ROLLMAT

WHEEL CLEANER

PRODUCT REPORT
/ AALBORG UNIVERSITY
/ SPRING 2022
/ INDUSTRIAL DESIGN
/ MSC04-ID05

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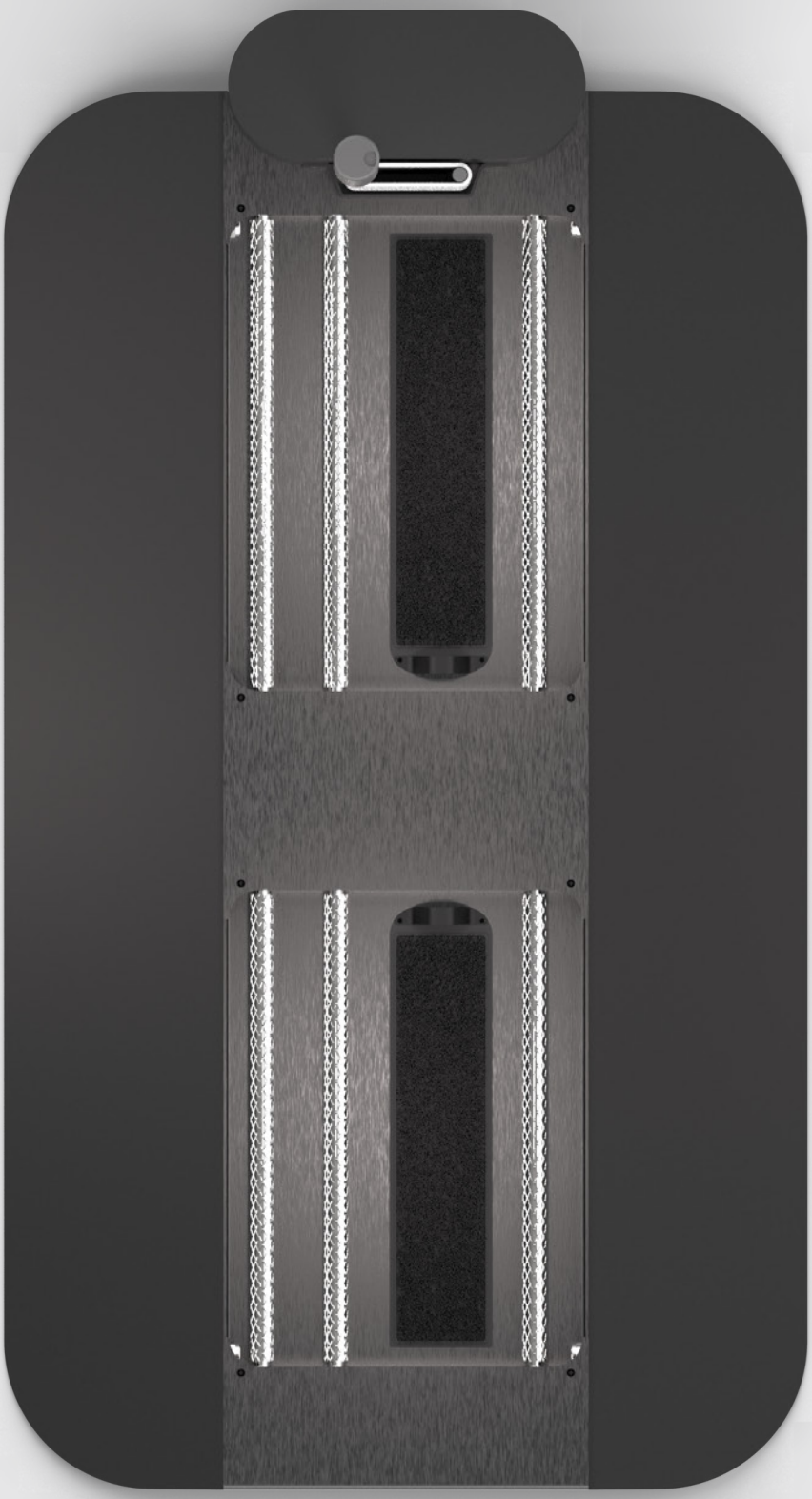

TITLE PAGE

Title	*ROLLMAT*
Theme	Wheelchair Assistive Device
University	Aalborg University
Study	Industial Design
Group	MSc04 - ID05
Project start	01/02-2022
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ABSTRACT

Sitting in a wheelchair reduces accessibility and makes almost every daily task more challenging. This includes the ability for wheelchair users to clean their wheels when entering home, which can result in the floor getting dirty frequently.

The purpose of the following project is to develop a solution that enables wheelchair users to clean their wheels independently when entering their homes. This is done by identifying user needs and product requirements through user collaboration, continuous ideation, prototyping and dimensioning, while ensuring feasibility and market potential.

The concept proposed is a doormat-like product for home entrances which enables the wheelchair wheels to spin. This facilitates the cleaning process, making it possible for the user to independently remove both the superficial dirt as well as the one stuck inside the grooves.

TABLE OF CONTENT

ENTERING HOME

When entering a house, most people can wipe off their shoes or take them off without putting much thought to it. Unfortunately, this situation is not as convenient for wheelchair users.

Cleaning the wheels is currently a laborious and time-consuming process for wheelchair users.

Additionally, many of these people are not able to remove the dirt from the wheels effectively, as they lack an adequate solution to do so. On top of that, many have issues trying to reach their front wheels, so they can only access the back wheels during cleaning.

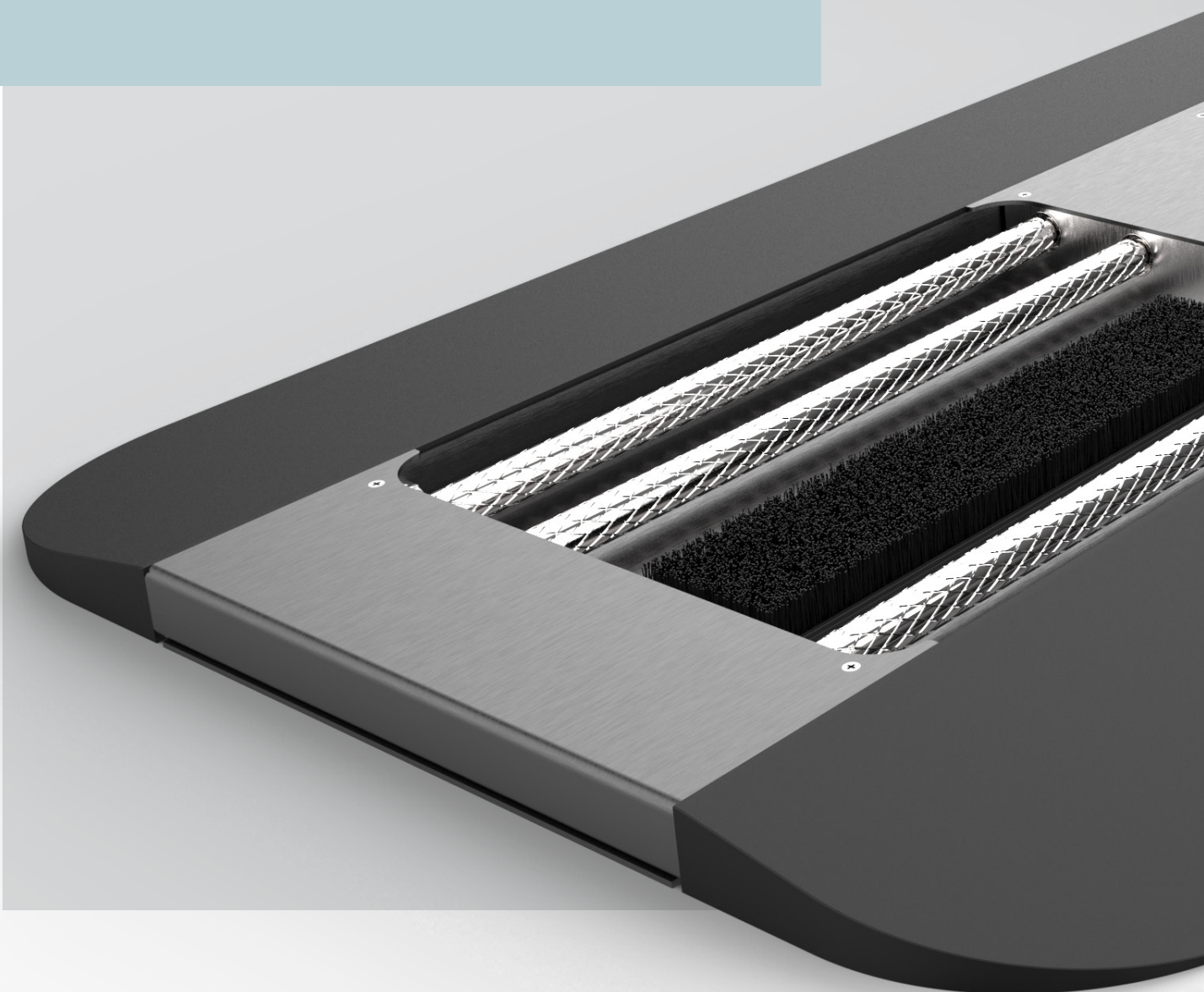

handicare
handicare

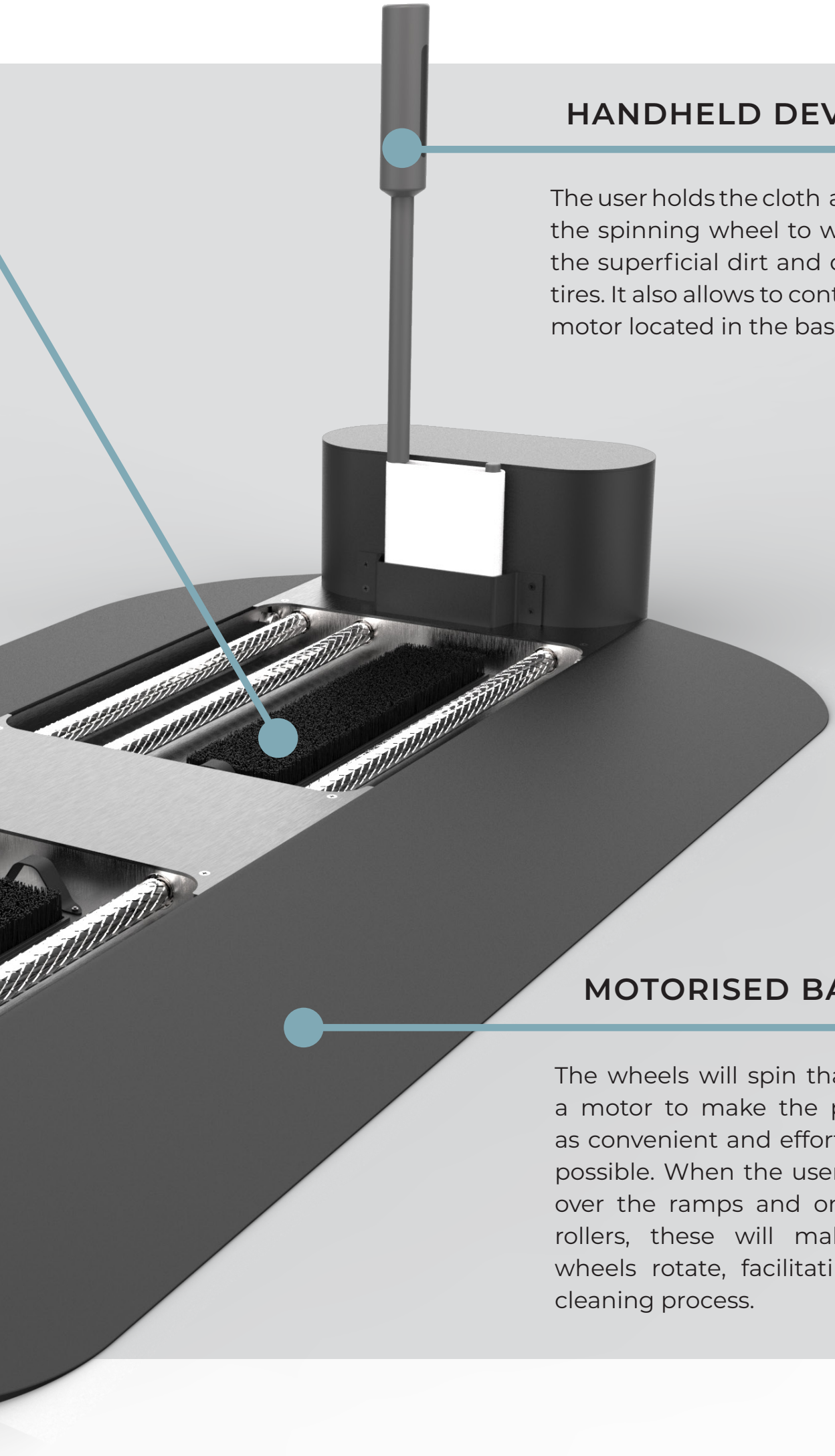
ROLLMAT
WHEEL CLEANER

ROLLMAT is a device that allows wheelchair users to clean their wheels when getting home. It could be seen as an entrance mat specially designed for people in manual wheelchairs. The base is only 27 mm in height to allow for an easy access, and it includes a motor to make the cleaning more convenient.

BRUSHES

A pair of removable brushes are located in the base. They are used to remove the dirt that is hard to access in the grooves of the rear wheels.





HANDHELD DEVICE

The user holds the cloth against the spinning wheel to wipe off the superficial dirt and dry the tires. It also allows to control the motor located in the base.

MOTORISED BASE

The wheels will spin thanks to a motor to make the process as convenient and effortless as possible. When the user drives over the ramps and onto the rollers, these will make the wheels rotate, facilitating the cleaning process.

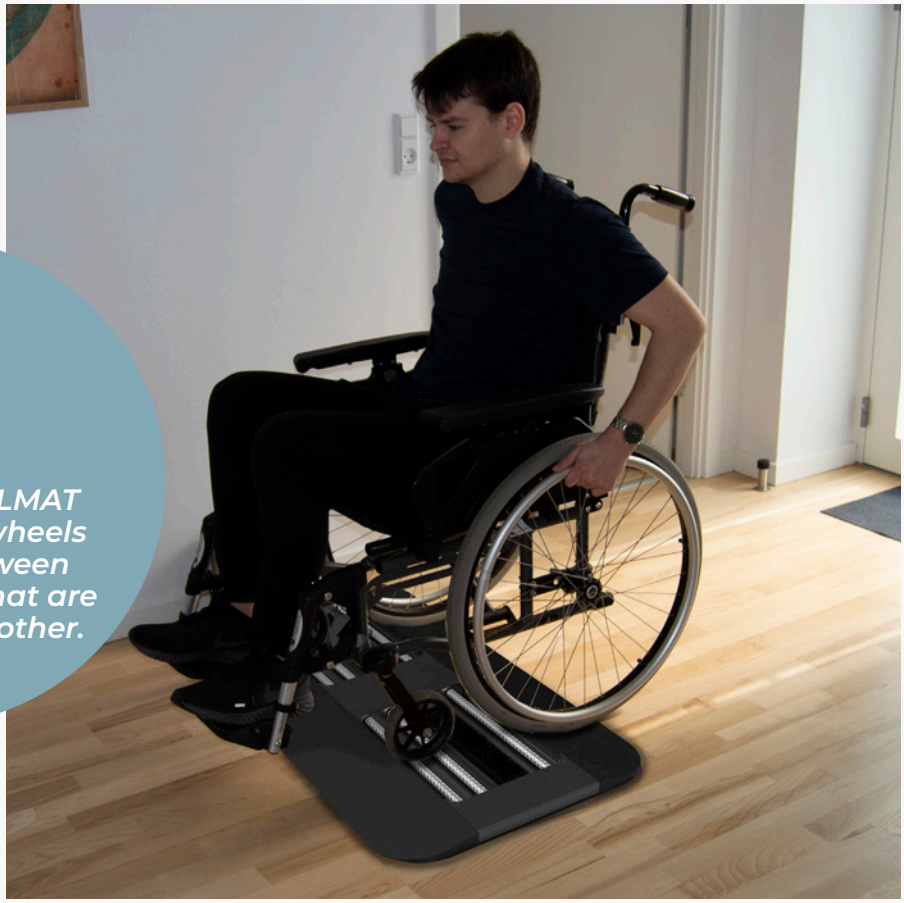
SCENARIO OF USE

1.

Entering the home.

2.

Closing the door.

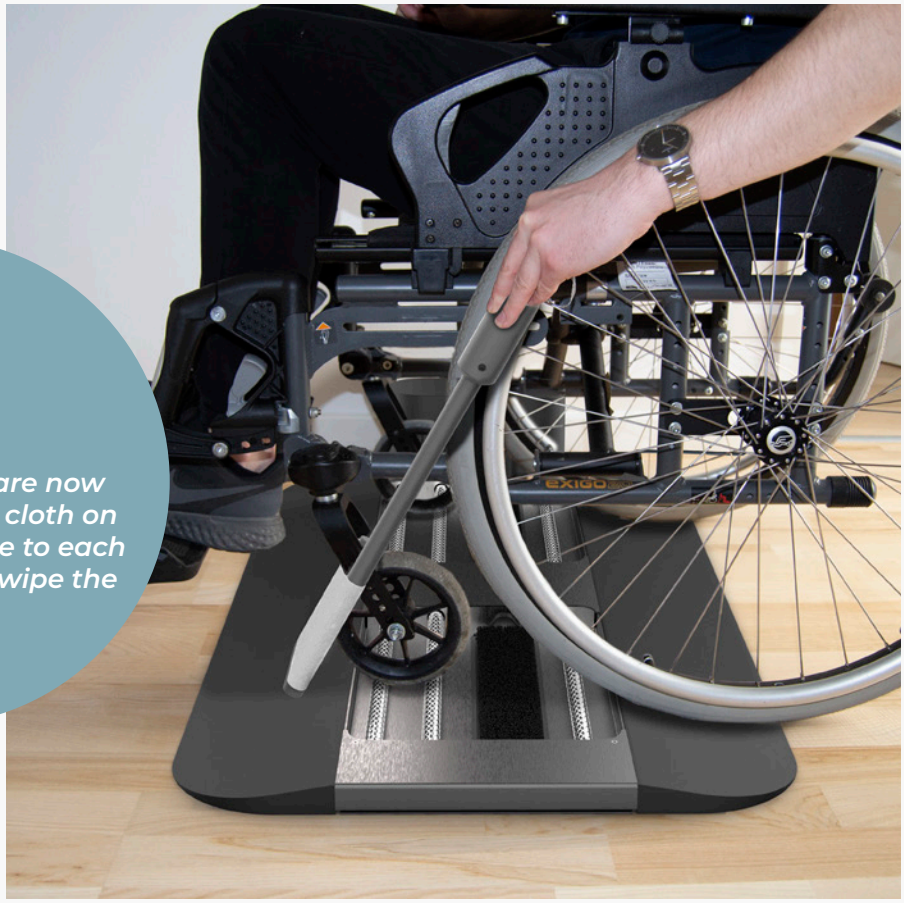


3.

Drive onto ROLLMAT until the front wheels are laying between the two rollers that are closest to each other.

4.

Pick up the handheld device and press the button on the handle to start the motor.

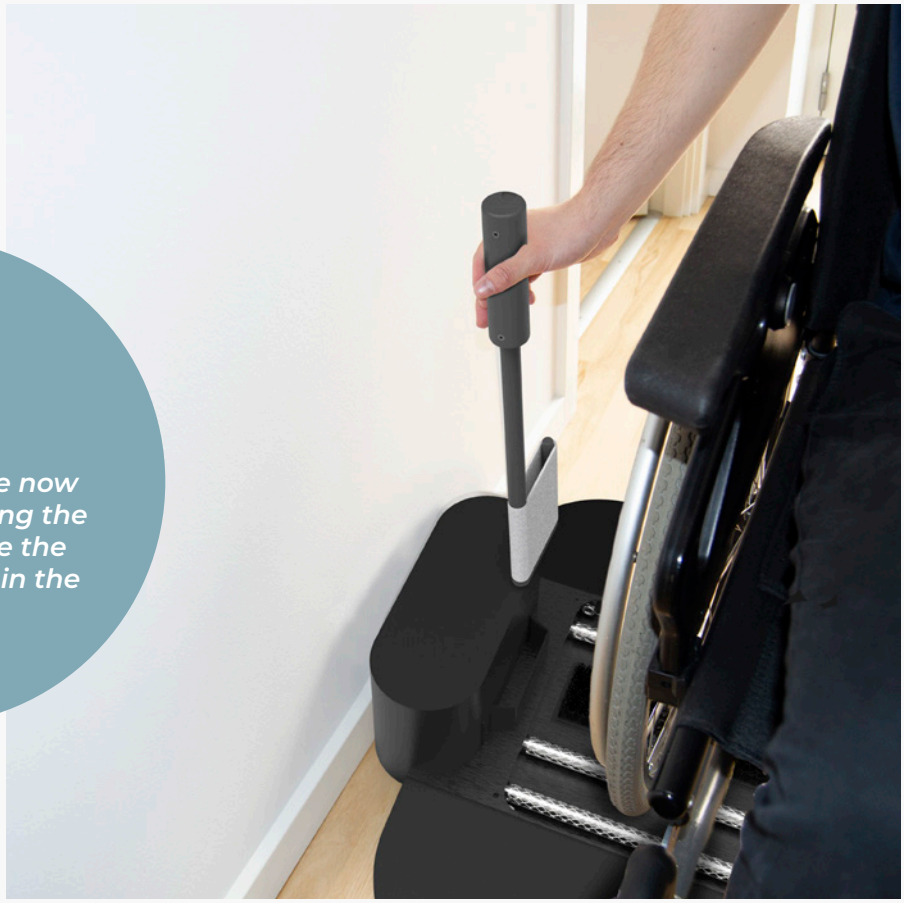


5.

The front wheels are now spinning! Push the cloth on the handheld device to each of these wheels to wipe the dirt off.

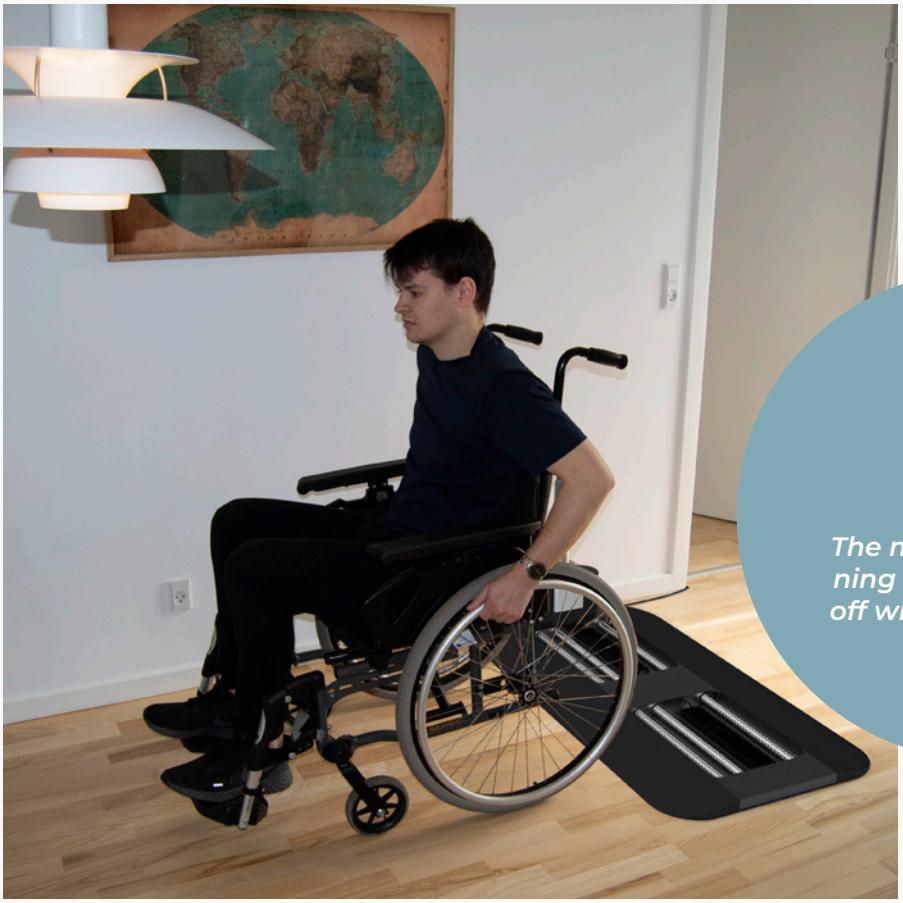
6.

Drive forward until the back wheels are on top of the first two rollers. These wheels start spinning, and they are cleaned by the cloth (handheld) and the brush (base).



7.

All the wheels are now clean! Stop pressing the button and leave the handheld device in the base.

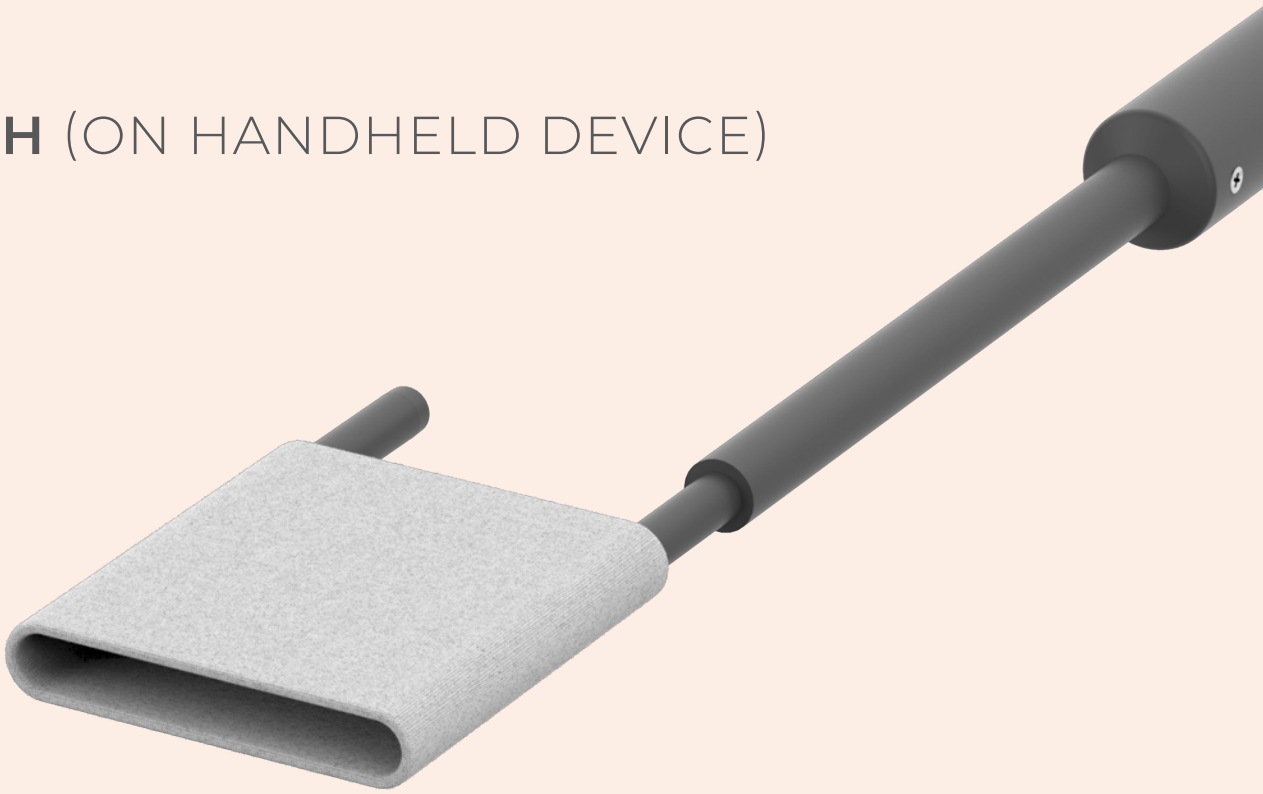


8.

The motor stops spinning the rollers. Drive off with clean wheels!

CLEANING

CLOTH (ON HANDHELD DEVICE)

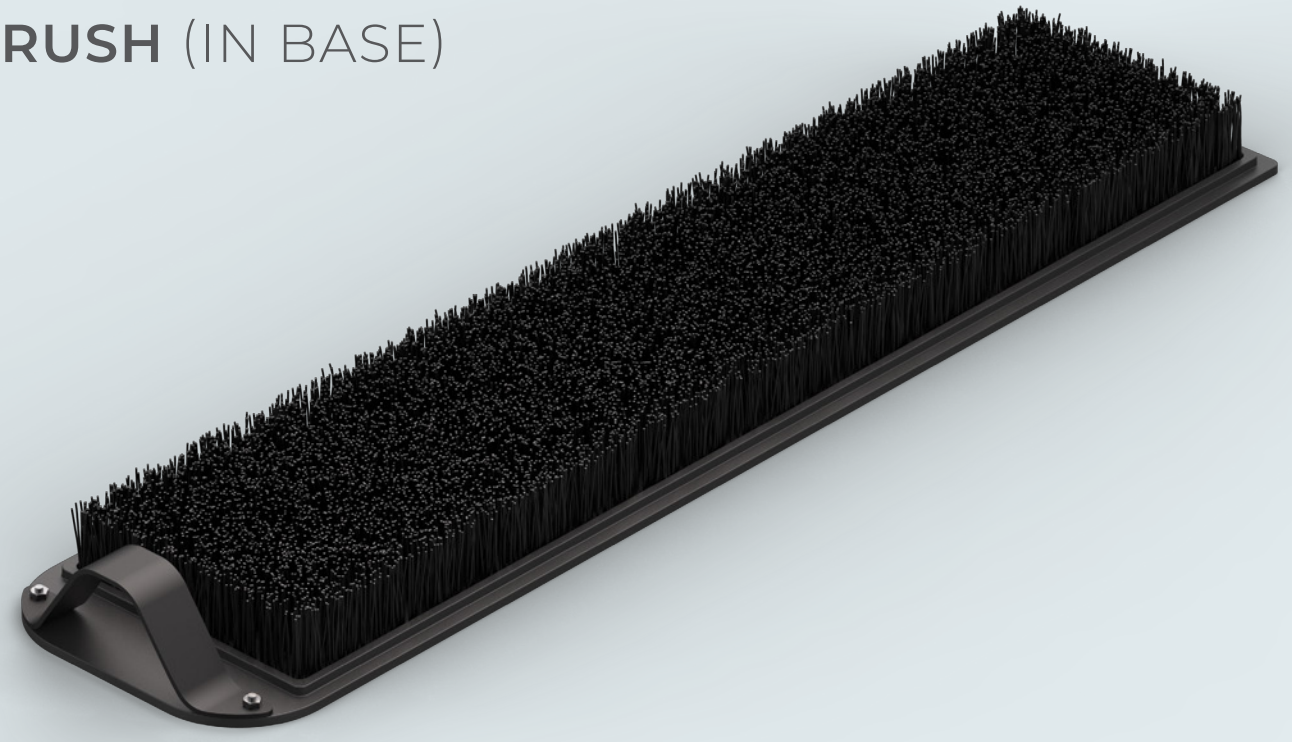


ACCESS TO WHEELS

The handle has an offset from the cloth, to allow comfortable access to both the front and rear wheels. When being pressed against the wheel, the cloth will wrap around the tire, making sure it is properly cleaned.

ELEMENTS

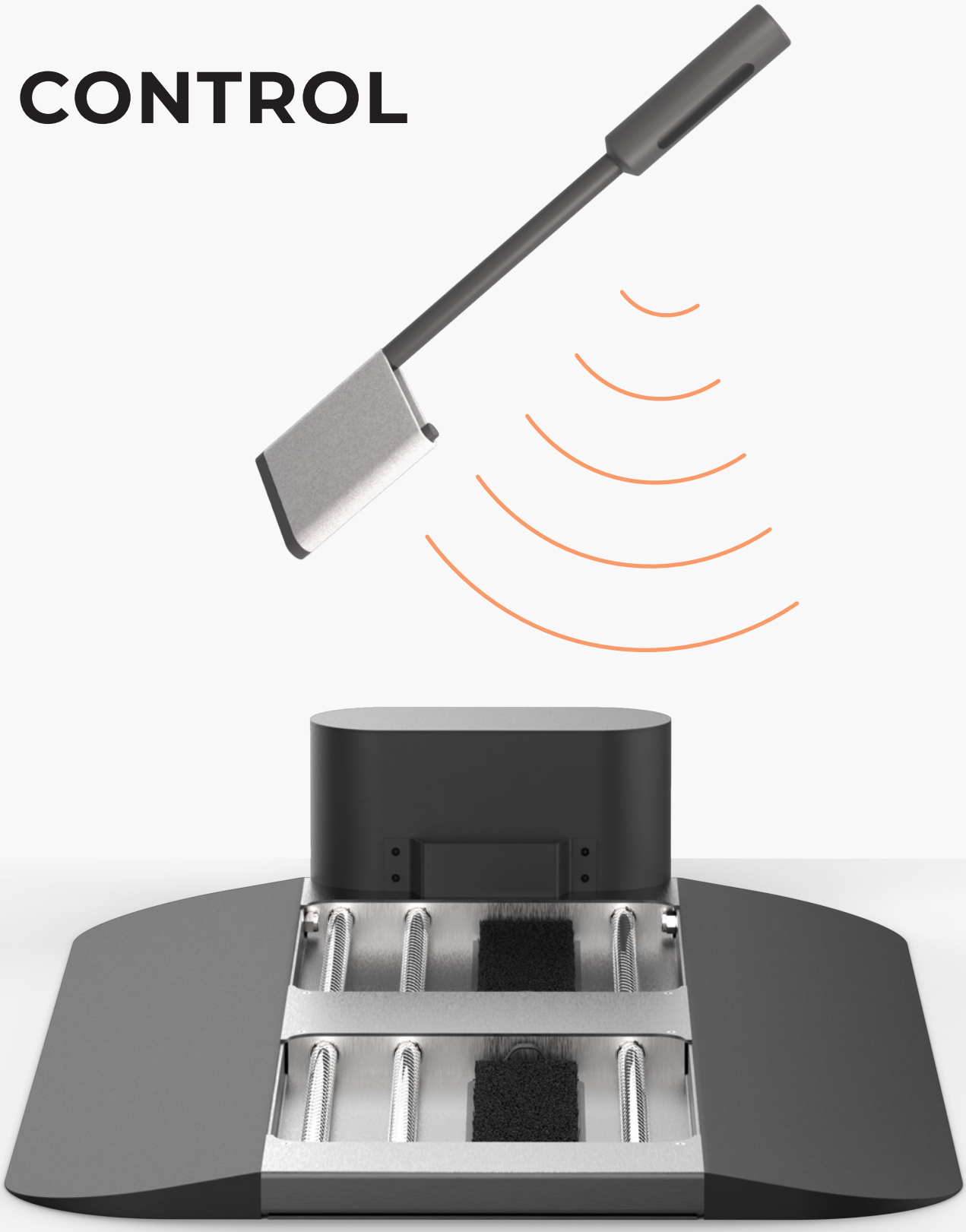
BRUSH (IN BASE)



CLEANING FROM THE BOTTOM

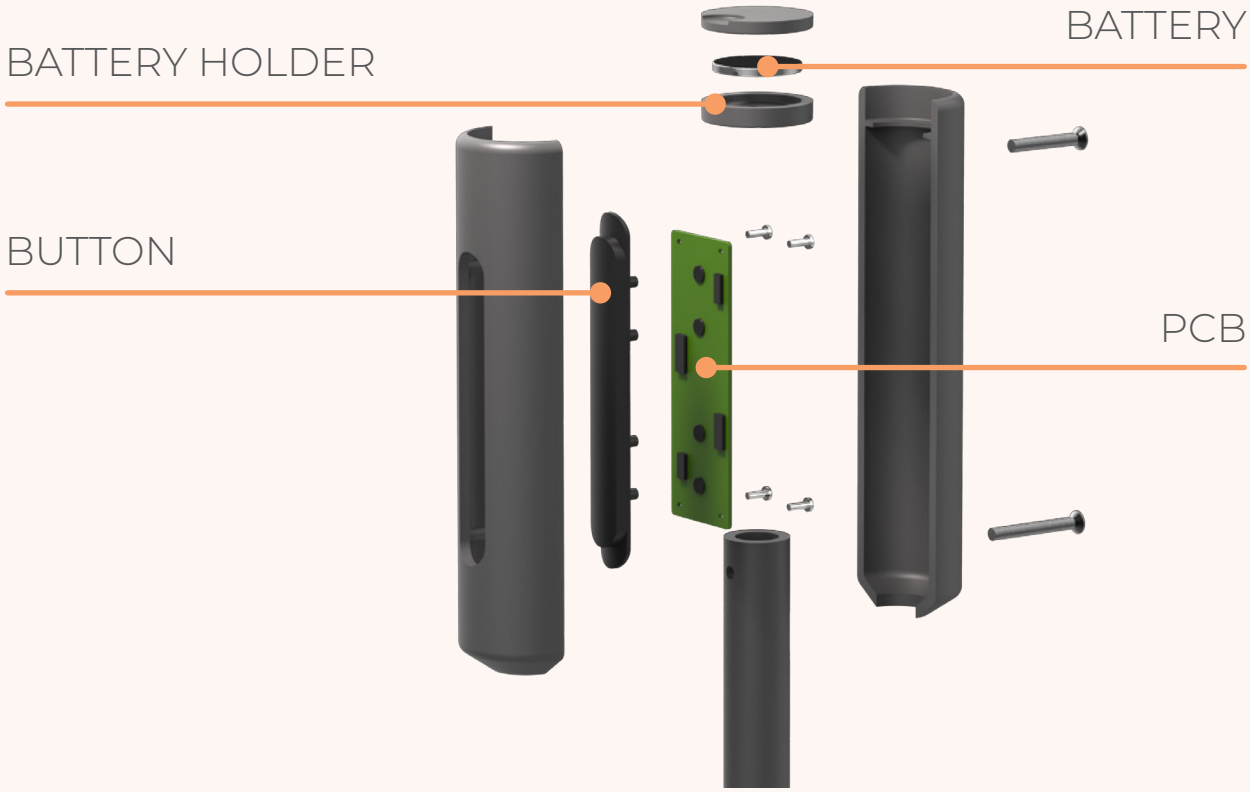
The brushes are located in the bottom to avoid spreading the dirt all over the place. They only remove the dirt from the rear wheels, as these wheels are the ones with deepest grooves that the cloth cannot reach.

CONTROL

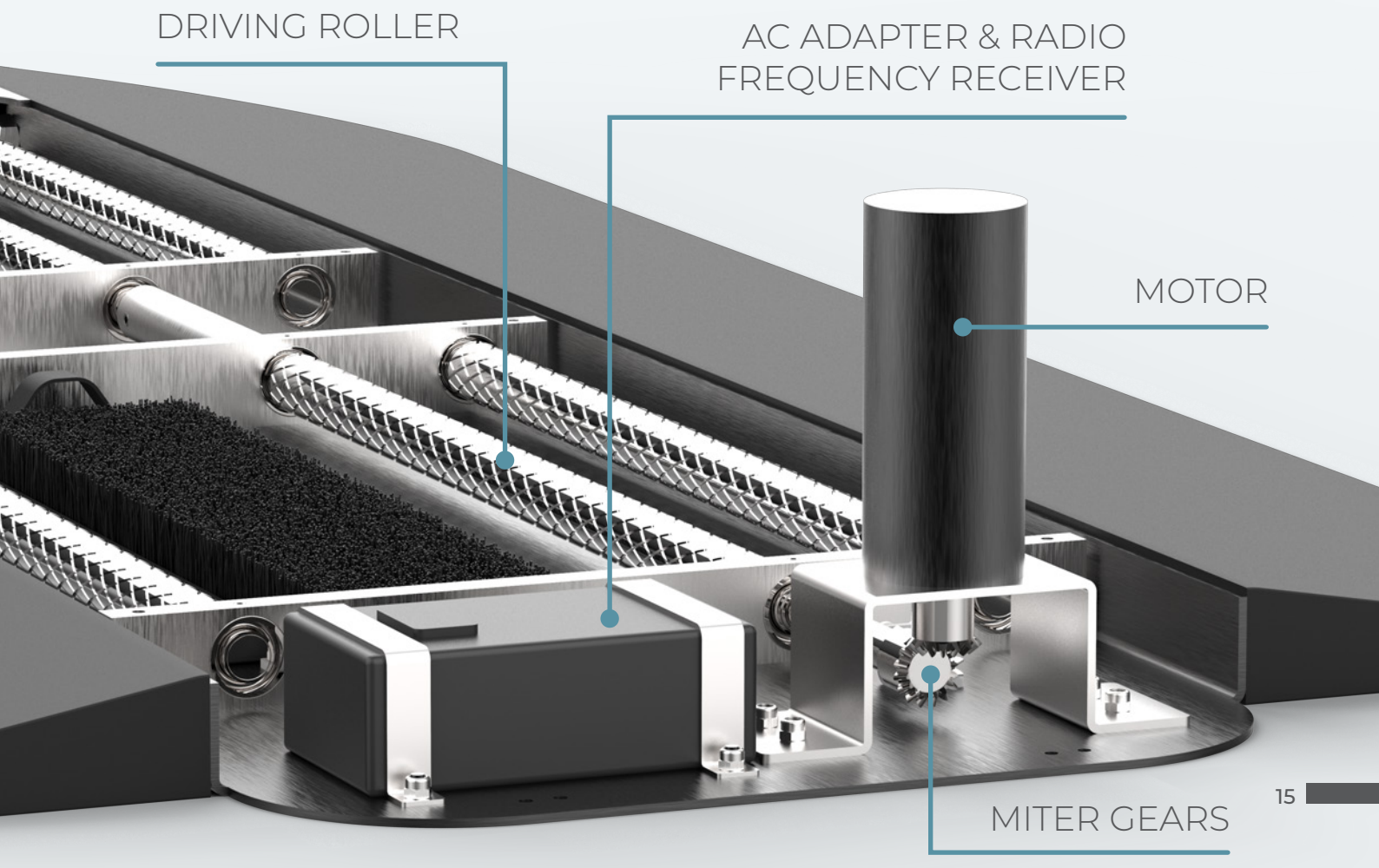


By pressing the button on the handheld device, a radio frequency signal is received in the base, which activates the motor. In case of emergency, the user can simply let go of the handheld device, and the system will just turn OFF.

HANDHELD HANDLE

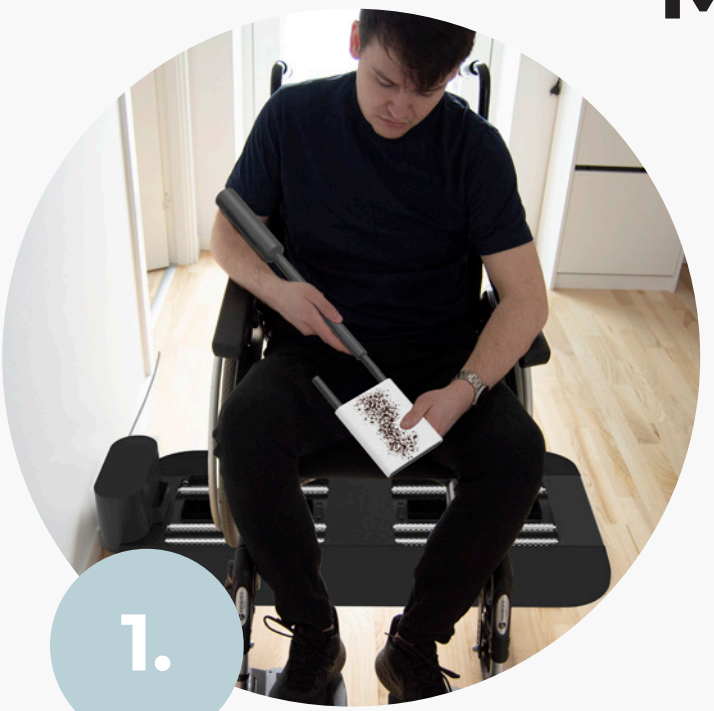


MOTOR COMPARTMENT



MAINTENANCE

EXCHANGING THE CLOTH



1.

When the cloth gets too dirty, it cleans less effectively.

2.

The user then removes it from the handheld device and throws it into the laundry basket.

3.

The user can then take a clean cloth and place it on the handheld device.

4.

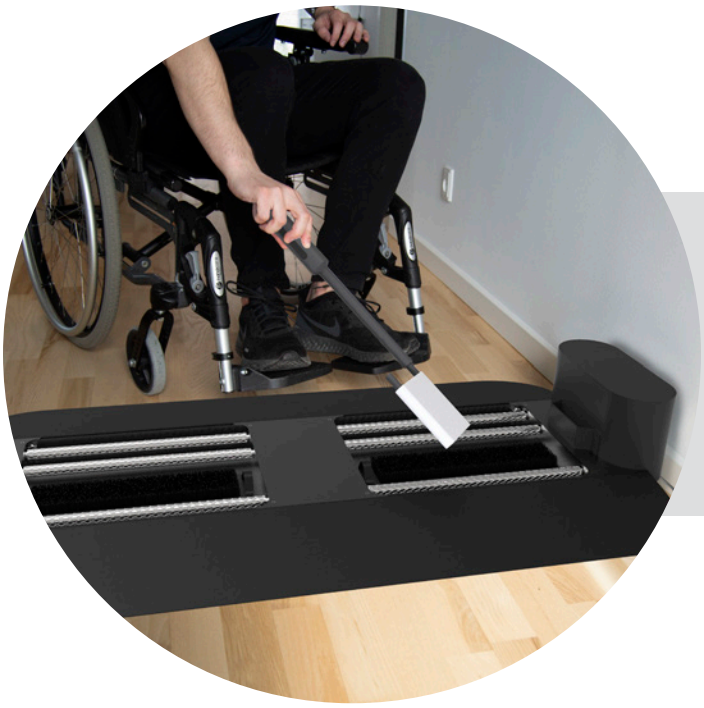
This process will probably be done on a daily basis, depending on how dirty the wheels are.

WASHING THE BRUSH

The two brushes are picked up from the base individually with a grabber.

The brushes can then be washed in the sink. After they are clean and dry, they are placed back in the base. Frequency: 1-2 times/month.

