
- How many times a day/week?
  When she has fully recovered from her last operation she wants to use it a few times a day.
- How long for each time?
  Approximately 5 min
- How far?
  Between different rooms inside the house. For example between the kitchen and the toilet.
- What are the difficulties while using it?
  She needs two or three people to lift her up from sitting position to standing in the walker as it is now.

### B.1.2 Movements

- Can she lean and support on her legs at all?
  No, the walker must support the full weight.
- Can she balance when on it?
  Yes, when on it she keeps her balance without problem.
- Can it move in any direction?
  She can move in all directions but right now after her operation she has a harder time to move to the right.
- Can she stop it by herself?
  Yes

### B.1.3 Further comments:

- She doesn't want a security belt or other things holding her because she needs and wants to move freely.
- She can lean forward and backwards approximately 30 degrees without problem. She can’t lean to the sides at all.
- She can lift her left shoulder a lot (appr 90 degrees) and the right shoulder a little bit (appr 45 degrees)
- She has recently done a leg operation and after that she lost a lot of muscle strength in her legs. Would be good with the walker to help her get back her strength.
- She needs someone to fix / block the walker when she is lifted on it so that it doesn’t move away.
- She really wants it to be able to work for both her chair and to the toilet. This would be very good to ease the work of her assistants.
- It would be good with a handle for the assistant to be able to help her move the walker if necessary.
- She can’t click on normal smartphone screens but she can click on pressure sensitive screens.
- Would need an emergency button if she is positioned wrong in any way.

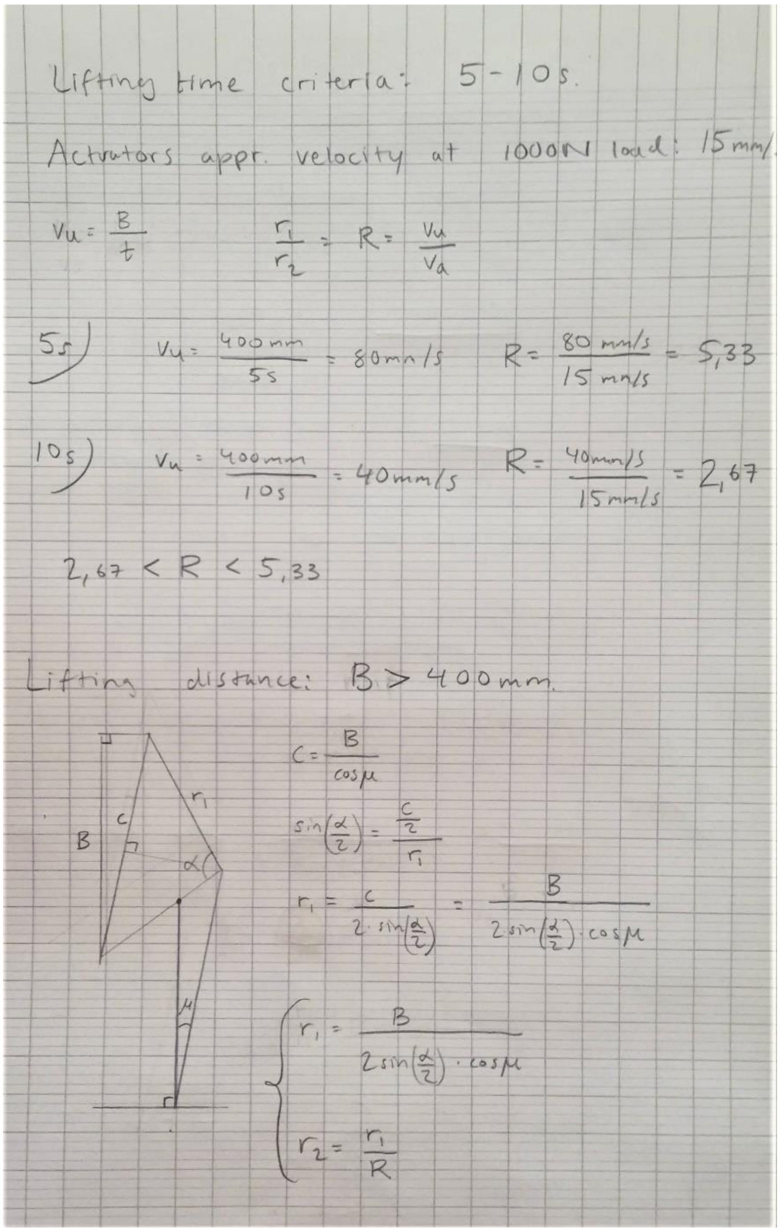
### B.1.4 Ergonomics

- Is the walker now good?
  Yes the size and dimensions of the existing walker is good.
- Do the armrests hold her well under the armpits?
  Yes, they hold her well but she would like to have them bent instead of straight for further comfort and also for security reasons. After testing it was also noticed that it would be better to have fixed armrests and not flexible ones.
- Is it possible to lift it vertically / diagonally?
  Yes, it shouldn't be any problem.
- Is it necessary with additional support to lift it? (security)
  The physiotherapist says no.
- If there are specific ergonomics things we need to think about:
  - when we lift it
  - when she is standing
  - to walk

  The physiotherapist says no.
- What is her specific situation?
  She was born with a lot of spinal problems, has done several spinal operations since.)

# Appendix C Calculations

## C.1 Dimensions linkage



Lifting time criteria: 5-10s.

Actuators appr. velocity at 1000N load: 15mm/

$v_u = \frac{B}{t}$ $\frac{r_1}{r_2} = R = \frac{v_u}{v_a}$

5s) $v_u = \frac{400\,mm}{5\,s} = 80\,mm/s$ $R = \frac{80\,mm/s}{15\,mm/s} = 5{,}33$

10s) $v_u = \frac{400\,mm}{10\,s} = 40\,mm/s$ $R = \frac{40\,mm/s}{15\,mm/s} = 2{,}67$

$2{,}67 < R < 5{,}33$

Lifting distance: $B > 400\,mm$.

$C = \frac{B}{\cos\mu}$

$\sin\left(\frac{\alpha}{2}\right) = \frac{\frac{c}{2}}{r_1}$

$r_1 = \frac{c}{2 \cdot \sin\left(\frac{\alpha}{2}\right)} = \frac{B}{2\sin\left(\frac{\alpha}{2}\right)\cdot\cos\mu}$

$$\begin{cases} r_1 = \frac{B}{2\sin\left(\frac{\alpha}{2}\right)\cdot\cos\mu} \\ r_2 = \frac{r_1}{R} \end{cases}$$

Determines that:

R = 2,67 - good with slow lift
- bigger min α if R smaller ⇒ good

B = 500mm - the bigger the smaller $r_1$ ⇒ good
- 100mm extra if toilet or other chair is lower

μ = 5° - the smaller the smaller $r_1$ ⇒ good
- needs to be somewhat leaning from advantages found in the further concept development.

tries different α

α = 90°) $r_1$ = 354,9 mm
$r_2$ = 132,9 mm

large

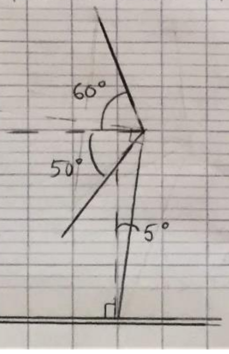
α = 100°) $r_1$ = 327,6 mm
$r_2$ = 122,7 mm

α = 110°) $r_1$ = 306,3 mm ⟸ best alternative
$r_2$ 114,7 mm

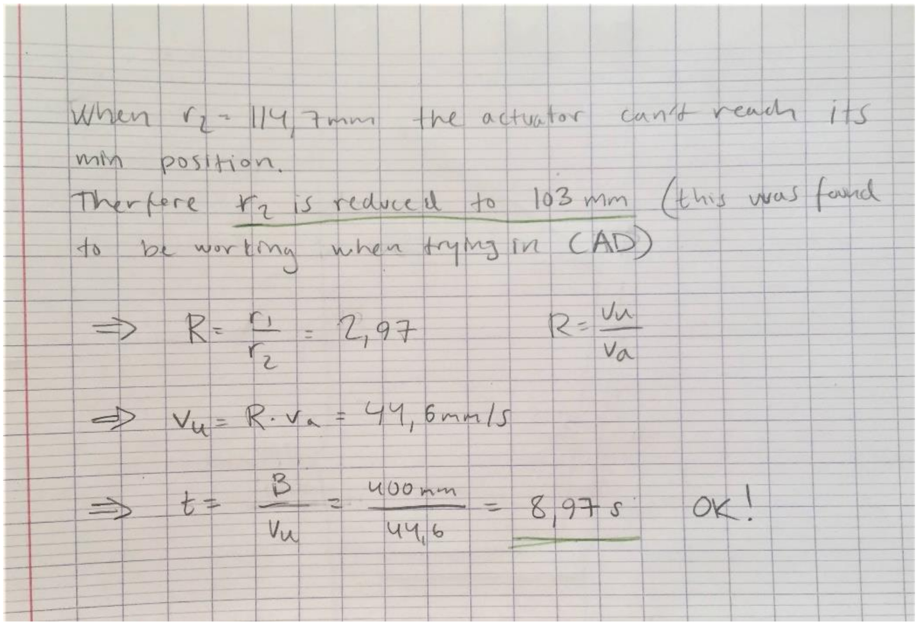
α = 120°) $r_1$ = 289,7 mm
$r_2$ = 108,5 mm

uncertain if it would work

⇒



max 60°
min-50°



When $r_2 = 114,7\,\text{mm}$ the actuator can't reach its min position.

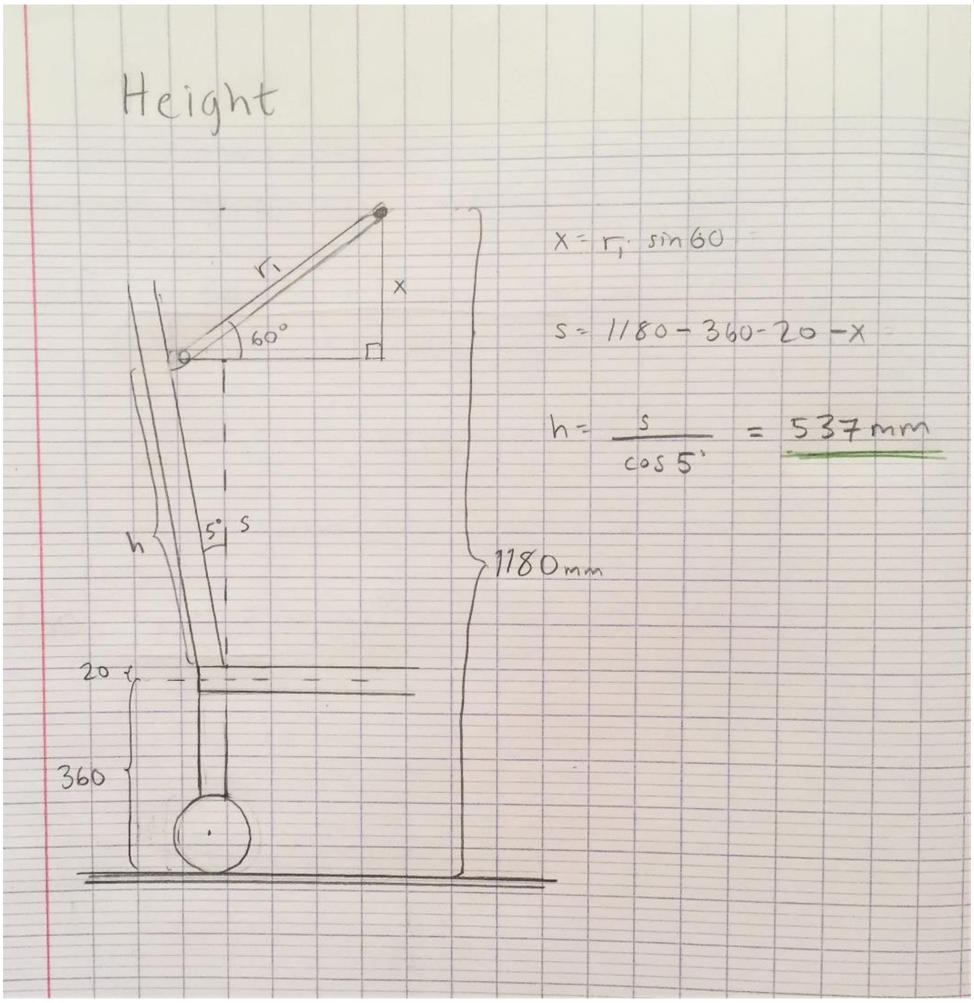
Therfore $r_2$ is reduced to $103\,\text{mm}$ (this was found to be working when trying in CAD)

$$\Rightarrow \quad R = \frac{r_1}{r_2} = 2,97 \qquad R = \frac{v_u}{v_a}$$

$$\Rightarrow \quad v_u = R \cdot v_a = 44,6\,\text{mm/s}$$

$$\Rightarrow \quad t = \frac{B}{v_u} = \frac{400\,\text{mm}}{44,6} = \underline{8,97\,\text{s}} \qquad \text{OK!}$$