KEEPING THE BASE CLEAN

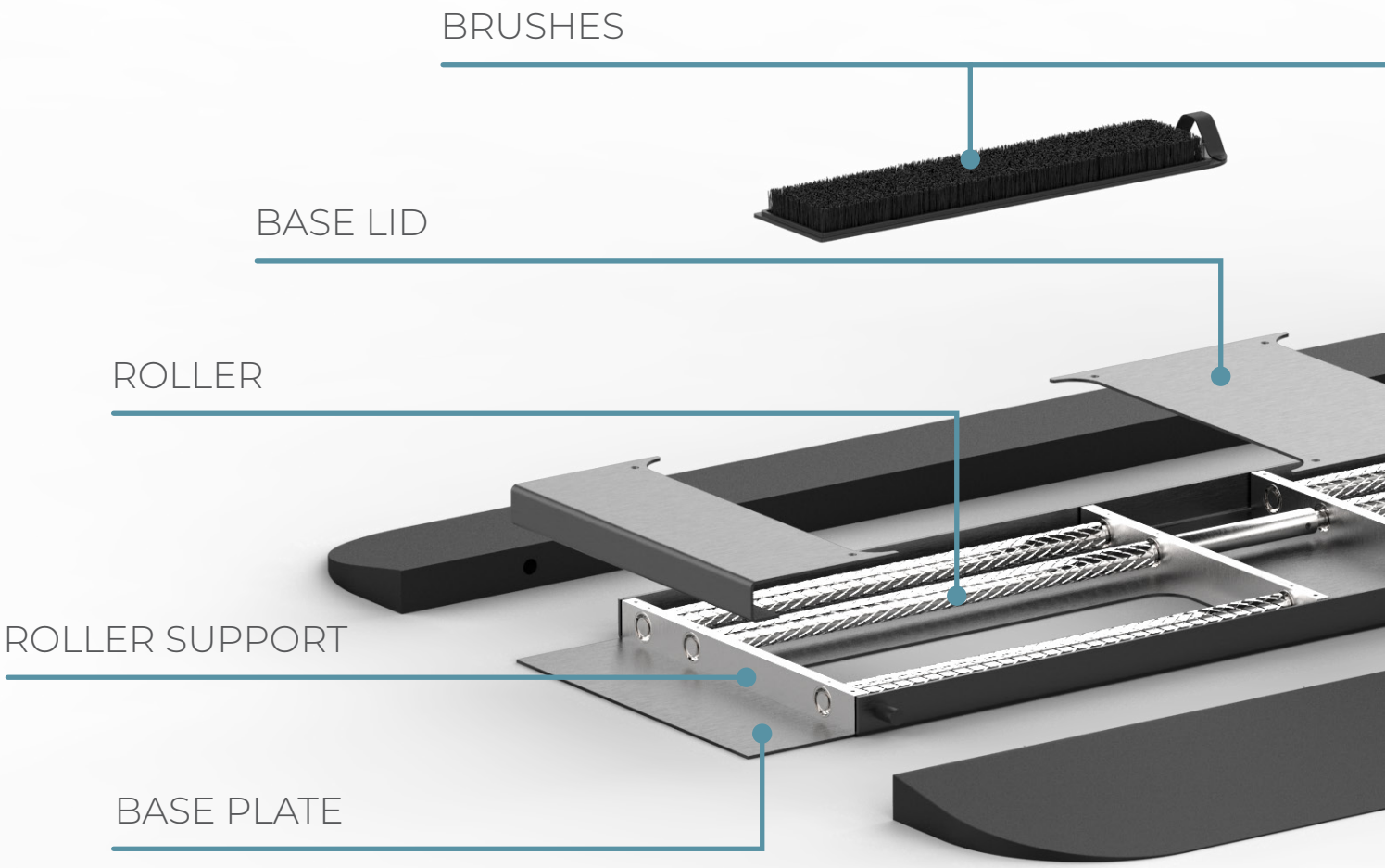


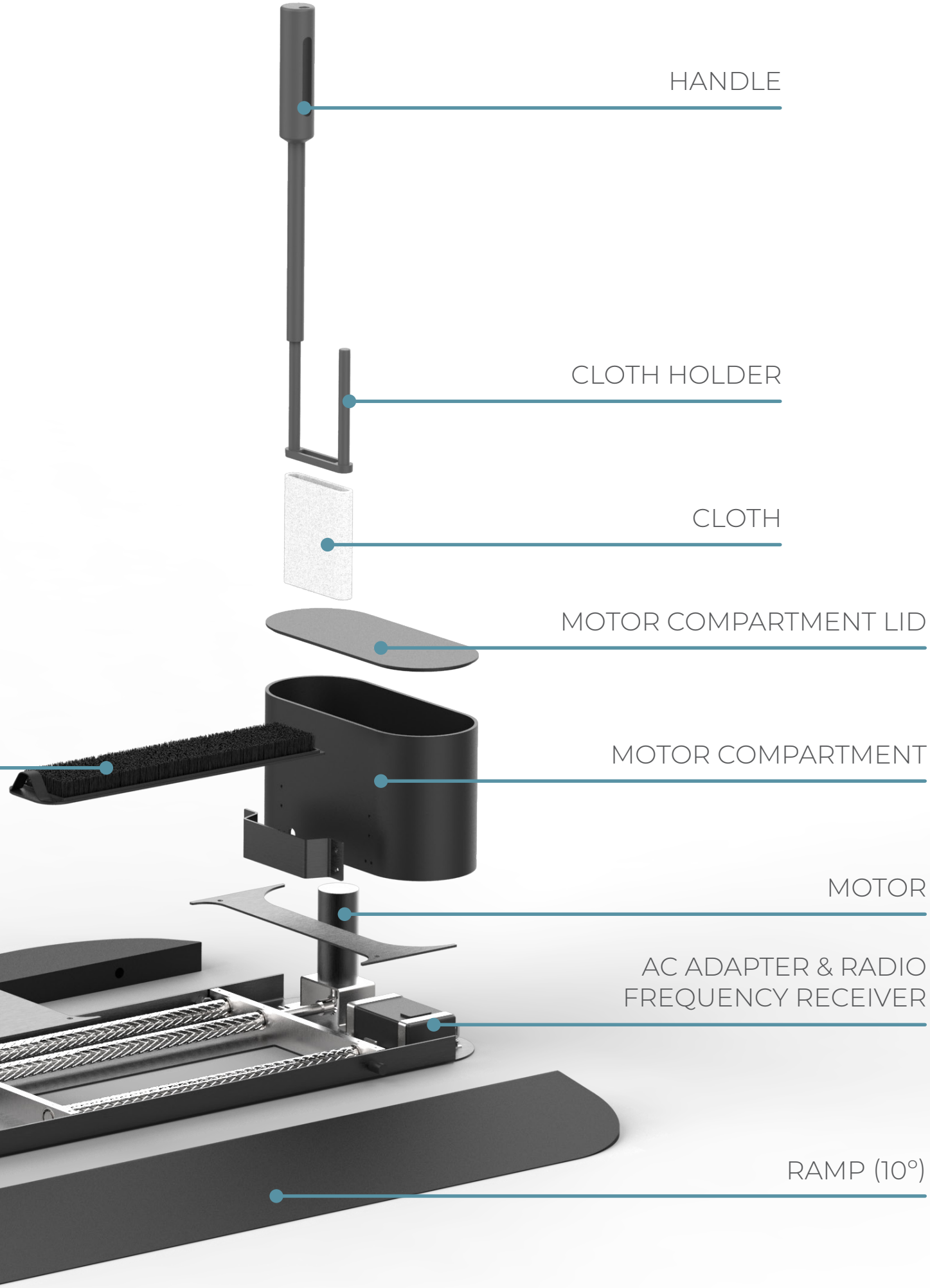
The rollers and the ramps can be wiped with the handheld device or a regular mop.

The bottom of the base can be vacuumed as a regular entrance mat.

COMPONENTS

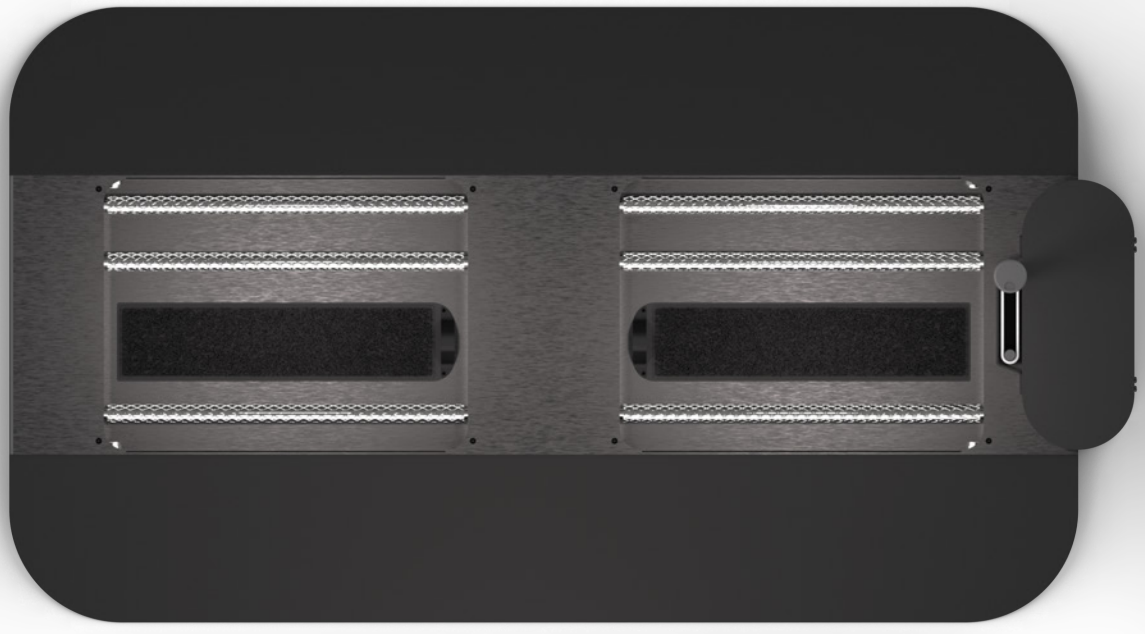
ROLLMAT consists of a base with three rollers to rotate the wheels, in which the middle one is powered by a motor. This motor is hidden away in a compartment in which the handheld device is stored when not in use. To enable the product to be used by all manual wheelchair users, ramps with an incline of 10° are placed on each side of the base.




HANDLE
CLOTH HOLDER
CLOTH
MOTOR COMPARTMENT LID
MOTOR COMPARTMENT
MOTOR
AC ADAPTER & RADIO FREQUENCY RECEIVER
RAMP (10°)

DIMENSIONS

The base of ***ROLLMAT*** is not much bigger than any other doormat, which makes it easy to drive over and to fit in the entrance.



MARKET

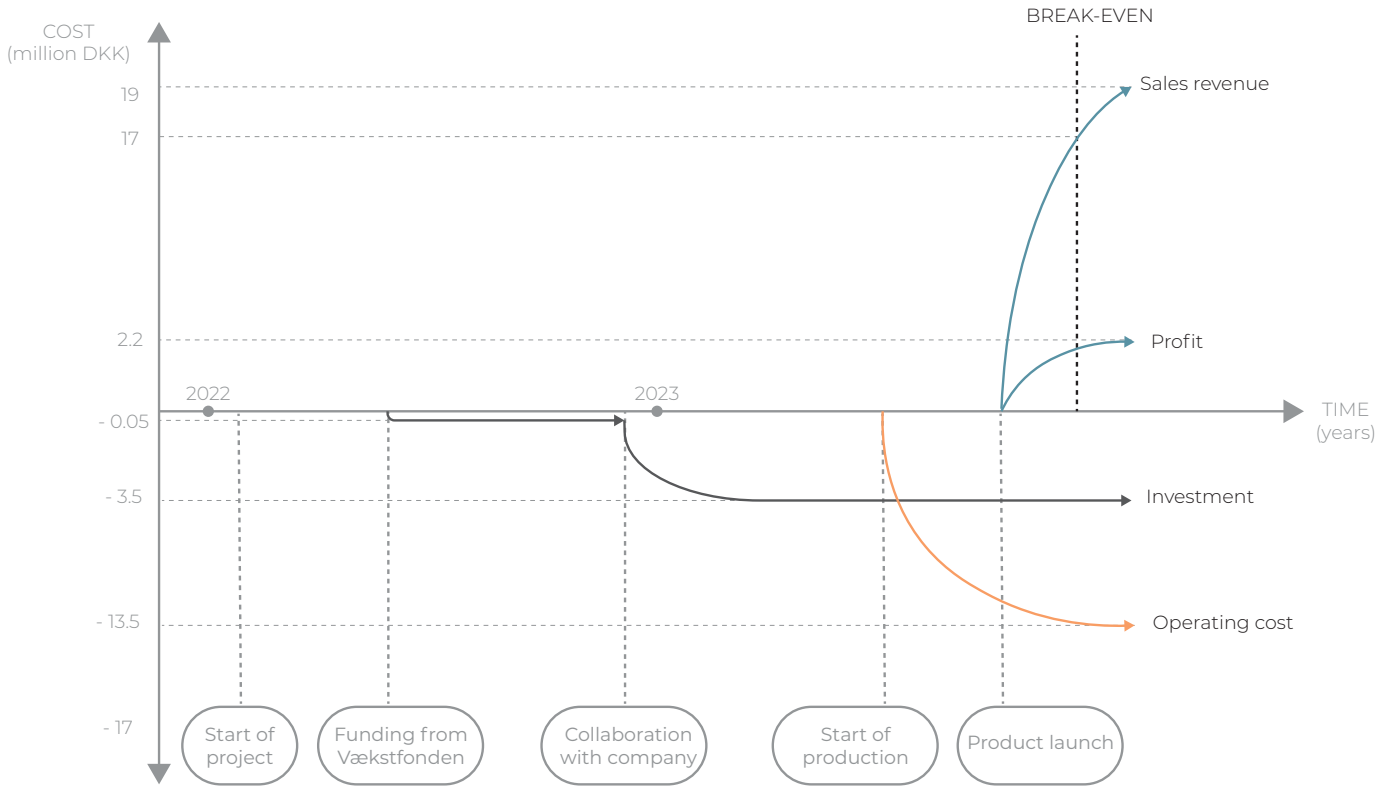
ROLLMAT is aimed towards active wheelchair users. For these people, the wheelchair is an extension of their body. They tend to have full mobility of their upper body, but low to none in the legs. The active wheelchair users are living independently and are able to do most everyday tasks like everybody else.

There are

53.000

manual wheelchair users in Denmark

IMPLEMENTATION PLAN



1) CONCEPT & BUSINESS PROPOSAL

(Feb. - May 2022, 4 months)

The team carried out the following tasks:

- Identification of problem, scenario and target audience.
- Competitor analysis - what solutions are out there.
- Tests with users - collect their feedback and interest.
- Verification of working principles through tests and calculations.
- Ideation and prototyping.
- Initial business strategy.
- Definition of final concept.

2) PREPARING TEST UNITS

(June - Sep. 2022, 4 months)

The team makes six test units to hand in to users. Vækstfonden will be the investment fund used to afford the manufacturing and development expenses. An estimated 50.000 DKK will be sufficient to cover these costs.

Suppliers are contacted, and units are assembled by the team members. Once test products are ready, they are delivered to two associations, two companies and an individual wheelchair user. The team keeps one unit for further testing.

3) TESTING & MVP

(Sep. - Nov. 2022, 3 months)

Meetings are arranged at each location a week after the units have been delivered. Based on user feedback, the team does small adjustments to the test units. The team then returns to these locations to collect their impressions and comments on the modified version.

The team then has an internal meeting to discuss which elements add the most value to the product. This “unit zero” is built as much as possible from the test units, and is the Minimum Viable Product (MVP).

BUDGET

The production cost of *ROLLMAT* was estimated based on the costing tool in Solidworks and by taking other similar product components as reference. These expenses include cost of material, manufacturing and assembly (including wages).

Two scenarios were presented:

- **Worst scenario** - it considers a batch size of 1000 units and the original cost of the standard components.
- **Best scenario** - it is based on a batch of 5000 units and the standard components are estimated to have a reduction in cost due to higher volume.

The best scenario was the one taken as reference for doing the graph in the implementation plan. It was considered that producing 5000 units is a more likely scenario than 1000 units, especially when Sunrise Medical is a company with international presence.

The retail price was estimated from a collaboration margin of 30% for the company.

PRODUCTIONS COST
(BEST SCENARIO)
2660 DKK

SALES PRICE
(BEST SCENARIO)
3800 DKK

4) WORKING WITH A COMPANY

(Dec. 2022, 1 month)

An agreement is made with the company Sunrise Medical. This company with headquarters in Germany has a international presence in the market of wheelchairs, including active wheelchair users. They would have the capabilities to finalise the development of the product and launch to market by using their existing partners and channels.

The team sells the product rights in exchange of getting hired and receiving royalties once the product hits the market.

5) FINAL DEVELOPMENT

(Jan. - May 2023, 5 months)

The team, together with a mechanical engineer from the Research & Development centre, makes the final optimisations to the product. These include meeting price requirements, conducting further users tests and increased focus on dimensioning of the system.

6) MANUFACTURING & LAUNCH

(June - Sep. 2023, 4 months)

Once the resultant product provides sufficient value at a feasible price and the required quality tests have been performed, the serial production commences. A first batch of 5.000 units is estimated by the team to be sufficient, but this will of course depend on the company's strategy.

The launch date is then established and the marketing team starts promotion of the product in exhibitions and their online platforms. The first units of the product are planned to be ready the fall in 2023, which will be the perfect timing to purchase a wheel cleaner.

ROLLMAT

WHEEL CLEANER

/ AALBORG UNIVERSITY
/ SPRING 2022
/ INDUSTRIAL DESIGN
/ MSC04-ID05

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ROLLMAT

WHEEL CLEANER

PROCESS REPORT

/ AALBORG UNIVERSITY
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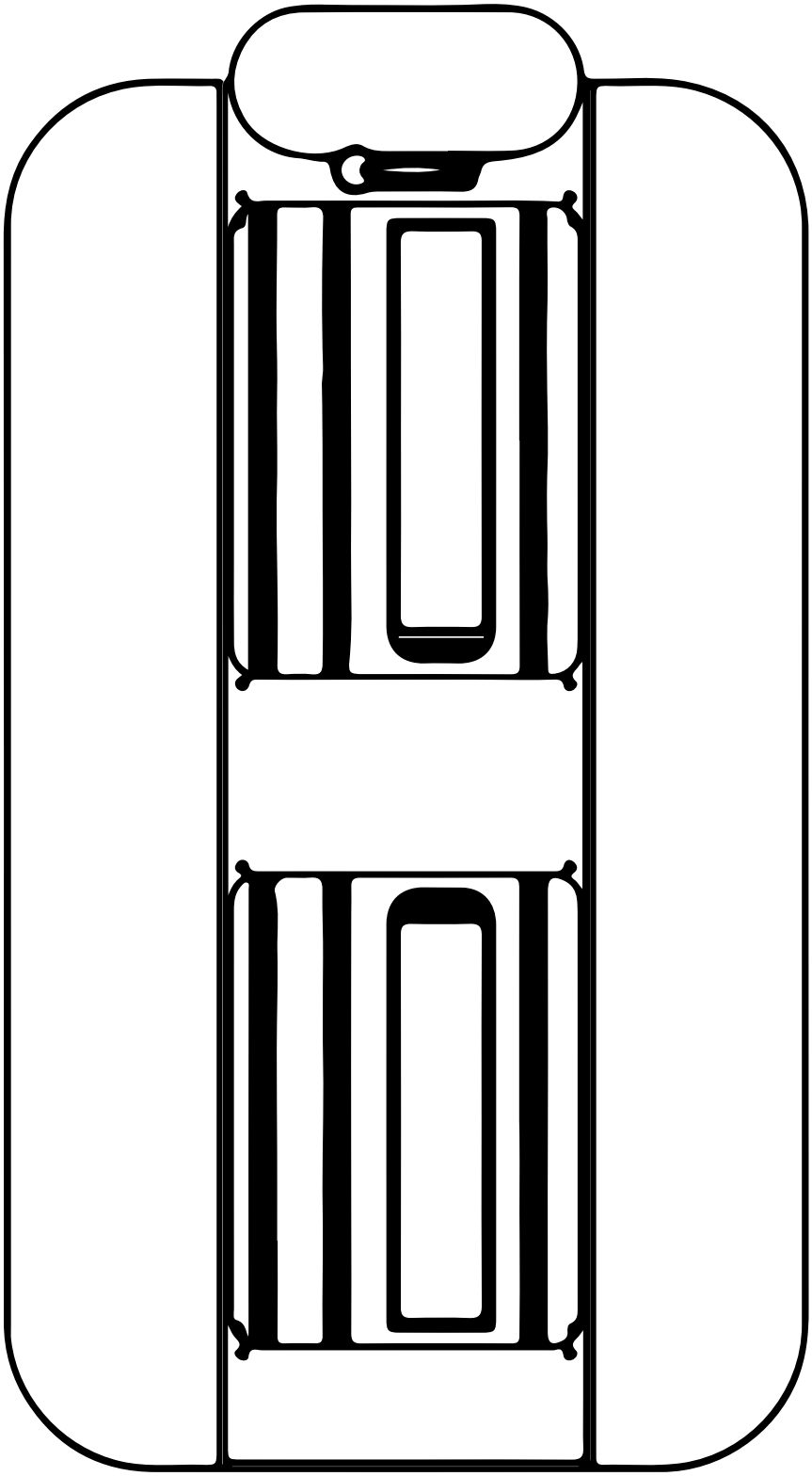

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Pages	98
Appendix	28

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PREPHASE

The following master's thesis project is developed by MSc04, Group 5, Spring 2022, Industrial Design, Aalborg University, with the topic of cleaning wheelchair wheels. The project consists of a product report, process report, technical documentation and appendix, and was developed in the period 1st of February - 25th of May.

Thanks to Christian Tollestrup and Jørgen Asbøll Kepler for the supervision during the project and a special thanks to all the wheelchair users who contributed with valuable insights.

ABSTRACT

Sitting in a wheelchair reduces accessibility and makes almost every daily task more challenging. This includes the ability for wheelchair users to clean their wheels when entering home, which can result in the floor getting dirty frequently.

The purpose of the following project is to develop a solution that enables wheelchair users to clean their wheels independently when entering their homes. This is done by identifying user needs and product requirements through user collaboration, continuous ideation, prototyping and dimensioning, while ensuring feasibility and market potential.

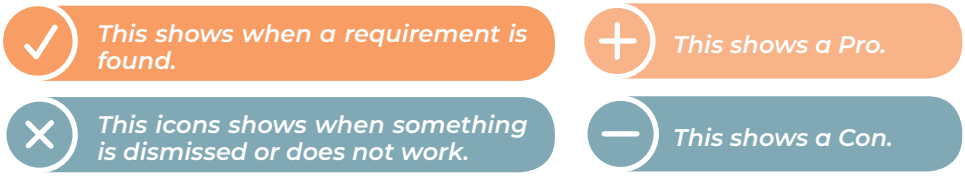
The concept proposed is a doormat-like product for home entrances which enables the wheelchair wheels to spin. This facilitates the cleaning process, making it possible for the user to independently remove both the superficial dirt as well as the one stuck inside the grooves.

READING GUIDE

The project consists of two reports, technical documentation, and appendix, and should be read in the following order: product report, process report, technical documentation and appendix.

The product report is a presentation of the product proposal, while the process report presents the progress from the initial research and ideas to the final proposal. The technical documentation is for further details of measurements, assembly, components, and production. The process report is divided into six phases, and should be read as spreads for the best experience.

When a new requirement is identified, it will be highlighted. The same will happen when an aspect gets dismissed or does not work. This will be illustrated with the following symbols:

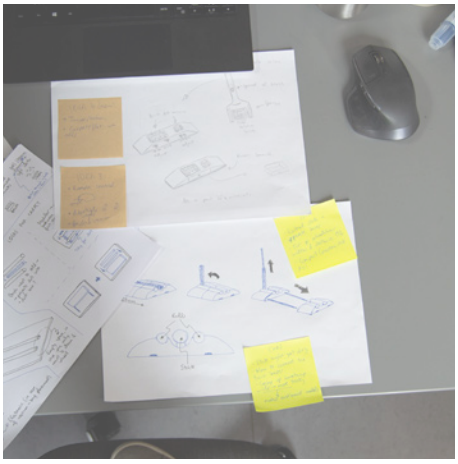


The references, including illustrations, follow the method of Harvard and are listed on page 96 of the process report.

TABLE OF CONTENT

1. FRAMING

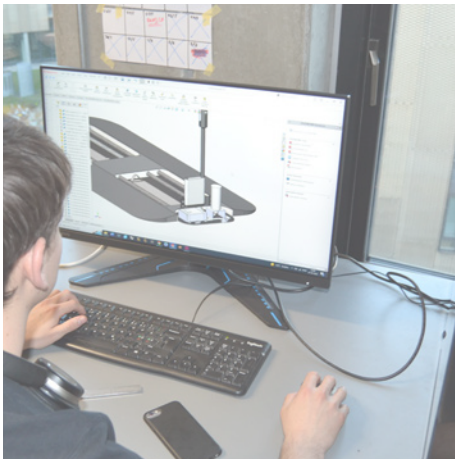
2. IDEATION



3. CONCEPTUALISATION

4. DEVELOPMENT

5. DETAILING



6. EPILOGUE

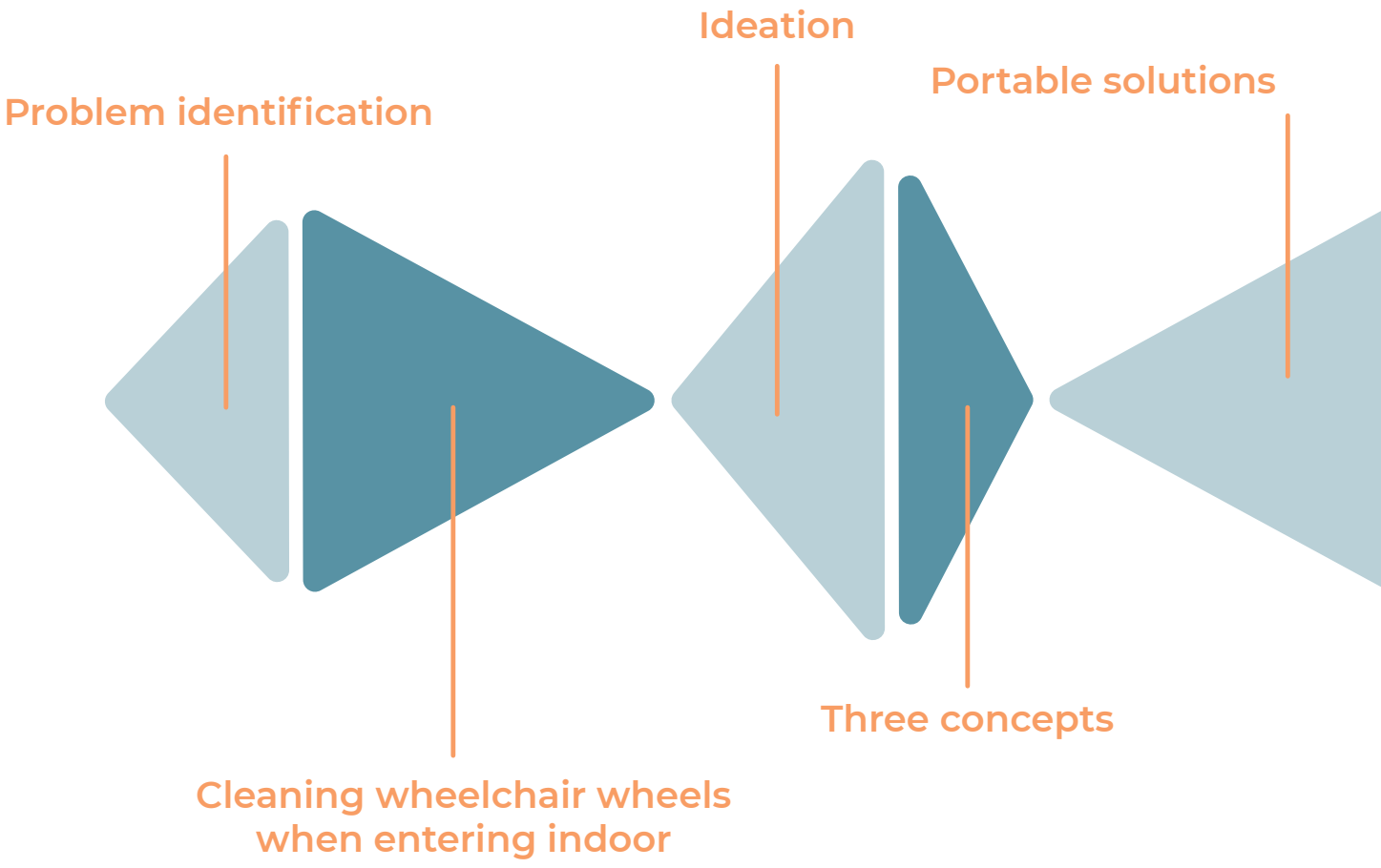
INTRODUCTION

Being a wheelchair user involves some limitations and boundaries for everyday life. To do daily tasks and objectives that those without a disability take for granted, can be difficult and for some impossible to do, unless assistance is provided.

This thesis focuses on how to reduce one of these limitations, more specifically, how to help wheelchair users to independently achieve clean wheels when entering their own home. Because unlike those with the ability to walk that just can take off their shoes, wheelchair users are dependent on their wheels as they cannot just leave behind.

PROCESS OVERVIEW

An overview of the process followed during the project is depicted on ill 0.1. It highlights the overall and main activities of the project.

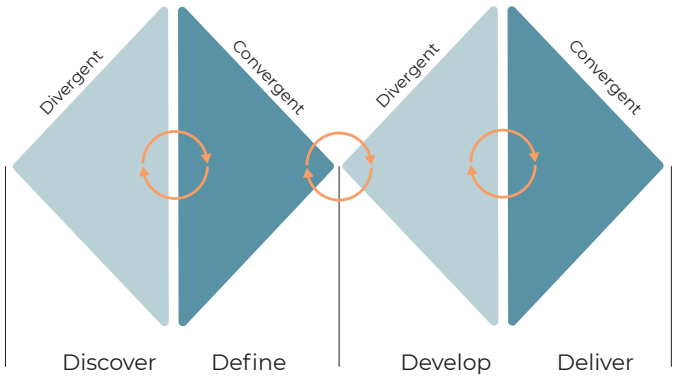


METHOD

DOUBLE DIAMOND

The process of the project has followed the concept of the Double Diamond model (Københavns Universitet, n.d.), where the process is divided into divergent and convergent phases.

Due to the complexity of design processes, the process have had several iterations of some of the phases.



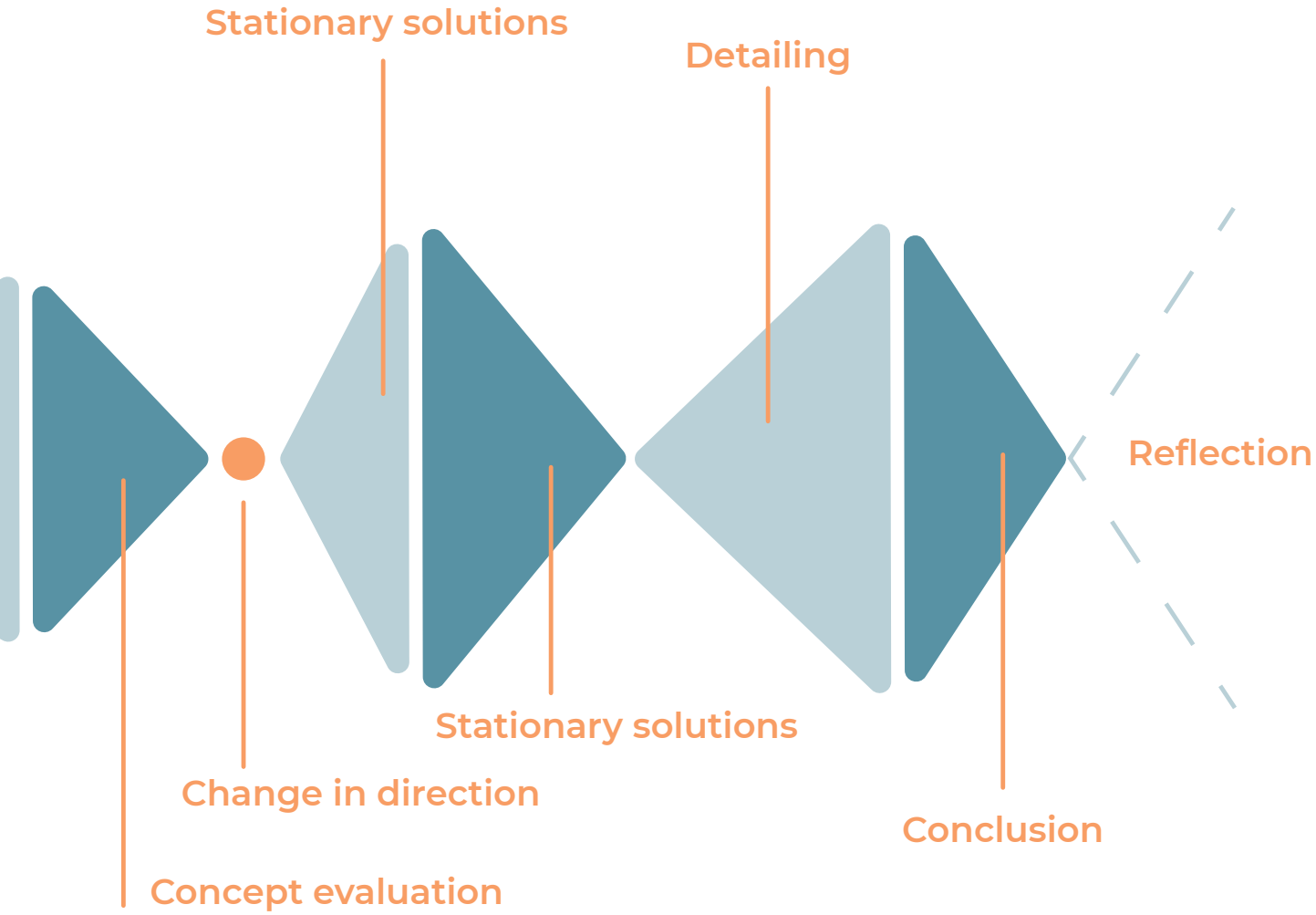
Ill. 0.1: Method

1. Discover
This phase is about understanding and exploring the problem and its complexity. The phase is divergent, as it seeks to understand all of the elements and issues related to wheelchairs and wheelchair users.

2. Define
This phase is about defining the problem, based on the knowledge from the previous phase. The phase is convergent, as the problem related to wheelchair wheel cleaning becomes more defined.

3. Develop
This phase is about developing concepts and the solution proposals for the defined problem. The phase is divergent as several concepts are being explored and tested, in search for the optimal solution for cleaning wheelchair wheels.

4. Deliver
The last phase is convergent, as it is about detailing and defining the end product proposal, including components and establishing a plan for production and launch.



Ill. 0.2: Process overview

Ill. 1.1: Person in a wheelchair in a park

1. FRAMING

In this first chapter, the goal of the project is defined. The problem is presented, as well as the context and the key elements needed to understand the future concepts, including target group, wheelchair characteristics and types of dirt, among others.

PROBLEM

Having a wheelchair allows people with disabilities to move around and do daily tasks that most people take for granted. The wheelchair is a tool, and extension of the user's body that makes their lives more independent. However, these people will still encounter situations that impose a challenge in their everyday lives, such as coming home with dirty wheels.

When entering their homes, most people just wipe off their shoes with a doormat and take them off to prevent making a mess inside. On the other hand, wheelchair users do not have the same opportunity. They cannot leave their wheelchair at the entrance as they need it for mobility, and owning an additional wheelchair for indoor usage is a luxury that not everyone can afford.

It was noticed through user interviews [App. 1] that each user seems to have their own way of cleaning their wheels. Sadly, these methods are often not cleaning effectively, so the wheels are still leaving a trail of dirt after them. Therefore, there was space for a more optimal solution to assist these people with the cleaning of their wheels.

Ill. 1.2: Wheelchair leaving a dirt trail behind

PROBLEM STATEMENT

Develop a solution that enables wheelchair users to enter indoor environments without leaving a trail of dirt as they go.

Ill. 1.3: Active wheelchair user

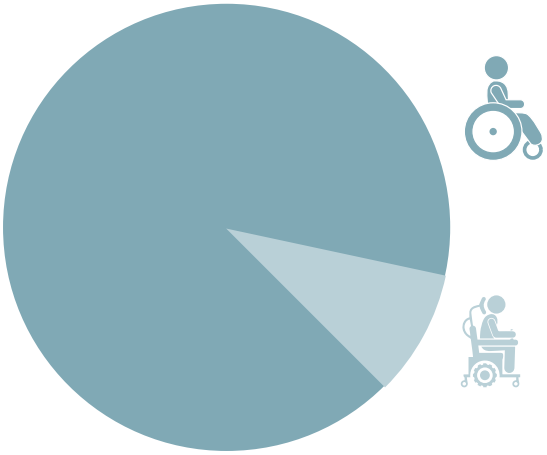
WHEELCHAIR USERS

IN DENMARK

The current number of people in wheelchair or other assistive devices is unclear. The most recent number the team was able to find during research is based on an investigation made by the National Board of Health and Welfare in Denmark (SFI) in 2009. This document states that approximately 58.000 wheelchairs were granted to people in need that year (Socialstyrelsen, 2014).

58.000
wheelchair users in Denmark (2009)

Ill. 1.4: Map of Denmark



Ill. 1.5: Chart - percentage of manual wheelchair users VS powered wheelchair users in Denmark

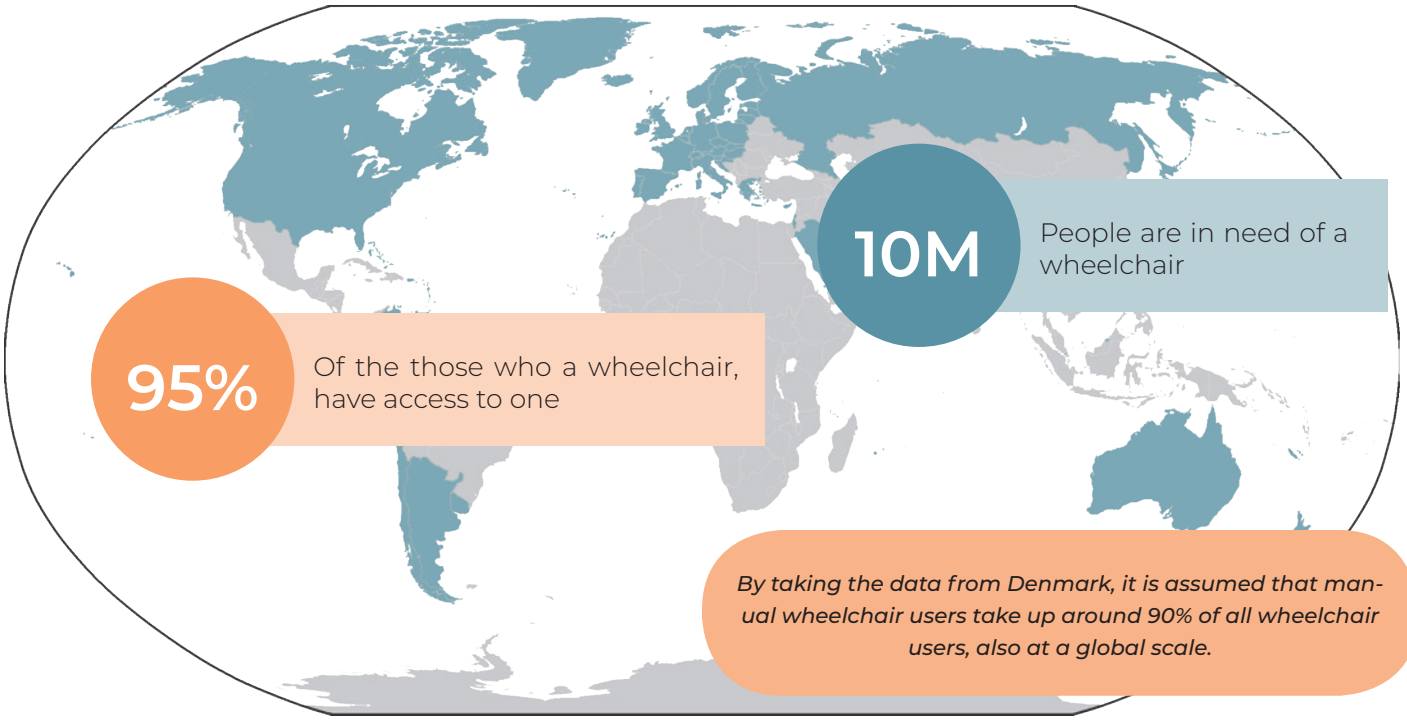
An estimation from the National Board of Health and Welfare in Denmark stated that out of 58.000 wheelchair users, about 53.000 were using manual wheelchairs and approximately 5.000 powered wheelchairs (Socialstyrelsen, 2014).

53.000
manual wheelchairs

5.000
powered wheelchairs

IN THE WORLD (DEVELOPED COUNTRIES)

In the 34 developed countries in the world, approximately 1% of the population requires a wheelchair. This is equivalent to around 10 million wheelchair users from the total population in these countries (Wheelchair foundation, 2021).



Ill. 1.6: World map with developed countries highlighted in blue

USERS INTERVIEWED

In order to get a more detailed understanding of the problem at hand, wheelchair users were reached. These interviews were done via video calls and phone calls to gain insight into the current user experience of cleaning wheelchair wheels [App. 1]. The users interviewed were:

JENS KRISTIAN

Manual wheelchair user

METTE

Manual wheelchair user

MICHELLE

Manual wheelchair user

HANS PETER

Manual wheelchair user

CLAUS

Manual wheelchair user

LOUISE

Powered wheelchair user

SØREN

Powered wheelchair user

Ill. 1.7: User panel

CONFIRMING THE ISSUE

All the users interviewed confirmed that they have issues cleaning their wheels when entering their homes. They told about the different ways they face this issue, and explained their workarounds. These workarounds and methods are described on the next pages.

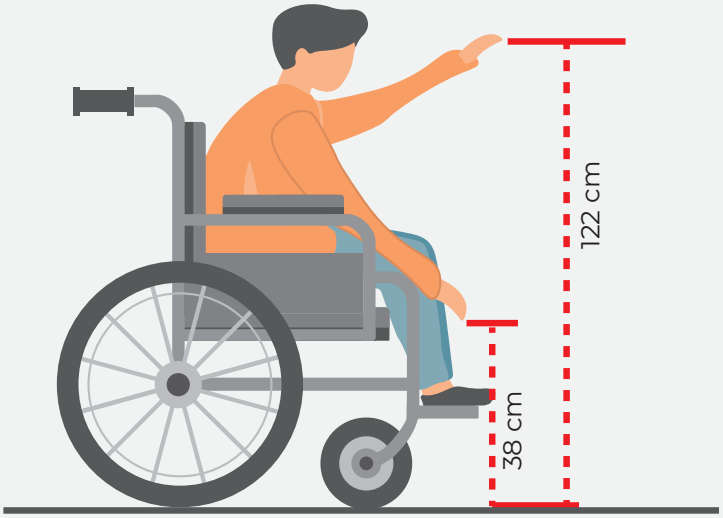
USER'S LIMITATIONS

REACH

The limitations that these people experience due to their disability are mainly related to reach. Based on anthropometric studies (UpCodes, 2010) the reachability of wheelchair users is determined.

One of the biggest problems that active users face is not being able to reach their front wheels, which become an obstacle when cleaning their wheels.

Ill. 1.8: User that cannot reach the front wheels



Ill. 1.9: Range for reach in terms of height for wheelchair users

The minimum height of reach is 38cm, and the most comfortable for them is located at a height of 90-120cm.

A solution must accommodate reachability, according to ill. 1.9.

DEFINING THE USER GROUP

To establish the user group, an investigation into the different types of wheelchair users was done. Wheelchairs can be categorised in many ways due to the high personalisation level of this market. Wheelchairs were divided into three categories: transport, active and comfort wheelchairs (Nielsen and Pedersen, 2021).

Ill. 1.10: Elderly person in a wheelchair

Transport wheelchair

Transport wheelchair users are often elderly people on retirement homes who are mobility impaired and in need of a wheelchair to move around. They do not need the wheelchair all the time, but use it occasionally during the day.

Ill. 1.11: Active wheelchair user

Active wheelchair

Active wheelchair users are individuals who permanently sit in a wheelchair but can use their upper body for moving around. These wheelchairs are often custom made, as it could be seen as an extension of their body.

Ill. 1.12: User of powered wheelchair

Comfort wheelchair

Comfort wheelchair users are people with little to no mobility in the body. The wheelchairs they use are often powered wheelchairs, and can also be custom made. They rely on their wheelchair for moving around, and they sit in it the whole day.

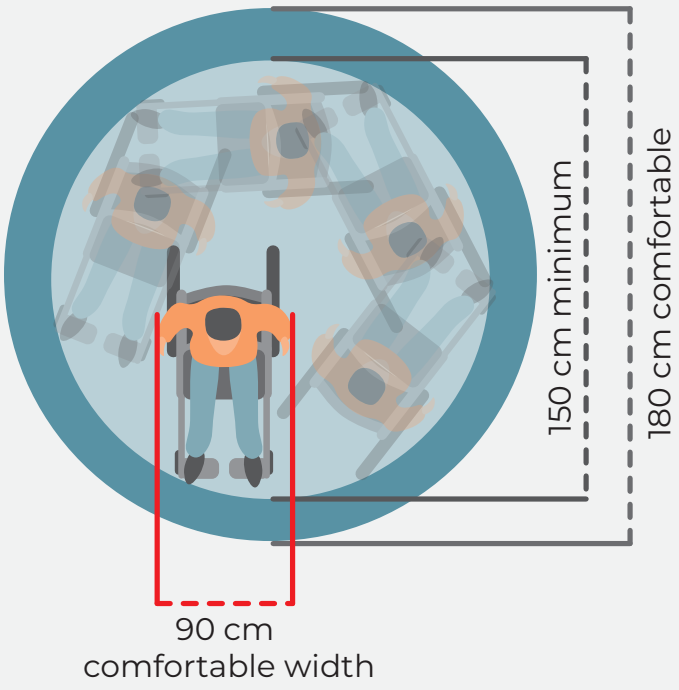
Each of these groups have different characteristics and needs. With the intention of narrowing down the aim of the project, it was established that active wheelchair users will be the customer segment in focus for the solution. These individuals have complete mobility of their upper body, but none or very limited on their lower body. This type of physical disability is referred to as “paraplegic”. Even though they can do most everyday life tasks independently, they also face some restrictions in terms of their mobility [App. 2].

The solution must be usable for active wheelchair users.

MANOEUVRING

Moving around in certain spaces might also be a challenge for wheelchair users. Based on anthropometric studies (National Disability Authority, 2020) the space required for users to manoeuvre is established. This space is determined by a circle in which the user can rotate 360° as depicted on ill. 1.13. This shows that wheelchair users require more space than others to move comfortably around.

This limitation might become an issue if the users need to drive around in order to clean their wheels. This is an issue as the space available in their entrance might not be sufficient. The anthropometric studies also state the maximum comfortable width a wheelchair user is able to go through is 90 cm (National Disability Authority, 2020). This is also the standard of most doors, to allow wheelchairs to get through them (Window World, 2022).



Ill. 1.13: Manoeuvring area for wheelchair user

They are able to rotate around comfortably on an area of 180cm x 180cm, and pass through spaces that are over 90cm in width.

CLEANING SCENARIO

In order to understand how the users currently clean their wheels, interviews were conducted. The team met one of the users at his home and asked him to show the process of cleaning the wheels. The process that the user followed is depicted below [App. 1 & 4].

STEP 1 - ENTERING THE HOME

The user drives over a ramp and a doorstep to enter his house.

Ill. 1.14: Interviewed user showing how he cleans the wheels of his wheelchair

STEP 2 - WIPING THE REAR WHEELS

The user removes the superficial dirt with a cloth.

STEP 3 - WIPING THE FRONT WHEELS

The user reaches the front wheels with difficulty.

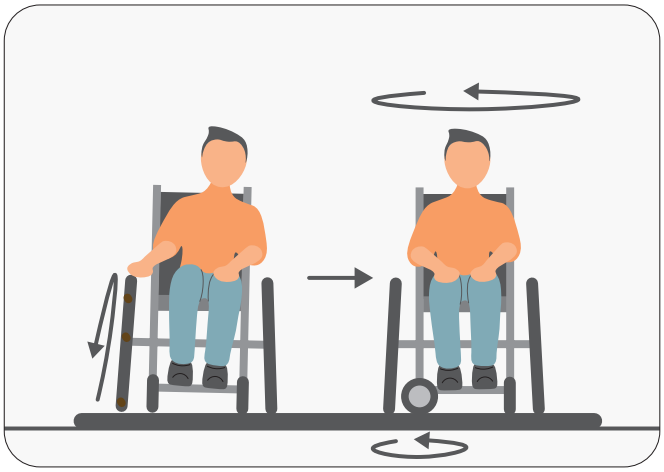
Seeing the cleaning scenario in person helped the team to understand the problems during this process. It was noticed that the user needed a lot of space for cleaning and that he had difficulties reaching the front wheels. Worst of all, the wheels were not completely cleaned at the end of the process.

The team was able to ask questions during the cleaning process to get a better understanding of why the user did what he did. On the next few pages, more workarounds and issues from the other interview [App. 1] are displayed.