## C.2 Height drawing and calculation



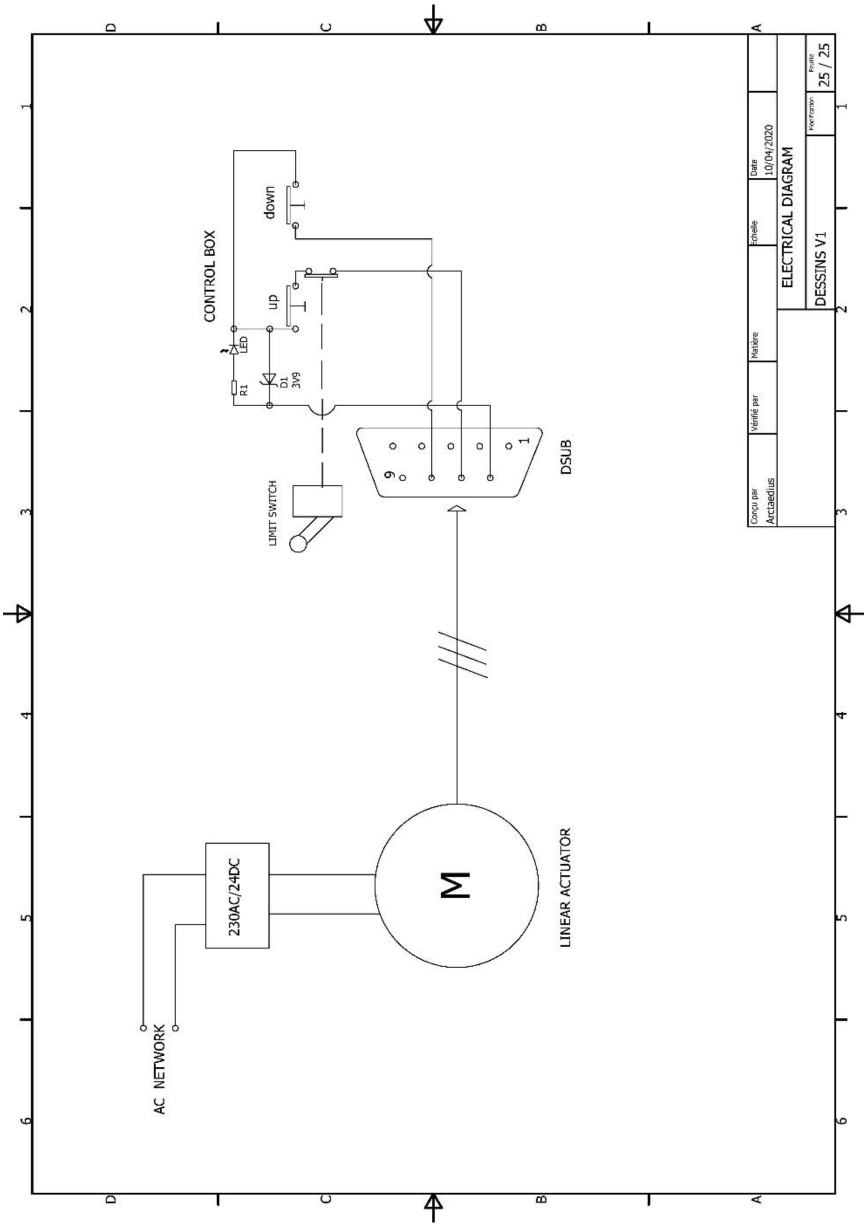
$x = r_1 \cdot \sin 60$

$s = 1180 - 360 - 20 - x$

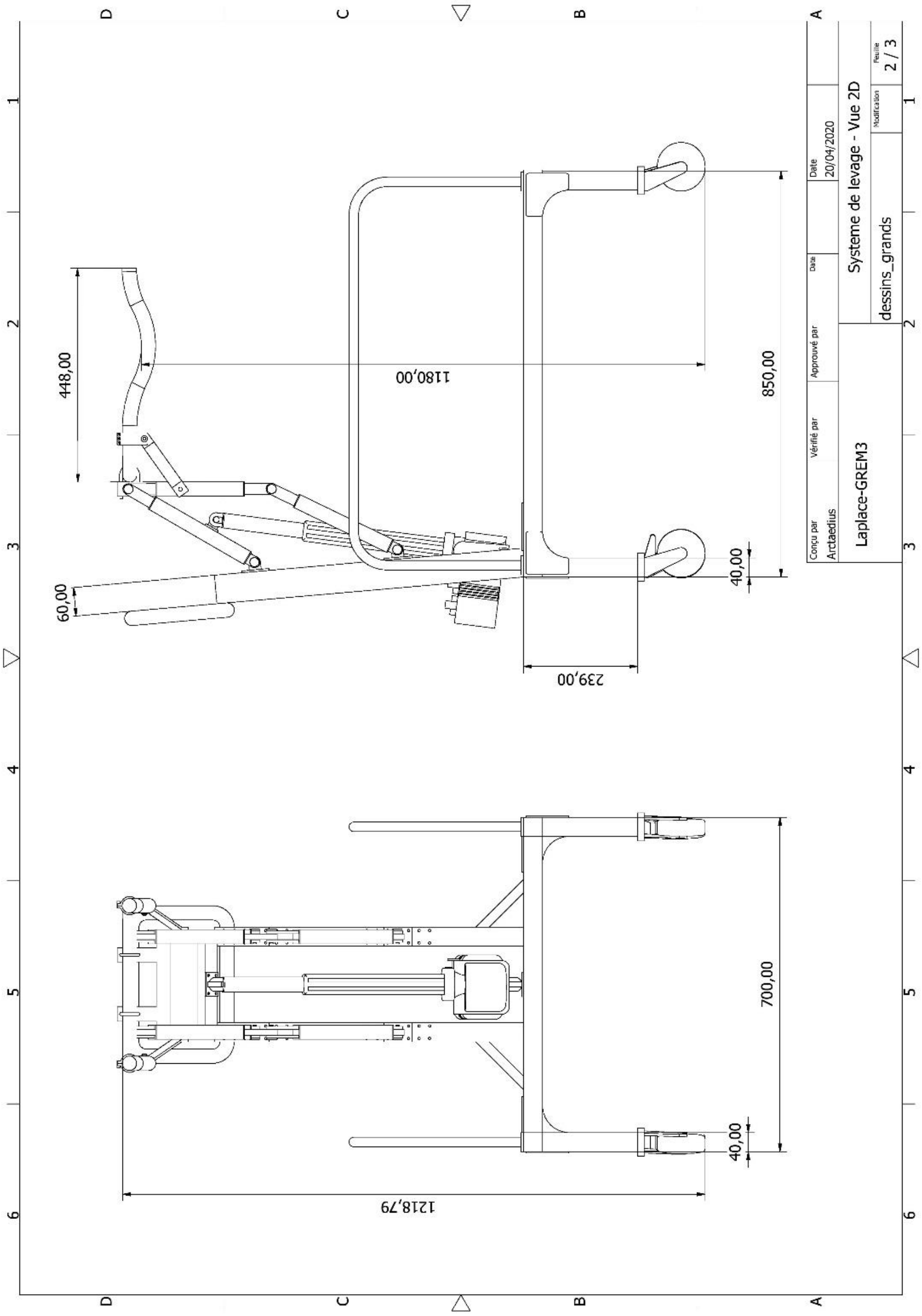
$h = \dfrac{s}{\cos 5^\circ} = \underline{537\,mm}$

# Appendix D Drawings

## D.1 Electrical Diagram

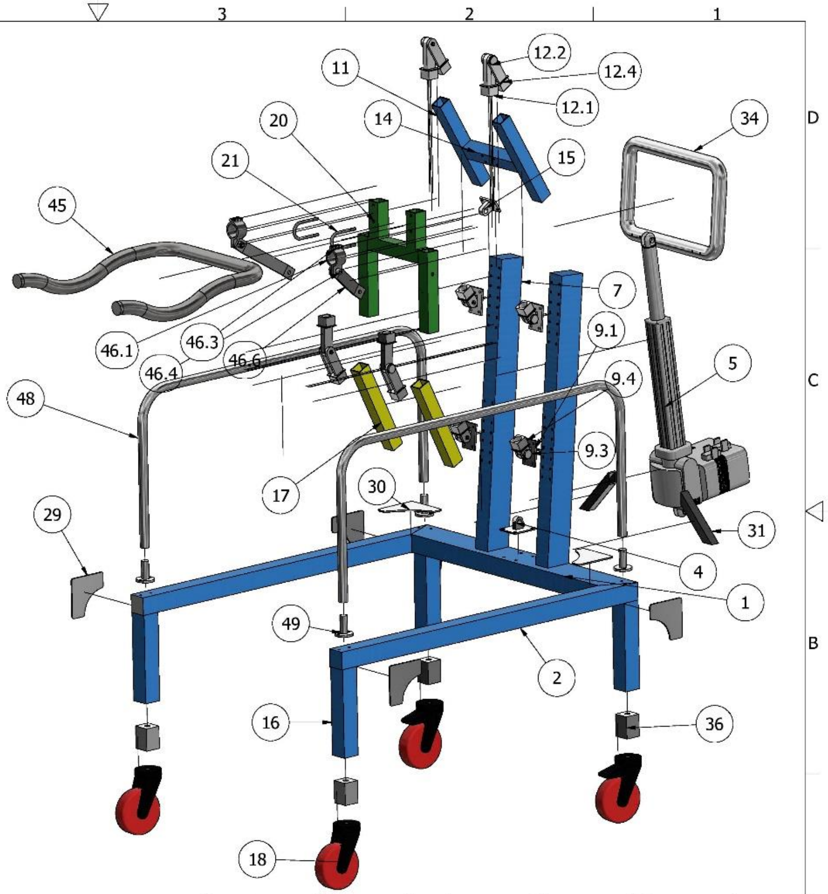


## D.2 Construction Drawings



LISTE DE PIECES

| ARTICLE | QTE | NUMERO DE PIECE | DESCRIPTION |
|---|---|---|---|
| 1 | 1 | avant bras | alu |
| 2 | 2 | bras | alu |
| 4 | 1 | base pivot verin | alu |
| 5 | 1 | linear actuator | Matrix 7, Ewellix |
| 7 | 2 | montant | alu, inserts M5 |
| 9.1 | 4 | base pivot | alu |
| 9.2 | 4 | coussinet | polymère, HPC |
| 9.3 | 8 | axe pivot | alu |
| 9.4 | 4 | pivot court | alu |
| 11 | 2 | barre parrallel b1 | alu |
| 12.1 | 4 | demi-pivot long | alu |
| 12.2 | 8 | axe pivot | alu |
| 12.3 | 8 | coussinet | polymère, HPC |
| 12.4 | 4 | pivot long | alu |
| 14 | 1 | barre parallel b2 | alu |
| 15 | 1 | haut pivot verin | alu |
| 16 | 4 | jambe | alu |
| 17 | 2 | barre parrallel j1 | alu |
| 18 | 2 | roulette | Tango, Hervieu |
| 20 | 1 | parallel devant | alu |
| 21 | 1 | cavalier | acier |
| 29 | 6 | renfort jambes | alu |
| 30 | 2 | renfort bras | alu |
| 31 | 2 | renfort montant | alu |
| 34 | 1 | manipulateur | inox |
| 36 | 4 | tube roulettes | alu |
| 45 | 1 | accoudoirs | inox |
| 46.1 | 1 | bride guidon | acier |
| 46.3 | 3 | AS 1420 - 1973 - M4 x 8 | Vis cylindriques à six pans creux, ISO |
| 46.4 | 1 | AS 1420 - 1973 - M8 x 25 | Vis cylindriques à six pans creux, ISO |
| 46.5 | 1 | AS 1112 - M8 Type 5 | Ecrous hexagonaux, ISO |
| 46.6 | 1 | patte guidon | acier |
| 48 | 2 | soutien | inox |
| 49 | 4 | tube soutien | alu |
| 50 | 4 | AS 1112 - M6 Type 5 | Ecrous hexagonaux métriques ISO, comprenant des écrous bas, à créneaux et à créneaux dégagés |



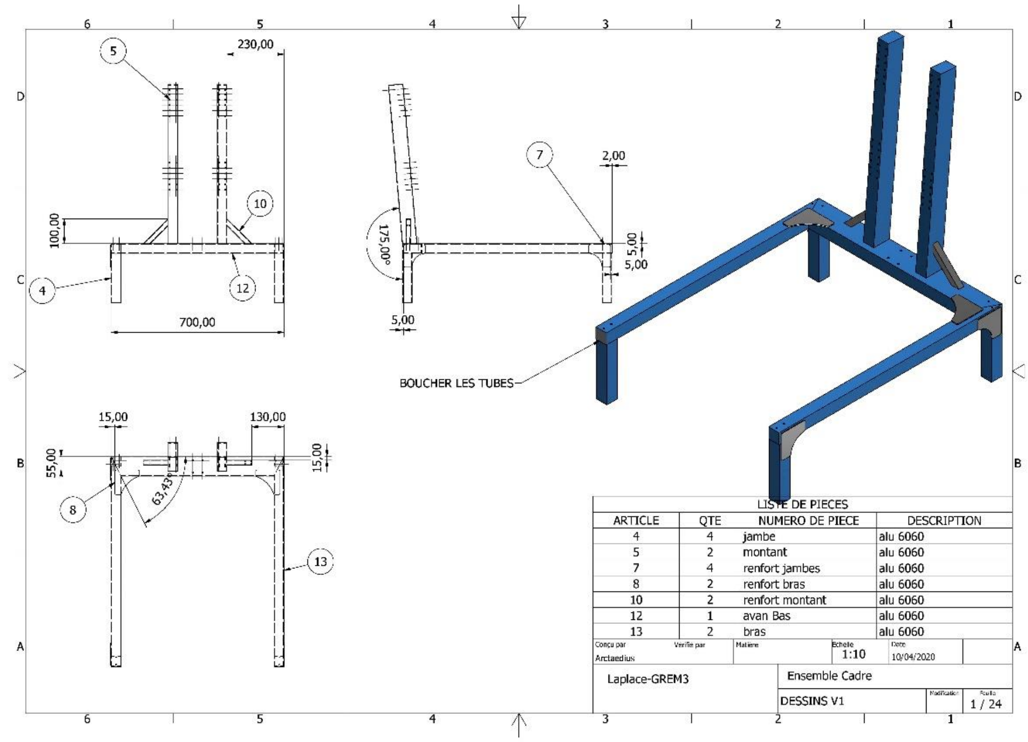
| Conçu par | Vérifié par | Approuvé par | Date | Date |
|---|---|---|---|---|
| Arctaedius | | | | 20/04/2020 |

Laplace-GREM3

Systeme de levage - Vue Éclaté

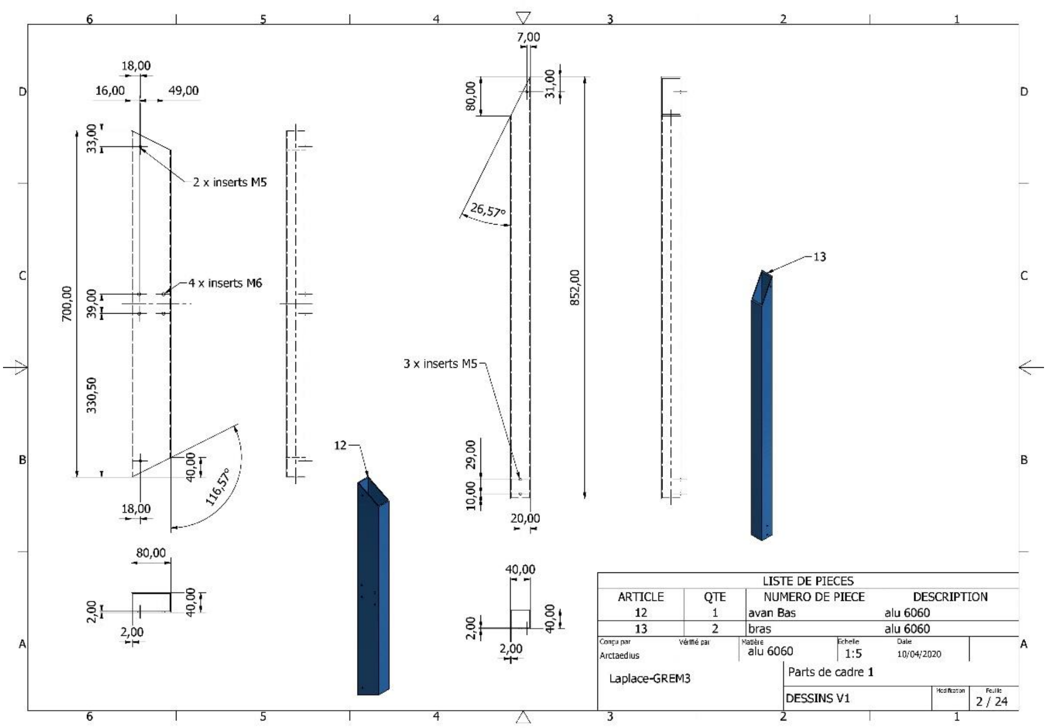
dessins_grands

| Modification | Feuille |
|---|---|
| | 3 / 3 |



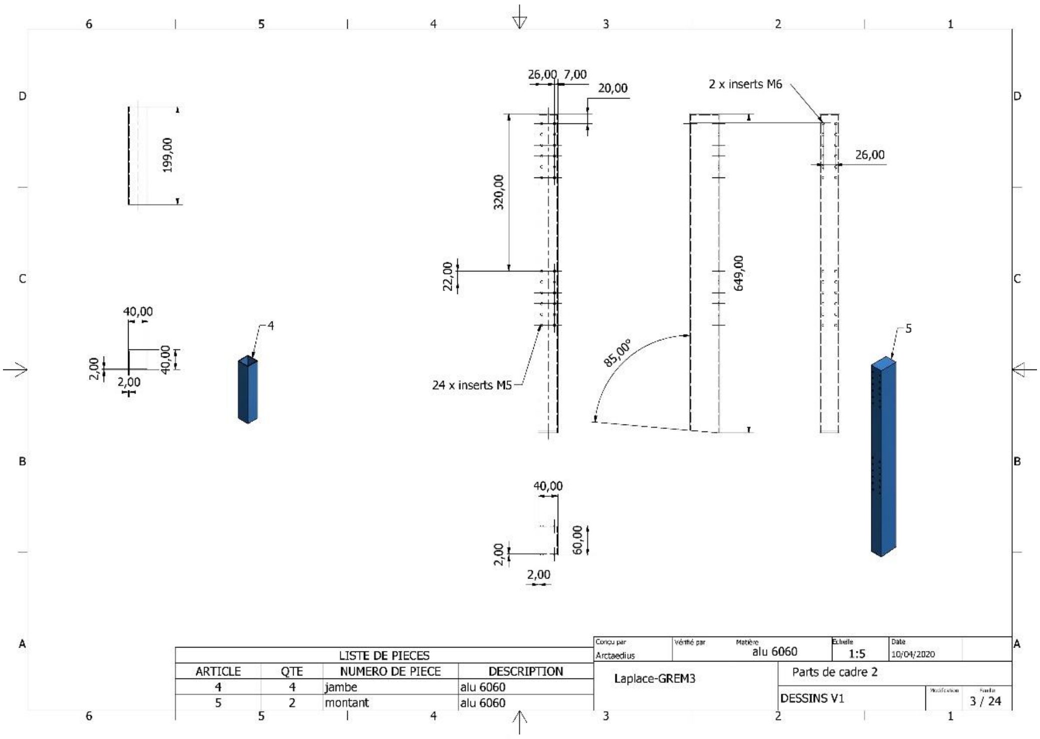
| ARTICLE | QTE | NUMERO DE PIECE | DESCRIPTION |
|---|---|---|---|
| 4 | 4 | jambe | alu 6060 |
| 5 | 2 | montant | alu 6060 |
| 7 | 4 | renfort jambes | alu 6060 |
| 8 | 2 | renfort bras | alu 6060 |
| 10 | 2 | renfort montant | alu 6060 |
| 12 | 1 | avan Bas | alu 6060 |
| 13 | 2 | bras | alu 6060 |

Conçu par Arctaedius
Verifie par
Matiere
Echelle 1:10
Date 10/04/2020
Laplace-GREM3
Ensemble Cadre
DESSINS V1
Modification
Feuille 1 / 24



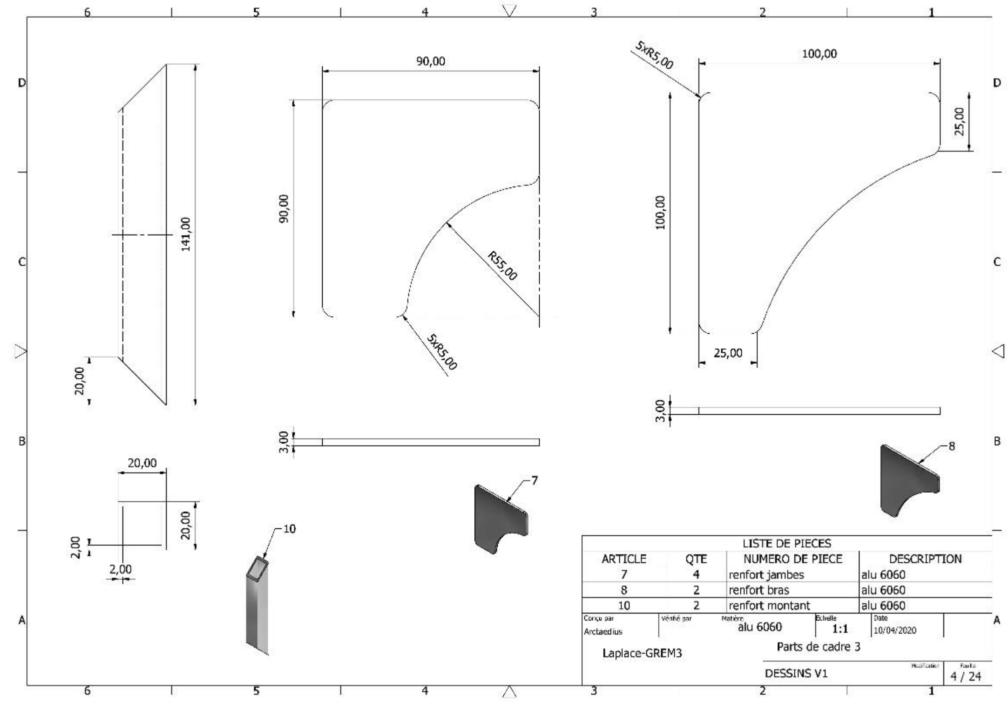
| ARTICLE | QTE | NUMERO DE PIECE | DESCRIPTION |
|---|---|---|---|
| 12 | 1 | avan Bas | alu 6060 |
| 13 | 2 | bras | alu 6060 |