CLEANING PROCESS

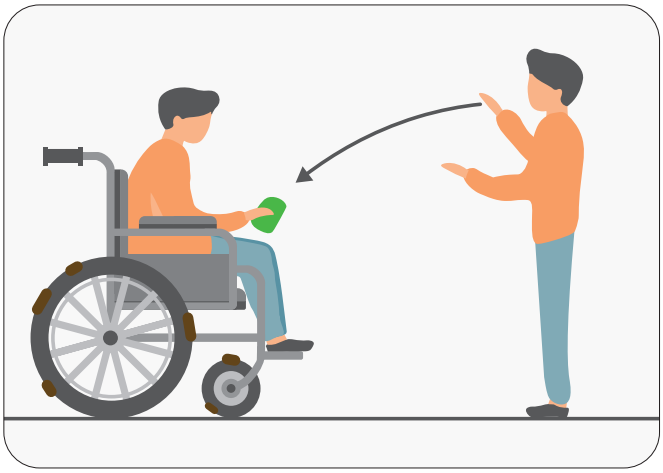
For wheelchair users, cleaning their wheels is a daily task that has not being facilitated in a proper way by existing solutions in the market. Some of the situations that these people will encounter during this process are depicted below.

THE WHEELCHAIR DANCE



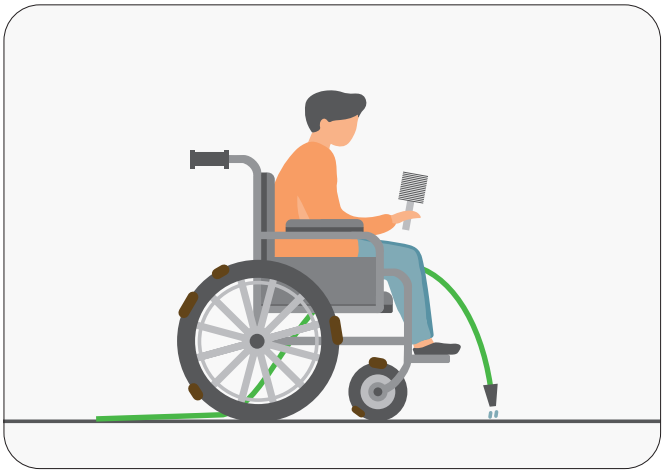
Some are able to lean to the side to clean one rear wheel at the time, and drive back and forth on the entrance mat to clean the front wheels. - Hans Peter

VISITING FRIENDS



Some borrow a towel or similar when visiting friends or family. - Michelle

HOSE & BRUSH/CLOTH



Some use a hose and brush outside to clean the wheels. Others use a cloth and a bucket. - Claus and Søren

TIME

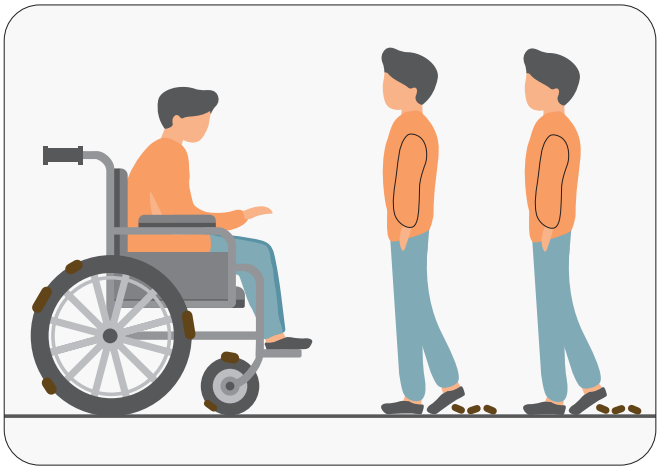
The cleaning process takes between 2 - 10 min. depending of the degree of cleaning. - Claus and Michelle

Ill. 1.15: Cleaning process

ISSUES

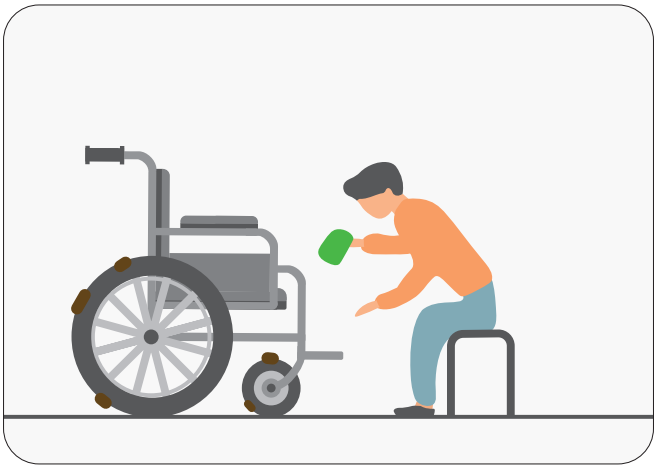
The lack of proper methods to clean the wheelchair wheels derives several problems that the user has to face on a daily basis.

DIRTY SHOES



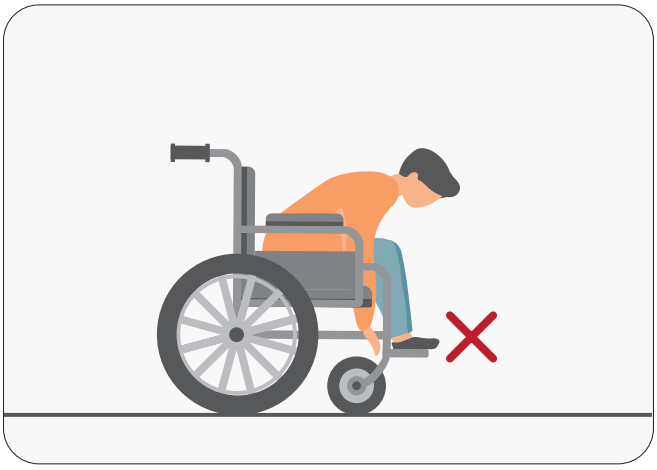
Some wheelchair users allow friends or family to go inside with they dirty shoes, because the floor is already dirty. - Jens Kristian

TRANSFER



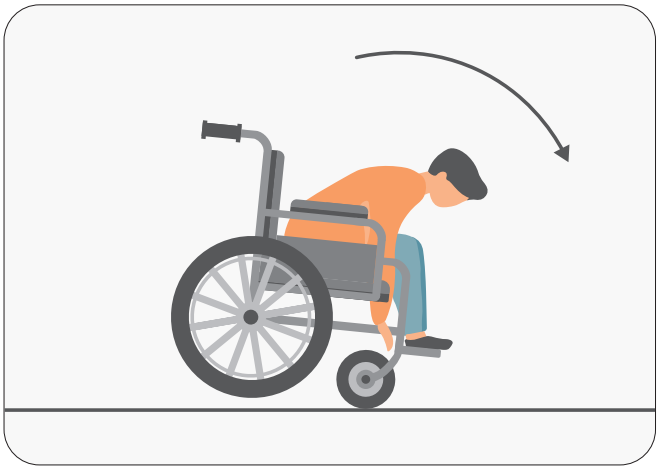
Not everyone is able to transfer to another chair and thus clean the wheels. - Michelle

REACHABILITY



Not everyone is able to reach the front wheels and some have a hard time doing so. - Hans Peter and Claus

POOR WHEELCHAIRS



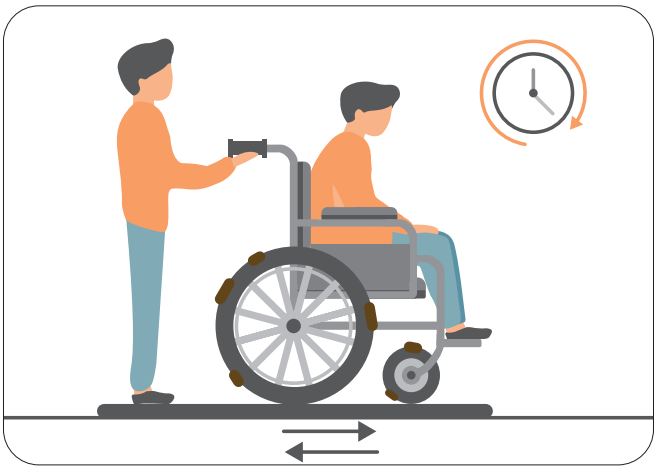
Many wheelchairs are poor in terms of balance, which might cause them to tip if the users lean too much forward. - Hans Peter

Ill. 1.16: Issues

STIGMA

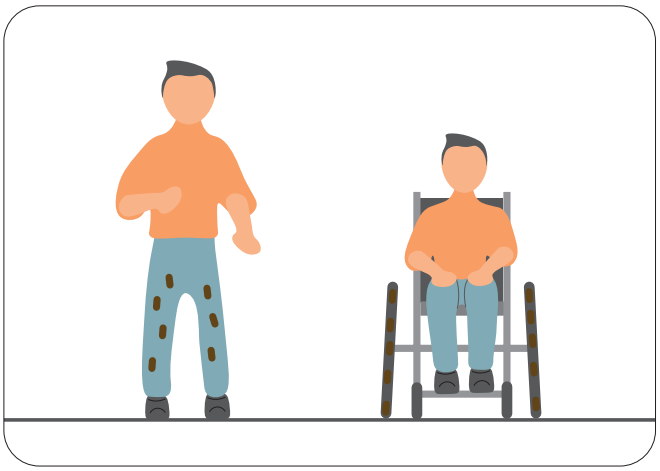
Wheelchair users often face situations where they need external help for cleaning their wheels, as otherwise they will have to drive around with dirty wheels. Either of these scenarios can affect the user's self perception and stigma.

FEELING LIKE AN OBJECT



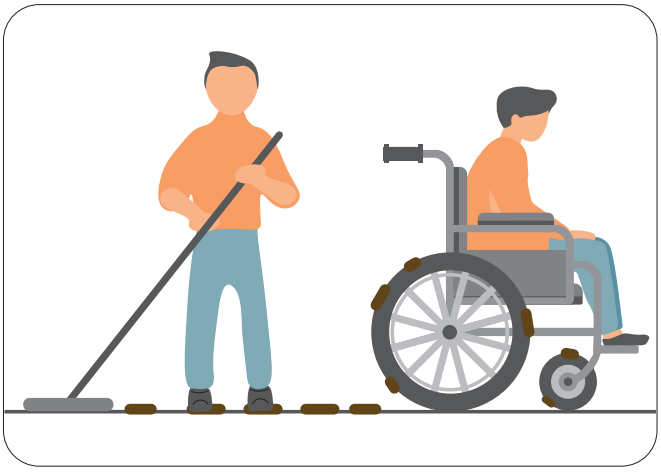
When visiting friends or family, some are being pushed back and forth on the carpet or have to wait in the entrance until the chair is dry, before they are allowed in. - Jens Kristian

SELF-IMAGE



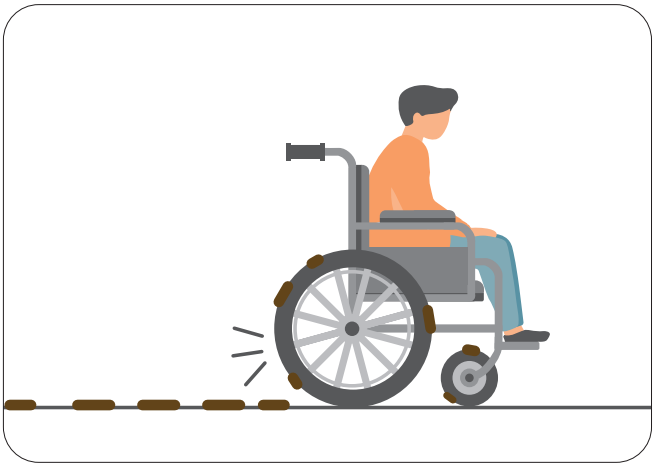
The wheelchair is a part of the user, similar to pants for any other. If the wheelchair/wheels are dirty, then so is the wheelchair user. - Louise

BEING A BURDEN



Some feel like a burden when visiting friends or family, as they have to clean afterwards. - Søren and Jens Kristian

NOISY



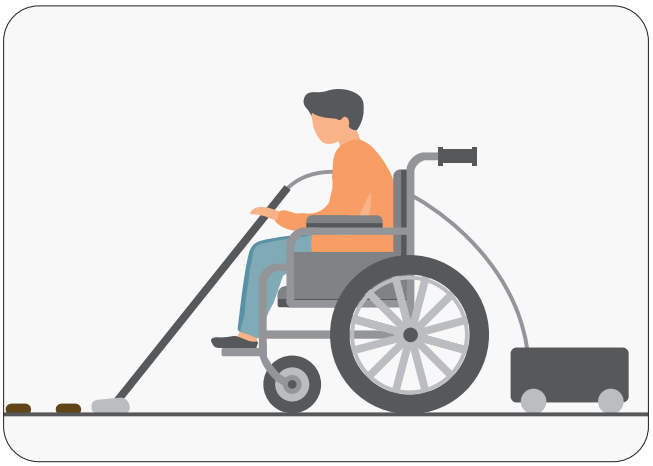
If not cleaned, the wheels get noisy due to sand or salt which can be embarrassing for the user. - Søren

Ill. 1.17: Stigma

WORKAROUNDS

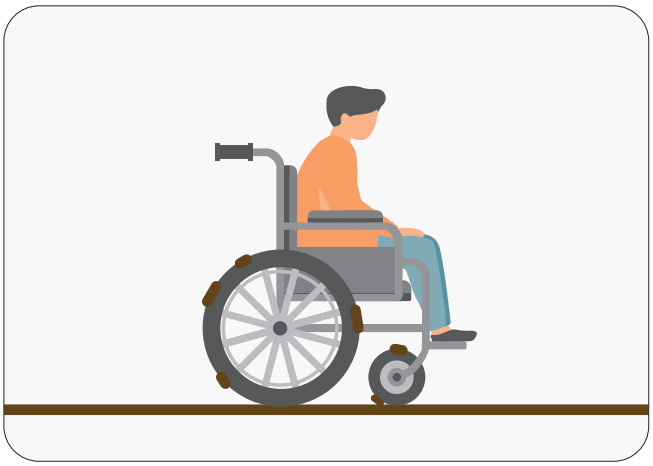
Many user's have found ways to at least partially solve the issues related with the cleaning of their wheels. These workarounds are often expensive and might even generate new issues.

VACUUM



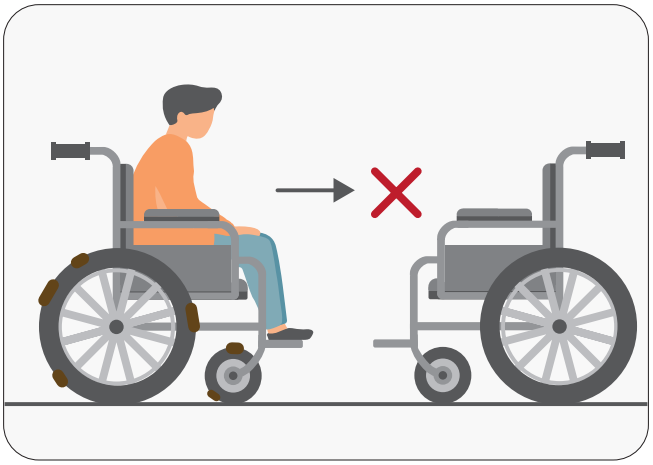
If only the entrance mat is used for cleaning, it usually requires an extra vacuum. - Michelle

CHANGING THE FLOOR



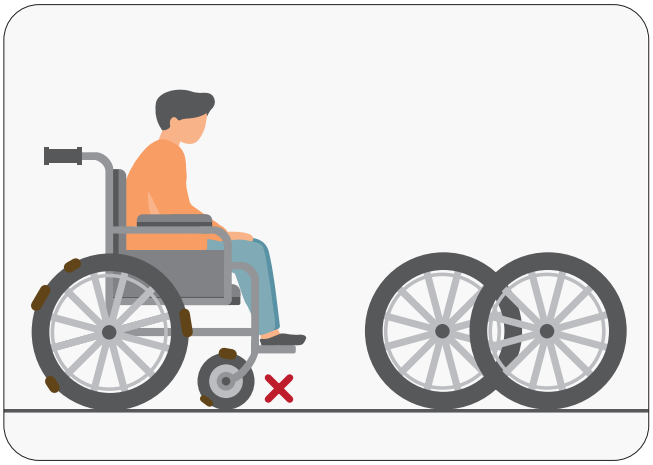
Some choose their house floor to be in dark materials, so it is more difficult to see the dirt trails. - Jens Kristian

BUYING A 2ND WHEELCHAIR



Most users only have one wheelchair, due to the high price point. - Hans Peter

MULTIPLE REAR WHEELS



Some own additional rear wheels for indoor usage, but this do not make the front wheels less dirty. - Claus

Ill. 1.18: Workarounds

These cleaning techniques, issues and workarounds have provided the team with a better understanding and an overview of the underlying problems associated to the cleaning of wheelchair wheels. This highlights the problem and the need for a adequate solution.

WHEELCHAIR SPECIFICATIONS

Nobody is 100% identical and this is also the case for wheelchair users. For this reason, many wheelchairs are custom-made for individual needs. This section shows the different elements that are present in a wheelchair, as well as considerations needed for making a solution that fits as many wheelchairs as possible [App. 3].

SIDEGUARDS

To protect the user from getting dirty while driving. Some have mudguards as well, which cover the top of the wheels.

BRAKE

Element that locks the back wheels, preventing them from spinning.

FOOTREST

Platform for placing your feet.

FRONT WHEELS

Compact wheels that allow the wheelchair to steer. Also referred as caster wheels.

WHEEL TYPES

A manual wheelchair usually has four wheels, two front wheels and two rear wheels. These wheels differ in size depending on the individual wheelchair (ill. 1.21.). The largest back wheel can be combined with the smallest front wheel and vice-versa, there is not a limitation in that regard.

Front wheels are most common with solid tires due to turning and rolling attributes with none or linear grooves, while the rear wheels usually are mounted with air tires with grooves, as depicted on ill. 1.20.

Ill. 1.20: Wheel with regular grooves (left), wheel with linear grooves (middle) and wheel without grooves (right)

ARM REST

Place where the arms of the users can rest if needed.

PUSH HANDLES

Used by an external person for pushing the user around.

SEAT & BACKREST

Spot where the user sits on the wheelchair.

PUSHRIMS

Rings used to transmit the motion from the hands of the user to the back wheels.

REAR WHEELS

Larger wheels that drive the movement of the wheelchair. Also called back wheels.

Ill. 1.19: Active wheelchair - Dalton Low

Rear wheels

Diameter
20 - 26” (50 - 66 cm)
Width
1” (2.5 cm)

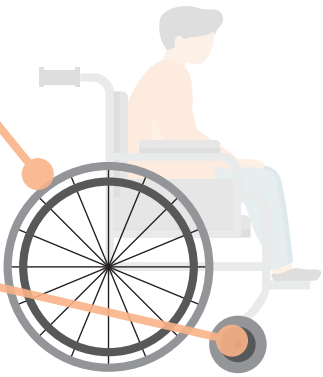
(Speight, 2020)

(The Accessible Planet, n.d.)

Front wheels

Diameter
3 - 8” (7.5 - 20 cm)
Width
1 - 2” (2.5 - 5 cm)

(MobilityBasics, n.d.)



Ill. 1.21: Rear wheels and front wheels of a wheelchair

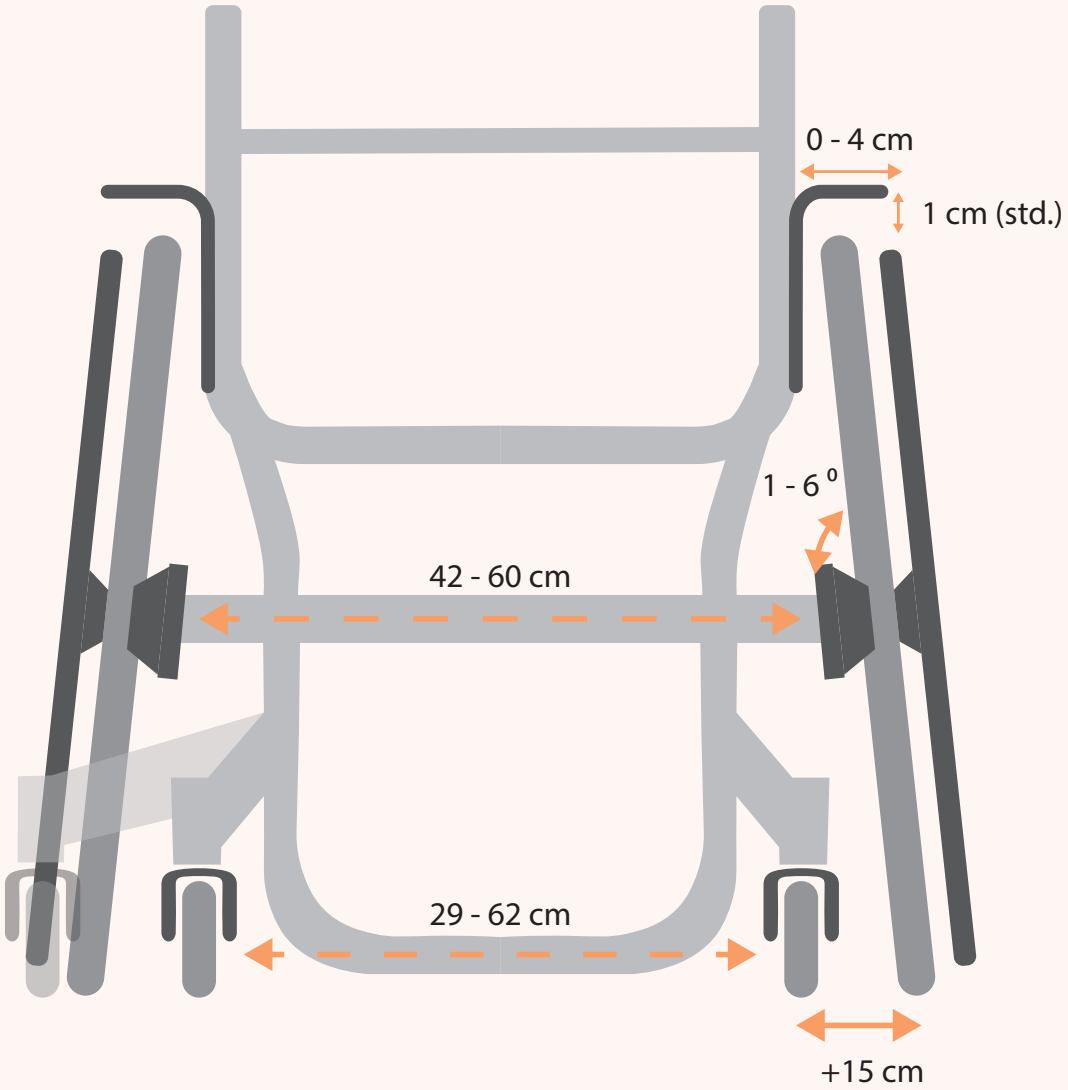
The solution must accommodate rear wheel sizes of 50 - 66 cm in diameter and 2.5 cm in width.

The solution must accommodate front wheel sizes of 7.5 - 20 cm in diameter and 2 - 5 cm in width.

WHEELCHAIR CUSTOMISATION

The parameters of the wheelchair that users are able to customise are many. In order to get an understanding of the measurement ranges of the different parts of the wheelchair that are available for modification, an order form from a wheelchair manufacturer was used as reference. In addition, the company's common practice of what is customisable and to which degree was also used as reference [App. 3].

FRONT VIEW



Ill. 1.22: Front view – active wheelchair

Between wheels

The width between the wheels varies depending on the user. The rear wheels span from 42 to 60 cm, while the front wheels span from 29 to 62 cm [App. 3]. This means that the front wheels can either be placed on the inner side or the outer side of the rear wheels, as depicted on ill. 1.22.

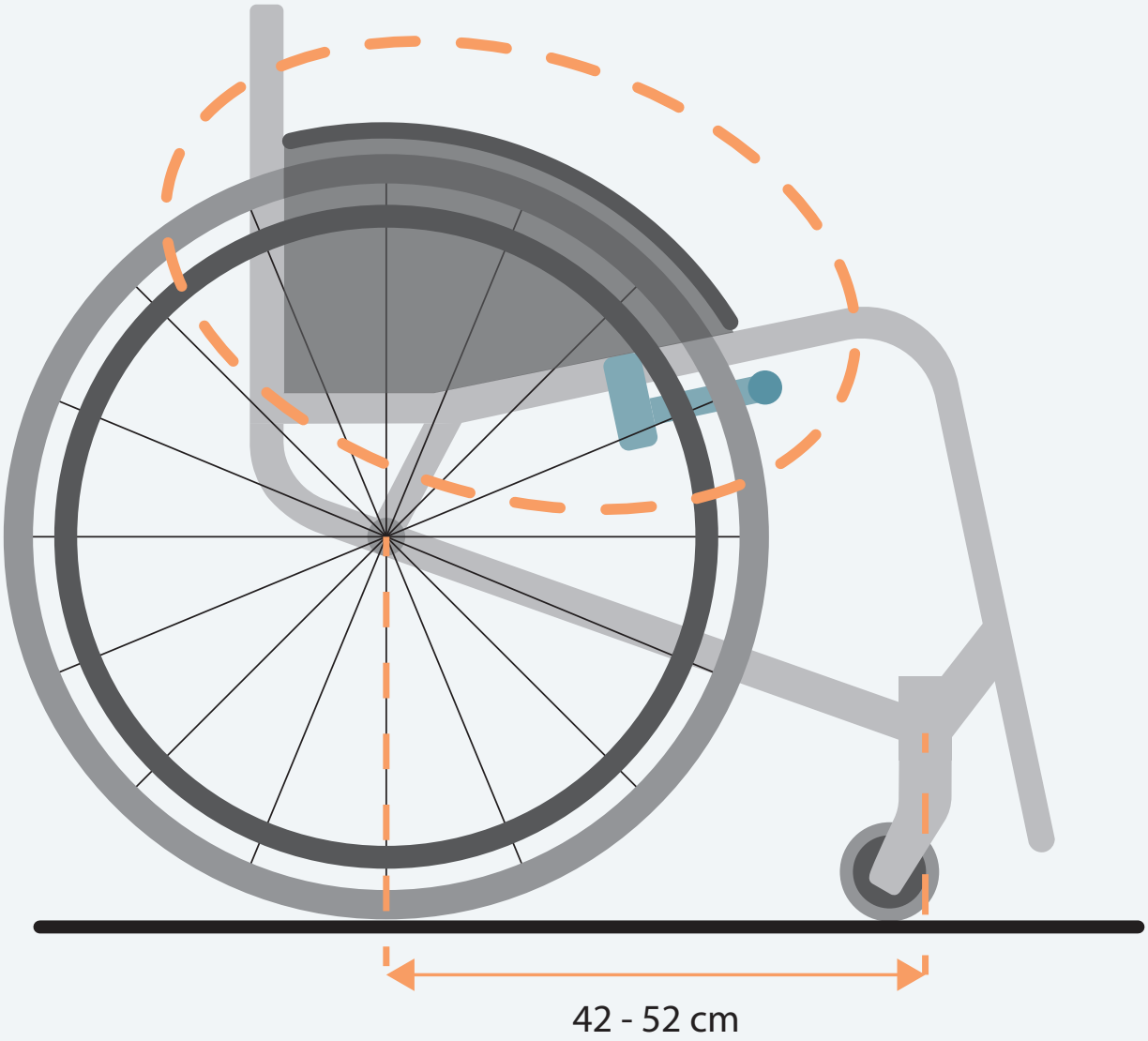
Camber angle

The rear wheels can also have a camber angle between 1° and 6°, which improves the driving experience by making the wheelchair more stable when turning. These camber angles increase the total width of the wheelchair [App. 3].

The solution must accommodate wheelchairs with a width of 40 - 60 cm.

The solution should try to accommodate wheel grooves, pushrims, mudguards and camber angles of 1-6°.

SIDE VIEW



Ill. 1.23: Side view – active wheelchair

Length

The distance between the front and rear wheels is also different from wheelchair to wheelchair. It spans between 42 and 52 cm [App. 13] which means that the total length of the chair also varies.

Accessibility to wheels

Due to the placement of the mudguards and the position of the brakes, cleaning the rear wheels from above may be difficult for many wheelchairs (ill. 1.23).

Mounting... where?

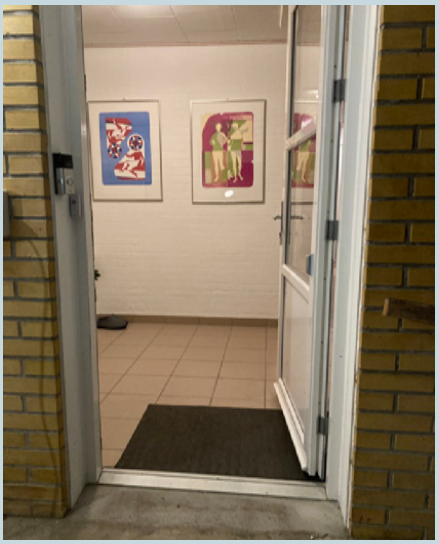
As there is no standard frame for wheelchairs, it is difficult to select a common place for attaching a mounted solutions.

CONTEXT - HOME ENTRANCE

To get an understanding of the space in which the product will be used, home entrances were analysed. This was done through mapping pictures of entrances from different wheelchair users to check the available space as well as the elements that will surround the product. Two examples of entrances are depicted below, one in a house and the other one in an apartment.

Interviewed user - Jens Kristian

He lives in a house and has enough space for manoeuvring in his entrance. He needs that space to clean his wheels, as he drives around during the cleaning process [App. 4].



Ill. 1.24: Entrance of interviewed user

Wheelchair user - Youtuber

This user lives in an apartment and does not have enough space for manoeuvring comfortably in his entrance [App. 5].

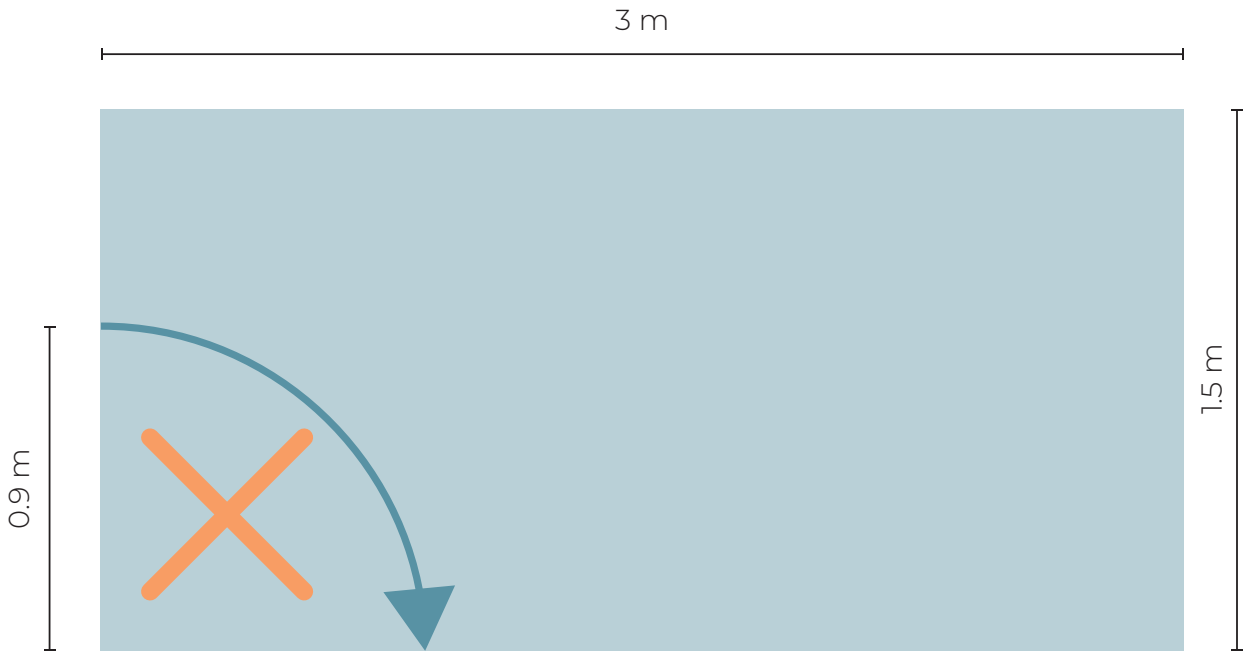
Ill. 1.25: Entrance from Youtuber that is a wheelchair user

MAIN TAKES

- The gap between door and floor is very small, so making a solution placed right at the entrance door is not viable.
- Entrances vary significantly in size, so making a product that fits the smallest situation (apartments) will be required. The furniture at the entrance does not differ from any other houses, but must be considered as it reduces the available space for a solution.

ENTRANCE DIMENSIONS

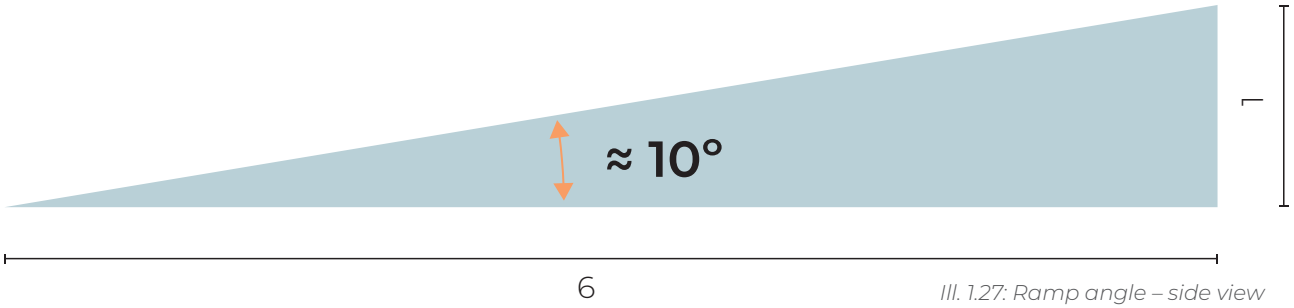
To establish the boundaries in terms of available space for operating a solution in the entrance, average sizes for entrances were used. The entrance takes approximately 4% of the total area of a house (Randel, 2019). As the average home area is about 112 m^2 (Danmarks statistik, 2016), this gives an approximate entrance size of 4.5 m^2. As average entrances have a width of 1.5 meters and doors have a recommended width of 0.9 meters (Randel, 2019), the dimensions of the average entrance are defined and displayed on ill. 1.26 [App. 5].



Ill. 1.26: Entrance dimensions – top view

RAMPS

To accommodate access for wheelchair users due to changes in floor level, ramps are a necessity. Many wheelchair users have ramps in order to get inside their homes. In order to understand what incline the users are capable of driving uphill, the recommended ramp angles for homes are investigated. For public ramps or slopes, an incline of 5° is required, whereas for the home use the user can decide what they feel comfortable with. A ramp with a slight incline, is longer but comfortable for every user to drive upon. But if space is a limitation, a steeper ramp of up to 15° could also be used. However, not every user is able to drive up this incline comfortably. The middle ground is 10° - it saves space while still being comfortable for most users (Braun ability, 2022). This is used as reference if ramps are used in the solution.



Ill. 1.27: Ramp angle – side view

The solution must be possible to use in the entrance of 3 m X 1.5 m

Ramps must not exceed 10 degrees incline.

DIRT & WHEELS

The team looked into how often wheelchair users would need to clean their wheels, in order to determine the frequency of use of the solution [App. 6]. The types of dirt that the user will encounter most often were also explored. The data obtained was based on places located in Aalborg (Denmark), so the data will probably differ in other locations.

FREQUENCY OF USE

Ten fellow students were asked about their daily habits to determine how many times per day they enter their home through their front door. The intention of this investigation was done as it was assumed that the average active wheelchair user would have a similar routine.

As a result, the team noticed similarities among the peers interviewed. These people enter their home for doing the following activities:

- COMING HOME FROM UNI/WORK
- TAKING OUT THE TRASH
- HOME AFTER A RUN/WORKOUT/WALK
- GROCERY SHOPPING

The interviewed students used their entrance door 3-4 times a day, or about **20 - 30 times a week.**

TYPES OF DIRT

By talking to a user, it became clear that the wheelchair users faces the same types of dirt as other people. The team members decided to analyse the different ground surfaces they came by on their way to university. The most frequent dirt types that the team encountered on a daily basis were:

Pavement & asphalt

Sand, small rocks & grass

Cobble stones

Ill. 1.28: Picture of the street in Aalborg

The dirt from these surfaces sticks to the wheels, especially if the ground is wet. Small particles of dirt - including sand, rocks, and salt (only during winter) - stick to the surfaces of the tires and some get into the grooves, which makes it trickier to remove. The interviewed user [App. 1] mentioned that he tries to avoid muddy paths, the same way any other would do. He also stated that getting mud on the tires is a way less common scenario, so the team shifted their focus away from this and only focused on the dirt described above.

The solution must be able to remove wet dirt from the wheels.

Ill. 1.29: Dirty wheelchair wheels

SEASONS

The weather conditions for Denmark through the year were investigated to determine the seasons in which rain, snow and frost are most frequent. These meteorological conditions will make the ground wet, which would influence the frequency of cleaning of the wheelchair wheels. This estimation is based on the assumption that users leave their homes with the same frequency during those months of the year. The numbers displayed below correspond to the average of days with different weather conditions in Denmark from 1990 - 2011 (Danmarks Meteorologiske Institut, 2012).

Ill. 1.30: Seasons

SPRING	SUMMER	FALL	WINTER
38 DAYS	38 DAYS	49 DAYS	47 DAYS
8 DAYS	0 DAYS	3 DAYS	6 DAYS
22 DAYS	0 DAYS	9 DAYS	53 DAYS

Ill. 1.31: Icons for snow, rain and frost (from left to right)

Ill. 1.32: Wheelchair user with a raincoat

YEARLY FORECAST

In Denmark there are around 150 rainy or snowy days a year (Danmarks Meteorologiske Institut, 2012), which means that the user's wheels are wet during half of the year. Even though it is not raining on a specific day, the ground could still be wet, which will cause the same effect in terms of attracting dirt to the wheels.

Additionally, in Denmark there are around 80 days a year that the temperature reaches 0° or below (Danmarks Meteorologiske Institut, 2012). This likely translates into salt in the streets during those days, which also sticks to the wheels.

DESIGN BRIEF

INITIAL PROBLEM DEFINITION

How to create a device which allows manual wheelchair users to independently achieve clean wheels when entering indoor environments?

VISION

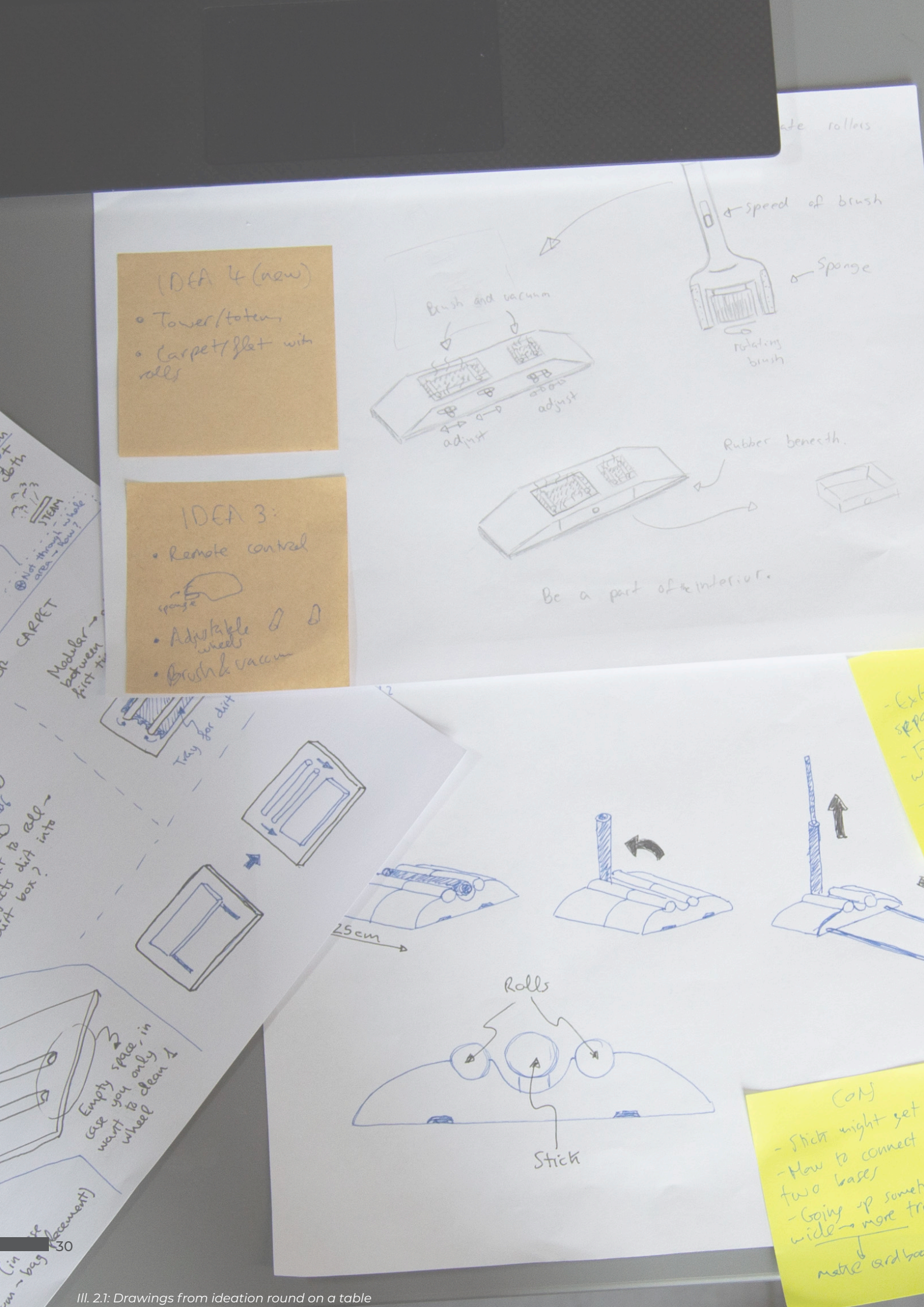
Make it as easy to clean the wheels on a wheelchair as it is to take of the shoes.

NEEDS

- The solution must be usable for active wheelchair users.
- It must be reachable, so at least 40 cm in height.
- It must accommodate rear wheel sizes of 50-66 cm in diameter and 2.5 cm in width.
- It must accommodate front wheel sizes of 7.5-20 cm in diameter and 2-5 cm in width.
- It must accommodate wheelchairs with a width of 40 - 60 cm.
- It must be used in the entrance of the house.
- Ramps must not exceed 10 degrees incline.
- It must be able to remove wet dirt from the wheels.

WISHES

- It should be transportable.
- The time from dirty to clean wheels should not exceed 2 minutes.
- It should also clean other parts of the wheelchair.
- The wheels should be both clean and sanitised for inside usage.



Ill. 2.1: Drawings from ideation round on a table

2. IDEATION

In this chapter, several ideation sessions are presented. Additionally, functional tests and cleaning tests are carried out. A reflection on the direction is presented at the end of the chapter.

MARKET ANALYSIS

At the start of the project, the team did a desktop research on existing cleaning solutions to get a picture of the market. A great number of products was found, but only a couple of them were available or have been available for purchase, whereas the rest were Do It Yourself (D.I.Y.) projects from people. Additionally, the team noticed through interviews with users and the municipality, that the products were not being sold as they should. The team then tried to answer the question: why are users not buying the available solutions? [App. 7]

AVAILABLE SOLUTIONS

Ill. 2.2: CleanWheels

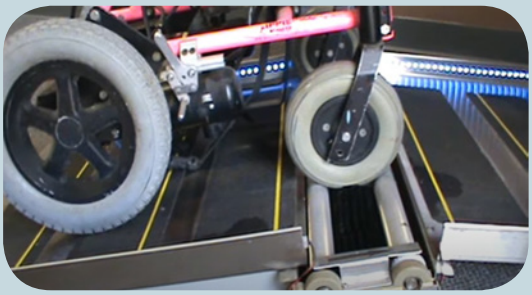
This is a manual wheel cleaner meant to be placed at the entrance of the home. It only brushes the rear wheels and has an elevated price point of about 3800 DKK (Gloria Mundi Care, 2022).

Ill. 2.3: Dækrenser - Home

This is a motorised wheel cleaner that requires to be installed in the entrance floor. It takes up a significant amount of space, it looks very industrial and is expensive to install. It is not possible to purchase this product anymore.

D.I.Y. SOLUTIONS & CONCEPTS

Ill. 2.4: Wheel socks for wheelchairs



Ill. 2.5: Wheel cleaning system

Ill. 2.6: Wheelcleaner prototype made by a group of students

Ill. 2.7: Water wheel cleaning system

Ill. 2.8: De-Fender: Wheelchair Wheel Cleaner

The abundance of these D.I.Y. products could mean that some of the main needs have not been meet sufficiently in terms of usability, clean level, price point or similar. This creates an opportunity to make a more desirable cleaning solution for wheelchairs.

MAIN COMPETITOR - CLEANWHEELS

CleanWheels is the only solution which is currently available for purchase on the Danish market. This product is a stationary wheel cleaner for the home that requires no installation. The user drives backwards onto it, and then spins the rear wheels manually. While the wheels are turning, a brush removes (some of) the dirt.

Ill. 2.9: Wheelchair user using CleanWheels

- ✓ *The solution must clean both rear and front wheels.*
- ✓ *The solution must clean more than a brush.*

User feedback

Why the users do not use CleanWheels [App. 1]

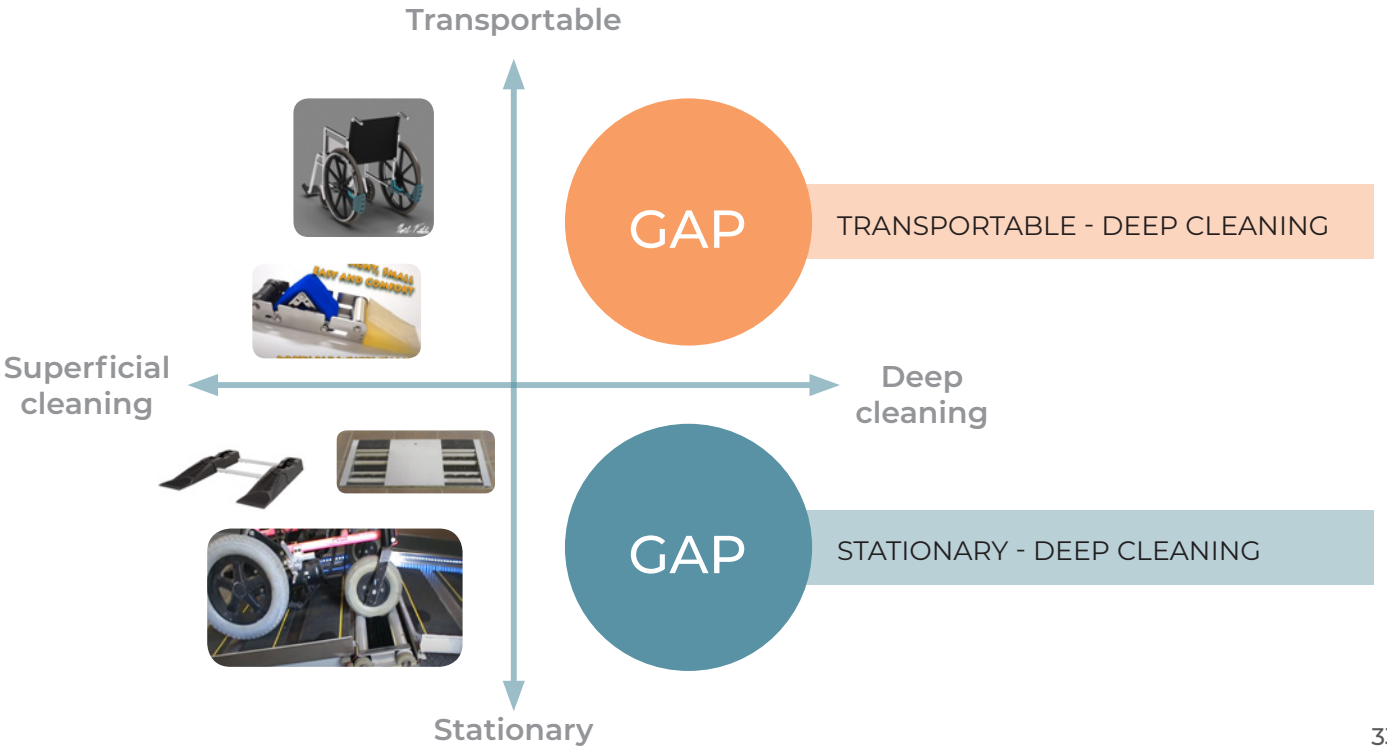
- *"The price point is a no-go, and the municipality will not help to pay for it."*
- *"It takes up a lot of space in the home."*
- *"It does not clean the wheels very well, only brushes off the dirt."*
- *"It only cleans the back wheels, and not the front wheels."*

The team's thoughts on CleanWheels

- *You drive back in your own trail of dirt after cleaning the wheels, making them dirty again.*
- *It does not fit into a home setting, more like a garage.*

MAPPING CURRENT SOLUTIONS

A mapping of the current solutions was made. The solutions were divided into the categories of "Transportable" and "Stationary", as well as "Superficial cleaning" and "Deep cleaning". The superficial cleaning only removes part of the dirt, while deep cleaning is removing all the dirt. It was noticed that there was a clear market gap in the deep cleaning section, both for transportable and stationary solutions. The team saw the opportunity to make a product proposal in either of these areas.