Conçu par Arctaedius
Vérifié par
Matière alu 6060
Echelle 1:5
Date 10/04/2020
Laplace-GREM3
Parts de cadre **1**
DESSINS V1
Modification
Feuille 2 / 24



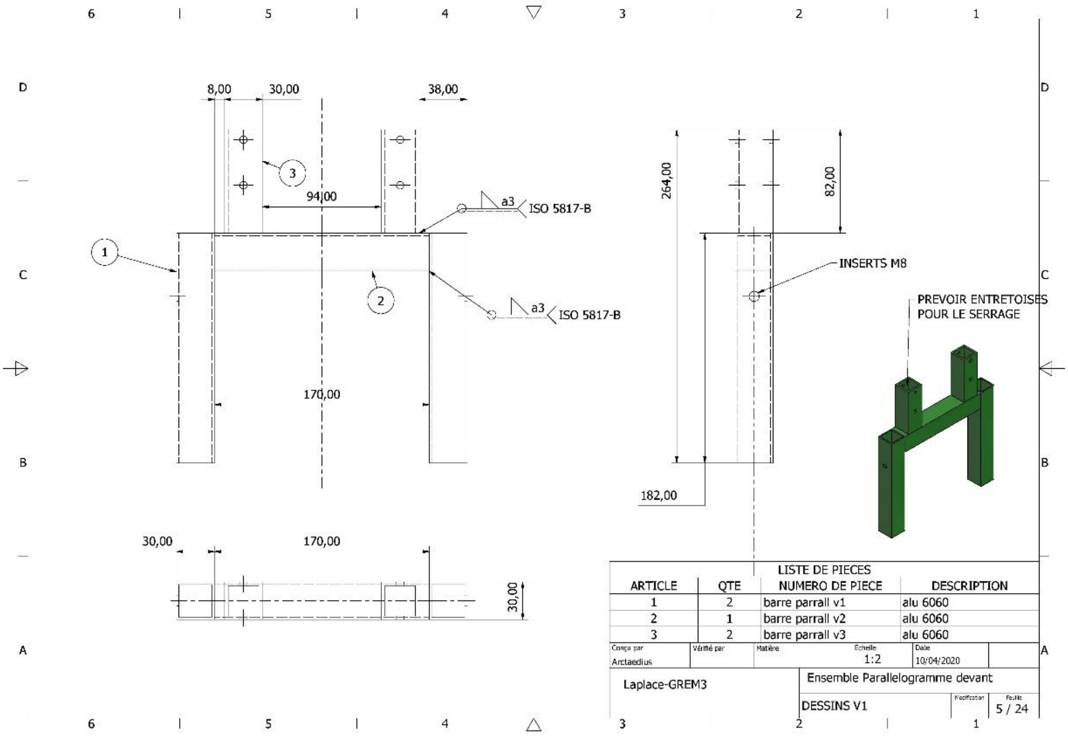
| LISTE DE PIECES | | | |
|---|---|---|---|
| ARTICLE | QTE | NUMERO DE PIECE | DESCRIPTION |
| 4 | 4 | jambe | alu 6060 |
| 5 | 2 | montant | alu 6060 |

Conçu par
Arctaedius
Vérifié par
Matière
alu 6060
Echelle
1:5
Date
10/04/2020
Laplace-GREM3
Parts de cadre 2
DESSINS V1
Modification
Feuille
3 / 24



| LISTE DE PIECES | | | |
|---|---|---|---|
| ARTICLE | QTE | NUMERO DE PIECE | DESCRIPTION |
| 7 | 4 | renfort jambes | alu 6060 |
| 8 | 2 | renfort bras | alu 6060 |
| 10 | 2 | renfort montant | alu 6060 |

Conçu par
Arctaedius
Vérifié par
Matière
alu 6060
Echelle
1:1
Date
10/04/2020
Laplace-GREM3
Parts de cadre 3
DESSINS V1
Modification
Feuille
4 / 24

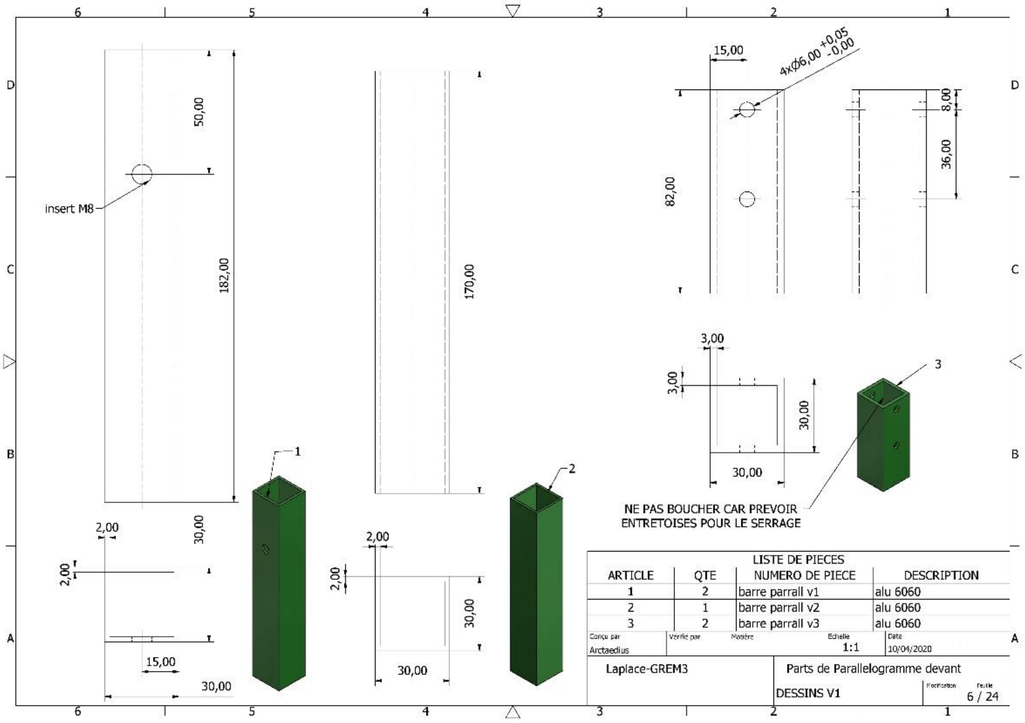


LISTE DE PIECES

| ARTICLE | QTE | NUMERO DE PIECE | DESCRIPTION |
|---|---|---|---|
| 1 | 2 | barre parrall v1 | alu 6060 |
| 2 | 1 | barre parrall v2 | alu 6060 |
| 3 | 2 | barre parrall v3 | alu 6060 |

| Conçu par | Vérifié par | Matière | Echelle | Date |
|---|---|---|---|---|
| Arctaedius | | | 1:2 | 10/04/2020 |

Laplace-GREM3
Ensemble Parallelogramme devant
DESSINS V1
Modification
Feuille 5 / 24

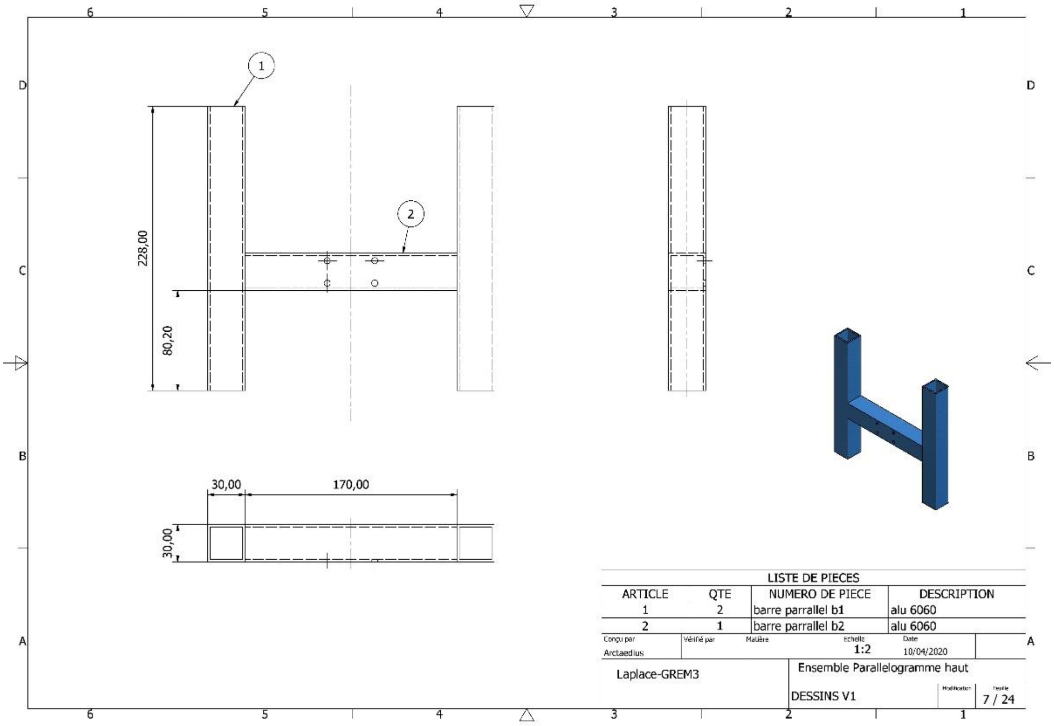


LISTE DE PIECES

| ARTICLE | QTE | NUMERO DE PIECE | DESCRIPTION |
|---|---|---|---|
| 1 | 2 | barre parrall v1 | alu 6060 |
| 2 | 1 | barre parrall v2 | alu 6060 |
| 3 | 2 | barre parrall v3 | alu 6060 |

| Conçu par | Vérifié par | Matière | Echelle | Date |
|---|---|---|---|---|
| Arctaedius | | | 1:1 | 10/04/2020 |

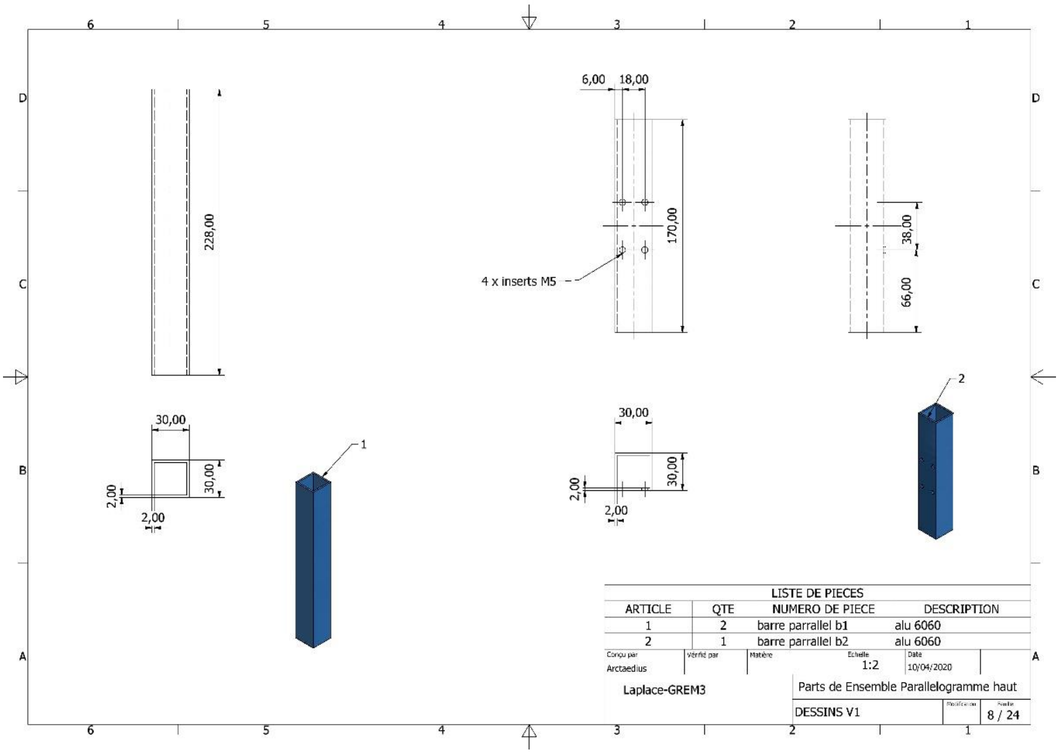
Laplace-GREM3
Parts de Parallelogramme devant
DESSINS V1
Modification
Feuille 6 / 24



LISTE DE PIECES

| ARTICLE | QTE | NUMERO DE PIECE | DESCRIPTION |
|---|---|---|---|
| 1 | 2 | barre parrallel b1 | alu 6060 |
| 2 | 1 | barre parrallel b2 | alu 6060 |

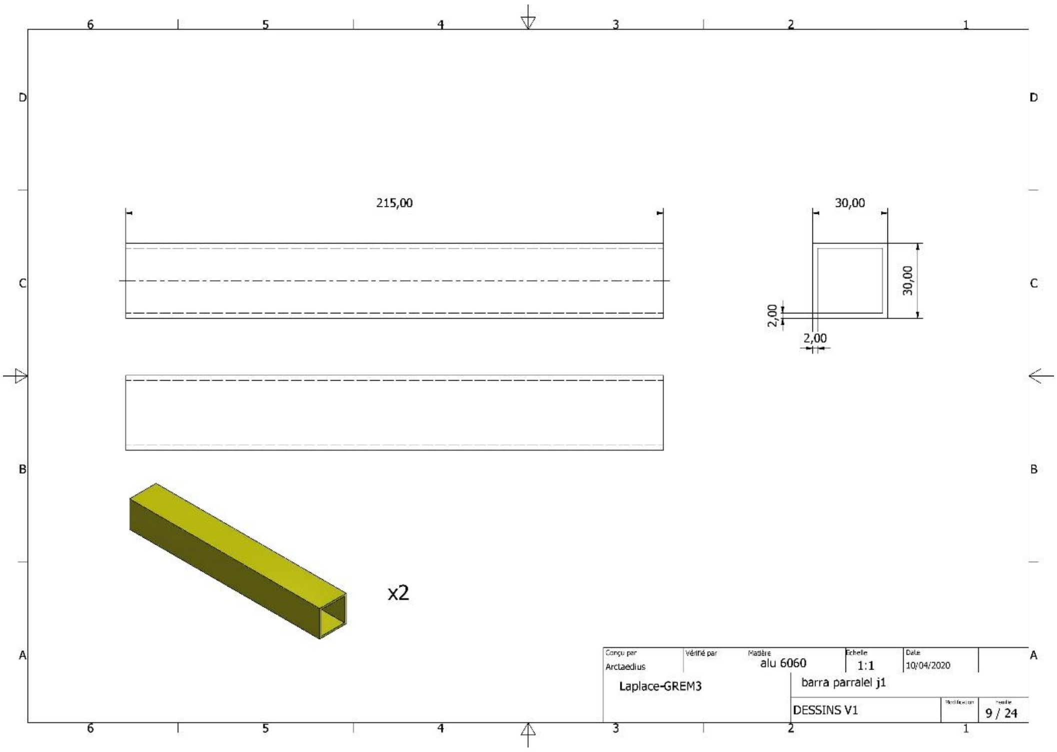
Conçu par Arctaedius
Vérifié par
Matière
Echelle 1:2
Date 10/04/2020
Laplace-GREM3
Ensemble Parallelogramme haut
DESSINS V1
Modification
Feuille 7 / 24



LISTE DE PIECES

| ARTICLE | QTE | NUMERO DE PIECE | DESCRIPTION |
|---|---|---|---|
| 1 | 2 | barre parrallel b1 | alu 6060 |
| 2 | 1 | barre parrallel b2 | alu 6060 |

Conçu par Arctaedius
Vérifié par
Matière
Echelle 1:2
Date 10/04/2020
Laplace-GREM3
Parts de Ensemble Parallelogramme haut
DESSINS V1
Modification
Feuille 8 / 24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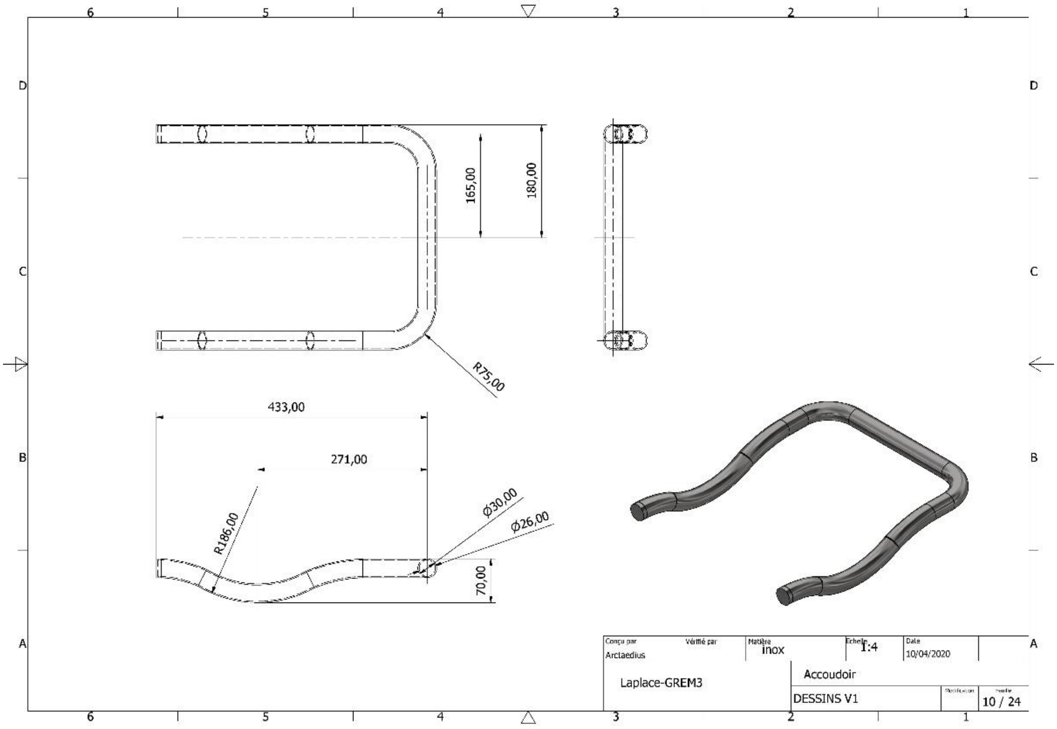
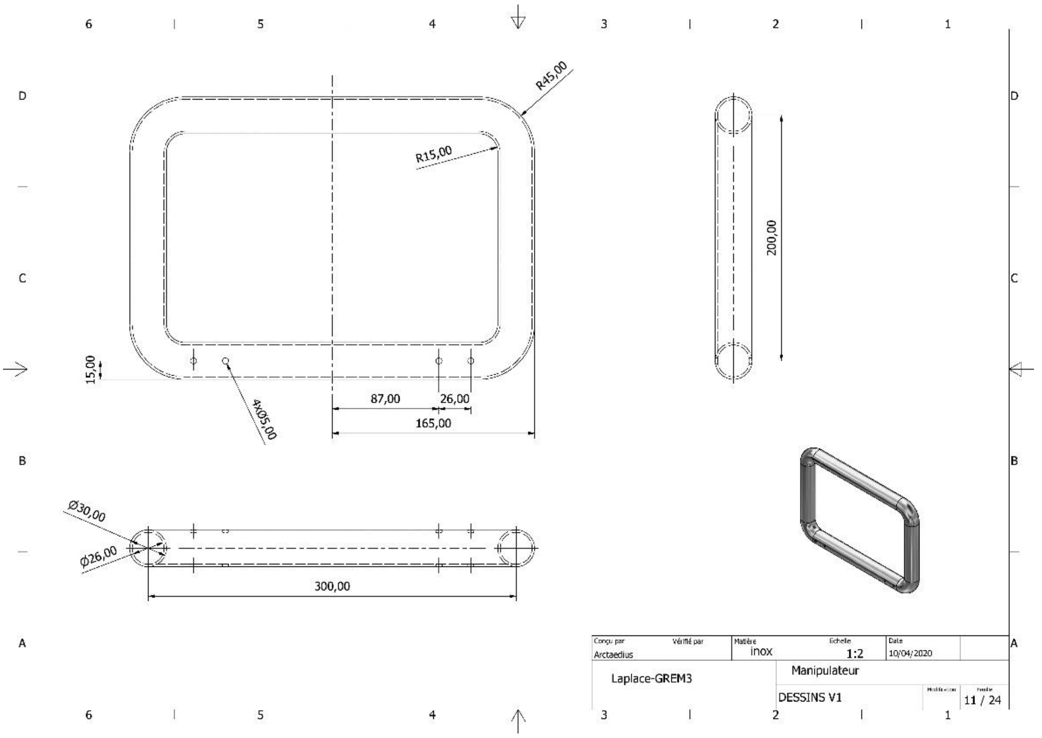
30,00
30,00
2,00
2,00
x2
Conçu par
Arctaedius
Vérifié par
Matière
alu 6060
Echelle
1:1
Date
10/04/2020
Laplace-GREM3
barra parralel j1
DESSINS V1
Modification
Feuille
9 / 24