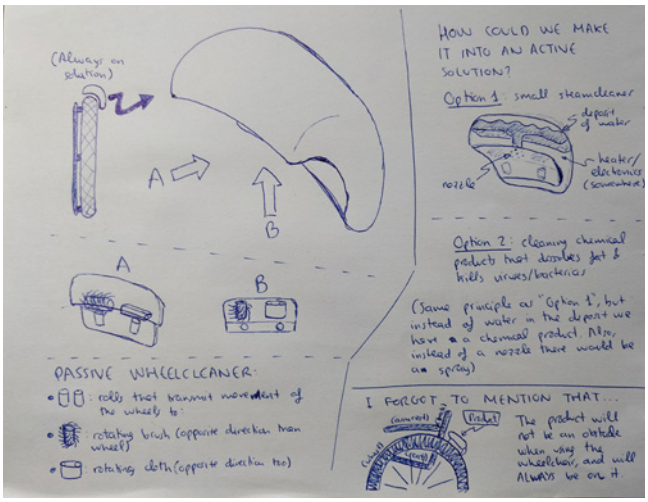
Ill. 2.10: Graph to map wheel cleaner solutions in terms of cleaning and transportability

IDEATION - PART I

The initial ideation rounds were made to start exploring possible solutions for cleaning manual wheelchairs. It was done through different methods like Reverse Brainstorm and What If (Tollestrup, 2004) [App. 8]. These methods were used to clear the head of ideas and put them on paper.

The ideas proposed could be collected in three categories:
1) Mounted on the wheelchair
2) Handheld devices
3) Ramps/lifting mechanisms

MOUNTED



Ill. 2.11: Drawing from ideation round – mounted solution

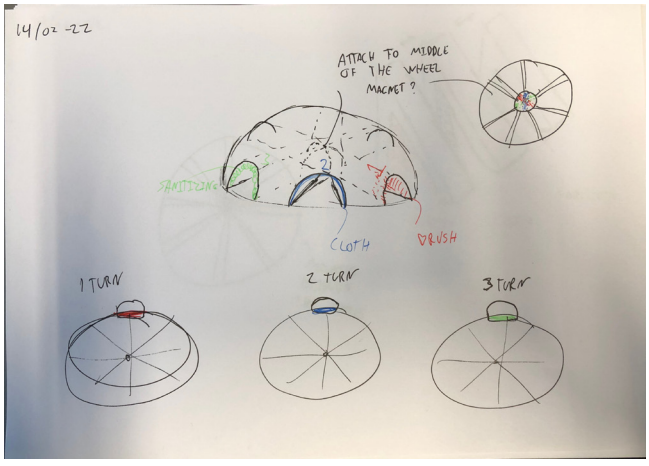
The mounted proposals are installed on the wheelchair and are left there, so the user always carries them around. The idea is that these products have a brush and a cloth for removing the dirt from the wheel while on the go.

- Does not clean the front wheels.
- Able to clean the wheels anywhere.
- Effortless for the user.

HANDHELD

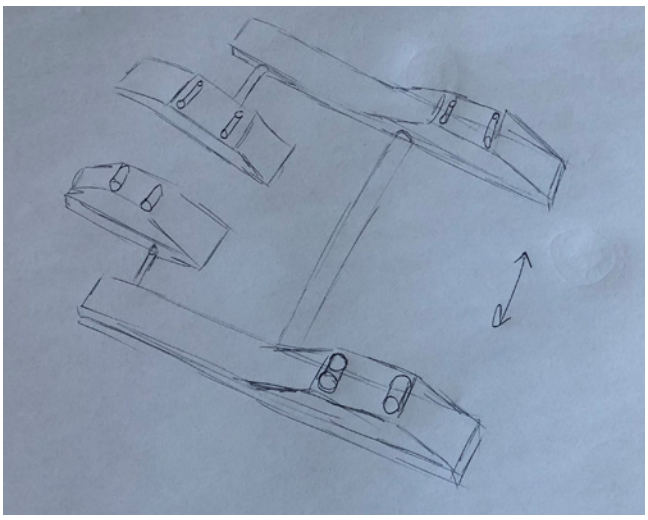
The handheld devices give the user more control over the cleaning of the wheels by making it easier to see when they are clean enough. The concept depicted has three cleaning tools in one. A brush to take off the dirt, a cloth to remove the water and some sanitiser to clean the wheels from bacteria and virus.

- The front wheels are not reachable.
- Requires more effort from the user.
- More control over the cleaning.



Ill. 2.12: Drawing from ideation round – handheld solution

RAMP



Ill. 2.13: Drawing from ideation round – ramp solution

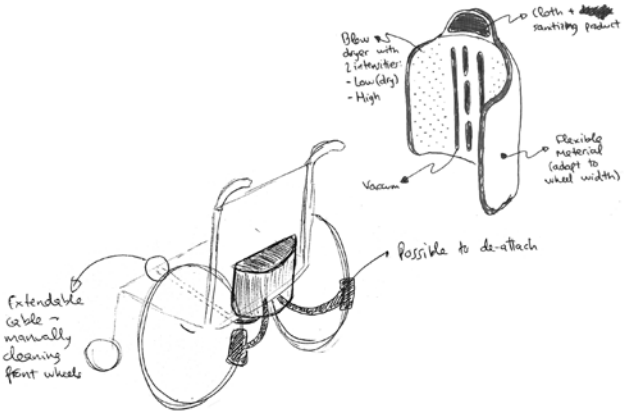
The ramps and lifting mechanisms are devices that elevate the wheel to make it easy to rotate without having to drive back and forth. The result is that the user can clean the wheels while staying in the same place. A brush is cleaning the wheels as they rotate on the ramp.

- Only brushes off the wheels.
- Large and not transportable.
- Cleans all four wheels.

INITIAL CHOICE OF DIRECTION

MOUNTED...OR NOT?

The initial decision was to work further on a mounted solution that is always attached to the wheelchair. This concept would be stored on the back of the wheelchair and has a motor to vacuum the dirt from the wheel after it has been brushed off. This device also allows to clean the front wheels with an attachment.



Ill. 2.14: Drawing from ideation round – chosen mounted solution

However, the perspective changed after an interview [App. 1] that made the team more aware about the importance of the weight for the users. The price of a lighter wheelchair would be several thousand DKK higher, so having an always-mounted solution might not be the way to go. This is also because by adding weight to the wheelchair, it required the users to use more power when driving. Additionally, every wheelchair has a different frame, making "one-fits-all" attachments very challenging (page 23).

On the other hand, many users seemed to like the possibility to have a transportable solution they could bring when needed [App. 4]. This made the team go back a few steps and look at solutions that users still could bring, but that were not mounted.

- Adds to much weight to the wheelchair.
- Unable to be removed easily.

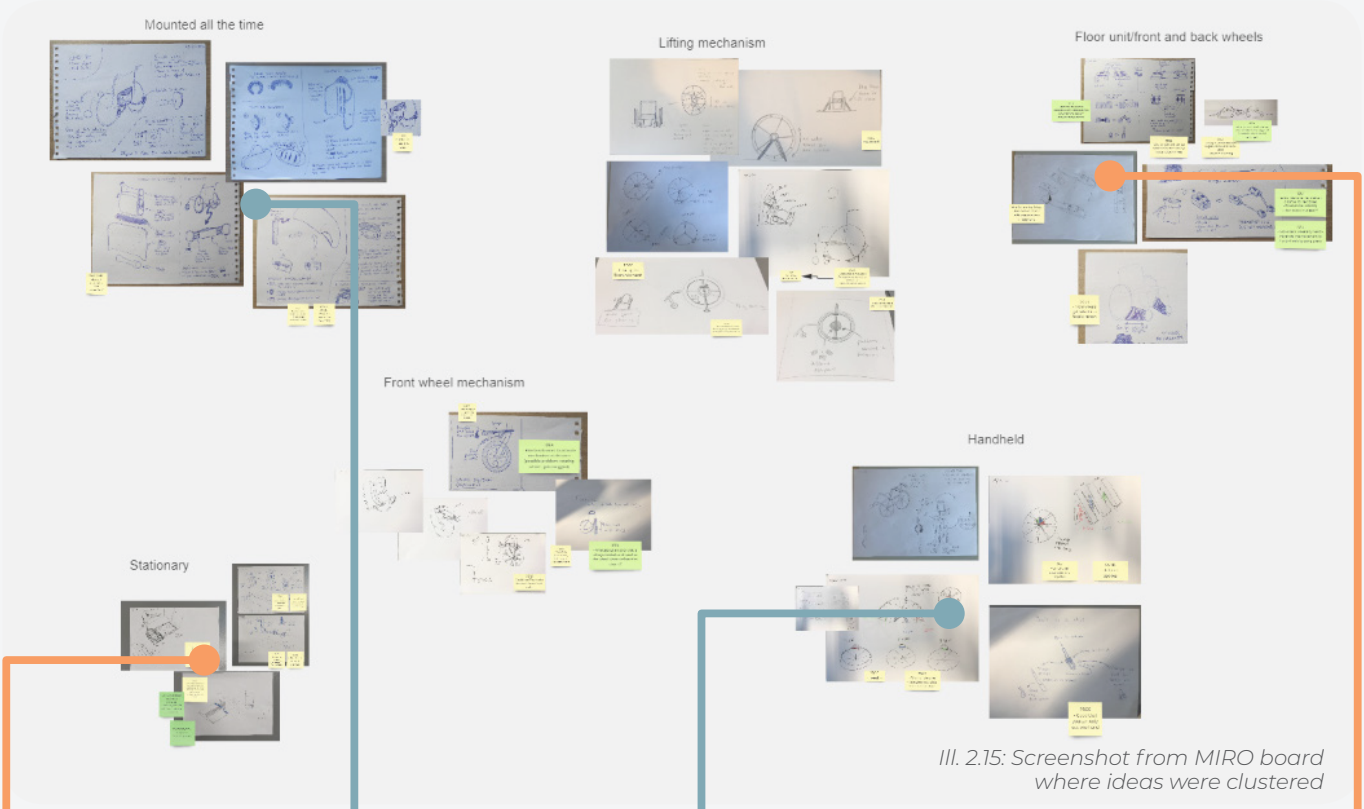
IDEATION - PART II

Several ideation rounds were made during the initial stage of the process. The way these ideation rounds were carried out was by allowing the team members to draw ideas individually in a defined time frame. Then, these ideas were discussed as a team, and Pros and Cons were identified for each idea [App. 8].

CLUSTERING IDEAS

For all the ideation rounds, the cleaning of both the front and back wheels of manual wheelchairs was considered. After some ideation rounds, the ideas were grouped together in categories with similar functionality and common characteristics. The result of the initial clustering resulted in the following categories:

- On-the-go mounted
- On-the-go handheld
- On-the-go floor
- Stationary



Ill. 2.15: Screenshot from MIRO board where ideas were clustered

STATIONARY

Solution that are permanently in the entrance, and that is intended to be used on a daily basis when the user gets home. It would be possible to make it larger than the transportable counterparts as it is not made to be moved around. This direction was continued.

ON-THE-GO MOUNTED

Solution which is always attached to the wheelchair. This direction did not seem attractive to users as the weight of the wheelchair is a crucial factor for them. Additionally, every wheelchair has a different frame, making a "one-fits-all" attachment challenging.

ON-THE-GO HANDHELD

Solution with two parts: a stick/handle and a cleaning element (brush or cloth). This direction was dismissed, as the users would have to spin and drive back and forth to obtain clean wheels. This process takes a long time and can even be embarrassing for the user.

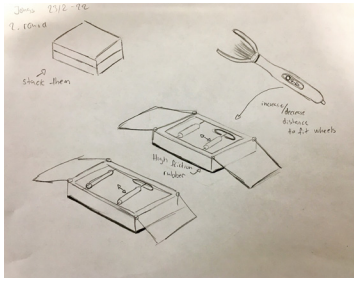
ON-THE-GO FLOOR

Solution that is placed on the floor so the user can drive over it, cleaning the wheels of their wheelchair. This direction was kept as it allowed the user to limit the space required for cleaning.

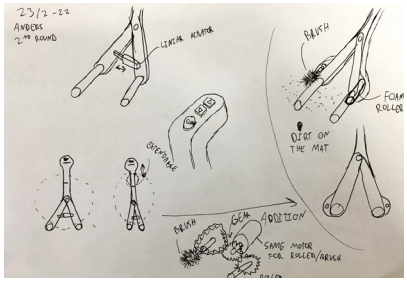
IDEATION ON CATEGORIES

After making the decision to continue with "**ON-THE-GO FLOOR**" and "**STATIONARY**", the team made more ideation sessions. An ideation session was made to shape three concepts, and a following ideation round was carried out to specify the appearance and function of each proposal. The three resultant directions were:

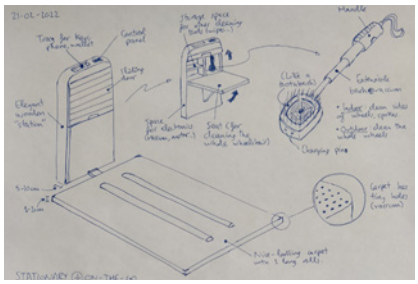
ON-THE-GO 1



ON-THE-GO 2



STATIONARY

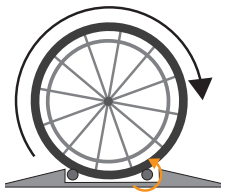


The pictures shown above are the sketches that led to the three concepts.

Ill. 2.16: Drawings from ideation round

3 CONCEPTS

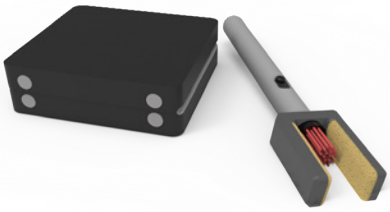
The concepts presented below follow the same basic working principle, in which two rollers are placed under the wheels to allow them to spin thanks to a motor. This allows the user to stay in the same place when cleaning the wheels. 3D models of the concepts were made, as well as cardboard models. The scenarios of use were simulated by the team by using the mock-ups, which allowed to identify improvement points for all concepts.

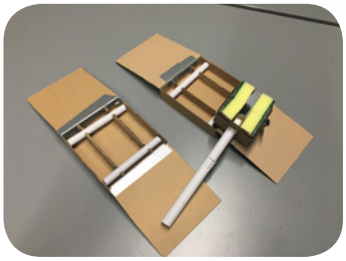


ON-THE-GO RAMP

This concept is divided in two main parts:

- Motorised bases with rollers - to spin the wheels of the wheelchair.
- Stick - to control the motor and pick up the bases from the ground. It has a brush and a sponge in its end for cleaning.





Ill. 2.17: On-the-go ramp concept - Render & mock-up

ON-THE-GO LIFT

This proposal has a mechanism that lifts the wheels. This is done by placing the product to the side of the wheels, and then activating the mechanism. The device is controlled from a L-shaped stick, which also includes a brush on its end. An inconvenience of this concept is that it requires the wheels to be cleaned one by one, which increases the duration of the cleaning process.

Ill. 2.18: On-the-go lift concept - Render & mock-up

STATIONARY

This solution is hidden as a piece of furniture in the entrance when not in use. When the users want to clean their wheels, they will unfold a ramp which contains some motorised rollers and a cloth and/or brush for cleaning the wheels. This direction was considered due to the frequency of use at the home compared to when visiting friends or alike.

Ill. 2.19: Stationary - Render & mock-up

The direction which was chosen to develop further was the **ON-THE-GO RAMP**. This solution can be used at home or anywhere else that the user need to clean their wheels. Also, two users mentioned during one of the visits that they would prefer a solution which could be used in more places [App. 4].

CLEANING TESTS

Several cleaning tests were done across the development of the project to determine "What is clean enough?". These tests consisted of making the wheelchair wheels or bike wheels dirty by driving over dirty surfaces and afterwards cleaning them with different cleaning methods [App. 10].

CLEANING TESTS - WHEELS

Various wheels were tested: without grooves (wheelchair available), with deep grooves (cruiser bike) and with slight grooves (city bike). It was noticed that the deeper the grooves in the tires, the harder it was to make the wheel fully clean as dirt got stuck into them.

Ill. 2.20: Wheel types: flat wheelchair wheel (top left), mountain bike wheel (top right) and city bike wheel (bottom)

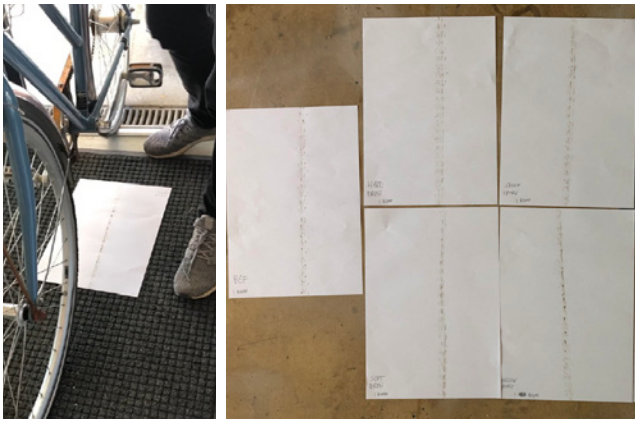
CLEANING TOOLS

Multiple cleaning methods were used, from a steam cleaner to various different sponges, brushes and cloths. It was found that brushes were better for wheels with grooves, because the bristles could get inside them and remove most of the dirt. Nevertheless, the brushes did not wipe off the water from the tires, so the wheels were still leaving trails of dirt when driving inside. A cloth was then used to dry the wheels, with better results.

Ill. 2.21: Cleaning tools used during tests

MEASURING CLEAN LEVEL

For analysing which cleaning method was more suitable for wheelchair wheels, a piece of paper was run over before and after the cleaning. It was concluded that a cloth was the best solution for drying the wheels, whereas hard brushes helps to remove the dirt from the grooves best. Now that the team was able to measure the clean level the question became: "What is clean enough?" This needed to be evaluated by wheelchair users.



Ill. 2.22: Dirty wheel running over a piece of paper (left) and comparison of several pieces of paper with dirt trails on them (right)

USER'S PERCEPTION OF CLEAN

A group of four wheelchair users was asked what would be the acceptable amount of dirt on the wheels for entering their home [App. 13]. This should provide the team with a measurable/comparable degree of cleaning, which can then be used to verify whether or not an acceptable degree of cleaning is achieved.

A piece of paper with different tire marks was shown to the users, from which they chose a trail they considered acceptable. The required degree of cleaning was rather high, and that is why it is difficult to illustrate.

It is possible to see the acceptable degree of cleaning for the users and what is achievable with brush and cloth in appendix 13. The required degree of cleaning established matches with the cleaning test with cloth and brush.

The solution must be able to clean front and rear wheels according to user's perception of clean [App. 13].

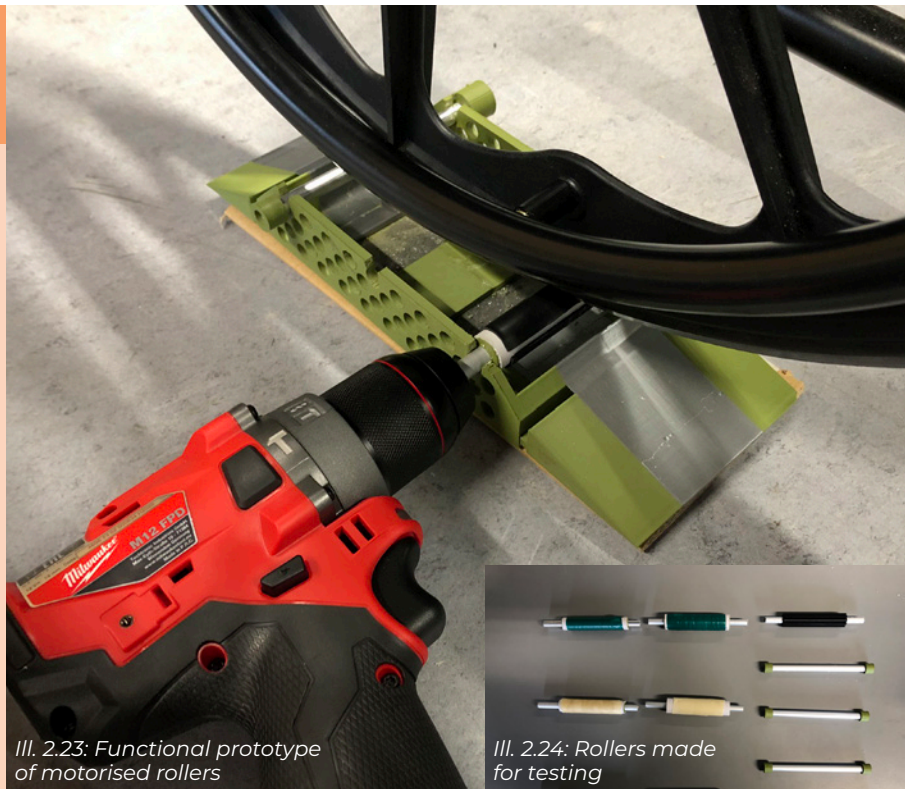
PROTOTYPE TESTING

The chosen concept had motorised rollers to spin rear and front wheels in order to clean. Therefore, this working principle needed to be verified. This was done through several tests with prototypes [App. 9].

ROTATING WHEELS WITH MOTOR

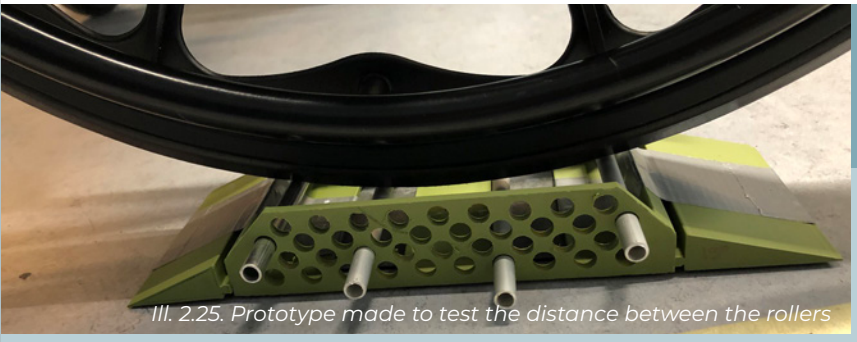
To verify if the rollers would rotate the wheels with a motor, one of the team members was placed in the wheelchair. It was possible to spin all the wheels, with and without user. However, how well the wheels rotated depended on which material was being used and therefore, considering the friction is important.

Several tests with various types of roller materials and sizes were carried out, with rubber being the most effective. However, due to wear and to avoid deformation of the rollers, a metal material might be of preference. Because of this, the required friction and strength analysis of the rollers should be calculated later, if the roller concept is maintained, to identify what kind of material is required.

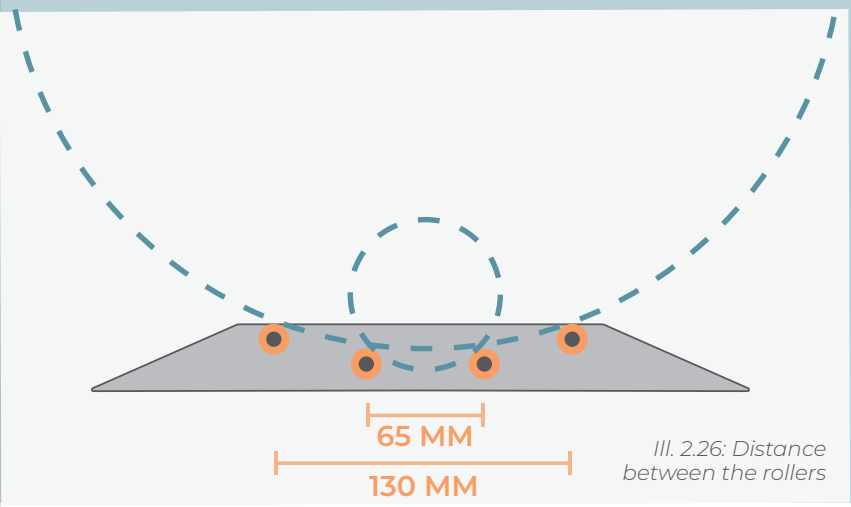


Ill. 2.23: Functional prototype of motorised rollers

Ill. 2.24: Rollers made for testing



Ill. 2.25. Prototype made to test the distance between the rollers



Ill. 2.26: Distance between the rollers

DISTANCE BETWEEN ROLLERS

In order for the user to feel secure when on top of the rollers, the minimum required distances between the rollers for both front and rear wheels were determined. This was done by testing various positions with the 3D printed mock-up as depicted on ill. 2.25. The mock-up had numerous holes to allow for different distances between the rollers for the front and rear wheels. The minimum distances that were concluded to be most suitable for different wheel sizes were:

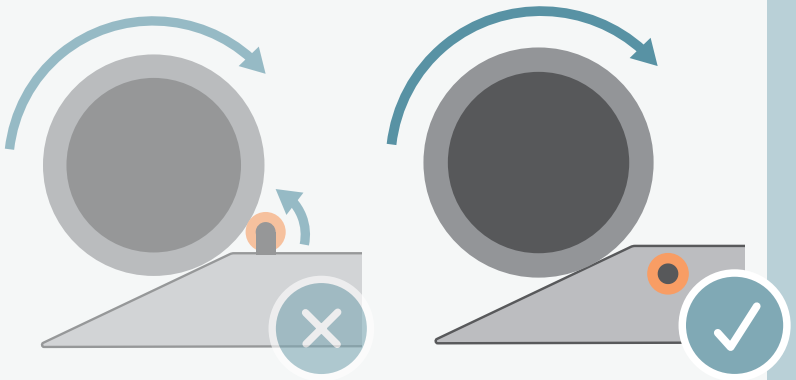
- ***At least 130 mm between the rollers for the rear wheels (from centre to centre).***
- ***At least 65 mm between the rollers for the front wheels (from centre to centre).***

Ill. 2.27: Prototype made to test where should the ramp end

TOP OF RAMP

During the tests, it was difficult to get onto the prototype if the top end of the ramp was below the top of the first roller as depicted on ill. 2.27. This happened as the wheel started to spin when touching the roller, preventing to drive over it.

The top end of the ramp must be on level with the top of rollers for the front wheels.



Ill. 2.28: Position of the roller - bad (left) and good (right)

RAMP ANGLES

In order to get a understanding and feeling of how hard it is for wheelchair users to drive over ramps, different ramp inclines were 3D printed. This was done to investigate whether it was possible to make the ramps shorter. The experiment was based on the team members ability to drive on to the ramp, and how much power was required. The team was able to drive over a ramp of 25°. However, this ramp angle was discarded by users later in the process as they agreed that 25° was too steep even for a short period of time. The final decision on the ramp angle was:

The ramp angles must not exceed 10°.

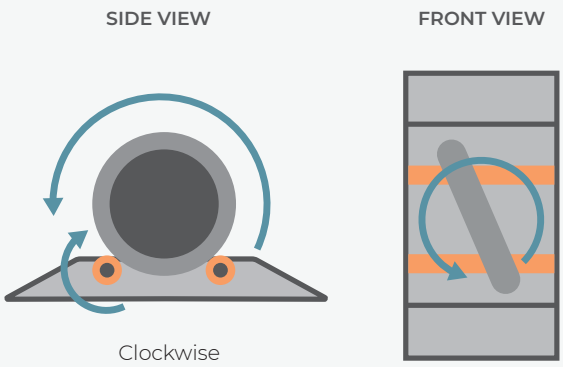
Ill. 2.29: 3D printed ramps of different angles: 10°, 15°, 20°, 25° and 30° (from left to right)

Ill. 2.30: Ramps installed in a test unit

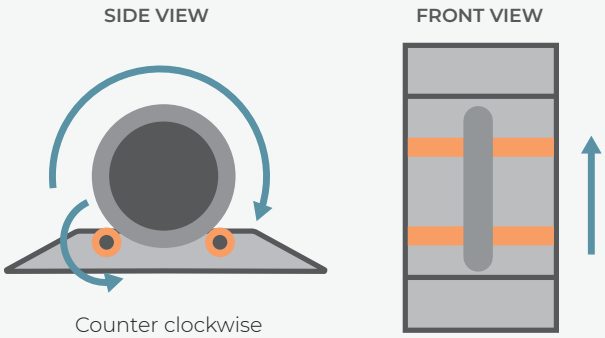
AVOID SPINNING FRONT WHEELS

During one of the tests, the rotation of the front wheels by the driving roller resulted in the wheel spinning out of place as depicted on ill. 2.31. To overcome this, it was later discovered that the roller has to turn counter clockwise as depicted on ill. 2.32. Doing so makes the wheels turn similar to if the user is driving forward, which will keep the front wheels in line.

The motor must rotate, so the front wheels spin forward.

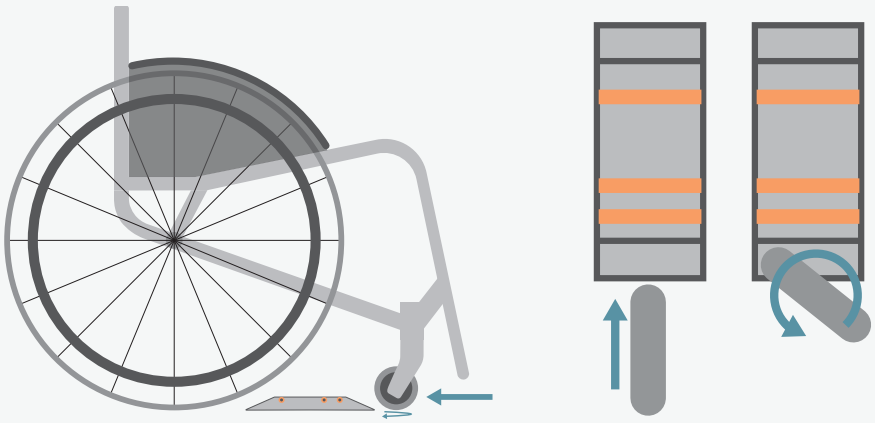


Ill. 2.31: Rotating the caster wheels clockwise



Ill. 2.32: Rotating the caster wheels counter clockwise

Ill. 2.33: Prototype placed on the floor between the caster wheel and the rear wheel



Ill. 2.34: If the wheelchair is driven backwards, the caster wheel will spin 180°

SOLUTION BETWEEN FRONT & REAR WHEEL

Another concept was tested, based on the idea of putting the product between caster and rear wheel to minimise the reach compared to placing it in front of the caster wheel. However, a conflict between the caster wheel and the ramp occurred when trying to back onto the product because the front wheel would rotate the wrong way. Because of this, placing the product between front and rear wheels is problematic.

The solution cannot be placed between front and rear wheel.

The prototype testing revealed several requirements for the concept, but it also created questions in terms of required friction, strength and motor specifications. But also, is a motor even required in the first place or can the rotation of the front wheels be done mechanically? Is it possible to use the rotation of the rear wheel to turn the front wheels as well?

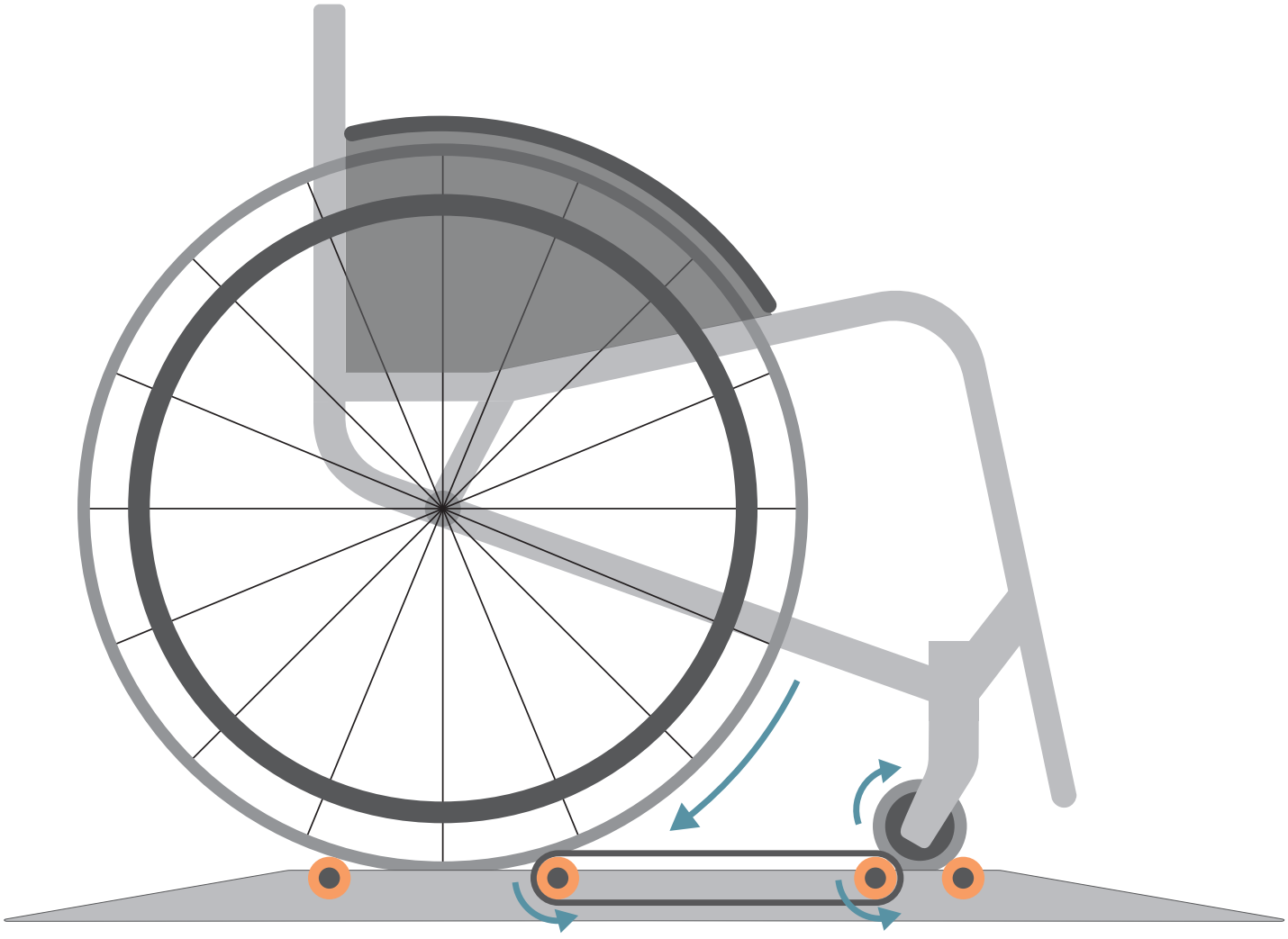
MECHANICAL SOLUTIONS

In regards to the technical aspects of the motorised concept, it was reflected on whether or not it would be possible to make a completely mechanical solution [App. 11]. This consideration process is explained in the following section.

TRANSMITTING MOTION FROM REAR WHEELS

The initial challenge with a mechanical solution was to figure out how to make the front wheels rotate. Hence, the team looked into mechanisms for motion transmission which could enable rotation of the front wheels by utilising the pushrims of the rear wheels.

Both worm gears and bevel gears were investigated. However, there was the challenge of adapting these mechanisms to different lengths, as the distance between front and rear wheels differ from wheelchair to wheelchair. Additionally, due to its large size, the solution would need to be foldable for facilitating transportation, which would be a complication.



Ill. 2.35: Wheelchair placed on top of mechanical solution that transmits motion from rear wheels to front wheels

The belt drive was chosen as a direction to clean all the wheels simultaneously. This was done by transmitting the rotation of the rear wheel to the front wheel through a pair of rollers connected by a belt. The user will do this by using the pushrims, as they are accustomed for driving around.

− Length adjustment to make it fit all wheelchairs.

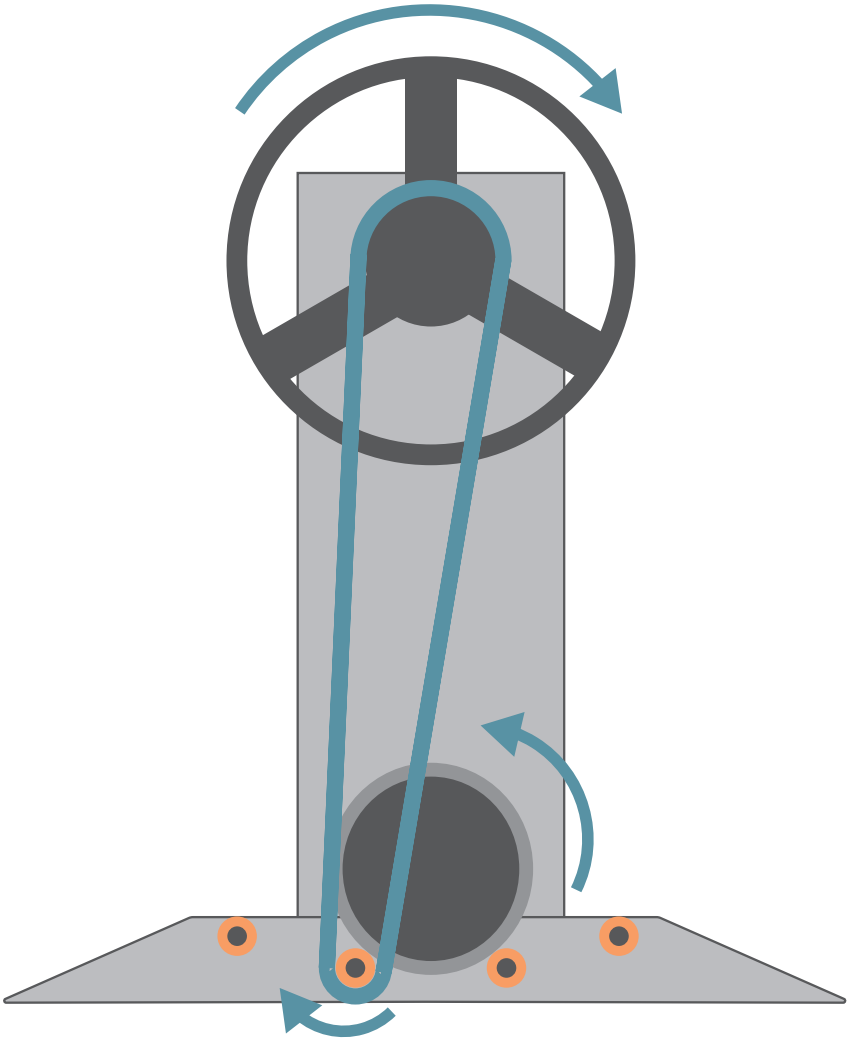
\+ Able to clean two wheels at the same time.

\+ Using a movement the user is used to.

TRANSMITTING MOTION BY HAND

To investigate other possibilities for rotating the front wheels without using the pushrims or a motor, other mechanisms that enable transmission of motion were explored. The working principle from hand bikes was identified and was considered to have potential. In this mechanism, the rotation made by hand is transmitted to the wheels.

In the case of the cleaning solution, the hand movement will be transmitted to one of the rollers in the base, which will make the front wheels spin. The user could potentially also use this mechanism for rotating the rear wheels, but it seems more natural and easier to use the pushrims in this case.



Ill. 2.36: Mechanical solution that transmits motion from hand movement to front wheels

This led to the idea of utilising a push handle - which would be needed anyway for placing the unit on the floor - to transmit the movement to the front wheels.

− Only clean one wheel at a time.

\+ Small form factor.

\+ Using a similar movement as the user is used to.

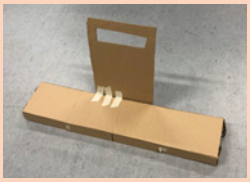
COMPARISON

The two concepts are quite different in terms of scenario. The belt-driven concept enables the user to clean two wheels at the same time. However, it is also a longer product, which makes it less portable than the other concept. The push handle concept, on the other hand, is more compact but only cleans one wheel at a time.

SCENARIOS OF 3 CONCEPTS

Prototypes of the three concepts - belt-driven, push handle and motorised - were built to simulate the scenarios for each of the directions. This was done to identify improvement points of the concepts, as well as evaluate their ease of use. Every concepts was simulated with one and two units (one for each side) [App. 12].

BELT-DRIVEN



Ill. 2.37: Belt-driven concept prototypes – functional prototype (left) and mock-ups (right)

PUSH HANDLE

Ill. 2.41: Push handle concept prototypemock-ups (right)

MOTORISED

Ill. 2.45: Motorised concept prototypes – prototypes with rollers (left) and prototype with handle (right)

DRIVING INTO ENTRANCE

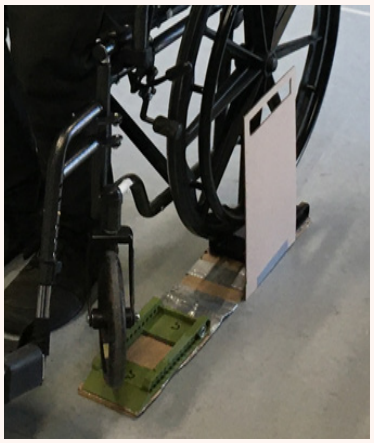
Ill. 2.38: Carrying the belt-driven concept on the lap while entering the home

Ill. 2.42: Carrying the product on the lap while entering the home

PLACING ON FLOOR

Ill. 2.39: Unfolding and placing the belt-driven concept on the floor (this must be done twice)

ROTATING WHEELS



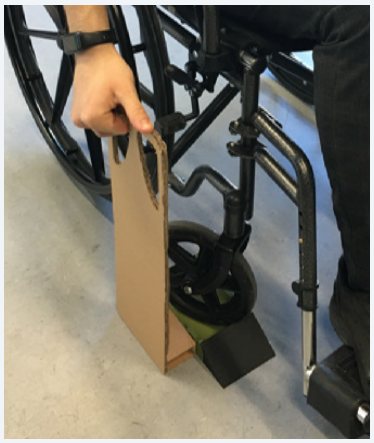
Ill. 2.40: Cleaning the wheels with the belt-driven concept

Drive onto the ramp and manually rotate the rear wheel. This cleans both front and rear wheels.

Ill. 2.43: Unfolding and placing the product on the floor (this must be done twice)

Ill. 2.44: Cleaning the wheels with the push handle concept

Turn the push handle to rotate the front wheel. Rotate the rear wheel by using the pushrims.



Ill. 2.46: Cleaning the wheels with the motorised concept

Press the button on the handle to activate the motor. This will make the wheel spin, making it possible to clean it.

It was realised that both concepts should consist of two units, as just using one would result in wet trails from the wheels on the opposite side. However, an awkward situation common to all units is picking them up. The user would need to drive sideways to do so, which seemed uncomfortable. Despite that, the motorised was evaluated as the best option due to its compactness, which makes it easier to carry, put down on the floor and pick up at the end of the process. The next step was to let actual users evaluate the concepts. To obtain more valuable results, all concepts were made as functional prototypes in terms of working principles.

VISITING USERS

The team arranged a meeting with some users that worked at Kørestolseksperten (Kørestolseksperten, n.d.), a company that makes and sells products for wheelchairs. The goal of this visit was to get some feedback on the three concept directions and to let them test the prototypes [App. 13].

3 CONCEPTS

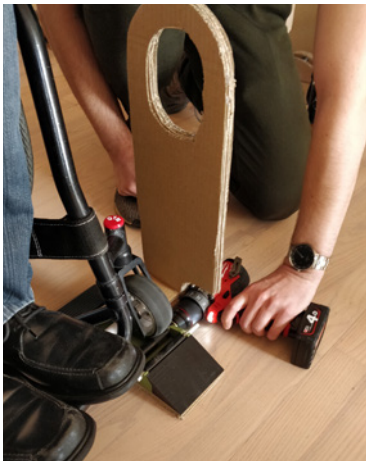
Concept 1 - Belt driven

Concept 2 - Push handle

Concept 3 - Motorised

Ill. 2.47: Functional prototypes of concepts

USER TESTING



Ill. 2.48: User testing the three concepts

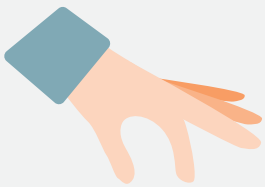
MAPPING PARAMETERS

When developing the solution many intertwined parameters came up. By modifying one parameter, others would also change. The team needed to figure out which parameters are more important and valuable to the users. The team asked the users at Kørestolseksperten to set these parameters in order of relevance [App. 4 & 13].

The users interviewed did not mind spending a bit more time if that meant their wheels would get properly cleaned. One mentioned that wheelchair users are used to everyday tasks taking double as long compared to other people, so the time was not as big of a concern as the team initially thought. They would also prefer a product which is easy to use and reach, even if that has an impact on the weight or the price. The team then kept the parameters on top of the list in mind when exploring and developing the concepts.

CLEAN LEVEL

Clean degree of the wheels - no trails, no visible dirt in grooves, etc.



REACH & EASE OF USE

Possibility to interact with the product in a comfortable and intuitive way.

FEEDBACK

The team got a large amount of insights from the users regarding the concepts presented.

- **Concept 1 - Belt driven**
  They liked that they were able to clean two wheels at the same time, but they thought it was too big to be transportable.
- **Concept 2 - Push handle**
  They liked that it was smaller and easier to place on the ground.
- **Concept 3 - Motorised**
  They thought the ramps were to steep, so it was hard to get onto to product.

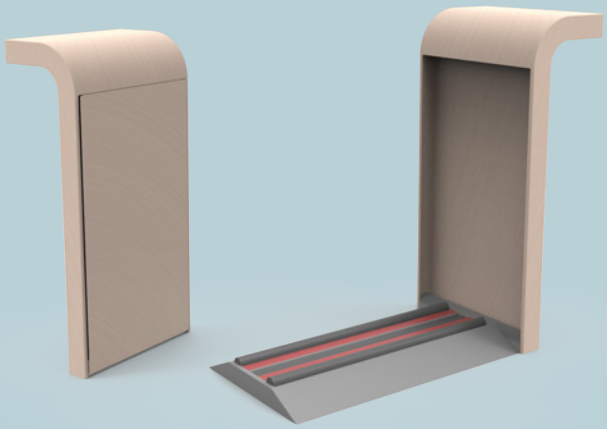
In general they liked the manual solution more than the motorised because it is more reliable - they preferred not to have batteries, as they would have to worry about the level of charge. The additional price of the motor and battery was also a concern.