165,00
180,00
R75,00
433,00
271,00
R186,00
Ø30,00
Ø26,00
70,00
Conçu par
Arctaedius
Vérifié par
Matière
inox
Echelle
1:4
Date
10/04/2020
Laplace-GREM3
Accoudoir
DESSINS V1
Modification
Feuille
10 / 24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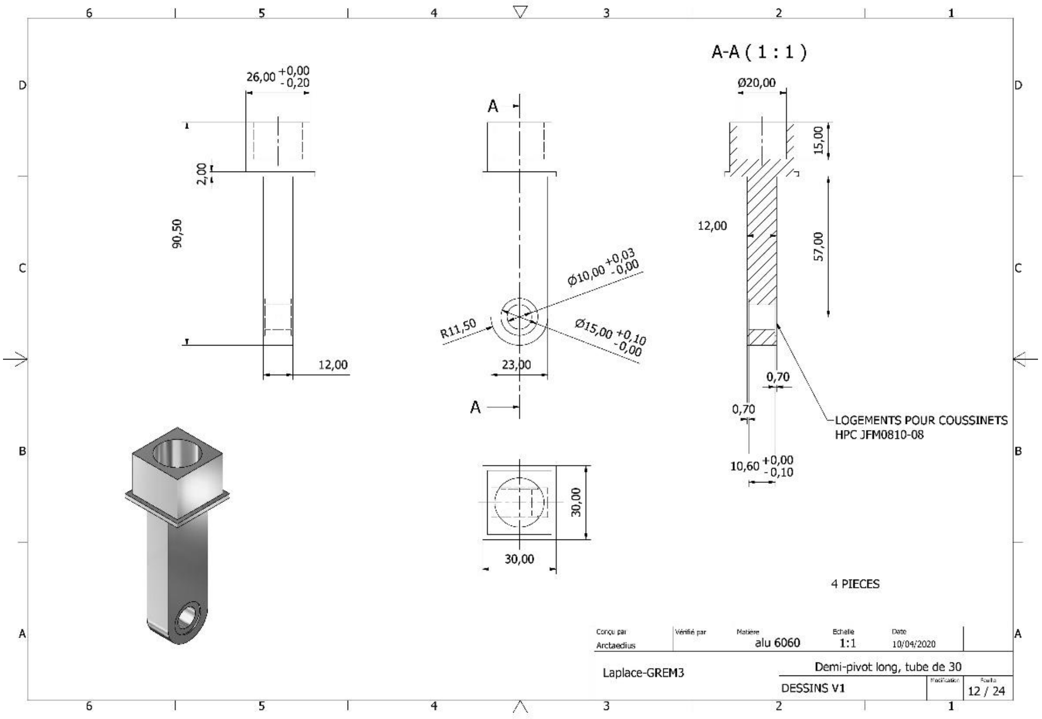
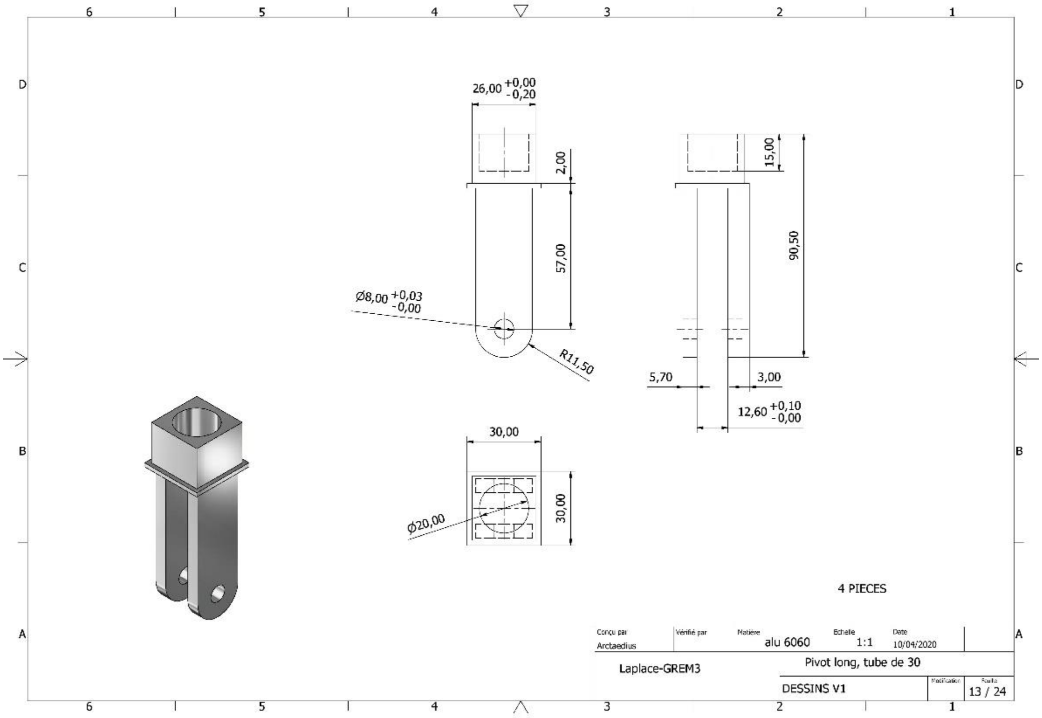
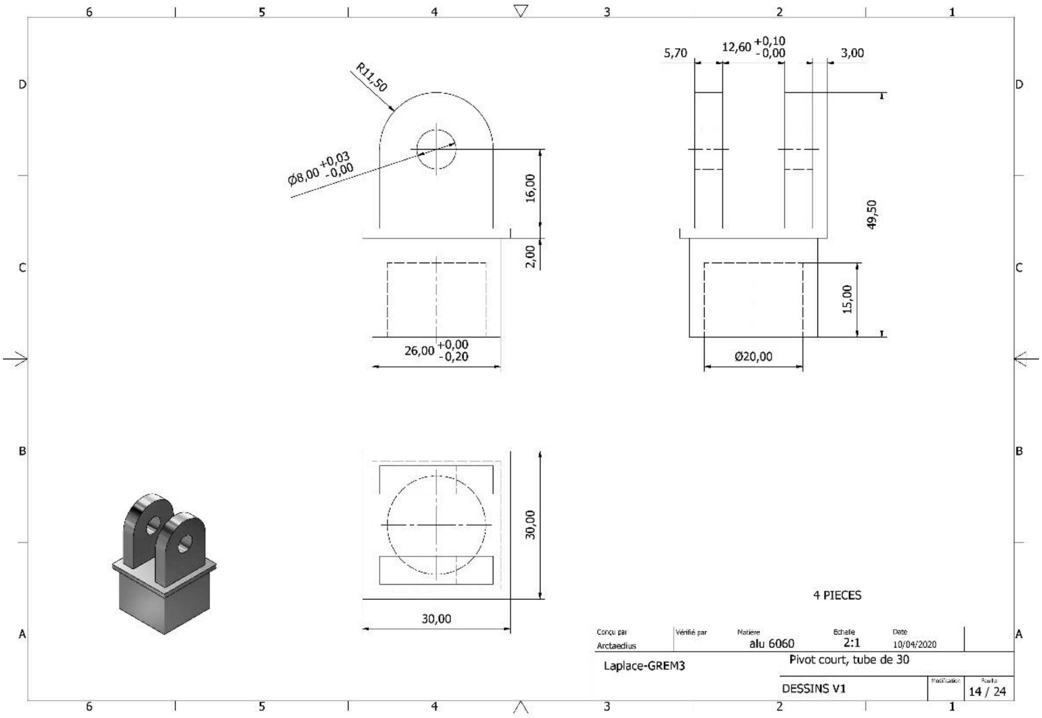
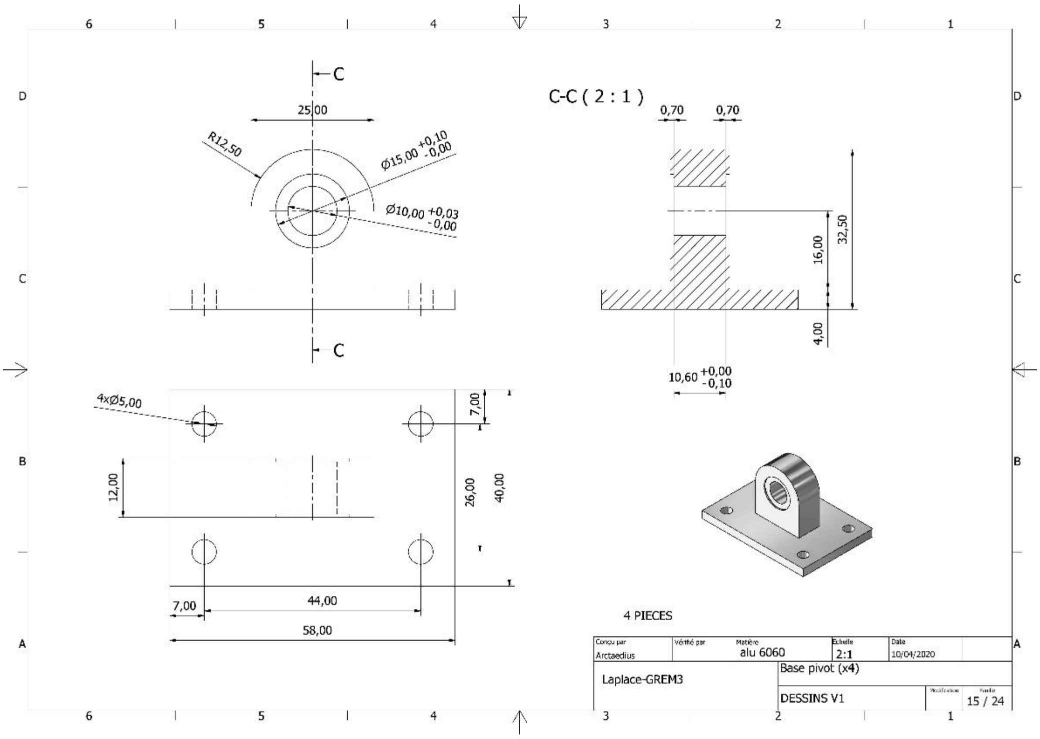
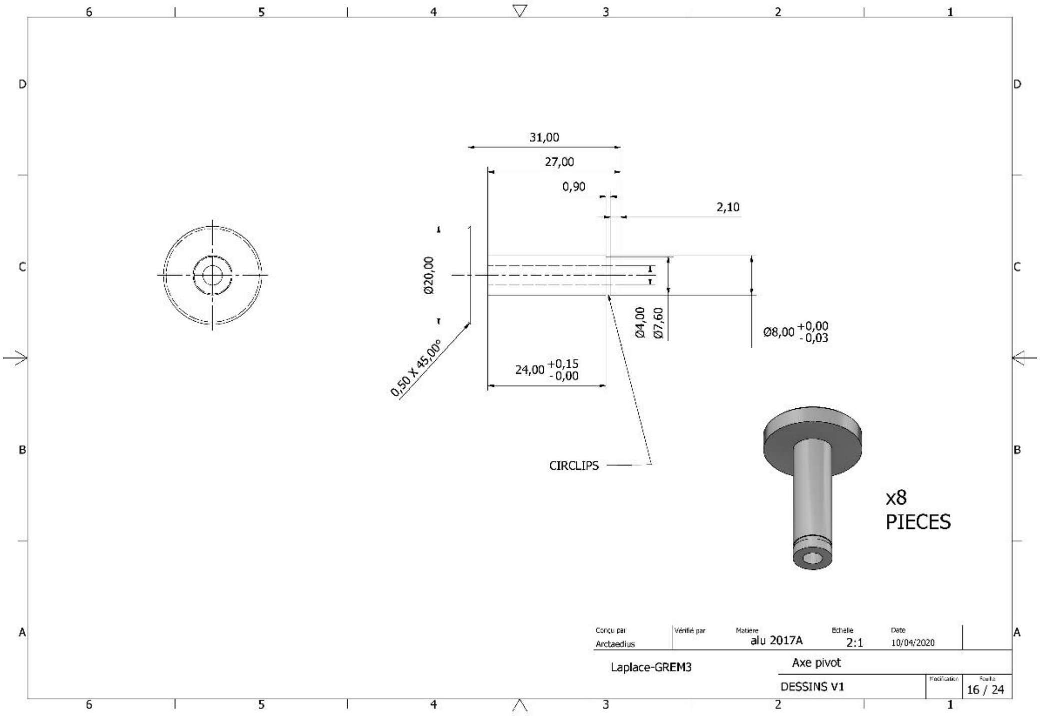
R15,00
200,00
15,00
4XØ5,00
87,00
26,00
165,00
Ø30,00
Ø26,00
300,00
Conçu par
Arctaedius
Vérifié par
Matière
inox
Echelle
1:2
Date
10/04/2020
Laplace-GREM3
Manipulateur
DESSINS V1
11 / 24


A-A ( 1 : 1 )
26,00 +0,00 -0,20
2,00
90,50
12,00
A
Ø10,00 +0,03 -0,00
R11,50
Ø15,00 +0,10 -0,00
23,00
A
30,00
30,00
Ø20,00
15,00
12,00
57,00
0,70
0,70
10,60 +0,00 -0,10
LOGEMENTS POUR COUSSINETS
HPC JFM0810-08
4 PIECES
Conçu par
Arctaedius
Vérifié par
Matière
alu 6060
Echelle
1:1
Date
10/04/2020
Laplace-GREM3
Demi-pivot long, tube de 30
DESSINS V1
12 / 24