In the end of the meeting, the team showed a picture of the stationary concept (ill. 2.49). Most of the users saw more potential in this concept due to the frequency of use in their own home. They also mentioned that they would rather have something placed in their home than something they would have to remember to take with them every time.

Additionally, they also commented on the price they would be willing to pay for a transportable and stationary solution, as well as their wishes in terms of weight and size for a transportable product.

The team members then started to question the direction of the project. On the next page, the reflection on whether to stick to the current transportable solution or change direction to a stationary is presented.

- ***Should not cost more than 2000-3000 DKK if transportable.***
- ***Should not cost more than 5000 DKK if stationary.***
- ***The weight should not exceed 2 kg.***



Ill. 2.49: First concept of stationary solution – folded (left) and unfolded (right)

COST

Money willing to invest in this type of solution.

WEIGHT & SIZE

Dimensions and weight of the product.

STIGMA

Feeling when using the product, with or without other people around.

TIME USED

Time from dirty wheels to clean wheels (by using the product).

Ill. 2.50: Illustrations of parameters

REFLECTION ABOUT DIRECTION

Based on the user's feedback and the findings originated from the research and testing with prototypes, the team decided to compare the two directions - transportable and stationary. For doing so, some of the key parameters for the transportable concept were evaluated to get a final conclusion on which direction to continue with [App. 14].

PRICE

Should not cost more than 2000-3000 DKK if transportable.

The users requirement based on what the users are willing to pay for a transportable cleaning solution. The cost could increase with a motor or a belt mechanism because of the complexity and price of these components.

BELOW 2000 DKK

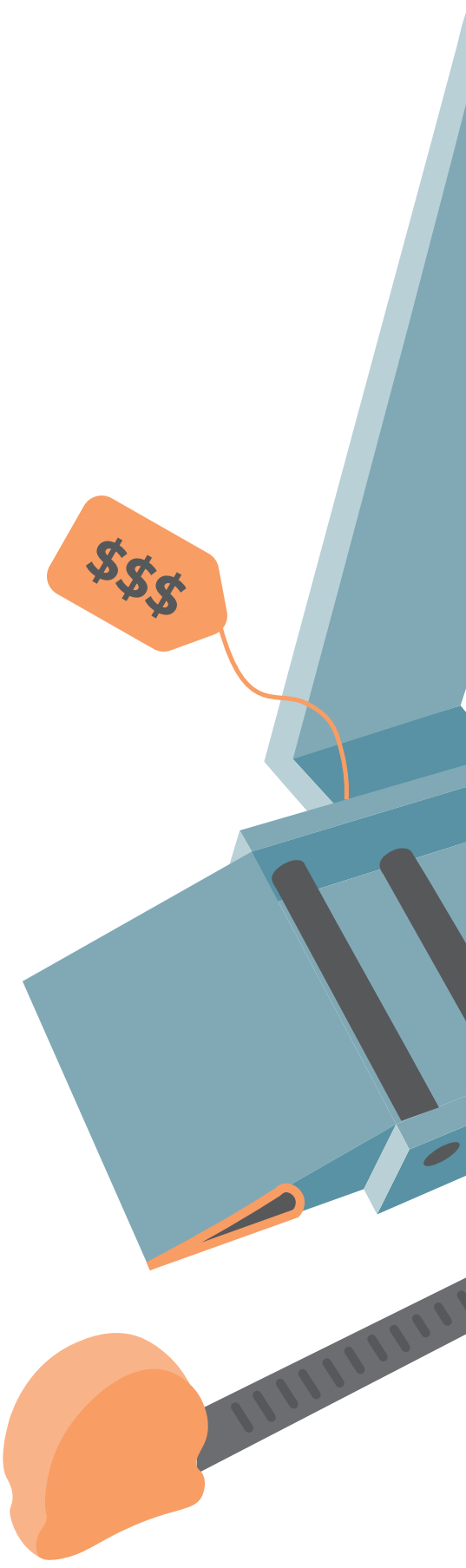
Simple and affordable product.

- Missing functionality.

ABOVE 2000 DKK

Adding functionality and better experience.

- Smaller market, not everyone is willing to pay for it.



RAMPS & SIZE

The ramps should not exceed 10°.

The ramps on the prototypes are too steep and should be 10°. By making the ramp with a 10° angle, the overall length of the ramp increases making the product less transportable.

BELOW 10°

Making a longer and larger product.

- Less transportable.
- Heavier product.
- Difficult to move around.

ABOVE 10°

Making a smaller, more transportable product.

- Smaller market, not every user would be able to get on it.

WEIGHT

The weight should not exceed 2 kg.

By making it motorised or just as large as it is now, the weight will be over the limit of what users are able and willing to carry along with them.

BELOW 2 KG

Liftable by the user

- Expensive lightweight materials.
- No motor, no mechanism.

ABOVE 2 KG

Adding motor/mechanism increases the weight

- Not transportable for the user.

Ill. 2.51: Transportable solution and its issues related to dimensioning, cost and weight

CONCLUSION

The different factors - dimensions, weight and cost - are conflicting with each other and affecting the overall usability of a transportable solution. A few example of **why the transportable solution is less feasible** are:

- Based on the price that the interviewed users were willing to pay for the solution, it does not seem feasible to afford the materials and mechanisms required.
- For the product to be comfortable to use by as many wheelchair users as possible, it will be quite large, which makes it less on-the-go.
- The weight limit for the transportable solution is too low considering that it should have a motor or mechanism.

The stationary solution has less restrictions in terms of weight and size, because it should not be moved by the user. This also allows to make more improvements on highly valued areas such as the clean level and ease of use.

Additionally, the user's that were contacted seemed to be willing to pay more for this product as its frequency of use will be higher than the transportable alternative. Because of all this, and due to the higher interest of the users, the team concluded that **the stationary direction was the way to go**.

Ill. 2.52: First concept of stationary solu

Ill. 3.1: Tools and prototypes on working table

3. CONCEPTUALISATION

After the shift in direction from a transportable to a stationary cleaning solution, new ideation rounds and tests were conducted. In the end, a concept was selected for further development.

DISMISSED NEEDS

Due to the change of direction some of the requirements became needless and are therefore discarded.

- It must be reachable, so at least 40 cm in height.
- *Should not cost more than 2000-3000 DKK.*
- *The weight should not exceed 2 kg.*

DESIGN BRIEF (REVISITED)

PROBLEM DEFINITION

How to create a device which allows manual wheelchair users to independently achieve clean wheels ***- meaning no wet trails and little to no dirt on the grooves -*** *when entering* ***their own home?***

VISION

Make is as easy to clean the wheels on a wheelchair as it is to take of the shoes.

NEEDS

- It must be usable for active wheelchair users
- It must accommodate wheelchairs with a width of 40 - 60 cm.
- The solution must be possible to use in the entrance of 3 m X 1.5 m
- Ramps must not exceed 10 degrees incline.
- The solution must be able to clean front and rear wheels according to user's perception of clean (App. 13)
- At least 130 mm between the rollers for the rear wheels (from center to center) To fit all wheel sizes.
- At least 65 mm between the rollers for the front wheels (from center to center) to fit all wheel sizes.
- The top end of the ramp must be on level with the top of rollers for the rear wheels.
- The motor must rotate, so the front wheels spins forward.
- Should not cost more than 5000 DKK stationary.

WISHES

- The time from dirty to clean wheels should not be more than 2 minutes.
- It should also clean other parts of the wheelchair.

DEFINING PRODUCT CATEGORY

Due to the shift in direction to a stationary solution, home entrances were analysed once again with the goal of identifying what attributes the solution should have - what is the product category and what should it fit into? [App. 15]

HOME ENTRANCES

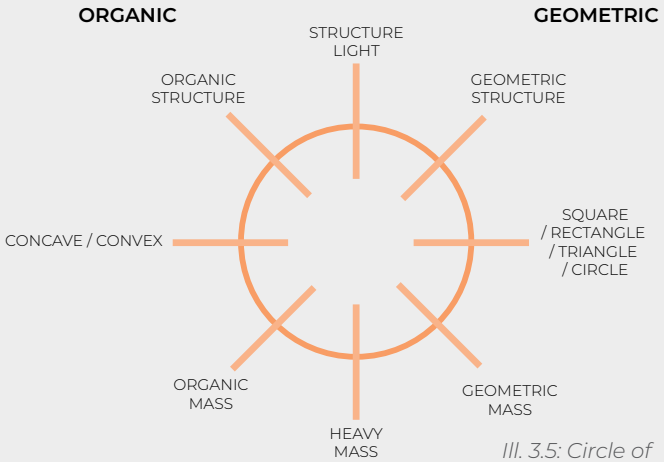
In order to make the product fit into wheelchair users' entrances, the team analysed this space of some of these people's homes. Despite minor differences, like the change of height of wall outlets and switches, the entrances of wheelchair users were seen to be similar to other people's entrances. Hence, the following analysis also considers home entrances from non-disabled people.

Ill. 3.2: Person in a wheelchair entering his home

Ill. 3.3: Roomba i3+ Robot Vacuum Cleaner

Ill. 3.4: Shoe rack - TROY BENCH

CIRCLE OF FORM



Ill. 3.5: Circle of form & contrast

PRODUCT CATEGORIES & FORM LANGUAGE

By analysing the elements placed at home entrances, two product categories were identified:

- **Furniture:** making the product a "furniture" would mean to make it look like other elements such as shoe racks, hangers and shelves. This could be done by the use of certain materials, like wood, and simple geometric shapes.
- **Gadget:** consumer products such as robot vaccum cleaners and air purifiers belong to this category. They are usually made of plastic and/or metal and their appearance is based primarly on their function.

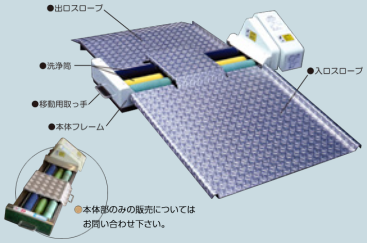
As a cleaning solution for wheelchair wheels is **closer linked to gadget products due to their functionality**, then the form development should accommodate a similar expression.

In order to make the solution fit in the home entrance, a form analysis of the other products in the entrance was done utilising the *Circle of form & contrast (Jaeger, 2012).* The existing products in the entrance are primarily geometric, either massive or structural. The materials differ between plastic, wood and metal, and the most common colours are black and white. These parameters should be kept in mind when developing the form.

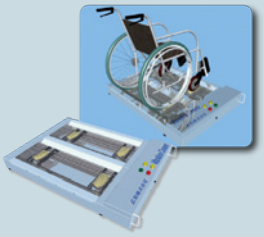
NEW MARKET RESEARCH

A second market research was carried out to ensure that the team did not miss any relevant competitor products. In the former market research, the terms were searched in Danish and English. However, this time the team tried to search in other languages including French, Chinese, Japanese and Korean, among others. This helped to find new products, which were then analysed by the team [App. 17].

MOTORISED SOLUTIONS



Ill. 3.6: Wheelchair wheel washer SC-750



Ill. 3.7: Wheelchair wheel washer CVC-04

Many of the current motorised solutions are huge and do not fit in the home setting due to their aesthetics. They have different technologies, such as water cleaning, which makes them expensive. Additionally, none of them consider how the user should replace the cleaning elements if needed.

NEW MAIN COMPETITORS

Ill. 3.8: Wheelster Mini – base (left) and stick (right)

Ill. 3.9: The Wheel Doormat

Wheelster Mini
This manual and portable solution lets the user clean their wheels one at a time by using a brush placed in the base and a wipe attached to a handheld stick. It is possible to clean the front wheels with the stick, but it requires the user to move around in circles (page 16). The ramp on the base is too steep, and the user has to drive back onto the dirt when going down.

The Wheel Doormat
This product consists of a doormat with implemented rollers and brushes to manually clean the wheels by spinning them with the pushrims. However, it assumes that the mat will clean the front wheels sufficiently, which showed to not be the case according to the tests done [App. 10]. It also does not have ramps, making it difficult to access for some users.

REFLECTION

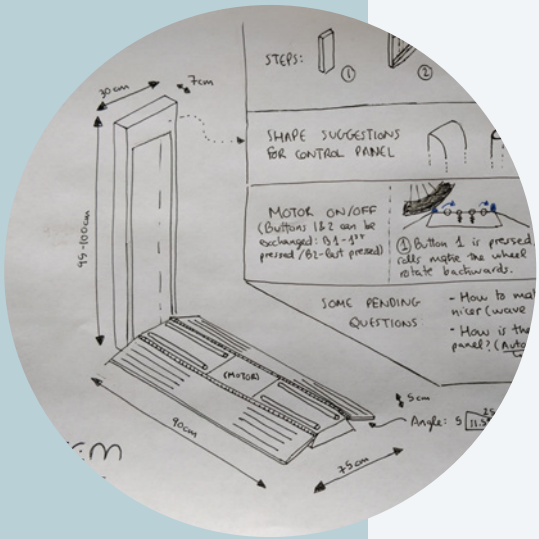
Even though more wheelchair wheel cleaners were identified, most of them still share the same issues as the previously found wheel cleaners and do not solve the problem fully. Nevertheless, this market analysis has provided the team with a better understanding of the main competitors: Wheelster Mini, The Wheel doormat and CleanWheels (page 33). The **attributes that makes these products fail** and that the team should avoid are:

CONS

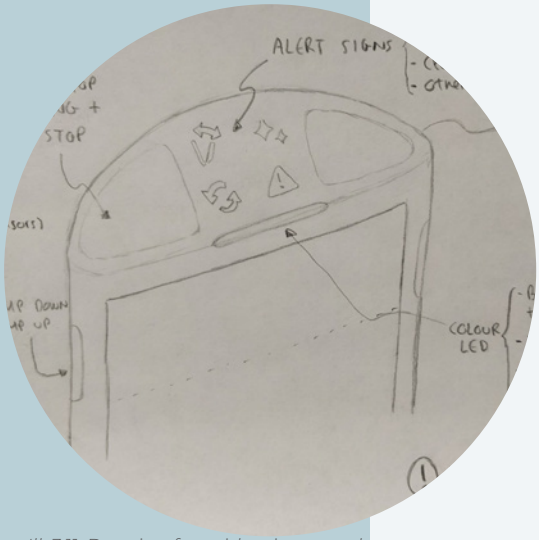
- They have too steep ramps or none at all.
- Some do not consider the cleaning of all wheels.
- Most do not consider how to change the cleaning elements
- Some require the user to go down the product from where they came with the dirty wheels.
- Some only brush but do not dry.
- Some include water but do not dry.
- Most of them are really large.
- Most do not fit in a home entrance, they look too industrial.

IDEATION ON STATIONARY

A new ideation round was done for the stationary solution after the shift in direction. This was done through sketching and testing of mock-ups, and resulted in the concept proposal on the next page [App. 16].



Ill. 3.10: Drawing from ideation round – stationary solution

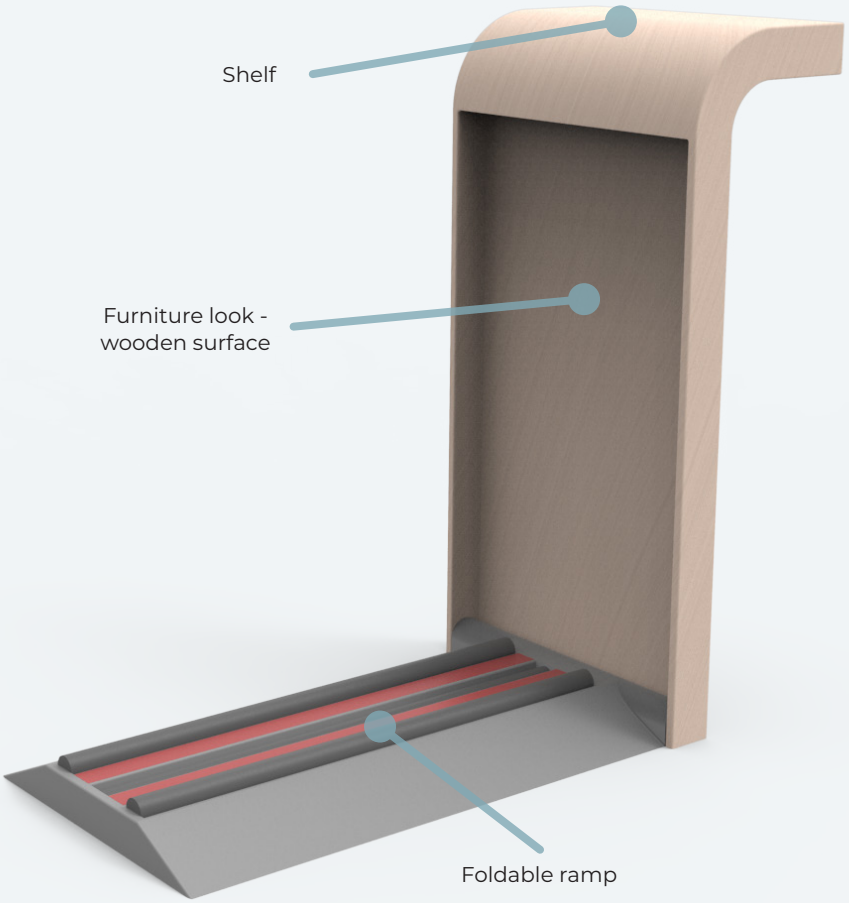


Ill. 3.11: Drawing from ideation round – stationary solution interaction

Ill. 3.12: Mock-up of a stationary solution proposal

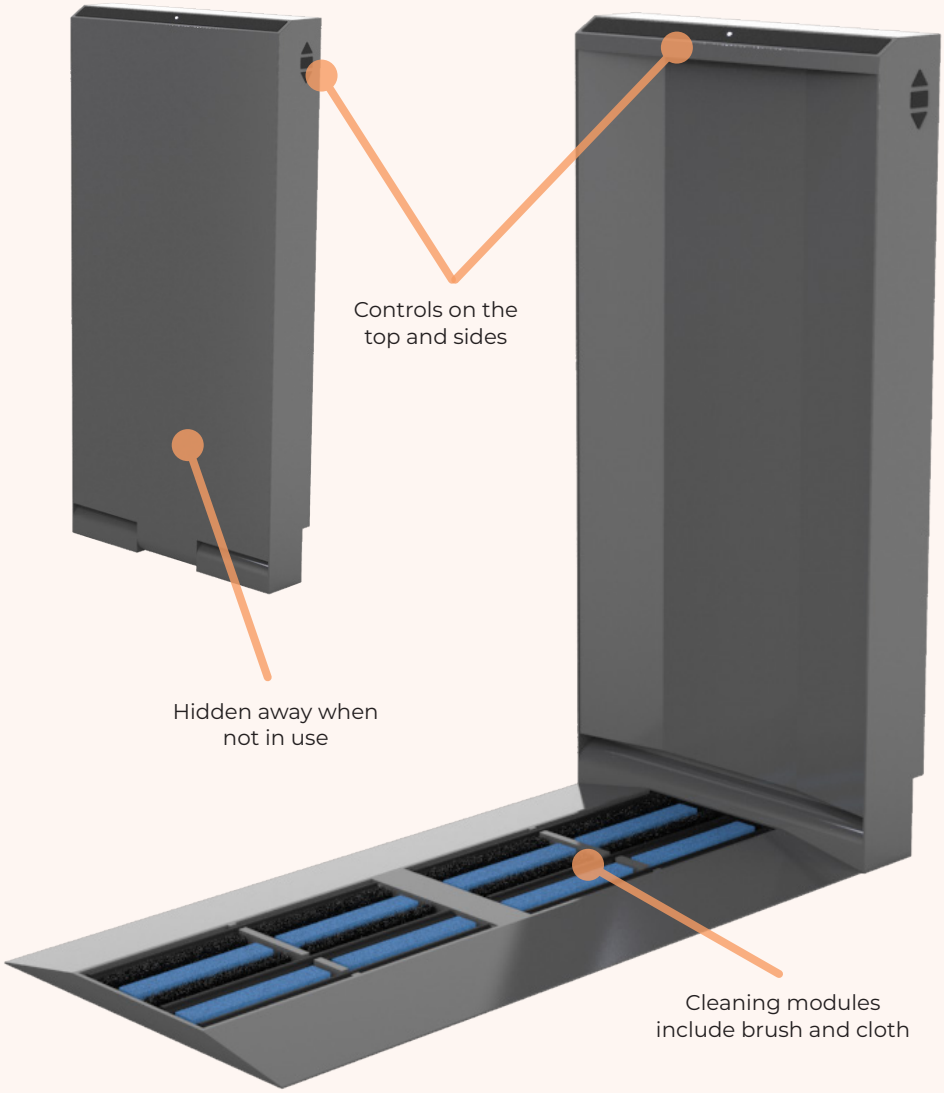
INITIAL SKETCHING & MOCK-UPS

Based on the original stationary concept, described on page 37 and depicted on ill. 3.13, additional sketching was done to widen the solution space. This led to a new stationary concept as depicted on ill. 3.14 on the next page.



Ill. 3.13: First concept of stationary solution – unfolded

NEW CONCEPT



Ill. 3.14: New concept of stationary solution – folded (left) and unfolded (right)

Ill. 3.15: Scenario of the new stationary concept (6 steps)

REFLECTION ABOUT CONCEPT

- Having a foldable ramp creates the problem of closing it after the cleaning process, as the users cannot reach the floor. Using a motor is an option, although a powerful one would be required as it has to lift the base at the point of rotation.
- The interaction with the buttons was slightly difficult as it required the user to lean forward while stretching an arm.
- All the dust and dirt laying in the brushes will fall into the tower and make it dirty inside once it is folded up.
- Emptying the cleaning modules may turn out to be problematic for the same reason - the dirt might fall to the ground when detaching these modules from the base.

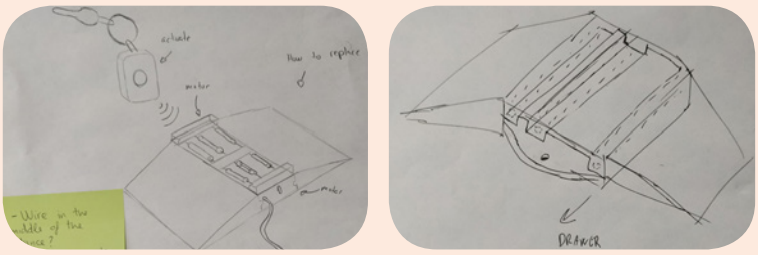
Then the team started to question ... **does it even need to be hidden away in the first place?**

CLEANING ELEMENT

The team decided to explore other product proposals that should not fold up and down. As a result, the cleaning modules were no longer accessible for the user. These cleaning elements have to be changed regularly as once these units get too dirty, they will no longer clean effectively. The question now is how often is that?

IDEATION - NON-FOLDABLE SOLUTIONS

A new ideation of a stationary concept was done in order to challenge the folding up and down mechanism. It paved the way for new concepts that are supposed to lay on the floor at all times [App. 16].

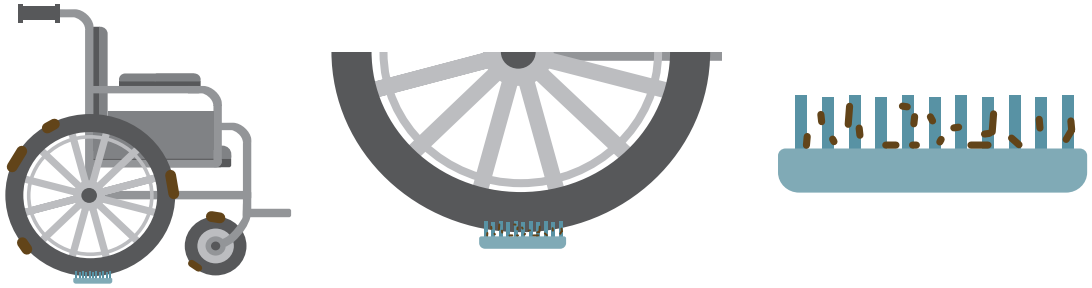


Ill. 3.16: Drawing from ideation round – always on the floor solutions

FREQUENCY OF REPLACEMENT

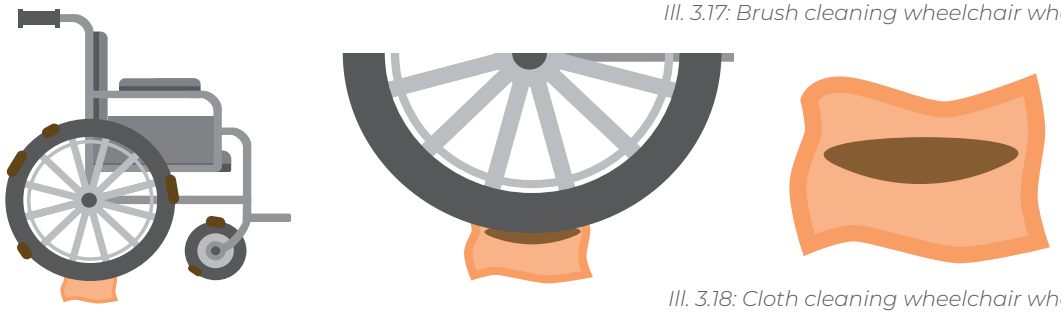
As explained in page 38, the most effective cleaning methods for wheelchair wheels were cloth, for superficial cleaning and drying, and hard brush, for removing dirt in the grooves of the tyre. This two elements have different characteristics [App. 18]:

BRUSH
The dirt is stored between the bristles, and can be removed easily afterwards, making it reusable.

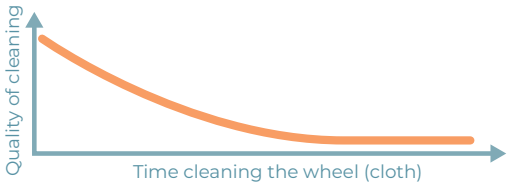


Ill. 3.17: Brush cleaning wheelchair wheel

CLOTH
The dirt is absorbed. Depending on the type of cloth used, it will need to be replaced and washed afterwards.



Ill. 3.18: Cloth cleaning wheelchair wheel



Ill. 3.19: Graph - Quality of cleaning VS Time cleaning (cloth)

This difference between the two cleaning elements is noticeable in the quality of cleaning over time. In the case of the cloth, its efficacy for clean decreases over time as it gets more dirty. It is not the case for the brush, as the dirt will just be collected on the lower part of the bristles, so the brush will need to be cleaned less often.

Therefore, **the surface of the cloth should be increased** so the same amount of dirt is more spread. This will reduce the frequency of replacement or washing of the cloth. This could be done in different ways:

Ill. 3.20: Cloth with three sides cleaning a wheel (up) and treadmill-like cloth cleaning a wheel (down)

A) Increasing the number of surfaces with cloth

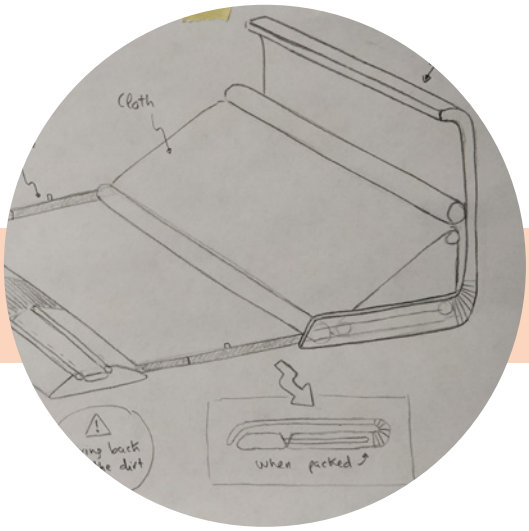
B) Increasing total surface area, by making a belt mechanism with a long and closed cloth.

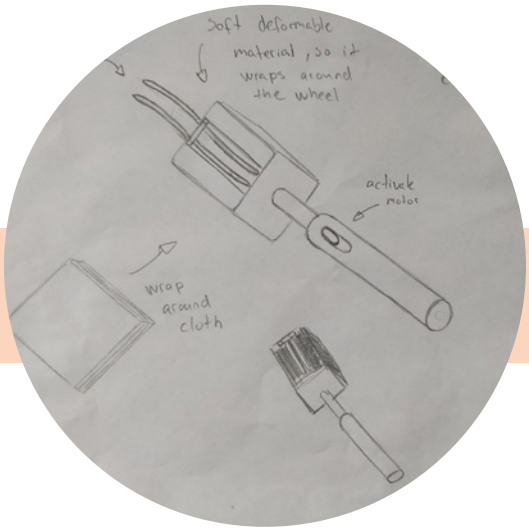
The cleaning elements must be replaceable by the user.

TWO CONCEPT DIRECTIONS

A new ideation was done based on the findings about the frequency of replacement of the cleaning elements. This led to two concept directions which share an almost identical scenario. These product proposals only differ on how the cloth is implemented and used, as depicted on ill.3.23 [App. 19].

IDEATION - FOCUS ON CLEANING ELEMENT





Triangle

This direction included concepts in which the cloth is placed in the base and has a similar working principle as a treadmill. In this case, the cleaning area increases and thus the frequency of replacement decreases.

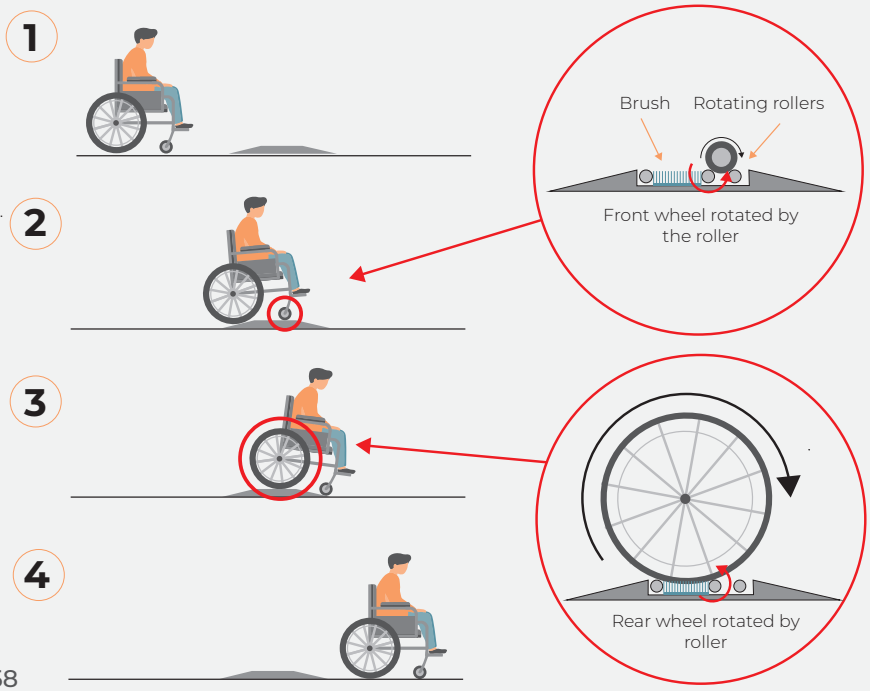
Handheld device

This theme consists of concepts in which the cloth is separated from the base and placed in an external handheld device. By doing so, the cloth can easily be replaced by the user when needed.

Ill. 3.21: Drawings from ideation round – Triangle concept (left) and handheld device concept (right)

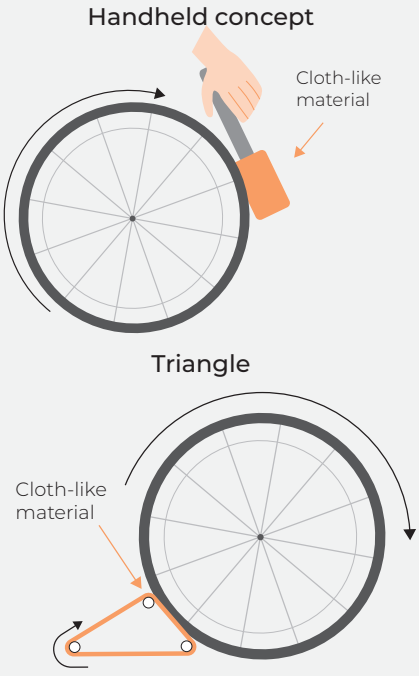
WORKING PRINCIPLES

SHARED PRINCIPLES



Ill. 3.22: Working principles of concepts – shared principles

DIFFERENCES



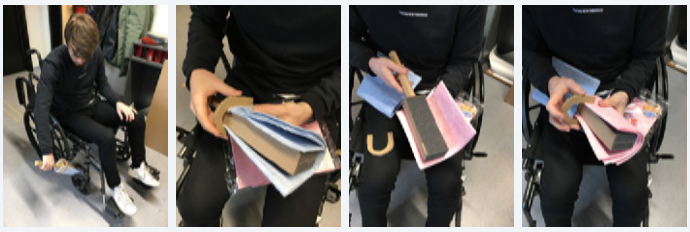
Ill. 3.23: Working principles of concepts

HANDHELD DEVICE

This concept enables the user to hide the base under a shoe rack. It has a motorised base, which enables the wheels to spin without effort. A handheld device is included for cleaning, which makes it easier to replace the cloth when needed. The motor is also controlled by the handheld device in terms of ON/OFF.

Ill. 3.24: Handheld device concept

Replacing cloth



Ill. 3.25: Replacing cloth on handheld device (4 steps)

Hidden position

Ill. 3.26: Base under shoe rack (left) and base moving out of shoe rack (right)

Push the handheld device to drag the base into position. This is possible thanks to some small wheels beneath the base.

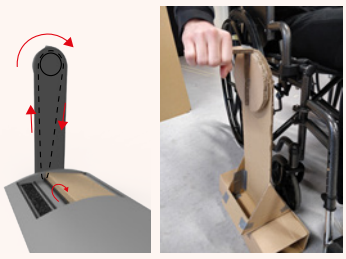
TRIANGLE

This concepts is always laying on the floor, and comes in two different versions - a manual and a motorised, as depicted on ill. 3.28 and ill. 3.29. The manual version works in a similar way as the transportable concept from page 43, in which a handle is used for rotating the front wheels. On the other hand, the motorised is turned ON/OFF by a small controller that can be placed in a key chain. In both cases the cloth works like a treadmill, and has a triangle shape.

Replacing cloth

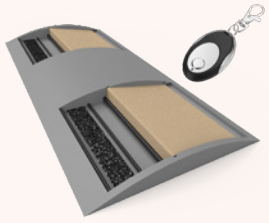
Ill. 3.27: Replacing cloth on triangle concept (4 steps)

Manual

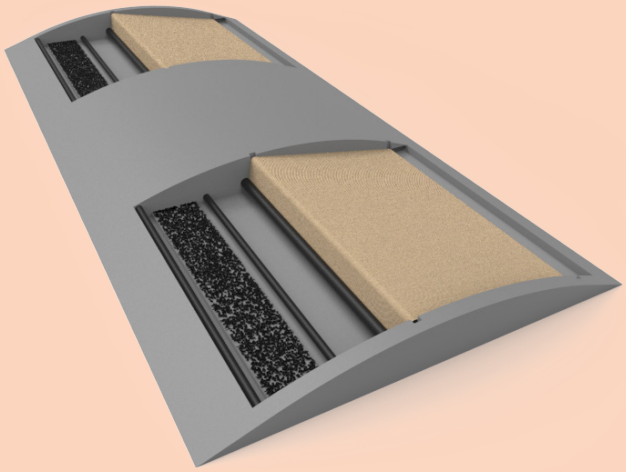


Ill. 3.28: Manual version of triangle concept – how it works

Motorised



Ill. 3.29: Motorised version of triangle concept – base and key chain controller



Ill. 3.30: Triangle concept

CONCEPT EVALUATION

The two concepts were presented to the users for feedback to help the team decide which one to develop further. Based on the comments and thoughts of the team members, the following Pros and Cons list was made [App. 19]:

	TRIANGLE	HANDHELD DEVICE
PROS	• The cloth has to be replaced less often. - *Team* • The user is being distanced from the dirt during the cleaning. - *Team* • Cleans two wheels at the time. - *Team* • Has potential for electric wheelchairs. - *Users*	• Easier to replace the cloth. - *Users* • Has more control over the cleaning process with the handheld device. - *Users*
CONS	• Needs an additional tool to pick up the cloth anyway. - *Team* • Difficult to reach and thus replace the cloth. - *Users* • Concern about the mechanism being more expensive due to its complexity. - *Team* • Uncertainty of the validity of the working principle and how well it cleans. - *Team* • Concern about the number of components in the base, which means more elements could potentially fail and thus the system. - *Team* • Less control over the cleaning, so the user will have to rely on the system. - *Team* • Might be tricky to check if the wheels are clean. - *Team*	• The handheld may be difficult to handle for some with impaired hand function. - *Users* • Only cleans one wheel at the time. - *Team* • The cloth has to be replaced more often. - *Team*

Other comments

- The motorised concepts are prefered, as less effort is required. (user)
- The hide away function may not be as important. Some seemed to like the option, while others would not bother to hide it away due to the frequency of use. (users)

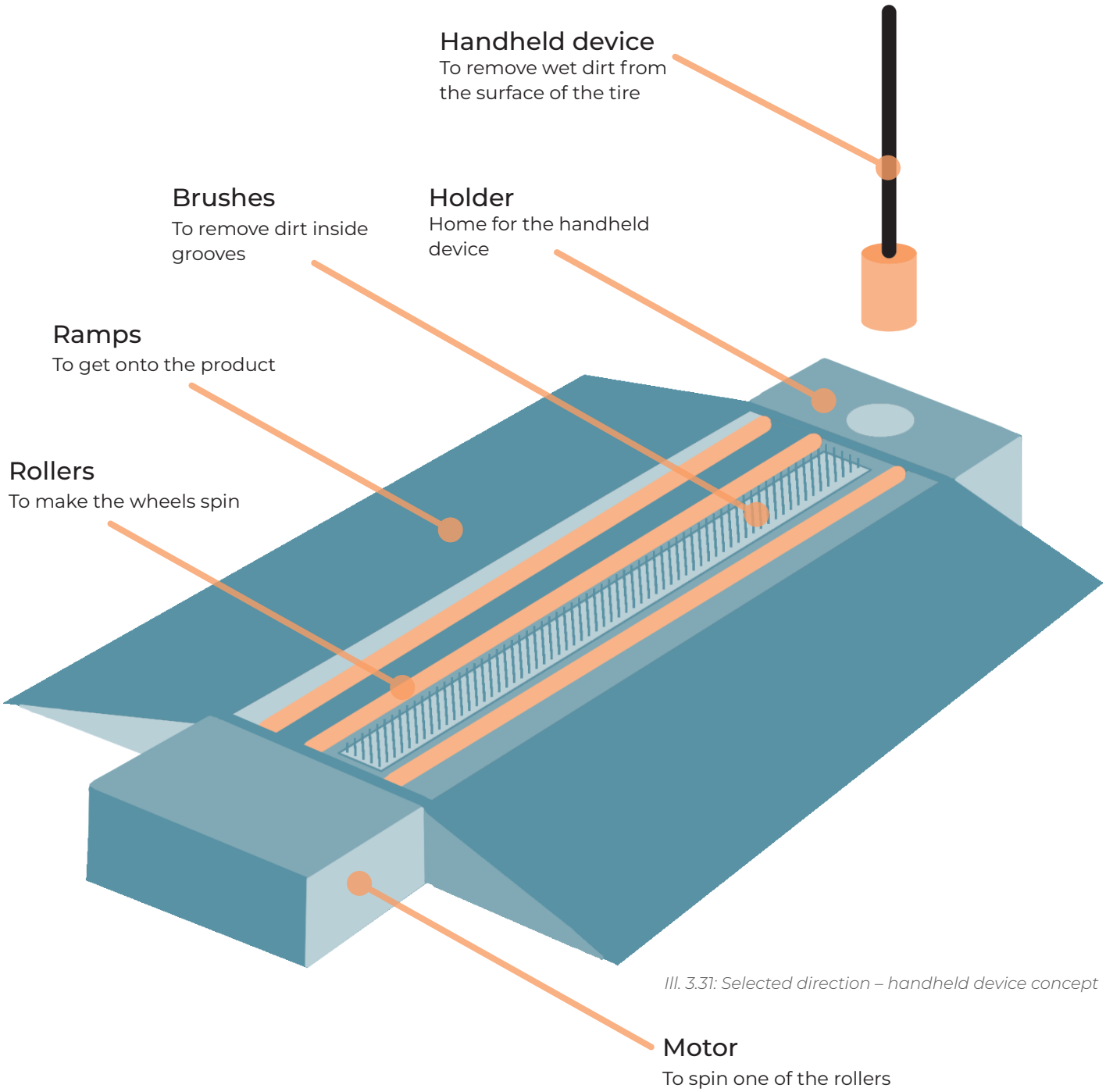
DECIDING A DIRECTION

Based on the Pros and Cons list and other comments from users, **the triangle concept was discarded**. This decision was based primarily on two of the disadvantages: the changing of the cloth, as it would be placed in the base, and its complexity in terms of mechanisms.

In the case of the handheld device concept, the cloth is more accessible, which makes the replacements easier. It also allows for more control during the cleaning process. Even though this concept cleans one wheel at a time, it is considered acceptable as the cleaning time should still be below 2 minutes approximately. The other Cons, such as the frequency of replacement and the difficulty of operating the handheld device for people with reduced hand/arm mobility were planned to be addressed in future stages. Additionally, the idea of hiding the product was discarded due to the lack of interest from users and added cost. However, it may be something that can be looked into at some point later on, as an add-on for example.

THE CONCEPT - HANDHELD

Based on the findings and reflections gathered from the chapter, an overview of the chosen proposal - handheld device concept - was done. The components needed in order to achieve the desired working principle are depicted on ill. 3.31 [App. 20].



Ill. 3.31: Selected direction – handheld device concept

NEXT STEPS

Based on this overview, the main elements of the concept are determined as a closure for this chapter. The next section will focus on the further development of the presented concept and further develop each of its individual components.

Ill. 4.1: Team members looking into mock-up

4. DEVELOPMENT

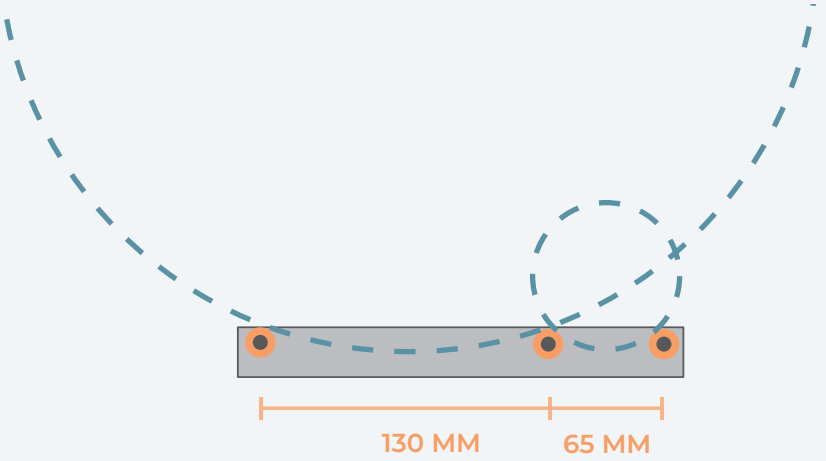
The direction is now fixed - stationary cleaning solution. The specific attributes to the concept will be explored in this chapter, including dimensions, working principle and components. The chapter ends by defining the scenario of the final version of the solution.

BASE DIMENSIONS

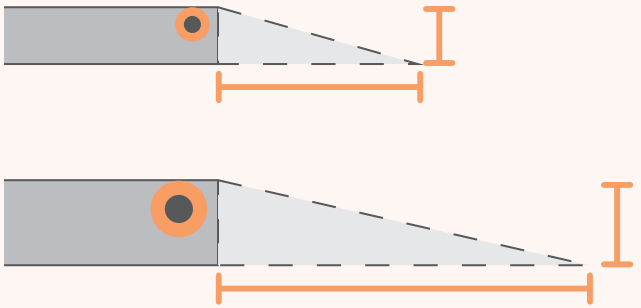
The size of the product is a key factor to consider, as it should accommodate most manual wheelchairs while still fitting in the user's entrances. In this section, the general dimensions of the base will be determined with the focus of making the product as small as possible.

ROLLER DISTANCE

The roller distances were determined by testing prototypes (page 39). The distance that accommodates all different rear wheels sizes is 130 mm from centre to centre. The distance for the front wheels is 65 mm. This means that the width of the base without ramps, must be at least 195 mm.



Ill. 4.2: Rollers – placement and distances



Ill. 4.3: Difference in ramp dimensions for a short base (up) and a high base (down)

HEIGHT OF BASE

Increasing the height of the base will have an impact on its overall size. This is due to the ramps getting longer as the 10° angle defined on page 40 must be kept. It was noticed that by slightly changing the base height, for example from 30 to 50 mm, the ramp length would change significantly, about 100 mm in this case. Therefore, the goal is to make the base as slim as possible in order to make the product as compact as possible.

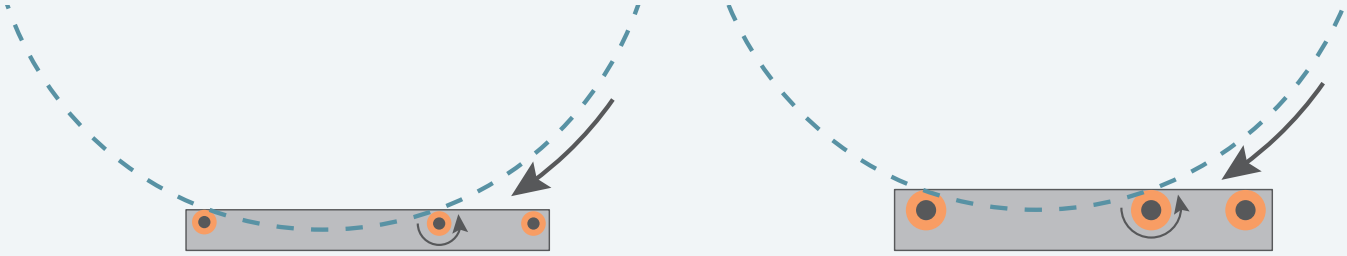
LENGTH OF BASE

The base should be long enough to fit all types of manual wheelchairs. This is challenging as there are no standard widths for wheelchairs due to their high degree of customisation. In order to establish the length of the base, the team looked at anthropometric studies (page 13) and standard measurements for doors as most manual wheelchairs are made to fit through them. The standard doors are 36" which is 90 cm wide (Window World, 2022), so this is the measurement taken as reference.

Ill. 4.4: Dimensions of a door

SIZE OF ROLLERS

The height is mostly based on the size of the rollers. Therefore, these need to have the smallest cross section possible to keep the base slim. However, bigger rollers would enable the motor to spin with a lower speed. The roller should also have a sufficient cross section to withstand the weight of the wheelchair and the user. Rollers of 16 mm in diameter were estimated to be sufficient for accommodating these different factors. This was verified in the calculations on pages 66 - 67.

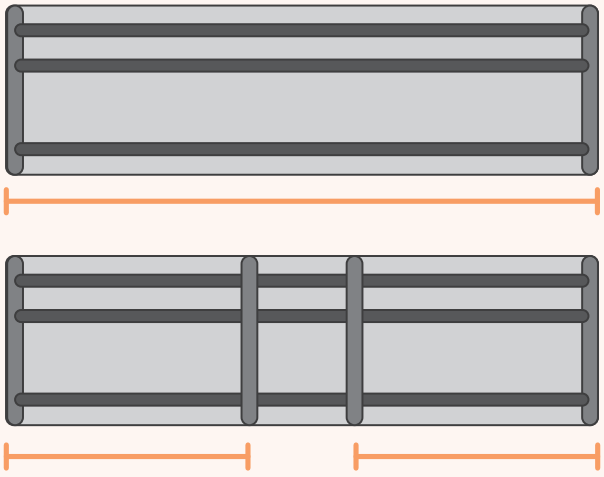


Having small diameter rollers would require the motor to spin the driving roller fast in order to rotate the wheelchair wheels at a comfortable speed.

Having larger diameter rollers would not require the motor to spin as fast to rotate the wheelchair wheels at a reasonable pace, but would make the whole base bigger.

Ill. 4.5: Base with small rollers (left) and base with large rollers (right)

MIDDLE PART



Ill. 4.6: Base with rollers going side-to-side (up) and base with support part in the middle (down)

Having rollers of 16 mm in diameter and around 900 mm in length that are only supported in the ends is not feasible as the deformation would be too large. This happens because the deformation that the rollers experience, when a load is applied, will depend on the distance between the supports. Therefore, more supports should be added to reduce that distance and thus the deformation of the rollers.

The extra supports will be added by making a middle part in the base. This part should not be too wide to ensure that it also fits narrow wheelchairs, but it should still shorten the rollers as much as possible. Making this modification allow the rollers not to have a noticeable deformation with the mentioned cross section. The calculations that led to this conclusion can be seen on pages 66 - 67.

CALCULATIONS I - DIMENSIONS OF

Ill. 4.7: Base with rollers (left) and ball bearing (right)

In order to get the product as low as possible, the rollers have to be as compact as possible. For this reason, **the acceptable dimensions - diameter and length - of the rollers are to be determined** [App. 22]. For the analysis, the worst case scenario was taken into consideration, consisting of a heavy wheelchair and user with a total weight (m_{total}) of 170 kg. The dimensions of the roller taken as reference are also established from the beginning.

Lenght of roller:

L = 340 mm

Radius of roller:

r = 8 mm

Material of roller:

Stainless steel

EXPERIMENT - LOAD DISTRIBUTION

In order to determine the required strength of the rollers, the weight distribution of the wheelchair including user is required. The **weight distribution was determined** as depicted on ill. 4.8 **by utilising scales** and percentage calculation. The value obtained allowed to calculate the load on the roller.

Weight distribution on rear wheels (64%):

$$m_{rear\ wheels} = m_{total} \cdot 0.64$$

Load on roller (from rear wheel):

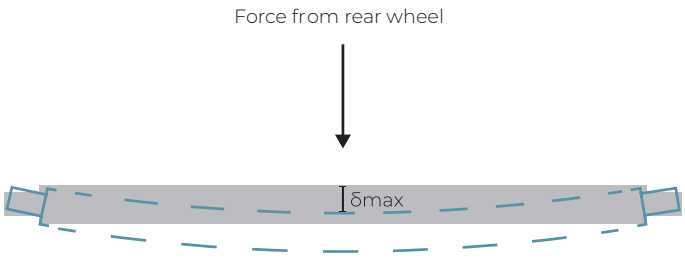
$$P = m_{rear\ wheels} / 2 \cdot g = 533.5\ N$$

Ill. 4.8: Determining weight distribution

F ROLLERS

DEFLECTION

Viewing each roller as a simple supported beam, the **maximum deflection** was determined. The value of 0.65 mm was considered **acceptable** as the user would not be able to notice it. Additionally, the calculated deflection only occurs when the rear wheel only rests on a single roller, compared to being supported by two as it will during the cleaning.



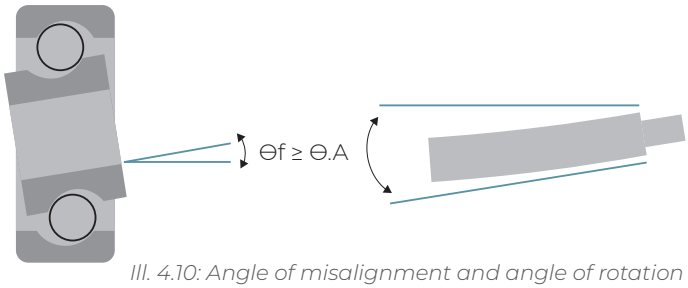
Ill. 4.9: Deflection of roller

Maximum deflection:

$\delta_{MAX} = P \cdot L^3 / 48 \cdot E \cdot I = 0.65$ mm

ANGLE OF ROTATION

Due to the rollers being supported by radial ball bearings, the angle of rotation of the rollers should not exceed the free angle of misallignment of the ball bearings to prevent damage. **The angle of rotation was** calculated and the value of 0.3° was evaluated as **acceptable** as most small ball bearings have a free angle of misallignment within that range (below 1°) (Dynaroll, n.d.).



Ill. 4.10: Angle of misalignment and angle of rotation

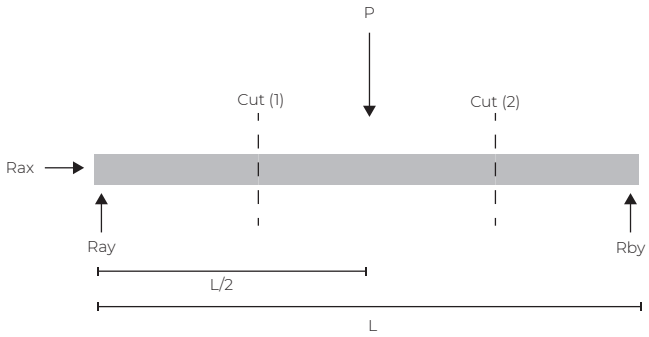
Angle of rotation:

$\Theta_A = P \cdot L^2 / 16 \cdot E \cdot I = 0.3°$

STRESSES

Setting up a free body diagram (FDB) of the situation, it is possible to **determine the factor of safety** based on the internal stresses in the rollers. This is done to ensure that the rollers will not fail due to yielding. Steps followed:

1. Calculate the reaction forces by utilising the equilibrium equations.
2. Obtain the internal forces.
3. Determine the bending and shear stresses based on these internal forces.
4. Use Von Mises formula to calculate the equivalent stress of the roller.
5. Obtain the factor of safety by comparing the Von Mises stress to the yield strength of the material (stainless steel).



Ill. 4.11: Free Body Diagram (FBD) of roller

Von Mises stress:

$\sigma_{vm} = \sqrt{((\sigma_x)^2 + 3 \cdot \tau_{xy}^2)} = 56.5$ MPa

Factor of safety:

$N_{safe} = S_y / \sigma_{vm} = 4.4$

CONCLUSION

Even though the rollers could be minimised due to the relatively high factor of safety, it is decided to maintain the dimensions, so the deflection and angle of rotation will not increase.

- ✓ *Roller size should be minimum 16 mm in diameter.*
- ✓ *Roller lenght can be as wide as 340 mm.*

CALCULATIONS II - DIMENSIONS O

In order to make the wheels spin, a **sufficient amount of friction between wheels and rollers** are needed, as well as **a motor with the needed torque and velocity** [App. 23]. Similar to the dimensioning of the rollers, the following calculations will be done for the worst case scenario. The forces will be determined based on ill. 4.13.

USER TEST - VELOCITY

Ill. 4.12: Testing functional prototype at user's home

The acceptable angular velocity of the rear wheel was determined through user testing. The user was placed on a functional prototype and shared with the team when the wheels were rotating fast enough for him.

TORQUE

The acceleration and moment of inertia are to be determined to obtain the torque. By establishing that the roller will reach the defined velocity in one second, the acceleration can be calculated. The moment of inertia can also be obtained with the available data.

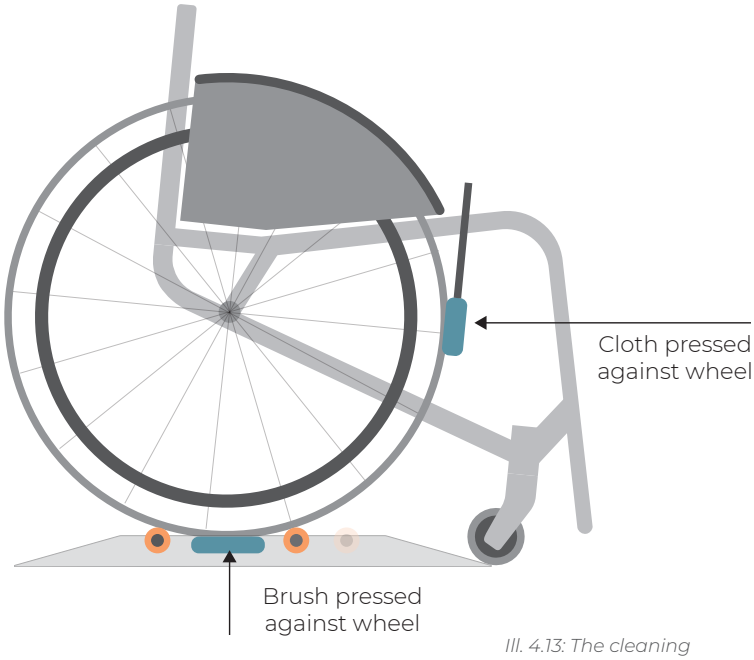
This calculation does not consider external forces, only the **required torque to turn the wheels if they are to spin freely**. Because of this, the frictional force to maintain equilibrium from the driven roller must be known. This will allow to calculate the moment and thus the total required torque.

FREE BODY DIAGRAM (FBD) - REAR WHEEL

After drawing the FBD, it was seen that there were too many unknowns compared to available equations. Therefore, **the frictional force (F_{FR}) and the friction coefficient (μ_r) can not yet be determined. The unknown forces to be determined to calculate these values are:**

- **F_{AC} = Force applied from cloth**
- **F_{NB} = Normal force brush**

These two forces will then be determined through real life experiments.



Ill. 4.13: The cleaning configuration

Radius wheel & radius roller:

r_{wheel} = 33 cm r_{roller} = 8 mm

Angular velocity:

$\omega_{rpm.wheel}$ = 4 rpms

Acceleration:

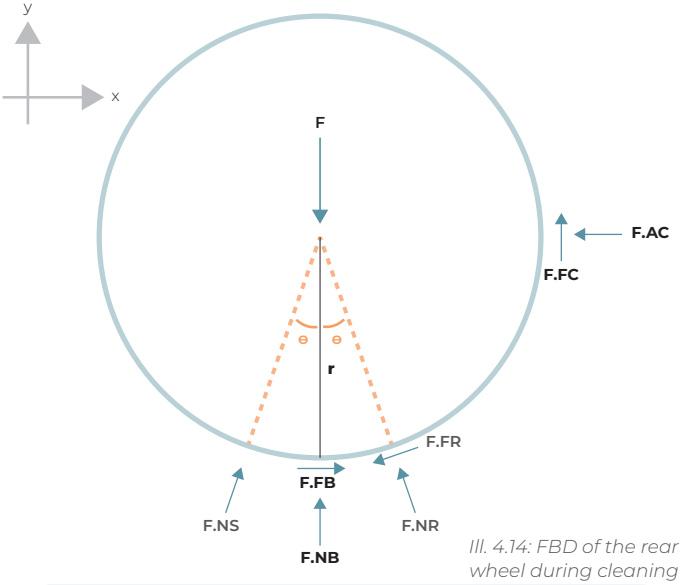
$A = \omega / t = 0.42\ rad/s^2$

Moment of inertia:

$I = m_{wheel} \cdot r_{wheel}^2 = 0.54\ kg \cdot m^2$

Torque (no external forces):

$T = I \cdot A = 0.23\ N \cdot m$



Ill. 4.14: FBD of the rear wheel during cleaning

Load on rear wheel:

$F = m \cdot 0.64 \cdot g = 1069\ N$

Angle:

$\Theta = 12°$

OF MOTOR & FRICTION

EXPERIMENT (CLOTH) - F_{AC}

The force that the handheld device does against the wheel was estimated **by pushing a cloth against the rear wheel and then approximately pushing with the same force against a scale**. As the friction coefficient of the cloth (μ_c) is also a known value of 0.3 (The Engineering Toolbox, 2022), it is then possible to determine F_{AC} and F_{FC}.

Ill. 4.15: Determining the cloth force

Force applied from cloth:

$F_{AC} = 0.5\ kg \cdot g = 5\ N$

Frictional force cloth:

$F_{FC} = \mu_c \cdot F_{AC} = 1.5\ N$

EXPERIMENT (BRUSH) - F_{NB}

The brush will be seen as a spring, where the stiffness of the brush and the change of height of the brush under the applied load can help determine F_{NB} and thus F_{FB}.

The experiment was conducted **by taking a brush and applying a known force**. Then, the change in height of the brush (δ_{exp}) is measured when loaded and unloaded, as depicted on ill. 4.17. The actual change of height of the brush (δ_{actual}) was measured from the 3D model following the principle on ill. 4.16. With this information, and assuming that the friction coefficient of the brush is equal to the one of the cloth, both F_{NB} and F_{FB} can be determined.

Stiffness of brush:

$k = F_{exp} / \delta_{exp} = 29.7\ N/mm$

Actual change in height of the brush:

$\delta_{actual} = 4\ mm$

Ill. 4.16: Change in height - brush

Friction coefficients:

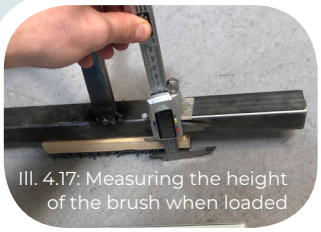
$\mu_b = \mu_c = 0.3$

Normal force brush:

$F_{NB} = k \cdot \delta_{actual} = 119\ N$

Frictional force brush:

$F_{FB} = \mu_b \cdot F_{NB} = 35.6\ N$



Ill. 4.17: Measuring the height of the brush when loaded

CALCULATING F_{FR} & μ_r

The forces calculated for the cloth and brush allow to **determine the rest of the forces through the concept of equilibrium.** The resultant **friction coefficient** of 0.095 **is evaluated as sufficient,** as the friction coefficient between rubber and steel is 0.64. **The frictional force will then be used to select a motor.**

Frictional force roller:

$F_{FR} = 37\ N$

Friction coefficient roller:

$\mu_r = 0.095$

CHOOSING A MOTOR

Knowing the frictional force of the roller, the required moment can be calculated. The total required torque for turning the wheels with the required velocity can now be determined, which can be used to define the motor. The required angular velocity of the roller to achieve the required angular velocity of the rear wheel is determined.

As a result, **the required torque, velocity and the power can be determined and thus a motor can be specified.**

Moment of roller:

$M = F_{FR} \cdot r_{roller} = 0.3\ N \cdot m$

Total torque:

$T_{total} = T + M = 0.53\ N \cdot m$

Angular velocity of roller:

$\omega_{rpm.roller} = r_{wheel} / r_{roller} \cdot \omega_{rpm.wheel} = 165.8\ rpm$

Power of motor (minimum):

$P = T_{total} \cdot \omega_{rpm.roller} = 9.14\ W$

CONCLUSION

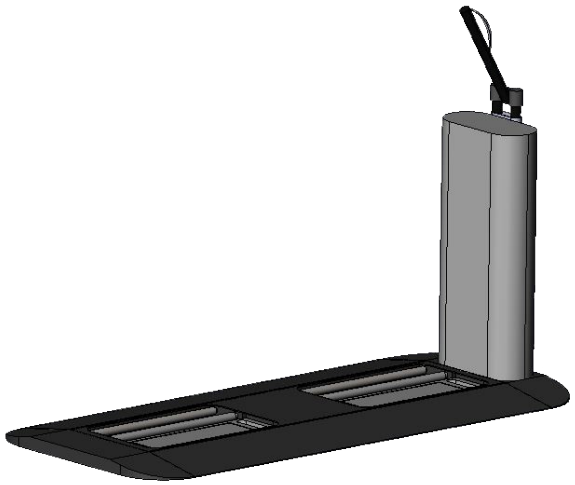
Ill. 4.18: Required motor

The DC motor (RS-Online, 2022) with planetary gearbox (51:1 ratio) depicted in ill. 4.18 fulfils the requirements and has the following overall dimensions: 105 mm long, 36 mm diameter. This motor is also reversible, so the user can shift the spinning direction if desired.

- ✓ *Stainless steel rollers fulfil the friction requirements of min. 0.095*
- ✓ *A motor with a minimum torque of 0.53 N . m and speed of 166 rpm is required.*

MOTOR COMPARTMENT

The shape got refined based on the base dimensions and to accommodate the form language described on page 53. During the development phase, the motor compartment had two different variants: a tall version and a short version. The Pros and Cons of these two directions are explored in this section [App. 24].



Ill. 4.20: Tall motor compartment version

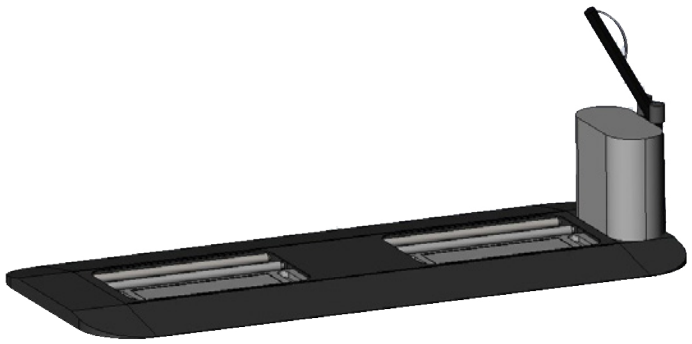
TALL VERSION

A tall motor compartment allows to control the motor from the tower. It also allows to make some room for storage of extra cloths, so clean cloths are always at hand for the user.

- + Extra cloths always available.
- + Controlling the motor directly on the motor compartment.
- − The compartment is tall just to have a button at a comfortable height.
- − Noticeable in the entrance due to its height.

LOW VERSION

Making the motor compartment as small as possible, makes the overall size of the wheel cleaner more compact and could be related more to a traditional doormat. It also requires that the handheld device works as a remote to control the motor.



Ill. 4.19: Low motor compartment version

- + The user is able to always have full control over the movement of the motor.
- + Less complex, requires less material, and looks more like a doormat
- − Could be confusing to use the handheld as remote for the motor.
- − No space for extra cloths.

DECISION

The direction chosen was the low version as the storage of additional cloths was not evaluated as bringing sufficient value compared to its cost, when users already have several options for storage in their entrance, such as drawers or shelves. The expression of the low version would also create a greater connection to a traditional doormat and thus shape its product identity.

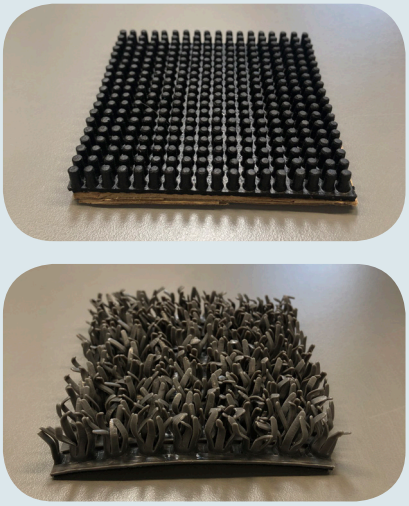
BRUSH IN THE BASE

The brush in the base also requires to be cleaned once in a while. To allow for a proper cleaning of this element, it should be possible to remove it from the base. Different ideas were explored in terms of how to pick it up from the base.

BRUSH SELECTION

The brush has proven to be an appropriate cleaning element for removing dirt from the grooves in the tire (see cleaning tests on page 38). However, due to the solution's limitations in terms of height and as the rear wheels cannot only rest on the brush (it would prevent the rollers from spinning the wheel), the bristles need to be short. The team tested two other brushes from entrance mats during the development process: one with plastic bristles and another with rubber bristles. From this, it was concluded that the plastic brush performed better, as the bristles could enter the grooves [App. 21]. Because of this, a low brush with plastic bristles similar in size to the one depicted on ill 4.21 is needed.

The brush must not go above the centre of the rollers.



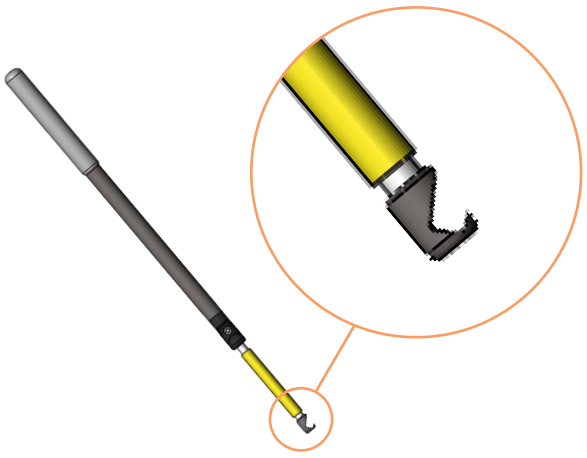
Ill. 4.21: Rubber brush (up) and plastic brush (down)

PICKING UP THE BRUSH

The team considered two possible methods for picking up the brush:

HANDHELD DEVICE

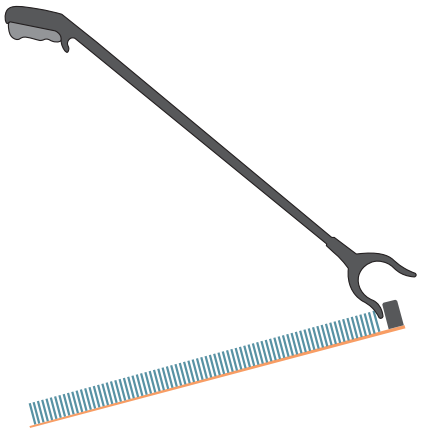
Adding some sort of hooks to the handheld device should make it possible to pick up the brush. However, due to the required precision, the size of the hooks, the limited space between the rollers and the added complexity, the hooks on the handheld were discarded.



Ill. 4.22: Handheld device with hooks at its end

GRABBER STICK

This product is something that wheelchair users and other people with reduced mobility use to grab objects that are out of reach - on a shelve or on the floor. **As users who cannot reach will own this product anyway, this tool might as well be used for picking up the brush when it is needed.**



Ill. 4.23: Grabber tool picking up the brush

The brush must be possible to replace with a grabber.

HANDHELD DEVICE

During the development of the handheld element, many different models were explored [App. 25]. The following pages present the process until the final handheld device is defined.

1. FIRST MOCK-UPS

The first mock-ups were very simple. They consisted of a handle and a cloth wrapped around a sponge. This sponge allowed the cloth to wrap around the wheel, making it possible to clean the sides of the tire as well.

Ill. 4.24: Prototypes of some of the initial concepts of handheld device

2. CHOOSING DIRECTION

Among the models made, the team chose one that consisted of two tubes and a handle. A sweatband could be wrapped around the tubes, which made it easier to clean the sides of the wheels. The elasticity of the sweatband allows the cloth to stay in place when on the handheld device without any locking mechanism.

Ill. 4.25: Prototype of handheld device concept with two tubes and a sweatband

3. TEST WITH USER

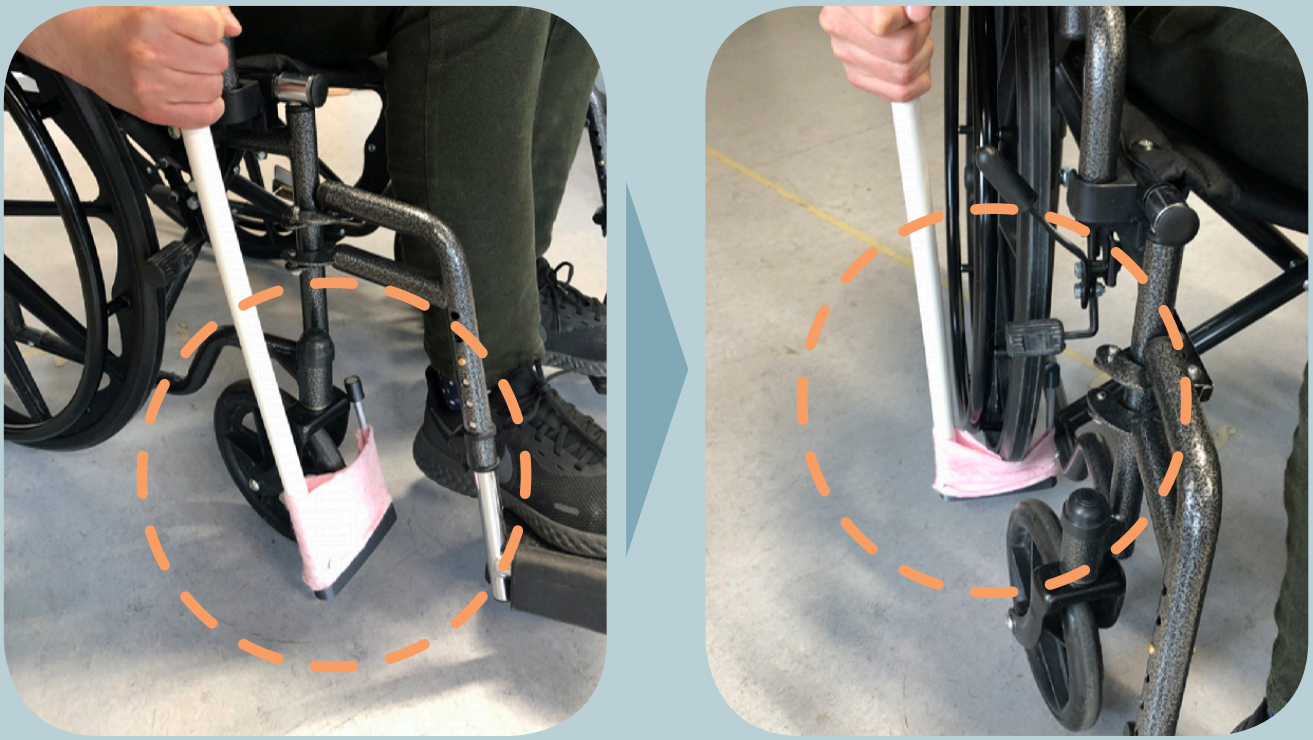
A final test with a user was made in order to get feedback on the overall concept, including the handheld device [App. 26]. The team brought a functional prototype so that the user could try it in order to figure out the small adjustments needed. The main takes were:

- The angle of the handle did not allow for a comfortable fitting of the wheel. He recommended that the handle should go to the side instead.
- The tubes should be more compact to fit the wheels better.
- The front wheels tend to be wider than the back wheels, so the team needs to consider this.

Ill. 4.26: Interviewed wheelchair user trying out the functional prototype of the concept

4. FINAL VERSION

The selected handheld concept was improved by taking into consideration the user's feedback. The final version have smaller tubes and the handle is made with an offset, so it can be positioned in front of the rear and caster wheels from the side as depicted on ill. 4.27.



Ill. 4.27: Prototype of final handheld device – version with connector on top (left) and final version with connector on bottom (right)

SCENARIO

Based on the development of the concept, a description of how the solution works is presented with a scenario. This is the final, overall concept that will be detailed in the next chapter.

1. The user enters the home, and is ready to use the product.

2. The user drives onto the product with the front wheels.

5. The user moves forward, positioning the back wheels on the product.

6. The user cleans the rear wheels one at a time.

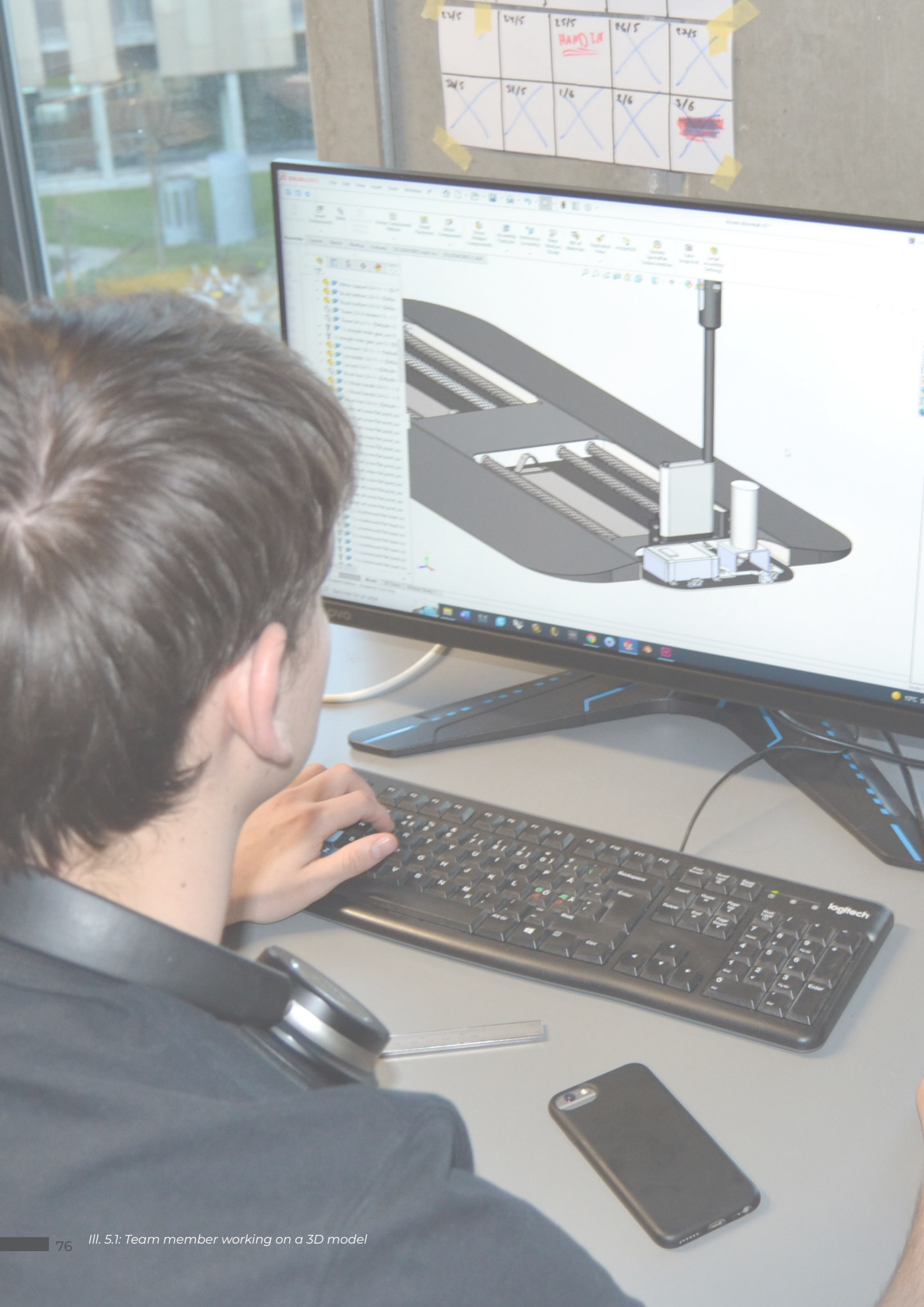
3. The user picks up the handheld device. The motor is activated by the handheld device, which makes the wheels turn.

4. The user cleans the front wheels one at a time.

7. The user deactivates the motor on the handheld device and puts it back.

8. The user drives down of the product with clean wheels.

Ill. 4.28: Scenario made with mock-up of the concept (8 steps)



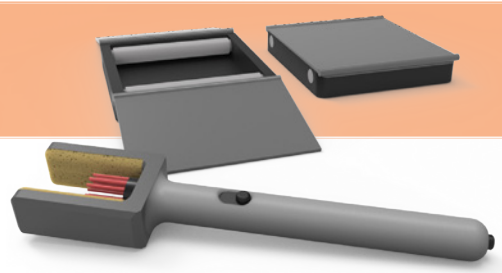
Ill. 5.1: Team member working on a 3D model

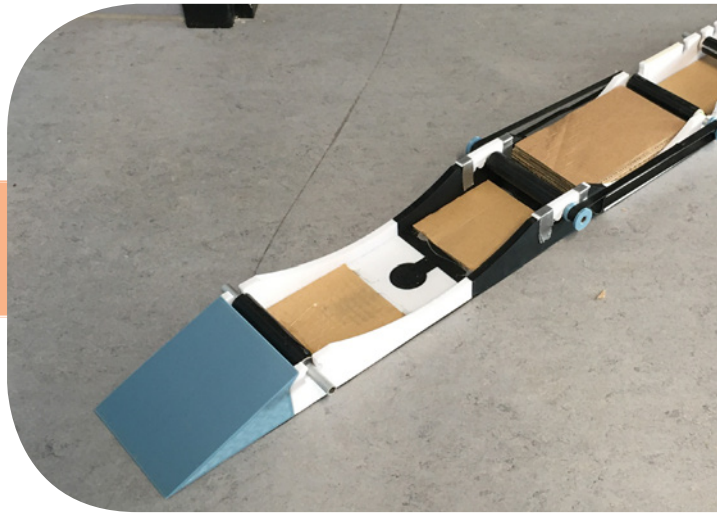
5. DETAILING

In this chapter, the concept has been fully defined and the characteristics and function of each of its components are presented. Additionally, an initial business strategy is presented, as well as a calculation of the estimated production cost of the solution.

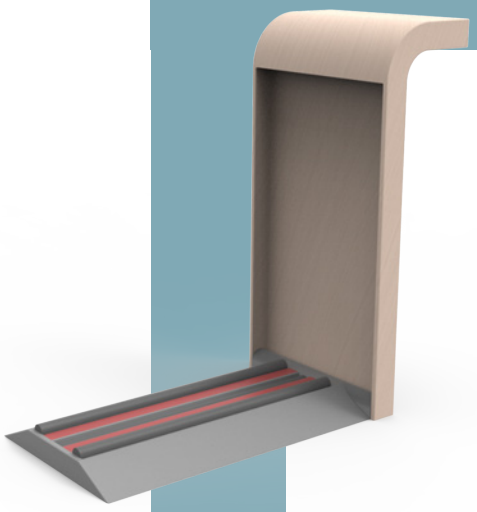
ITERATIONS - OVERVIEW

An overview of the different main concept iterations made throughout the project are presented in this section.





Ill. 5.2: Initial concept – on-the-go ramp



Ill. 5.4: Initial concept – stationary

Ill. 5.7: Stationary concept – tall motor compartment version

Ill. 5.5: Stationary concept – 2nd version

Ill. 5.6: Stationary concepts – handheld device version (left) and triangle version (right)

Ill. 5.3: Three transportable concept directions: belt-driven (left), push handle (middle) and motorised (right)

Ill. 5.8: Stationary concept – final version

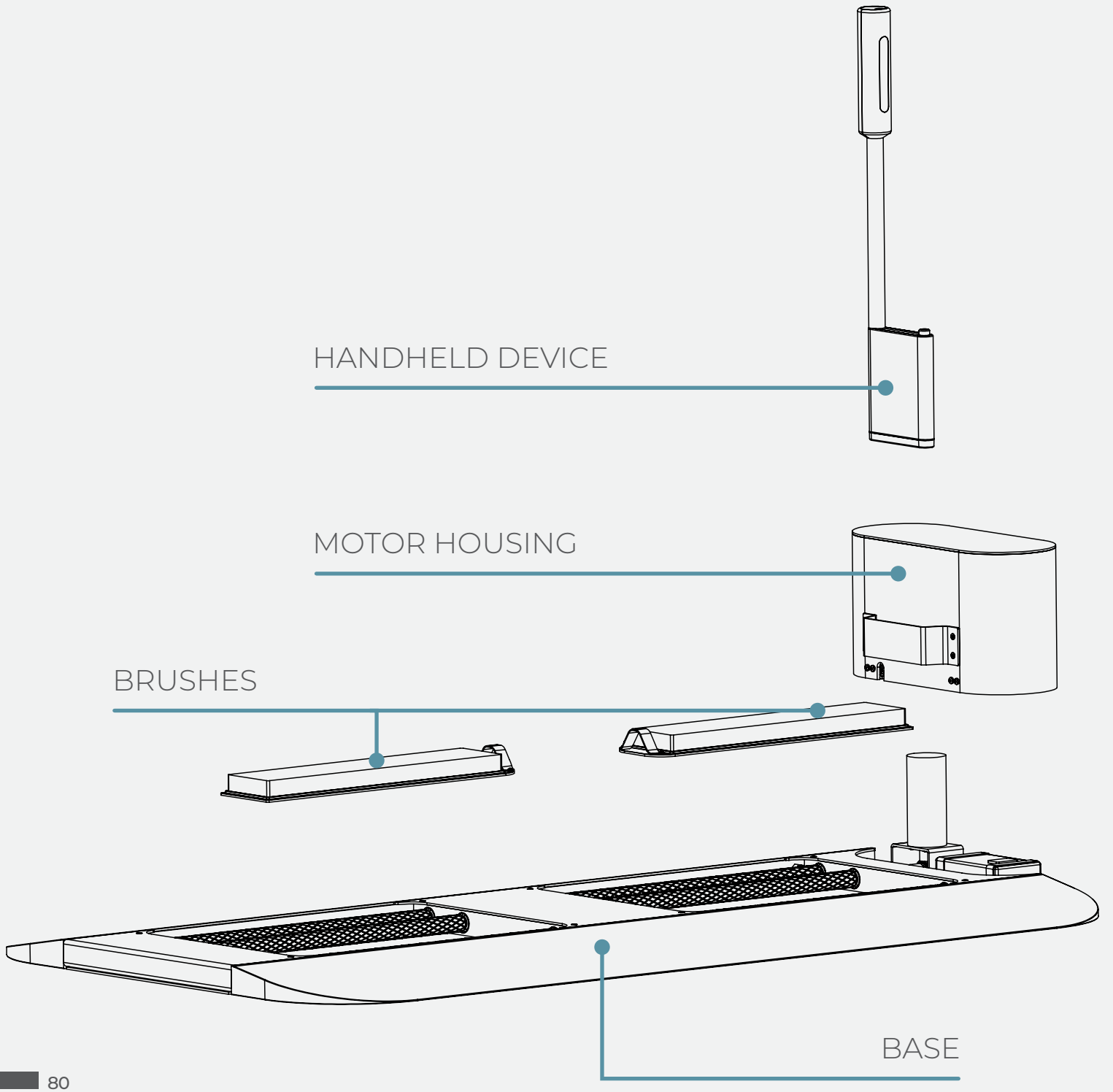
EXPLANATION

After making the initial concepts, the team continued exploring the transportable direction and discarded the stationary. During the process, the team realised that this direction was not feasible and re-explored the initial stationary concept (see page 48). Multiple versions were created over time until reaching the final stationary concept depicted on ill. 5.8.

COMPONENTS & ASSEMBLY

PRODUCT OVERVIEW

The product consists of four sub-assemblies: the base, the motor housing, the brushes and the handheld device (ill. 5.9). Each sub-assembly will be displayed and explained in terms of assembly, material and manufacturing.



Ill. 5.9: Exploded view – product overview

HANDHELD DEVICE

The handheld device is the controller and at the same time the cleaning element responsible of wiping off the superficial dirt of front and rear wheels. Thanks to the length of 400 mm, the access to all wheels is facilitated.

1) CLOTH

The cloth is made in a elastic textile, similar to sweat-bands. This is done so it attaches to the handheld device without falling off under operation.

2 & 3) CAPS

To close off the handheld device, two injection moulded end caps are positioned, one at the handle and the other at the cylinder in the bottom.

4) PUSH BUTTON & PCB

In order to communicate with the motor, an injection moulded ABS push button is connected to the PCB inside the handle.

5 & 6) CYLINDERS & CONNECTOR

The cloth is kept in place by two extruded cylinders, which are connected by an injection moulded link in the bottom. These are glued together and glued to another extruded profile, which is connected to the handle.

7) BATTERY & HOLDER

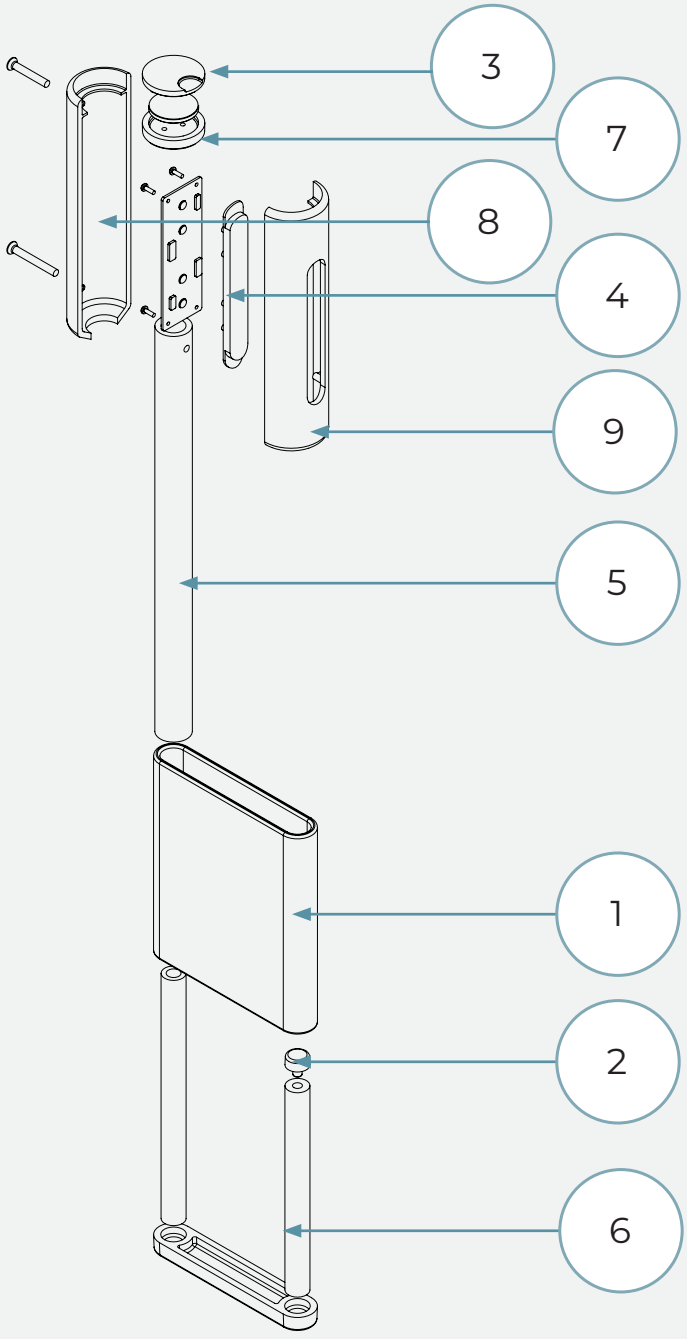
To power the handheld, a small exchangeable battery is mounted in a small injection moulded ABS holder within the handle, which are connected to the PCB.

8 & 9) HANDLE

The handle consists of two injection moulded ABS parts, which contain the electronics.

ELECTRONICS

In case of issues with the electronics, it is possible to disassemble the handle via the screws, as depicted on ill. 5.10. However, the rest is glued together, as the need for changing the cylinders was evaluated not as important compared to the additional manufacturing process and cost required for making holes for screws.



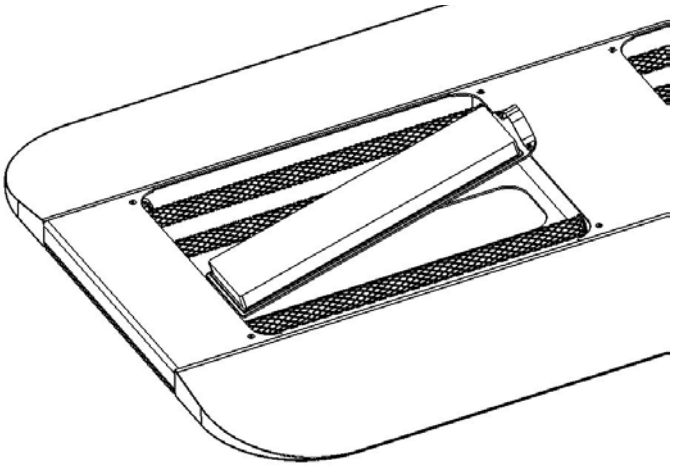
Ill. 5.10: Exploded view – handheld device

BRUSHES

Two brushes are positioned in the base in order to remove the dirt within the grooves of the rear wheels, which is inaccessible for the handheld device.

1) BRUSH PLATE

As the brushes have to be changed occasionally for cleaning and to accommodate users with reduced arm strength, they must be lightweight. Because of this, the base of the brush is made in injection moulded ABS on which the brush is glued onto. The brush plate is made to fit in the cut-through in the bottom plate, so it is stuck in place under the cleaning operation, but at the same time not completely fixed to ease the replacement.



Ill. 5.11: Brush being removed from the base

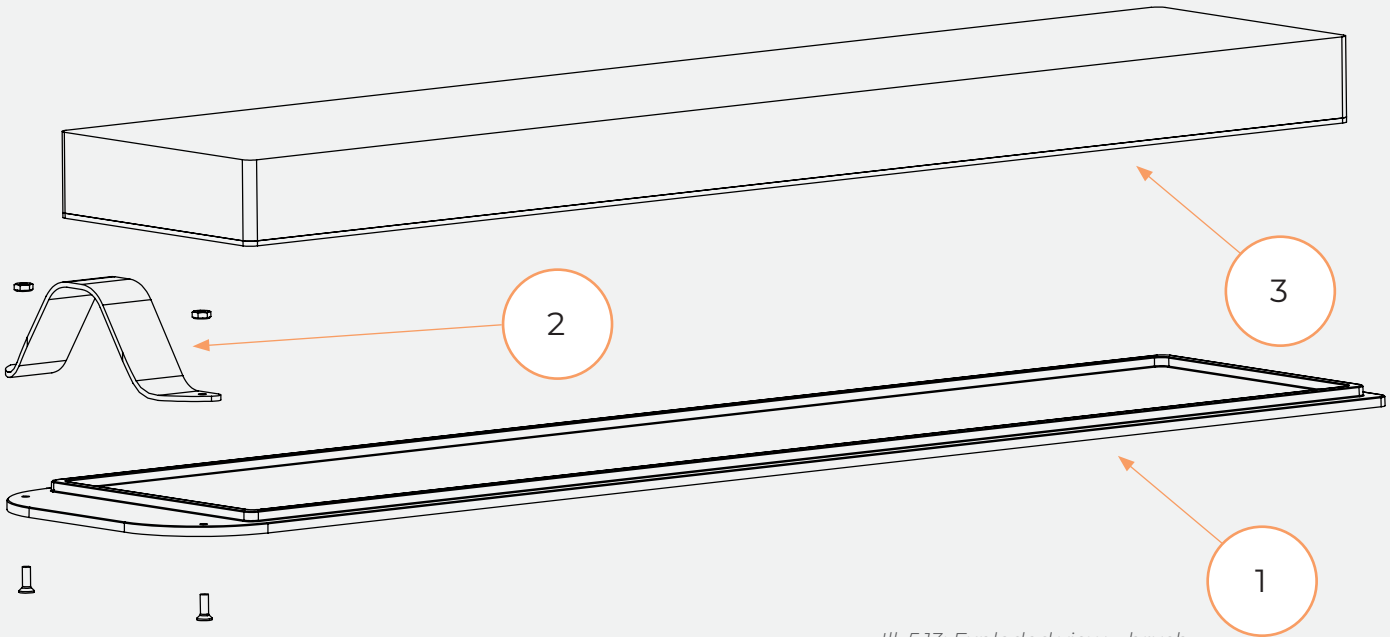
2) HANDLE

For the user to grab the brushes, rubber handles are attached. This is chosen in case the user drives over the handle of the brushes by mistake. In that case, the rubber will just deform and go back to its original state afterwards, unlike an ABS handle. The handle can be grabbed by the user with a grabber.

3) BRUSH

The brush itself is made with hard plastic bristles, so the front wheels are able to pass without sinking into the brush.

Ill. 5.12: Grabber picking up brush from the base



Ill. 5.13: Exploded view – brush

MOTOR HOUSING

To close off and shelter the motor and other electronics within the base from dirt, a housing is surrounding these components. This sub-assembly also function as home for the handheld device.