26,00 +0,00 -0,20
2,00
57,00
15,00
90,50
Ø8,00 +0,03 -0,00
R11,50
5,70
3,00
12,60 +0,10 -0,00
30,00
30,00
Ø20,00
4 PIECES
Conçu par
Arctaedius
Vérifié par
Matière
alu 6060
Echelle
1:1
Date
10/04/2020
Laplace-GREM3
Pivot long, tube de 30
DESSINS V1
13 / 24


R11,50
Ø8,00 +0,03 -0,00
16,00
2,00
26,00 +0,00 -0,20
5,70
12,60 +0,10 -0,00
3,00
49,50
15,00
Ø20,00
30,00
30,00
4 PIECES
Conçu par
Arctaedius
Vérifié par
Matière
alu 6060
Echelle
2:1
Date
10/04/2020
Laplace-GREM3
Pivot court, tube de 30
DESSINS V1
14 / 24


C
C
C-C ( 2 : 1 )
25,00
R12,50
Ø15,00 +0,10 -0,00
Ø10,00 +0,03 -0,00
0,70
0,70
32,50
16,00
4,00
10,60 +0,00 -0,10
4xØ5,00
7,00
12,00
26,00
40,00
7,00
44,00
58,00
4 PIECES
Conçu par
Arctaedius
Vérifié par
Matière
alu 6060
Echelle
2:1
Date
10/04/2020
Laplace-GREM3
Base pivot (x4)
DESSINS V1
Feuille
15 / 24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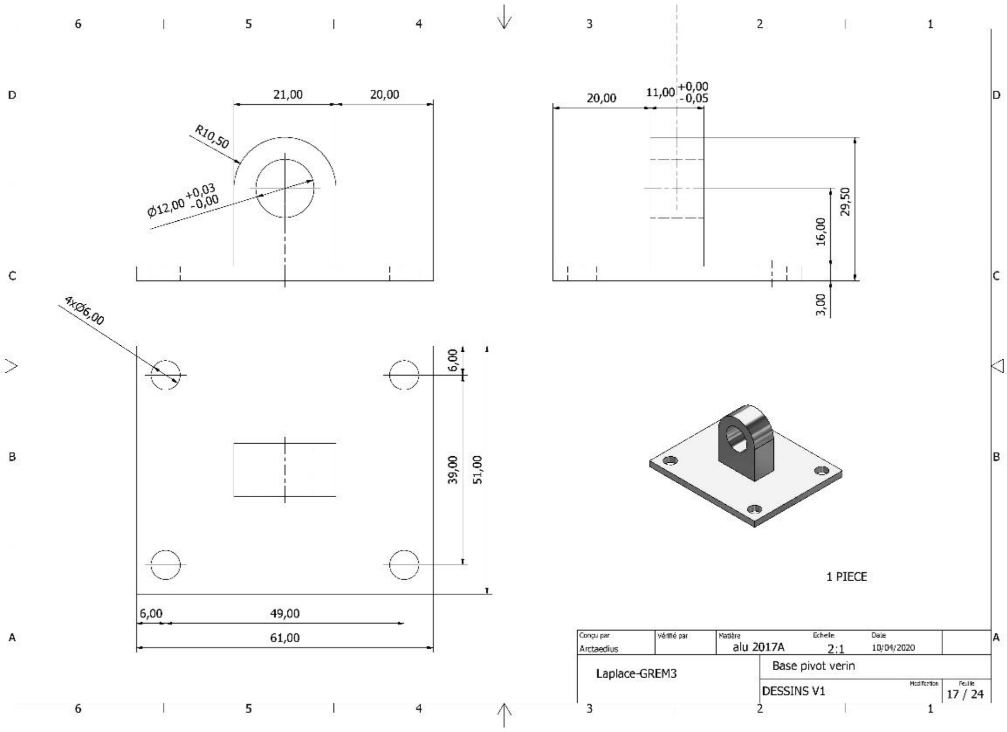
27,00
0,90
2,10
Ø20,00
Ø4,00
Ø7,60
Ø8,00 +0,00 -0,03
0,50 X 45,00°
24,00 +0,15 -0,00
CIRCLIPS
x8
PIECES
Conçu par
Arctaedius
Vérifié par
Matière
alu 2017A
Echelle
2:1
Date
10/04/2020
Laplace-GREM3
Axe pivot
DESSINS V1
Feuille
16 / 24



1 PIECE

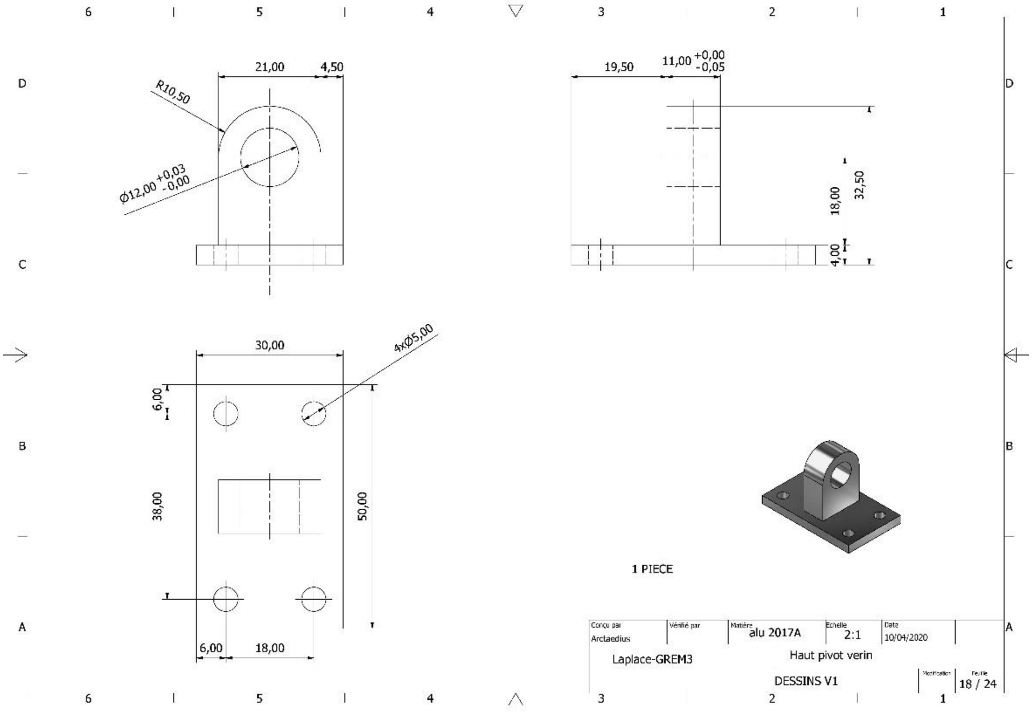
| Conçu par | Vérifié par | Matière | Echelle | Date | |
|---|---|---|---|---|---|
| Arctaedius | | alu 2017A | 2:1 | 10/04/2020 | |

Laplace-GREM3

Base pivot verin

DESSINS V1

| Modification | Feuille |
|---|---|
| | 17 / 24 |



1 PIECE

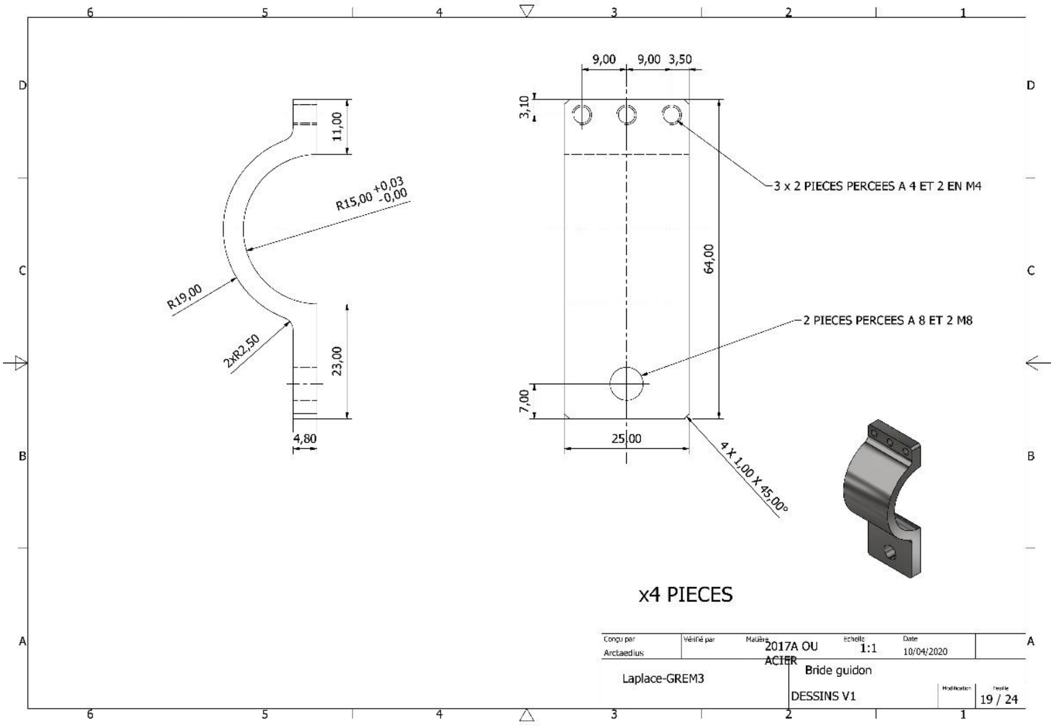
| Conçu par | Vérifié par | Matière | Echelle | Date | |
|---|---|---|---|---|---|
| Arctaedius | | alu 2017A | 2:1 | 10/04/2020 | |