1) HOUSING

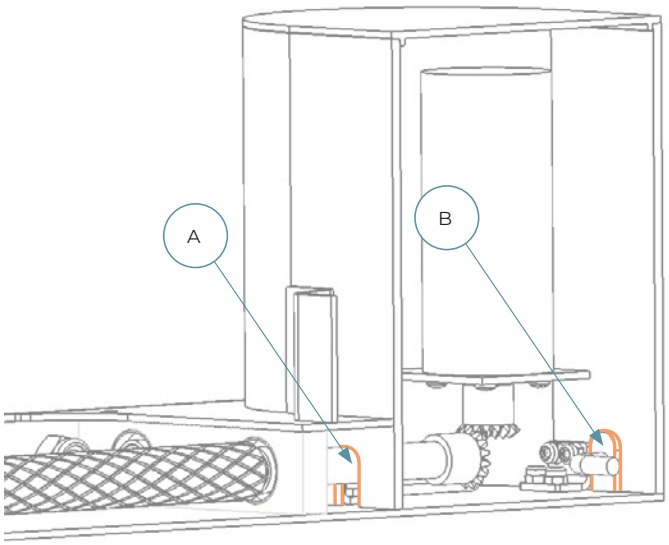
The housing is produced in an ABS extruded profile with additional milling. This is done to attach it to the bottom plate and for attaching the holder for the handheld device. It is also made to provide an entrance for the rollers (A) and an exit for a power supply wire (B), as depicted on ill 5.14. The housing is attached to the base with L-shaped brackets made in bended sheet metal.

2) LID FOR MOTOR HOUSING

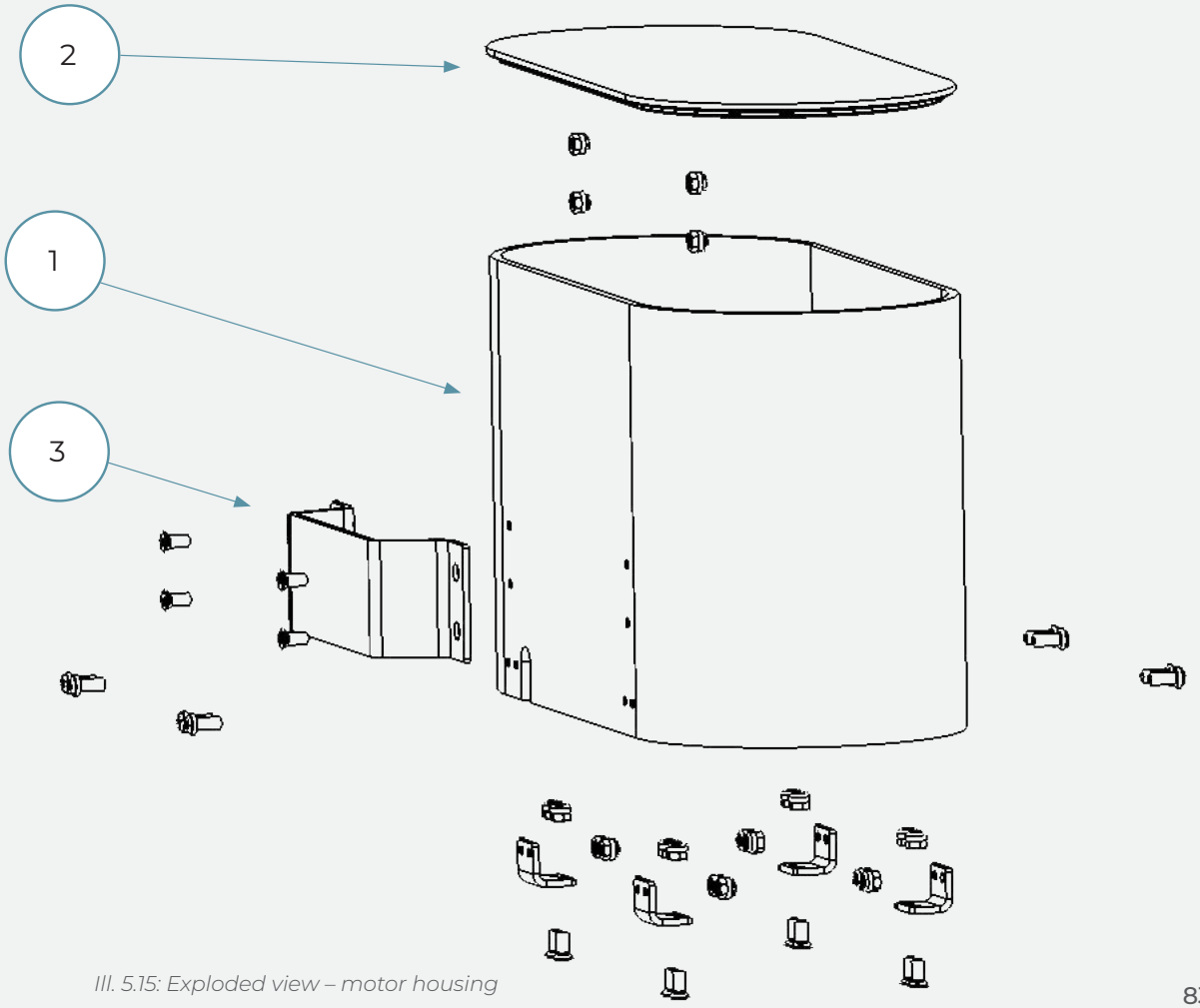
To close off the motor housing, an injection moulded ABS lid is placed on top, which is detachable in case of issues with the motor or other electronics.

3) HOLDER FOR HANDHELD DEVICE

To place the handheld device next to the product for easy access, an injection moulded ABS profile is attached to the housing, which works as a holder.



Ill. 5.14: Section view – motor housing



Ill. 5.15: Exploded view – motor housing

BASE - OUTER PART

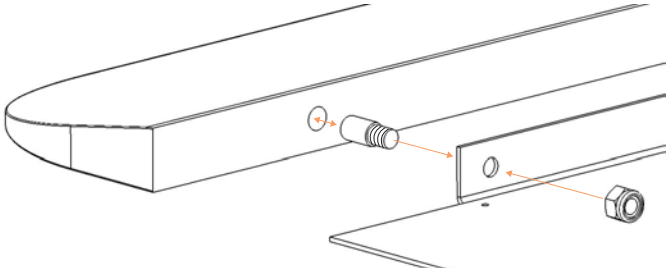
The base is the main part of the product. Due to its complexity, it will be divided into an outer and an inner part. The outer part could be seen as the elements that surround the rollers.

1) BOTTOM PLATE

To accommodate and achieve a solid base for fixating the rest of the components, a piece of bended sheet metal with milled holes for fixations is chosen. To avoid the industrial look from some of the existing products, it is powder coated with black paint.

2) RAMPS

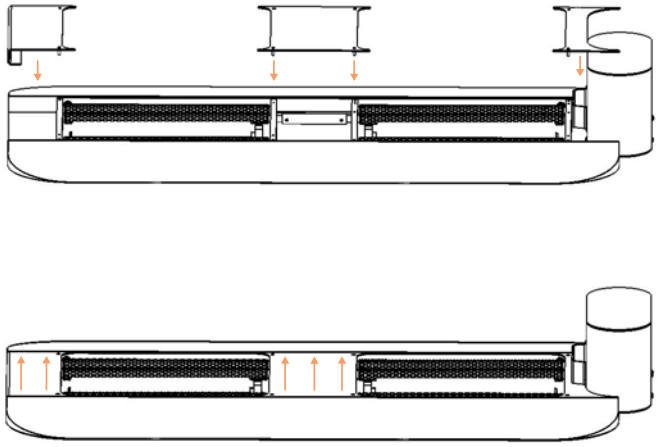
For accessing the product, ramps are needed. In order for users to get onto the product without pushing it away in the process, friction with the floor is needed. Because of this, the ramps will be made in solid rubber through moulding. This will make the ramp durable and minimise the industrial look compared to ramps in sheet metal. The ramps are attached to the bottom plate with threaded inserts.



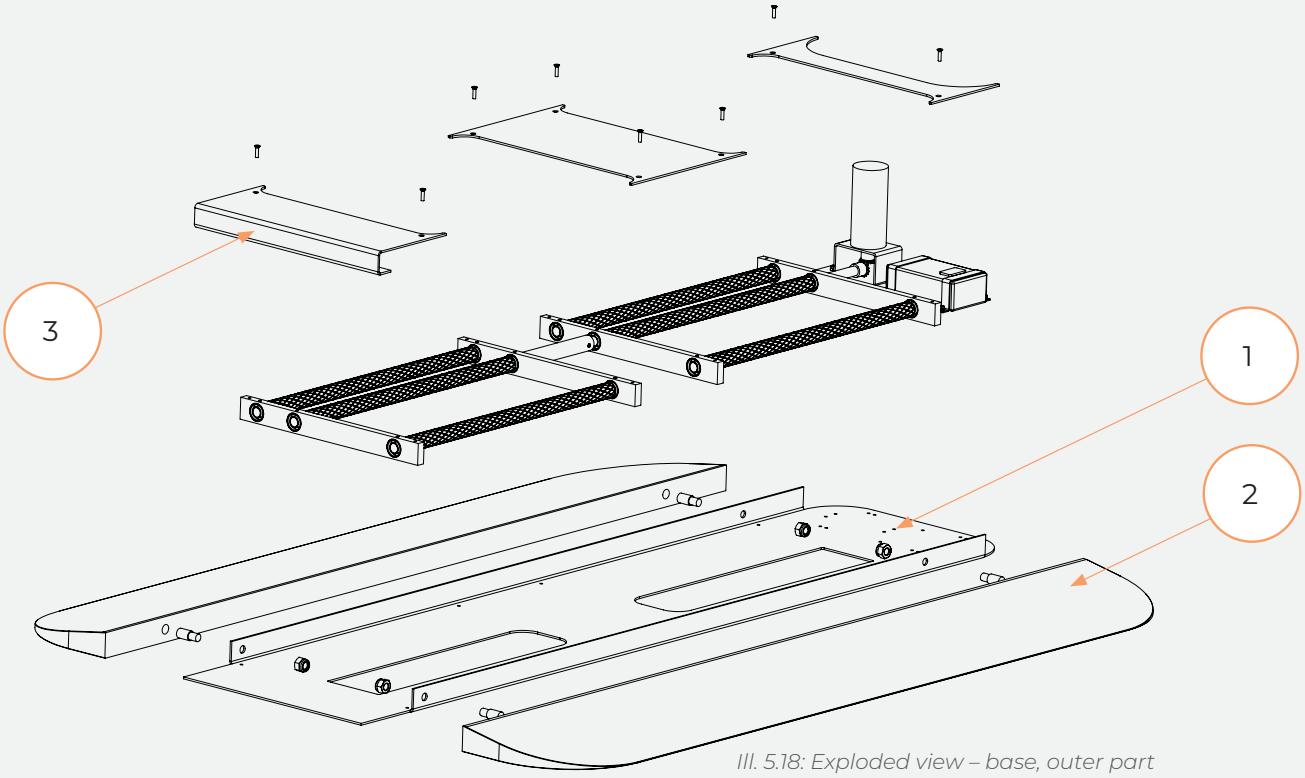
Ill. 5.16: Exploded view – ramp attachment to base

3) TOP LIDS

To close off the base and enable users to pass over the product in the middle and side, three sheet metal lids are mounted onto the roller supports. This is chosen over plastic, as otherwise they would require additional supports underneath to be able to withstand the load. To avoid having an industrial look, they are powder coated with black paint.



Ill. 5.17: Exploded view – top lids



Ill. 5.18: Exploded view – base, outer part

BASE - INNER PART

The inner part contains all the components related to the rollers. These components allow the wheels to rotate to facilitate the cleaning process.

1) ROLLERS

The rollers will be made in stainless steel due to its strength and resistance to corrosion, unlike aluminium which is sensitive to salt, which likely will be on the wheels during winter. The rollers will be manufactured through turning. To enhance the grip between rollers and wheels, the rollers will have a knurled surface.

2) ROLLER SUPPORTS

The rollers are supported by blocks of stainless steel with drilled holes for mounting the ball bearings. Additional holes are drilled for fixations onto the bottom plate.

3) ROLLER CONNECTOR

In order to connect the two driving rollers (so only one motor is needed) a connector is utilised. This is produced in a steel tube with drilled holes for tightening.

4) RADIAL BALL BEARINGS

In order to achieve smooth rotation of the rollers, ball bearings are utilised. As the rollers will be loaded radially, radial ball bearings are used. The bearings will be attached to the rollers by press fit, as bearings with locking collars would increase the height significantly due to their size. This would be an inconvenience as the base should be as low as possible.

5) GEARS

To transmit the movement from the motor (vertical) to the rollers (horizontal), miter gears are utilised.

6) AC ADAPTER

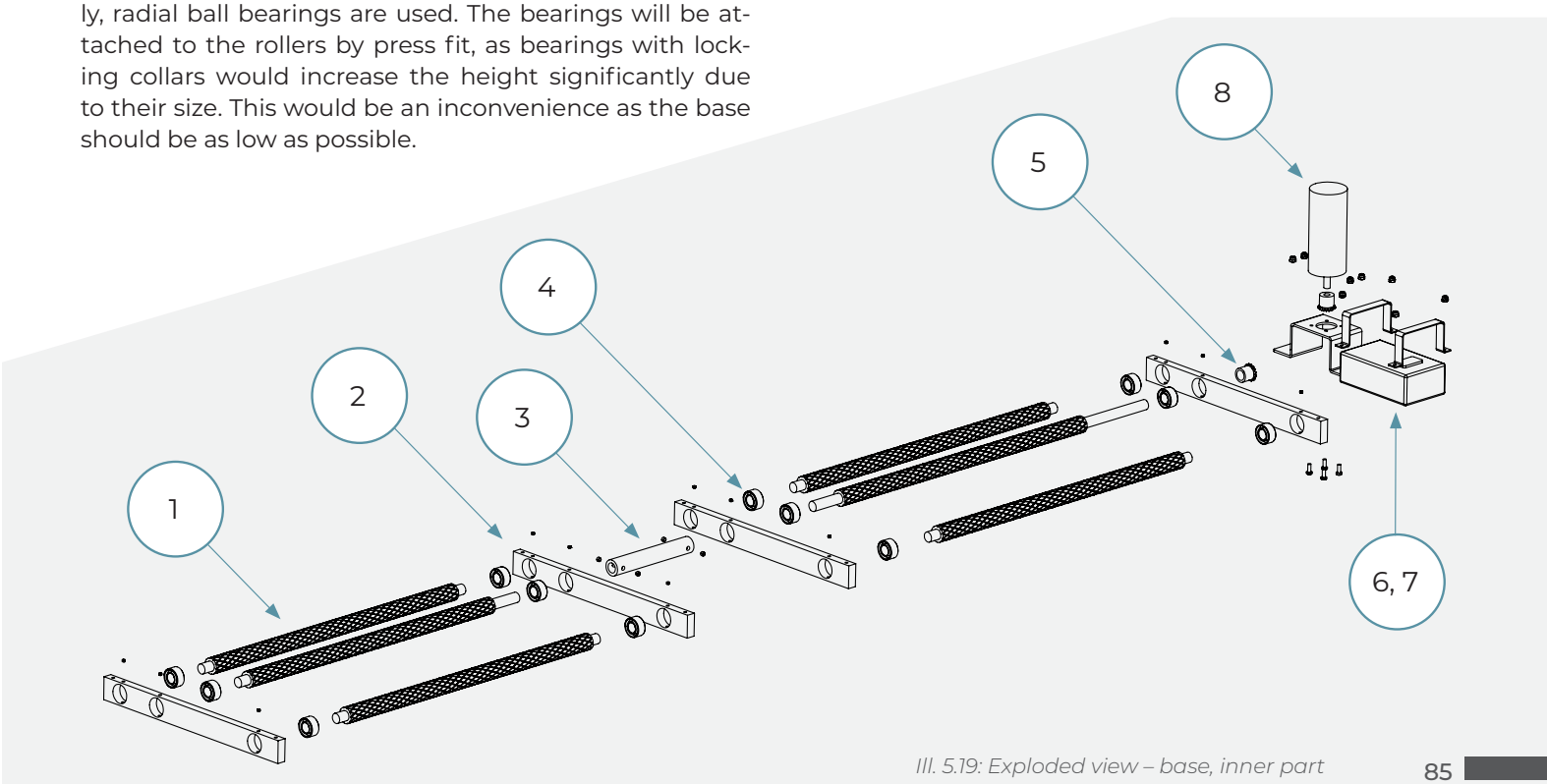
To power the DC motor, an AC adapter is needed. This is attached to the bottom plate by brackets in sheet metal.

7) RADIO FREQUENCY RECEIVER

To activate the motor through the handheld device, a radio frequency receiver is connected next to the AC adapter.

8) MOTOR & MOUNT

Due to the low height of the rollers, the motor has to be positioned upwards. Because of this, the motor will be mounted on a piece of bended sheet metal which is attached to the bottom plate.



Ill. 5.19: Exploded view – base, inner part

MANUFACTURING COSTS

In order to determine the sales price, it is a necessity to firstly figure out the costs of production and assembly. This is done by utilising different sources, such as the costing tool from SolidWorks and other product components which can be used as reference [App. 27]. Doing so, it was possible to determine two different cost scenarios and get an overview of where the cost comes from and where costs can be saved:

MACHINED STEEL PARTS

Due to the strength-related demands of the product, many of the parts are made in steel, manufactured by machining. Because of that, the cost of these parts barely differ in terms of batch size, as the cost is based on material and manufacturing costs. This makes many of the components in the base, such as rollers, roller supports and sheet metal parts almost fixed in terms of costs, unless special quantity discounts are negotiated with potential manufactures. This is not included in the cost estimation.

MOULDED PLASTIC PARTS

Most of the plastic parts are chosen due to density and to distance the product from its industrial looking competitors. Moulds are needed for production, which involves a high initial cost. However, as opposed to the needed steel parts, many of the plastic parts will become less expensive with increased batch size. This gives incentive for reduced costs and to offer the product cheaper for the customers.

STANDARD COMPONENTS

Utilising standard parts reduces costs, and that is why the solution has included them when possible. These components often come with discounts for increased batch sizes. This means that components such as the motor, bearings, gears and electronics should be feasible to purchase for lower prices. The prices of these parts were estimated from European and US manufactures. For this reason, it is considered feasible to get reduced prices for many of these components by obtaining them from Chinese manufacturers instead.

ESTIMATED COST

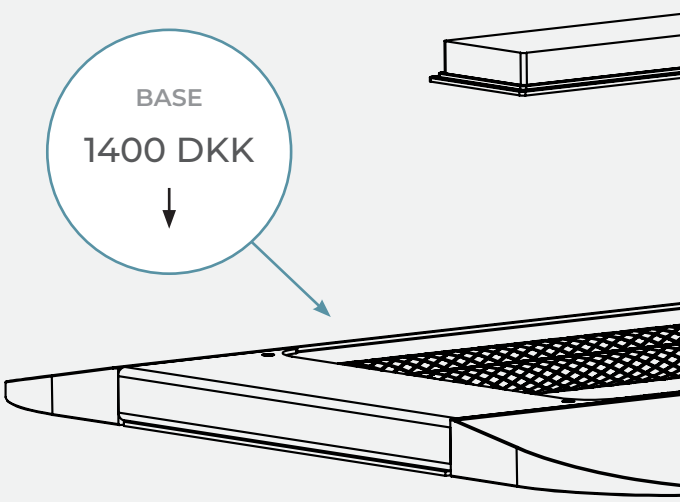
Having these different considerations in mind, the possible cost of the product was determined for the worst and the best scenario.

- The worst case is based on a batch size of 1000 units and the original cost of the standard components
- The best case is based on a batch size of 5000 units and a cost for the standard components of 50% compared to their original price.

WORST CASE
3100 DKK

BEST CASE
2660 DKK

BASE
1400 DKK



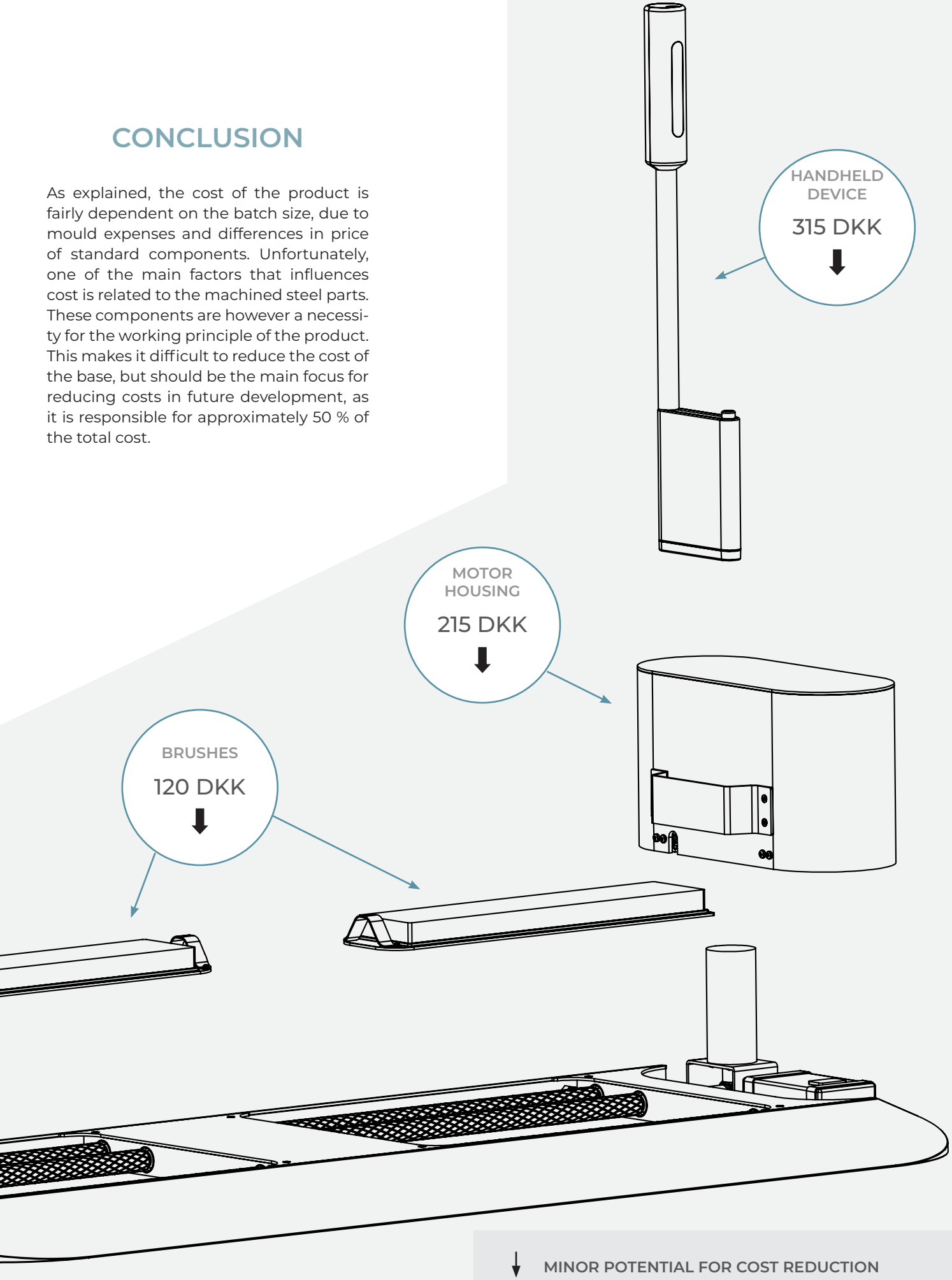
940 DKK

OTHER COMPONENTS:

- Motor
- Bearings
- Screws, nuts & inserts
- Electronics
- Gears

CONCLUSION

As explained, the cost of the product is fairly dependent on the batch size, due to mould expenses and differences in price of standard components. Unfortunately, one of the main factors that influences cost is related to the machined steel parts. These components are however a necessity for the working principle of the product. This makes it difficult to reduce the cost of the base, but should be the main focus for reducing costs in future development, as it is responsible for approximately 50 % of the total cost.



Ill. 5.20: Exploded view – main parts (handheld, motor housing, brushes and base)

↓ MINOR POTENTIAL FOR COST REDUCTION

⬇ MAJOR POTENTIAL FOR COST REDUCTION

MAINTENANCE

FREQUENCY

The product is expected to be used 1 to 3 times a day by the user, although this frequency might vary depending on the time of the year [App. 6]. It is estimated that the cloth would need to be replaced after 1 - 5 uses, and it is therefore convenient that is it on the handheld device for easier access. On the other hand, the brush will only need to be washed every 1 - 4 weeks and will be picked up from the base with a grabber. In terms of wear, the brushes and the cloth are expected to have a lifetime of 6-12 months depending on the usage.

REPARATIONS

The rollers, ball bearings, gears and motor are expected to get damaged at a faster rate as they endure the biggest forces. Other components, such as the ramps and base lids are more likely to experience visible wear due to the frequent contact with the wheels of the wheelchair.

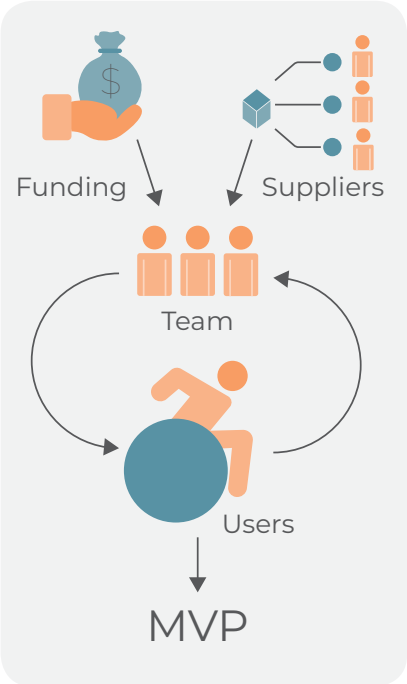
These parts are not easily exchangeable by the user due to reach, complexity and precision requirements. Hence, these components might need to be replaced by a professional or someone with technical knowledge.

BUSINESS STRATEGY

1. MINIMUM VIABLE PRODUCT (MVP)

After being done with the master's degree, the team will aim to create six test units of the product to hand in to users. This will require:

- **Funding source**, to afford the development of the MVP. The investor selected is Vækstfonden (Vækstfonden, n.d.) and the amount requested will be 50.000 DKK to cover the costs during this period.
- **Suppliers**, that will provide the raw materials and the manufacturing processes.
- **Users**, including associations, wheelchair companies and a specific user.
- **Human resources**, the team efforts to arrange all the orders and assembly the components, as well as deliver the units to the users and make the improvements needed.



Ill. 5.22: Key partners required to create the MVP

With the participation of all these parties, the team is expecting to be able to shape the MVP as a result of the tests performed with users.

The resources of the team will be very limited in terms of production and sales capabilities. Therefore, a partnership with a company is sought.

Selecting a company - Sunrise Medical

The organization selected was Sunrise Medical (Sunrise Medical, n.d.), an innovative manufacturer of wheelchairs and related devices. They have their headquarters in Germany, and have an international presence in the sector. Additionally, they have three proprietary brands - RGK, Sopur and Quickie - that make active wheelchairs, which means they already target the desired user group of the product.

Type of collaboration

After considering different collaboration possibilies, the team decided to sell the rights of the concept. As a condition of this agreement, the team will be hired by the company during the development of the product (approximately one year) and will receive 2% royalties when the product reaches the market.

The team will then have more resources available to make and launch the product, and a stable source of income. Additionally, the team will get to work in a real company and potentially get hired afterwards.

The use of the product over time might result in wear and tear. This means that considerations regarding maintenance and replacement are needed to extend the lifetime of the product to ensure the best cleaning performance [App. 28].

CLEANING MAINTENANCE

ROLLERS

The rollers can be cleaned with a regular mop, or by pulling the cloth a bit down on the handheld device and using it to wipe the dirt off (ill. 5.21).

BASE & MOTOR HOUSING

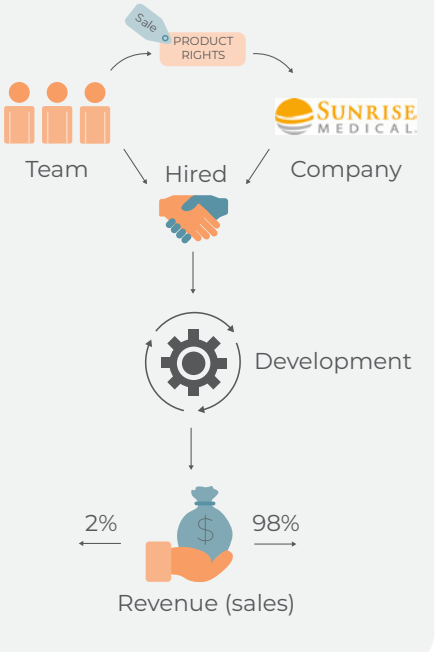
Active wheelchair users are usually able to live on their own and thus do tasks such as vacuuming or mopping the floor. Therefore, it is assumed that the users will be able to clean the base and the motor housing using either of these two methods. Those people who cannot do these tasks on their own will usually not live alone and will require assistance for these tasks.

Ill. 5.21: Cloth halfway on the handheld device

The team utilised the Business Model Canvas (Osterwalder and Pigneur, 2010) to make a business plan with the goal of creating a scalable and feasible product. The customer segment of the product is active wheelchair users and allowing for a proper cleaning of all the wheels in a convenient and independent way is the value proposition. The key partners to make the product a reality were divided based on the stages of the development process [App. 29]. Below, a concept of business plan to make the product a reality is presented.

2. COLLABORATING WITH A COMPANY

From Sunrise Medical's perspective, they will be provided with a new product idea that will fit perfectly in their portfolio and differentiate them from their competitors. Additionally, the team has already done the conceptualization process, market analysis and collected interest from users, which will saves the company some resources and speed up the process.

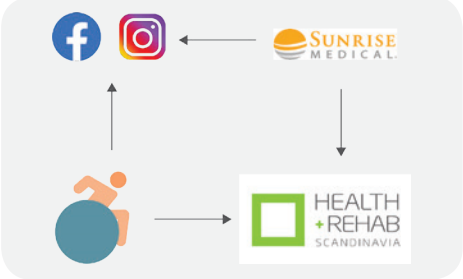


Ill. 5.23: Type of collaboration with Sunrise Medical

Marketing

For promoting this type of product - functionality-focused and with an elevated price point - the team strongly believes that getting people to try the product before buying will help to boost sales. The company could display it physically at exhibitions, like Health & Rehab Scandinavia (Health & rehab, n.d.) and make agreements with associations (disabilities unions, para-sport clubs, etc.). This strategic placement will let people know that the product exists and promote it via word-of-mouth.

Sunrise Medical will then use their existing channels to reach the customers. This includes their website, social media platforms, retailers and customer service. The company will also follow the performance of the product in the market, which will help them to make future moves such as selling in other markets or creating new versions of the product.



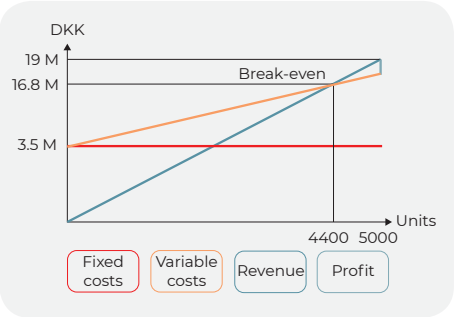
Ill. 5.24: Marketing strategy

Investments & revenue

Together, the company and the team will continue the development of the product to make it ready for scalability in production as well as to ensure its financial feasibility. The cost structure for this process will include all the manufacturing expenses (including processes, materials and wages) and distribution and promotion. The revenue stream will rely only on the sales of the product.

Break-even

Based on the cost of the product in terms of manufacturing and assembly, the sales price for one unit was estimated based on a 30% margin for Sunrise Medical. This made it possible to determine the point of break-even for a batch of 5000 units, including other expenses such as marketing salaries, rent, etc.



Ill. 5.25: Break-even graph


handicare
handicare

6. EPILOGUE

REQUIREMENT FULFILMENT

NR.	NEED	UNIT	FULFILMENT
1	It must be usable for active wheelchair users	Binary	Yes
3	It must accommodate wheelchairs with a width of 40 - 60 cm.	mm	Yes
4	The solution must be possible to use in the entrance of 3 m X 1.5 m	m^2	Yes
5	Ramps must not exceed 10° incline.	°	Yes
6	It must be able to clean front and rear wheels according to user's perception of clean [App. 13].	Binary	Yes
7	At least 130 mm between the rollers for the rear wheels (from center to center) to accommodate all wheelsizes.	mm	Yes
8	At least 65 mm between the rollers for the front wheels (from center to center) to accommodate all wheelsizes.	mm	Yes
9	The top end of the ramp must be on level with the top of rollers for the front wheels.	mm	Yes
10	The motor must rotate, so the front wheels spins forward.	Binary	Yes
11	Should not cost more than 5000 DKK if stationary.	DKK	Yes
12	The cleaning element must be replaceable by the user.	Binary	Yes
13	Roller size should be minimum 16 mm in diameter.	mm	Yes
14	Roller length can be as wide as 340 mm.	mm	Yes
15	Stainless steel rollers fulfil the friction requirements of min 0.095.	Binary	Yes
16	A motor with a minimum torque of 0.53 N . m and speed of 166 rpm is required.	Binary	Yes
17	The brush must not go above the center of the rollers.	mm	Yes
18	The brush must be possible to replace with a grabber.	Binary	Yes

CONCLUSION

A lot of wheelchair users struggle with dirty wheels when entering their homes, leaving a mess as result. This master thesis project proposes a solution, developed through user research and iterative ideation and testing processes with the goal of accommodating an appropriate solution that consider both user needs and technical and market feasibility.

The developed product, ***ROLLMAT***, is a doormat-like product for home entrances that enables rotation of all the wheelchair wheels. The rear wheels are being brushed and the users can utilise a handheld device for wiping and drying off the rest of the wheels - including the front wheels.

The product aims to solve an everyday problem and provide more independence to wheelchair users.

REFLECTION

The product is able to clean the wheelchair wheels in a sufficient way. This was verified by testing the working principles individually. This includes the cleaning, the rotation of the wheels, driving on and off the product, etc. Even though not all these were tested simultaneously in one prototype, it is assumed that the working principles will work together.

PRODUCT

PICKING UP THE BRUSH

The brushes in the base need to be changed eventually. This is done with the grabber that the users already have. However, a way to pick up the brush with the handheld could also be implemented. This might be beneficial for the users, so they do not need to bring the grabber in order to pick up the brush. Also, as the handheld device is placed in *ROLLMAT* anyway it might be beneficial to reconsider this choice.

ACCOMMODATING MOTOR SKILLS OF USERS

In the process report, it is described that active wheelchair users are people with full mobility in their upper body including their hands and arms. However, some wheelchair users may have lack of fine motor skills, and therefore have difficulties holding the handheld device. Because of this, additional research on the motor skills of wheelchair users, including tests with users, will be a necessity to fully understand the requirements. This could lead to a redesign of the handle or an add-on to accommodate these users.

MOTOR NOISE

During the tests with the concept, the team noticed a potential issue with the motor regarding noise. This may be a result of using a drill as motor, where a real motor will probably be less noisy or the motor housing will be able to reduce the noise. Despite that, it might not be a significant issue when compared to other electronic products in the home like a vacuum cleaner.

ADD-ONS

During the process, the team discarded the idea of having a place for extra cloths integrated into the solution, since entrances tend to have shelves or storage spaces. However, for future development and sales, it might be beneficial to offer this option as a simple add-on to the motor compartment, for example.

PRODUCT FAMILY

ROLLMAT consists of two ramps to allow the user to drive onto and over the product. Nonetheless, with its product architecture, it can easily be converted into a wheel cleaner installed in the floor. A user mentioned during one of the visits that he would prefer to have the solution installed in the floor being aware of the additional cost for installation. This will also enable the product to expand to other use cases like retirement homes, stores or other public places, with and without ramps.

Even though it would be preferable to accommodate powered wheelchairs as well this would require a whole new product. This is because powered wheelchairs require a different way of rotating the wheels as some wheels are already motorised. Additionally, the users of these wheelchairs are even more limited in terms of reach and mobility, hence an alternative to the handheld device will be required.

COMPROMISES

The reason for discarding the portable direction was the number of compromises that had to be made. These restrictions would result in a product that would not improve the user experience to a sufficient degree that somebody would pay for it. Because of that, the stationary direction was chosen. However, compromises were also present in this direction, which can be seen in the product proposal.

HEIGHT OF THE CONCEPT
Ramps are needed to get onto the rollers and clean the wheels, as an installation in the floor would not be affordable or possible for many users. This requires the product to have a certain height. The team has tried to lower this distance to make the product as compact as possible. The height is defined by the rollers, so their dimensions were optimised as much as possible. It was difficult to find a middle point in terms of size, as making the rollers too small or too large would have implications in terms of strength and accessibility.

However, the team evaluates that the product has reached a middle point in which the rollers are strong enough to withstand the required weight while having a height that makes the experience of driving over it similar to driving through a regular doormat or a doorstep.

PRICE & AUTOMATION
Wheelchair users have limited reach which makes it difficult to do many daily tasks by themselves, including cleaning their wheels. Because of this, some of the solutions made for these people need to be automated to accommodate disabilities, unlike “ordinary products”. These modifications often require additional components which will increase the price point of these products.

This is one of the reasons why the handheld device concept was chosen over the triangle concept (see page 60). The handheld concept has a lower complexity which makes it more affordable. Choosing this direction was a compromise that reduced the envisioned product idea, but on the other hand made a more feasible product in terms of pricing and usability, unlike many of its fully automated competitors.

PROCESS

BE CRITICAL TO USER FEEDBACK
The initial direction of a portable solution was primarily chosen due to user feedback, when showing the three initial concepts (page 37). Here, the users chose the portable concepts over the stationary, partly because of their compact size. A major error associated to this was to show them three different sized models in cardboard and postulate that all three can do the same which resulted in users picking the smallest one. This mistake was realised later in the process, which could have been avoided if the team had been more critical about the user feedback considering what type of models were presented to them.

ACCESSIBILITY TO USERS
During the process, the team had access to several users through video and phone calls. However, due to the lack of users in the area where the team members lived, visits were time-consuming, which limited the user involvement in the project.

As the team had access to wheelchairs, it was possible to simulate a lot of the concepts without involving users. Still, more user involvement, especially at the point of investigating the transportable solutions, may have been beneficial and enabled the team to move away from that direction sooner in the process.

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Ill. 1.20: Wheel with regular grooves (left), wheel with linear grooves (middle) and wheel without grooves (right)

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Ill. 2.6: Wheelcleaner prototype made by a group of students
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Ill. 2.7: Water wheel cleaning system
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Ill. 3.1: Tools and prototypes on working table

Ill. 3.2: Person in a wheelchair entering his home
Entrance from Youtuber that is a wheelchair user
Adapt To Perform (2020) Awesome Wheelchair Accessible Home! (Independent Quadriplegic). Available at: https://www.youtube.com/watch?v=mgYCUWPXxo0.

Ill. 3.3: Roomba i3+ Robot Vacuum Cleaner
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Ill. 3.7: Wheelchair wheel washer CVC-04
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Ill. 3.8: Wheelster Mini – base (left) and stick (right)
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Ill. 3.9: The Wheel Doormat
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Ill. 3.29: Motorised version of triangle concept – base and keychain controller
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Ill. 4.4: Dimensions of a door
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Ill. 4.18: Required motor
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APPENDIX CONTENT

ROLLMAT

WHEEL CLEANER

/ AALBORG UNIVERSITY
/ SPRING 2022
/ INDUSTRIAL DESIGN
/ MSC04-ID05

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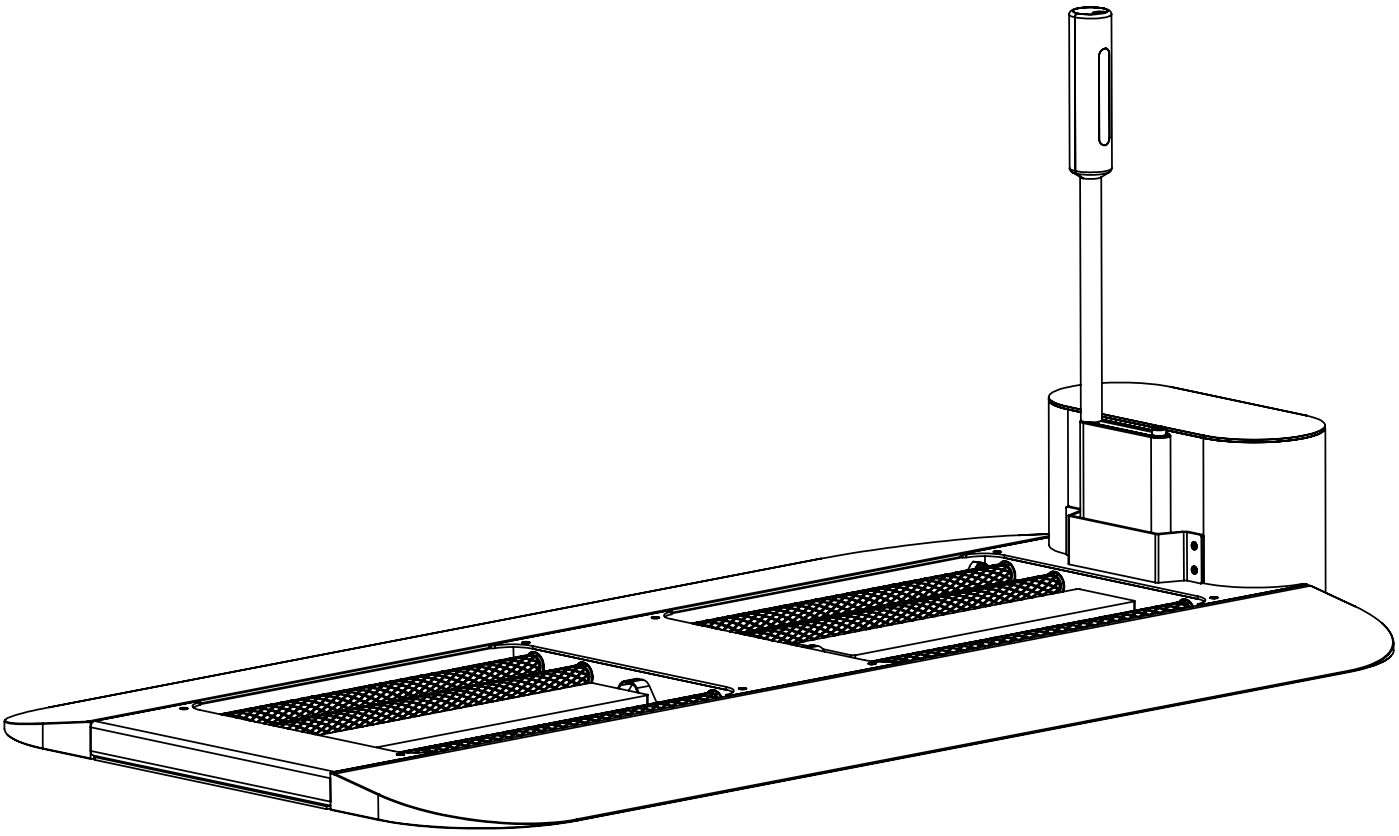
TECHNICAL DRAWINGS

/ AALBORG UNIVERSITY
/ SPRING 2022
/ INDUSTRIAL DESIGN
/ MSC04-ID05

ANDERS LINDRUP NIELSEN
ROMÁN JAVIER ANDALUZ PINEDO
JONAS SPROEGEL PEDERSEN

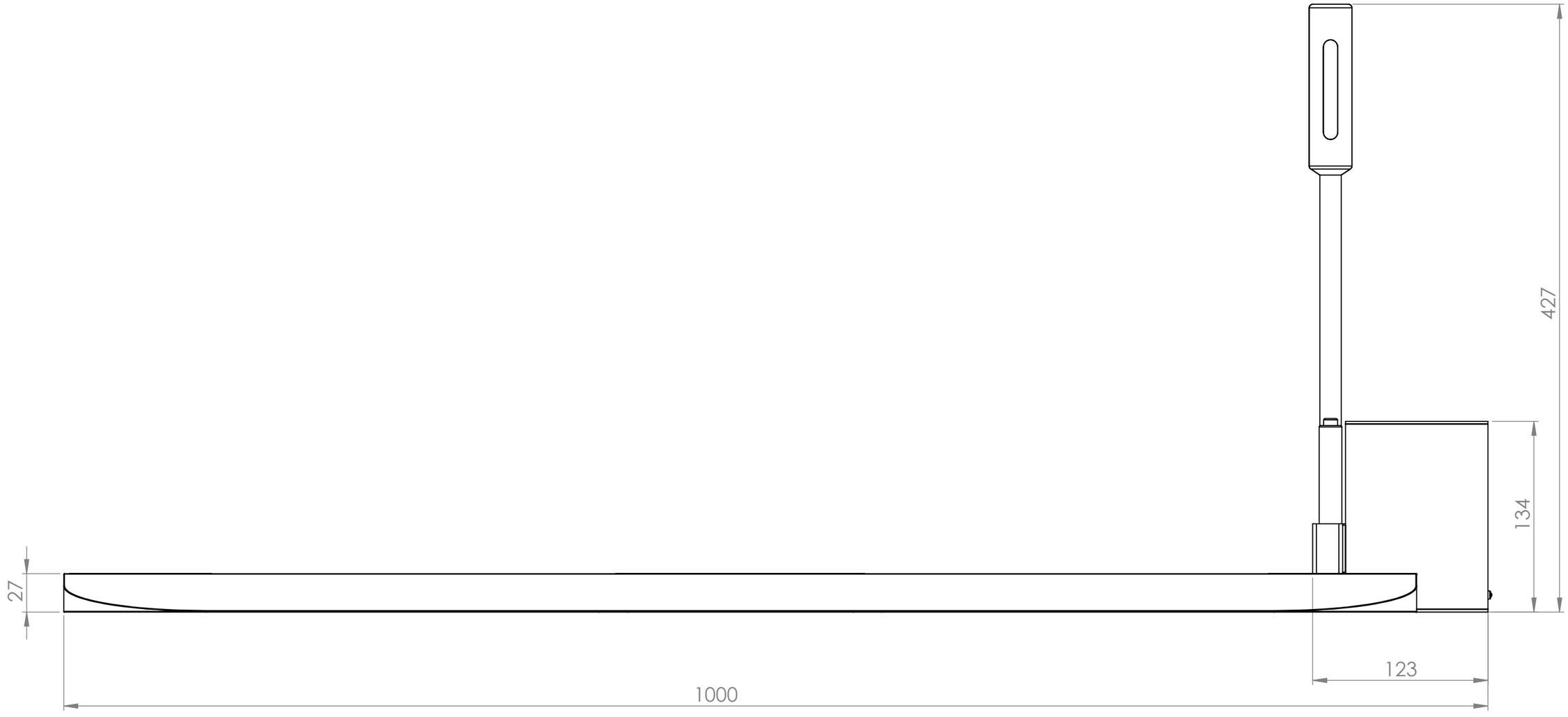


Disclaimer:

Some components lack measurements, which can only be measured if the 3D model is available due to non-geometic conditions. Because of this, contact MSC04 - ID05 for these files if needed.