Laplace-GREM3

Haut pivot verin

DESSINS V1

| Modification | Feuille |
|---|---|
| | 18 / 24 |

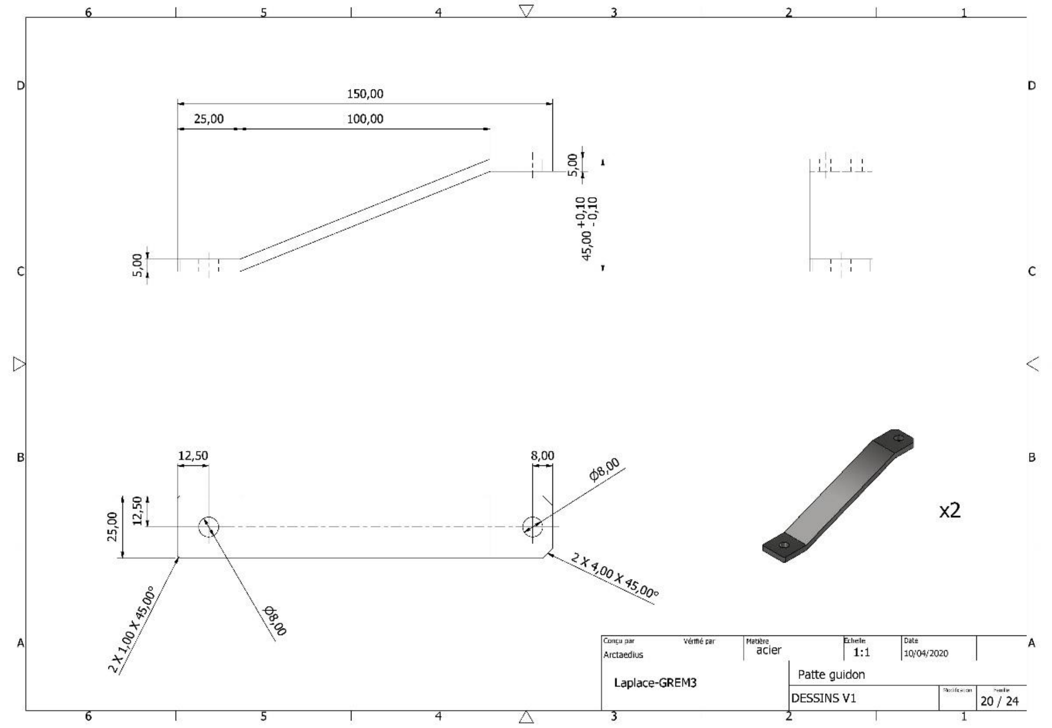


3 x 2 PIECES PERCEES A 4 ET 2 EN M4

2 PIECES PERCEES A 8 ET 2 M8

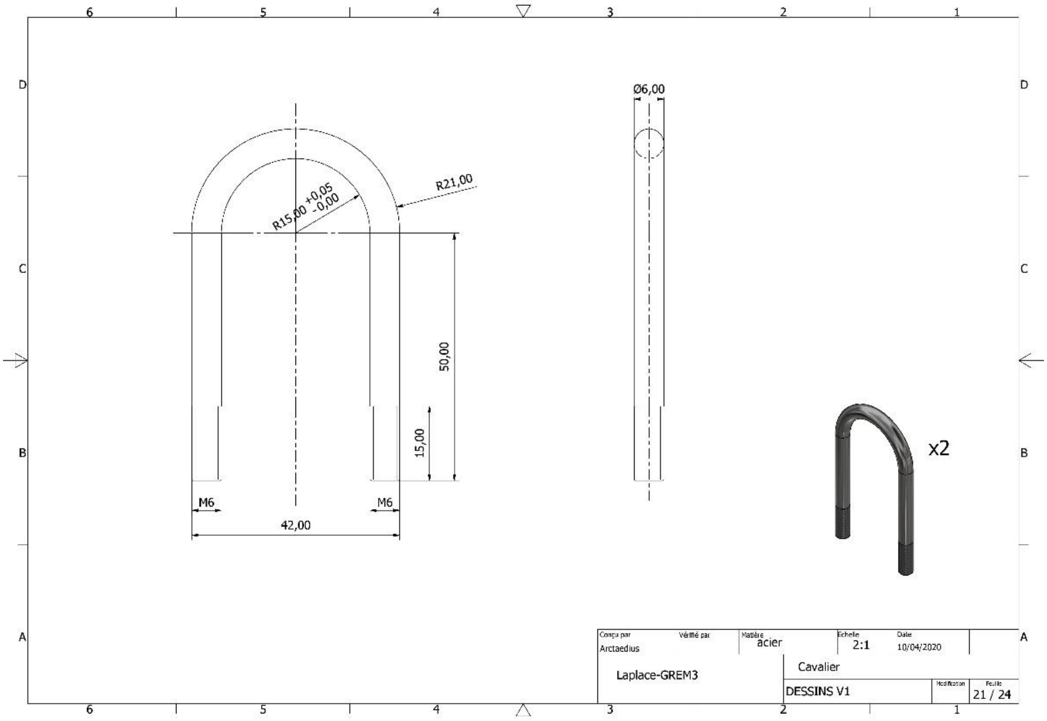
x4 PIECES

Conçu par: Arctaedius
Vérifié par:
Matière: 2017A OU ACIER
Echelle: 1:1
Date: 10/04/2020
Laplace-GREM3
Bride guidon
DESSINS V1
Modification:
Feuille: 19 / 24

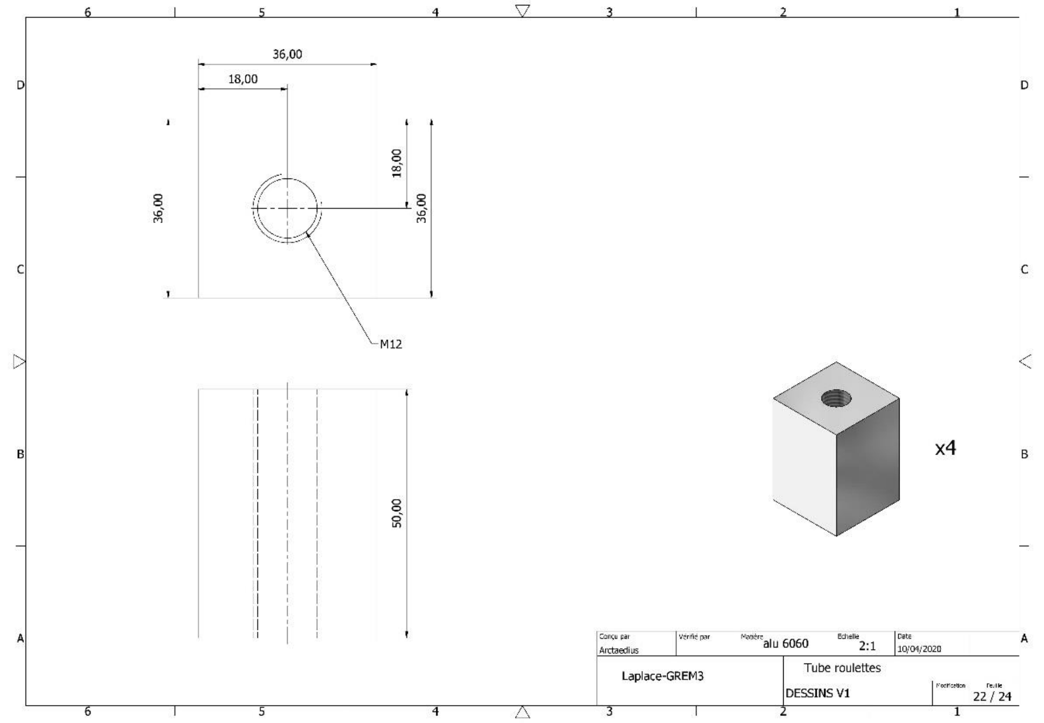


x2

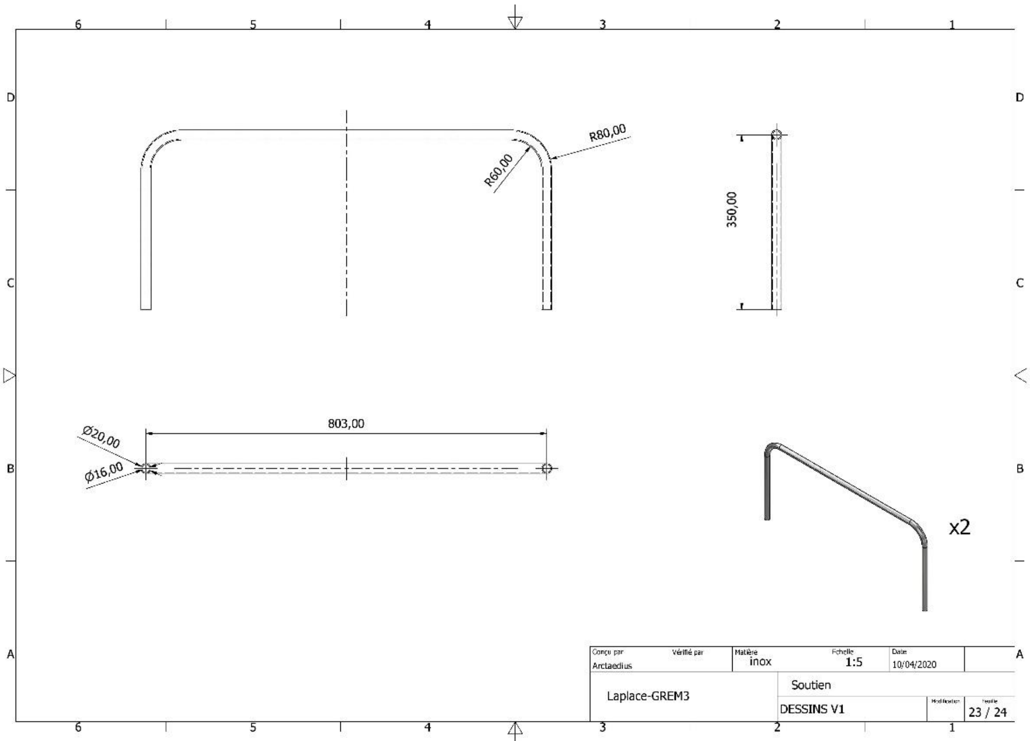
Conçu par: Arctaedius
Vérifié par:
Matière: acier
Echelle: 1:1
Date: 10/04/2020
Laplace-GREM3
Patte guidon
DESSINS V1
Modification:
Feuille: 20 / 24



| | | | | |
|---|---|---|---|---|
| Conçu par<br>Arctaedius | Vérifié par | Matière<br>acier | Echelle<br>2:1 | Date<br>10/04/2020 |
| Laplace-GREM3 | | Cavalier | | |
| | | DESSINS V1 | Modification | Feuille<br>21 / 24 |



| | | | | |
|---|---|---|---|---|
| Conçu par<br>Arctaedius | Vérifié par | Matière<br>alu 6060 | Echelle<br>2:1 | Date<br>10/04/2020 |
| Laplace-GREM3 | | Tube roulettes | | |
| | | DESSINS V1 | Modification | Feuille<br>22 / 24 |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R60,00
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x2
Conçu par
Arctaedius
Vérifié par
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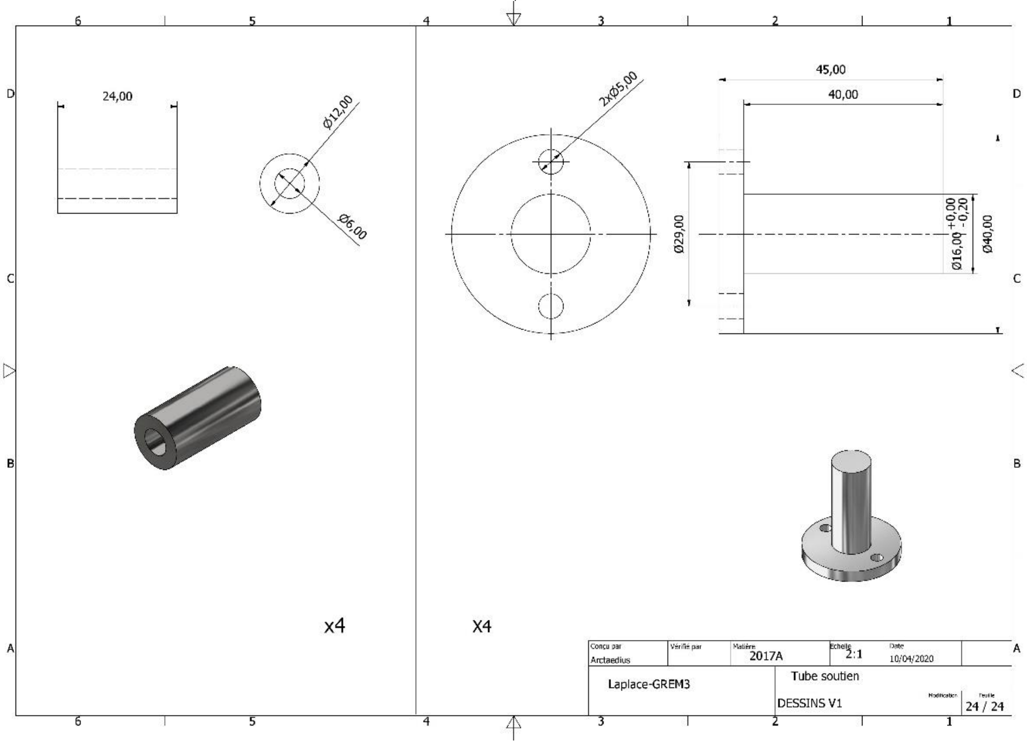
10/04/2020
Laplace-GREM3
Soutien
DESSINS V1
Modification
Feuille
23 / 24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Conçu par
Arctaedius
Vérifié par
Matière
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Echelle
2:1
Date
10/04/2020
Laplace-GREM3
Tube soutien
DESSINS V1
Modification
Feuille
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