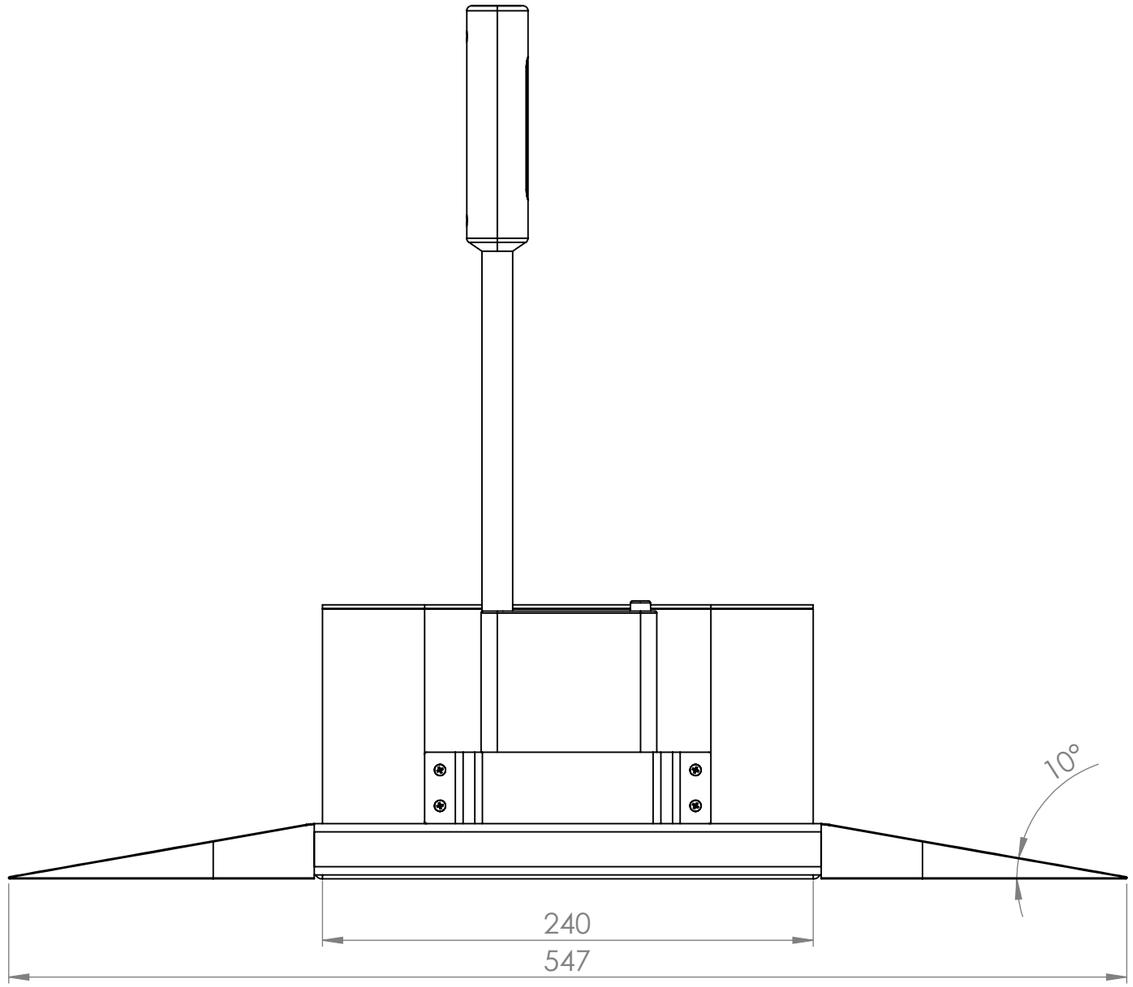
Table of content

SIDE VIEW



Side view	Product
MSC-ID4 GR. 5	Size A3
Date: 10/5/2022	Scale: 1:3

FRONT VIEW



Front view	Product
MSC-ID4 GR. 5	Size A3
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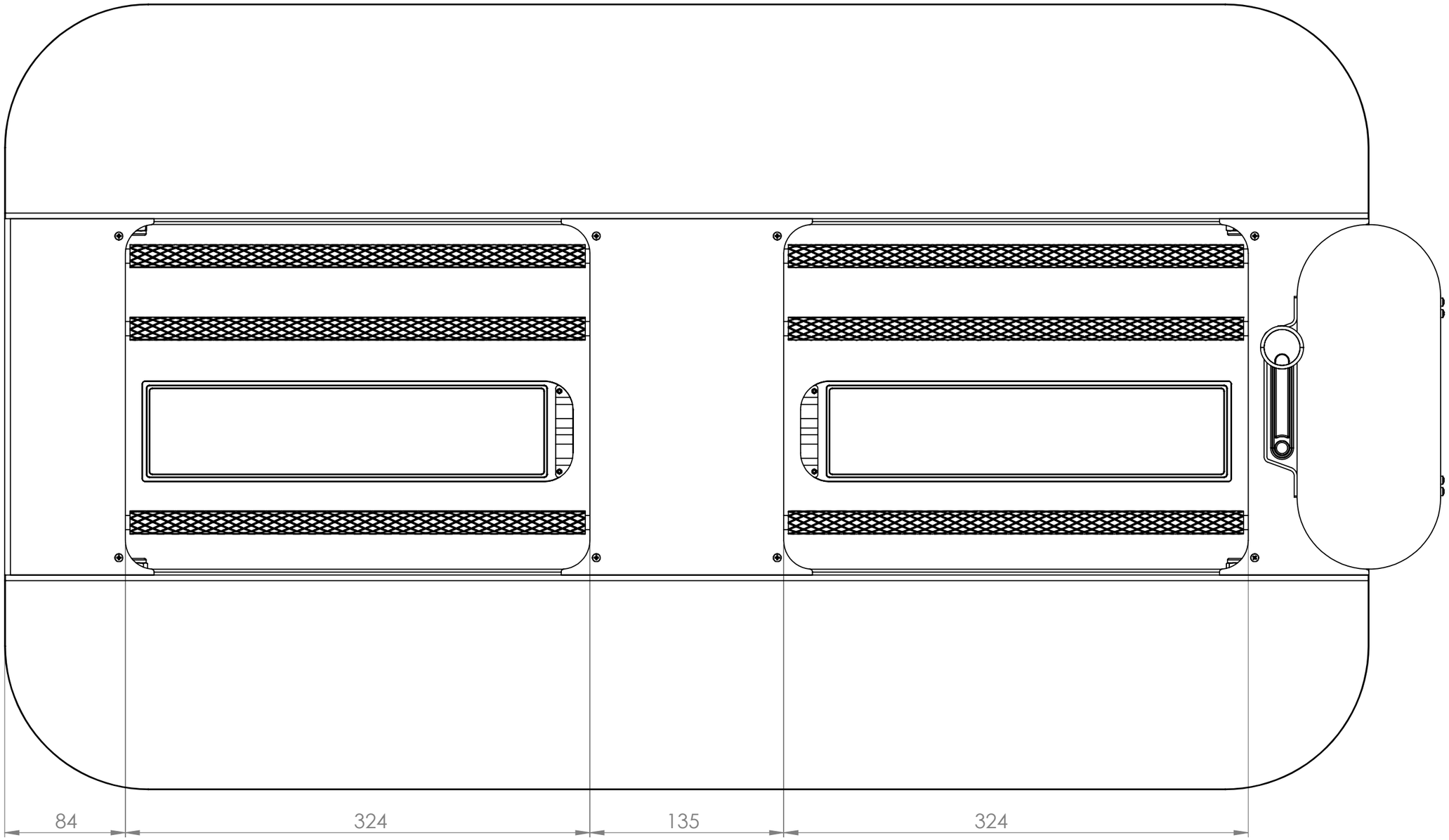
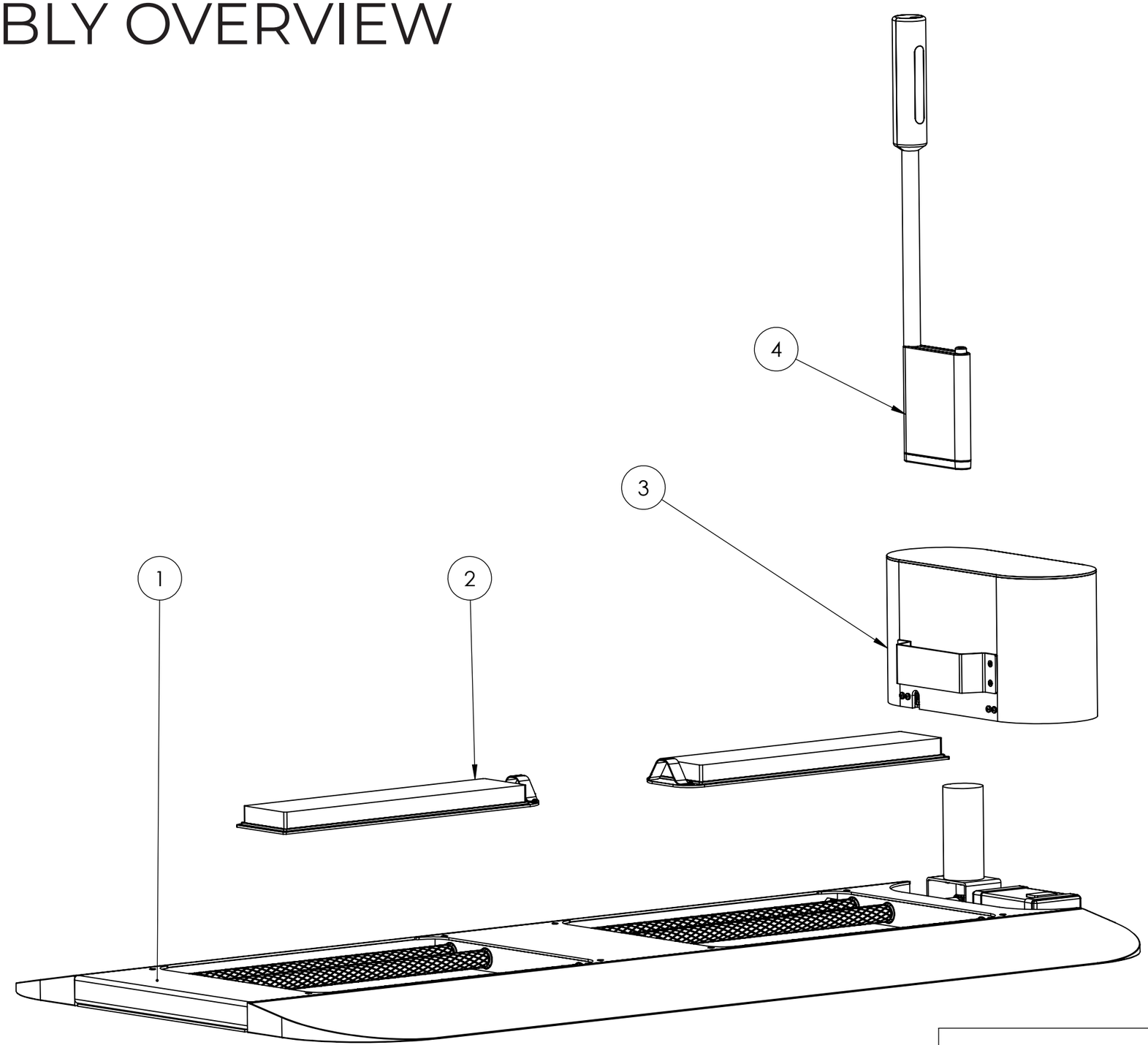
TOP VIEW



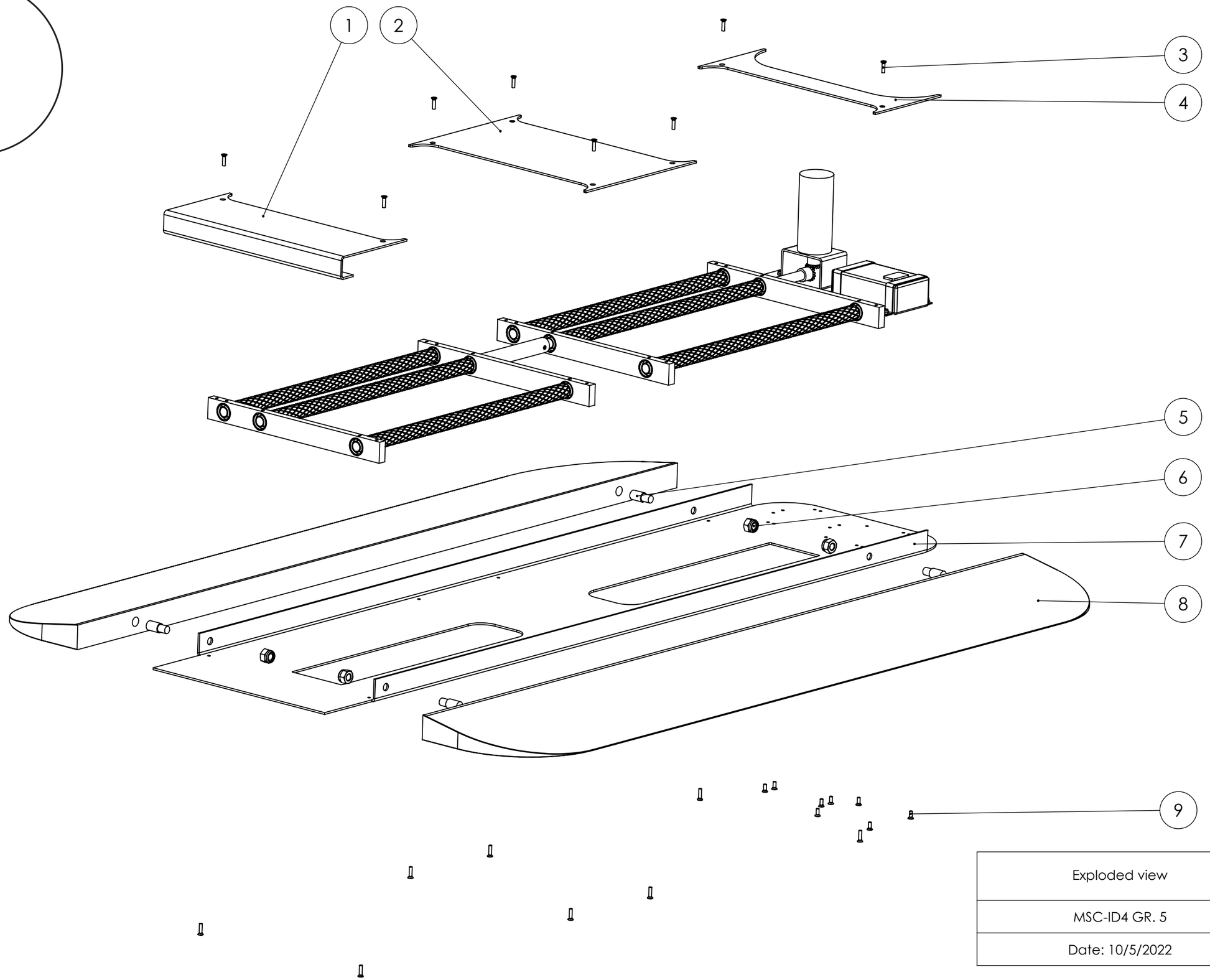
Top view	Product
MSC-ID4 GR. 5	Size A3
Date: 10/5/2022	Scale: 1:3

SUBASSEMBLY OVERVIEW



Exploded view	OVERVIEW
MSC-ID4 GR. 5	Size A3
Date: 10/5/2022	Scale: 1:4

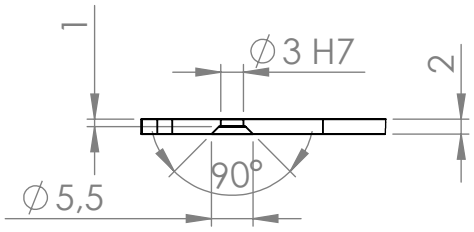
1A



Exploded view	Base (A)
MSC-ID4 GR. 5	Size A3
Date: 10/5/2022	Scale: 1:4

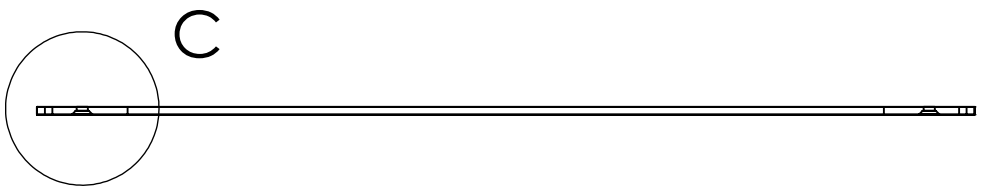
BILL OF MATERIALS

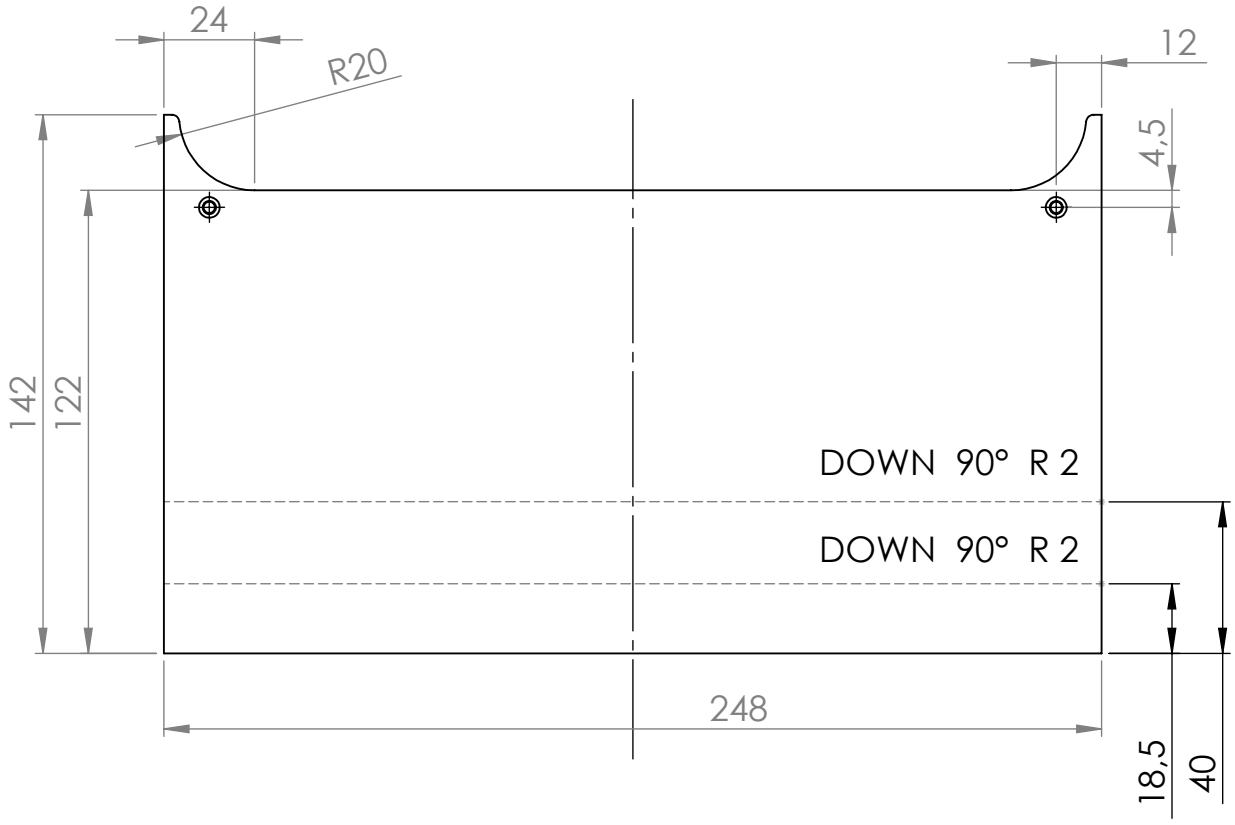
Nr.	Title	Qty	Material	Production	Surface treatment
1.	Left lid	1	Sheet metal (steel)	Cutting & bending & milling	Powder coating
2.	Middle lid	1	Sheet metal (steel)	Cutting & bending & milling	Powder coating
3.	ISO 7046-1-M3x12-Z-12N	16	-	-	-
4.	Right lid	1	Sheet metal (steel)	Cutting & bending & milling	Powder coating
5.	Thread inserts	4	-	-	-
6.	ISO 7040-M8-N	4	-	-	-
7.	Bottom base	1	Sheet metal (steel)	Cutting & bending & milling	Powder coating
8.	Ramp	2	Rubber	Moulding	-
9.	ISO 7046-1-M3x8-Z-8N	8	-	-	-



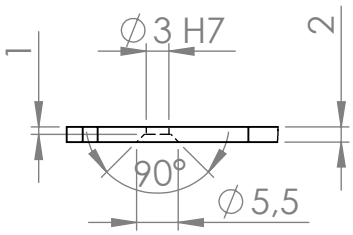
DETAIL C

SCALE 1 : 1



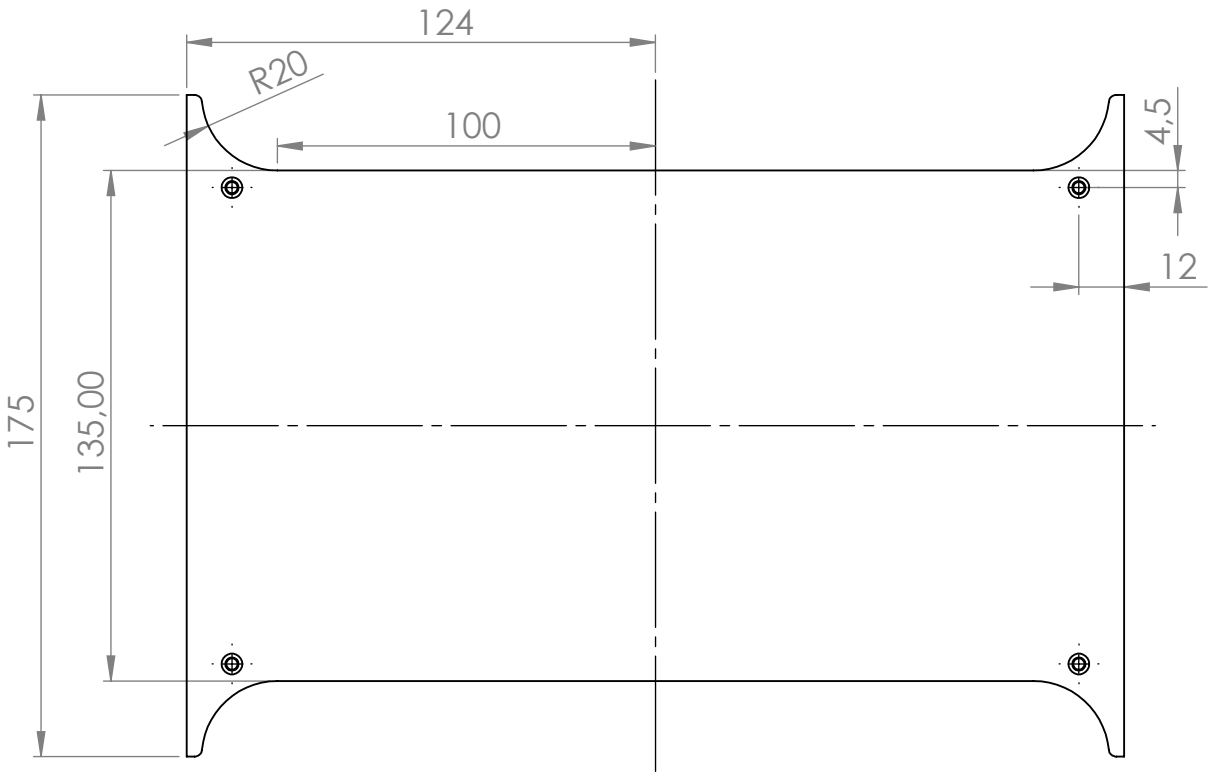


Titel: Left lid		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 1 (Assembly 1A)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Sheet metal		DATE: 10/5/2022	Scale: 1:2



DETAIL A

SCALE 1 : 1



Titel: Middle lid		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
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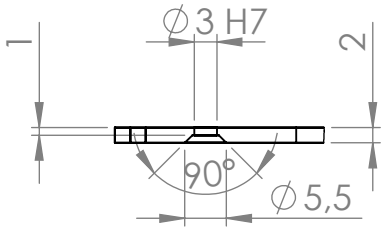
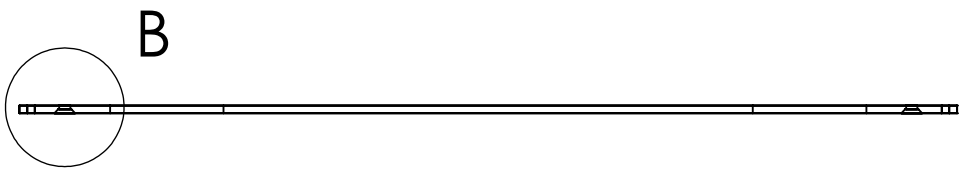
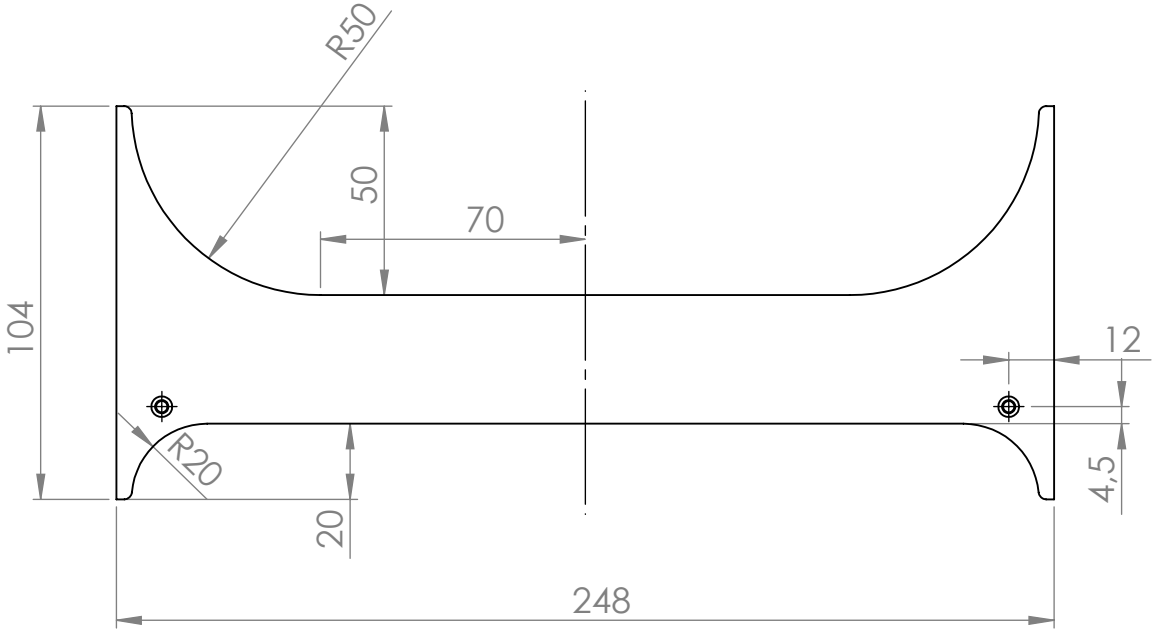
Material: Sheet metal		DATE: 10/5/2022	Scale: 1:2



DETAIL B

SCALE 1 : 1





Titel: Right lid		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
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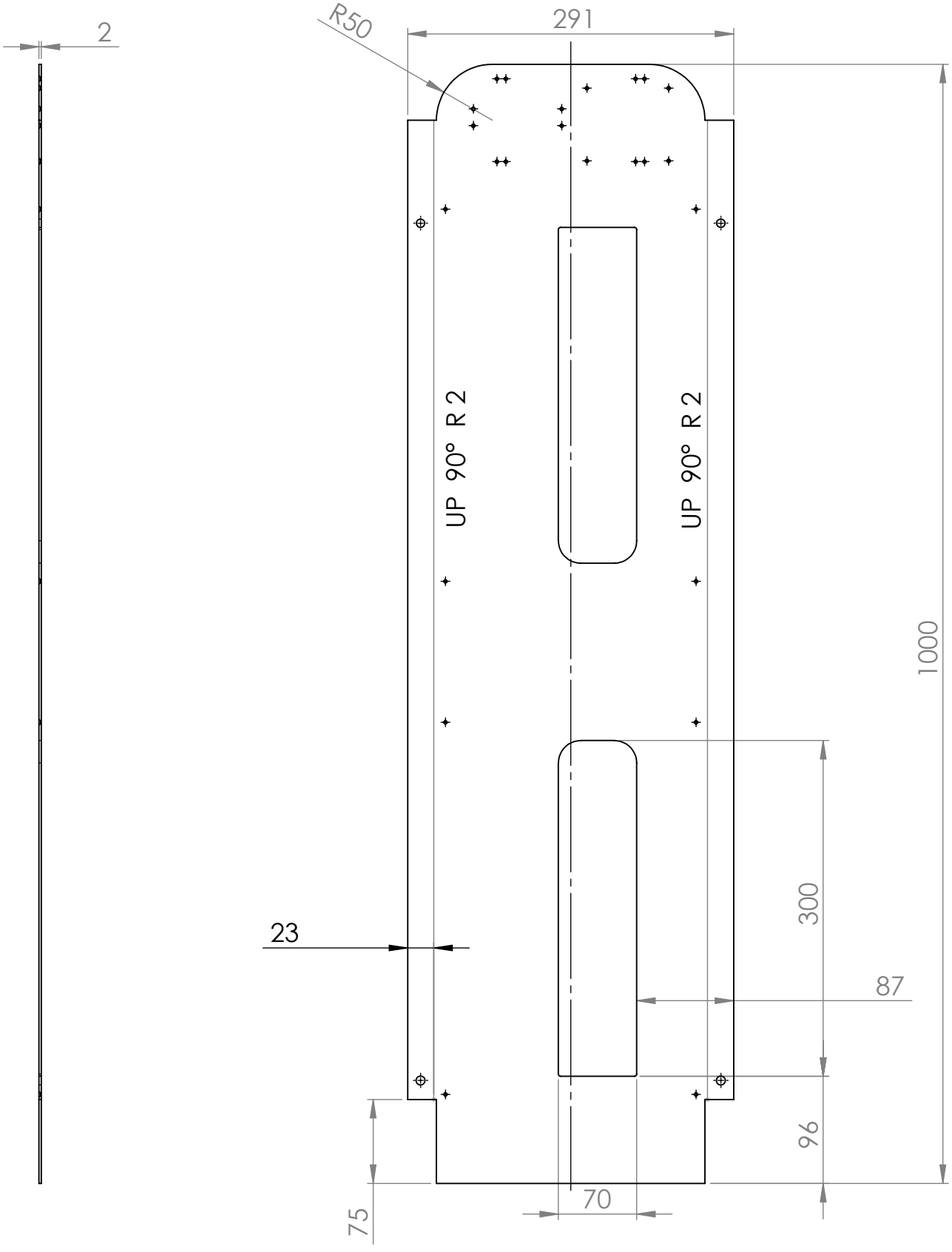

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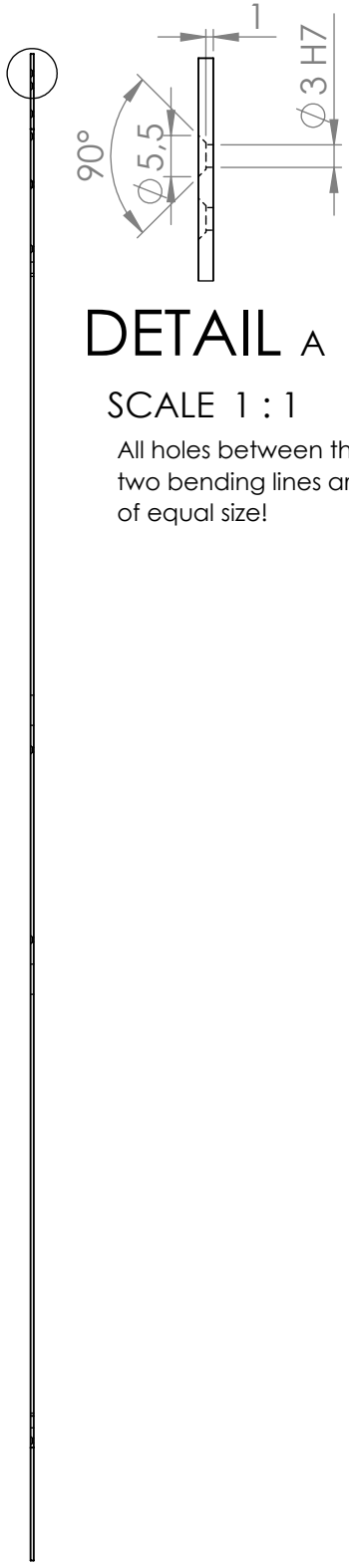
Material: Sheet metal		DATE: 10/5/2022	Scale: 1:5

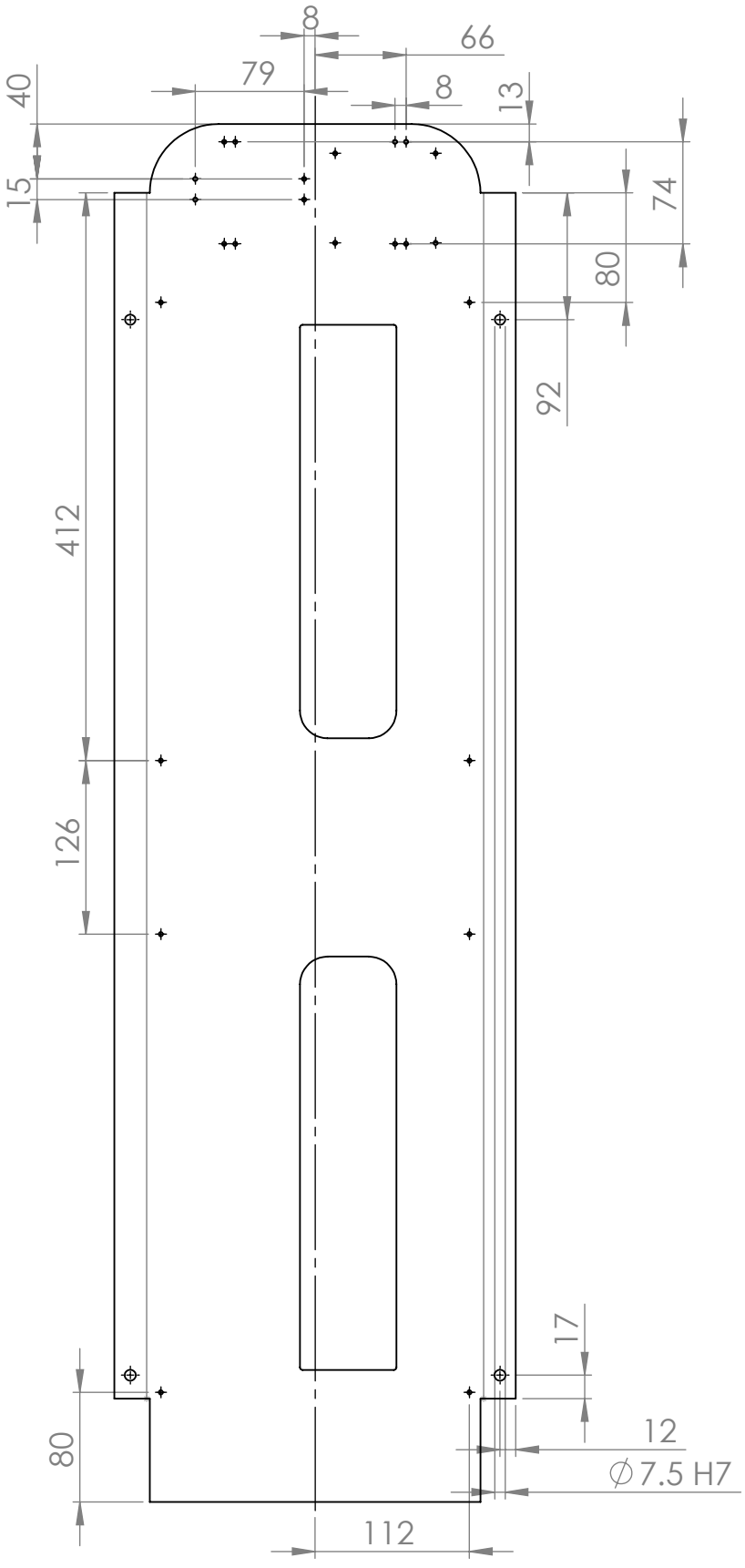
A



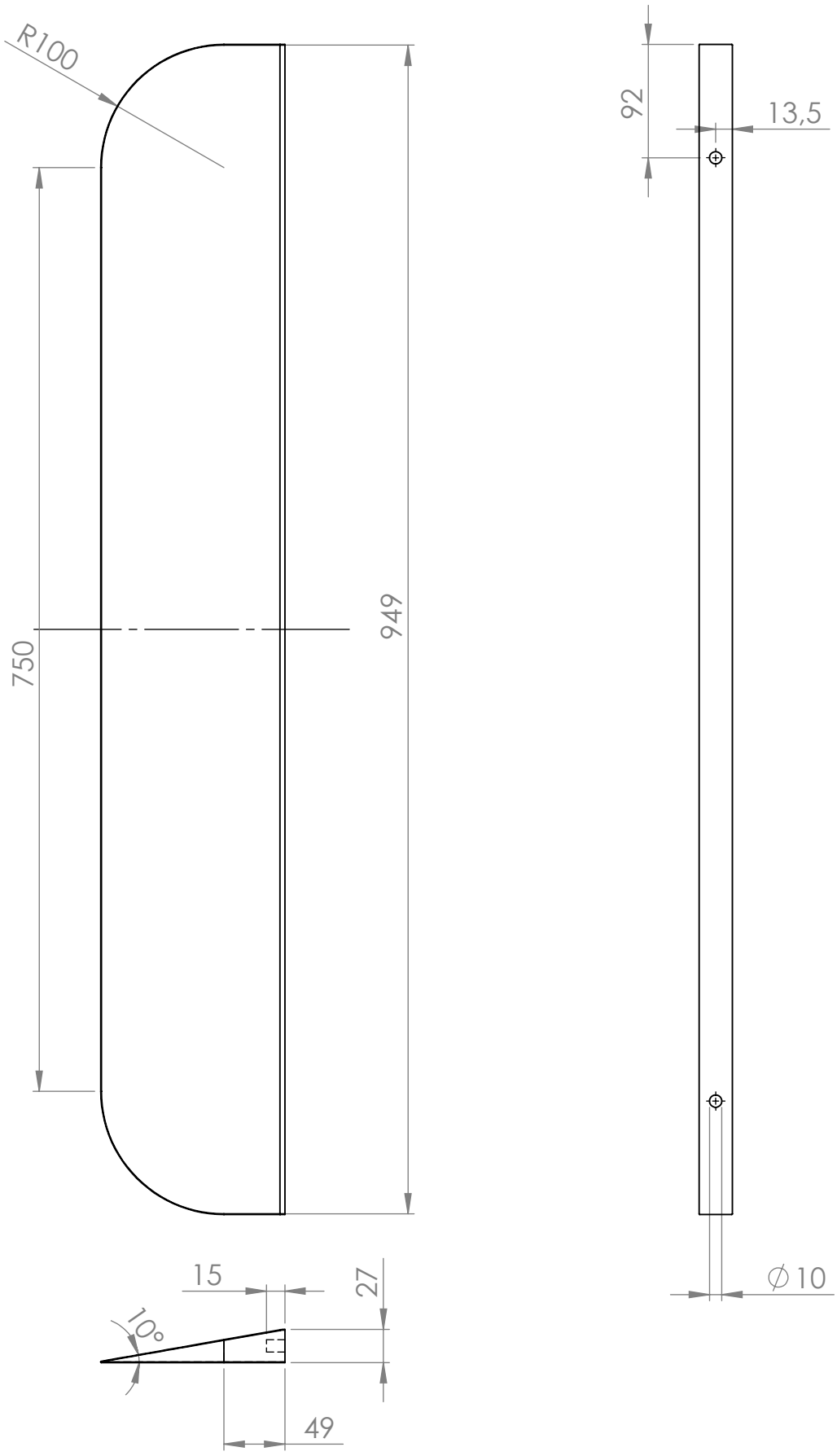
DETAIL A

SCALE 1 : 1

All holes between the two bending lines are of equal size!

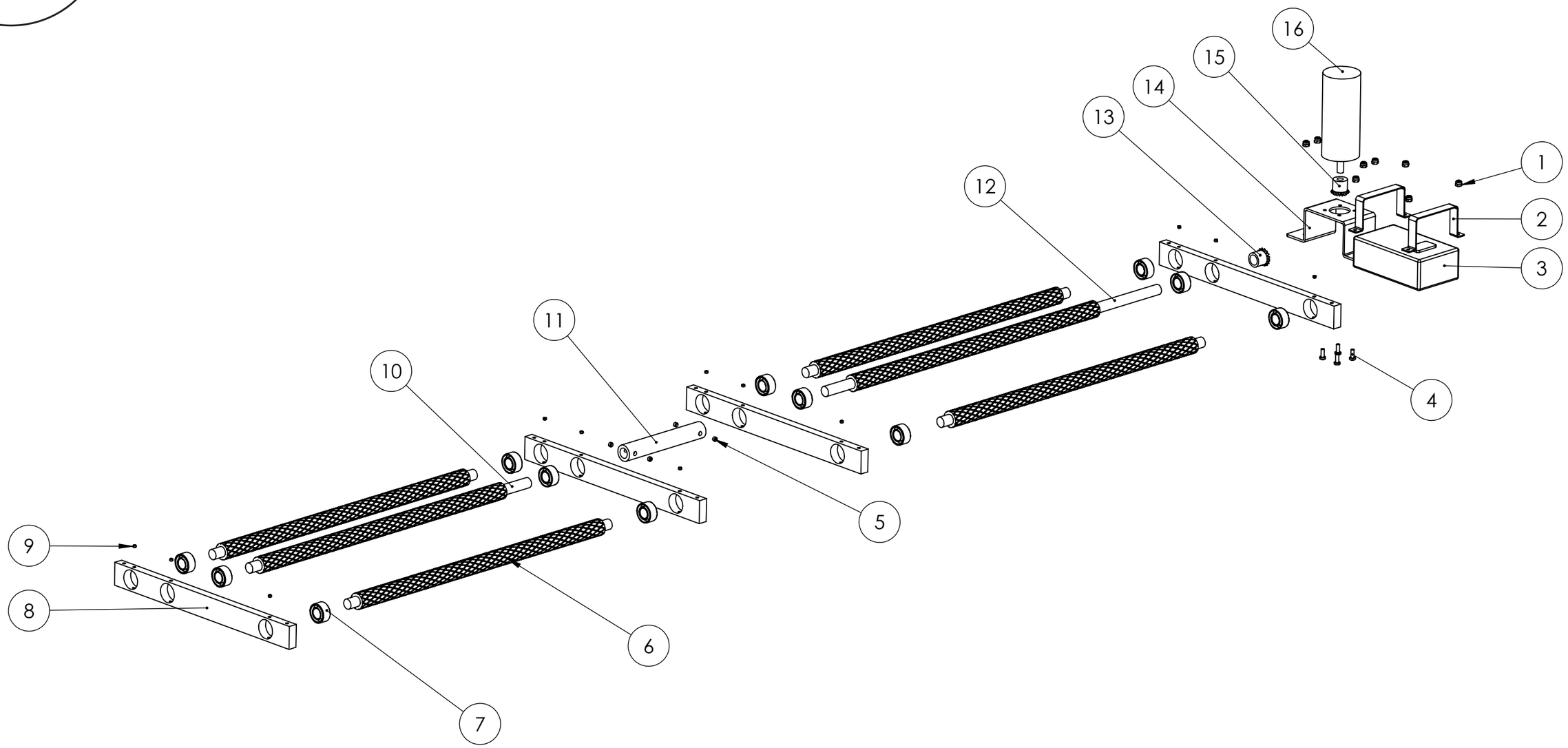


Titel: Buttom base (1b)		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 7 (Assembly 1A)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Sheet metal		DATE: 10/5/2022	Scale: 1:5



Titel: Ramp		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 8 (Assembly 1A)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Rubber		DATE: 10/5/2022	Scale: 1:5

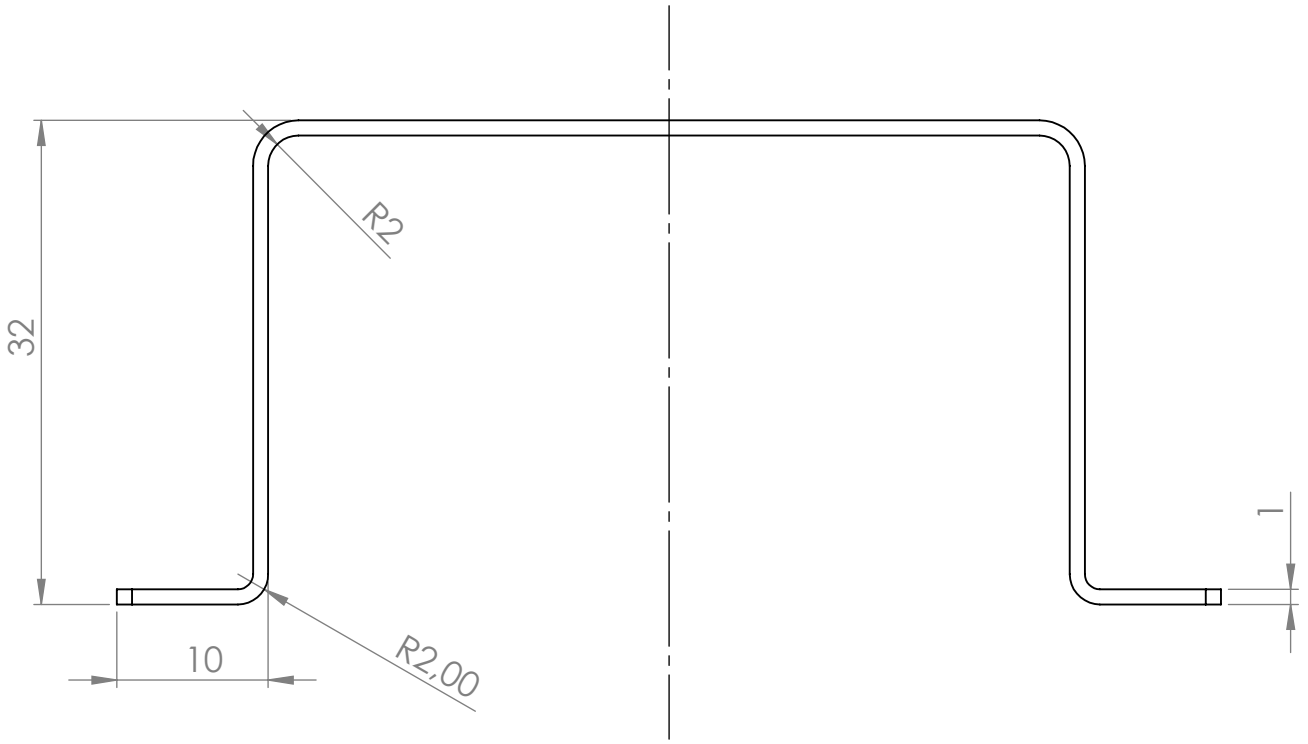
1B

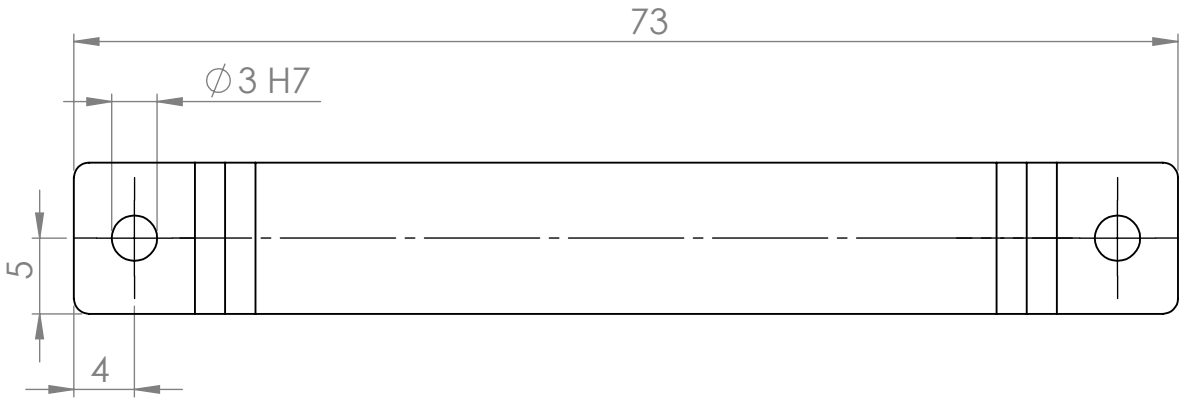


Exploded view	Base (B)
MSC-ID4 GR. 5	Size A3
Date: 10/5/2022	Scale: 1:4

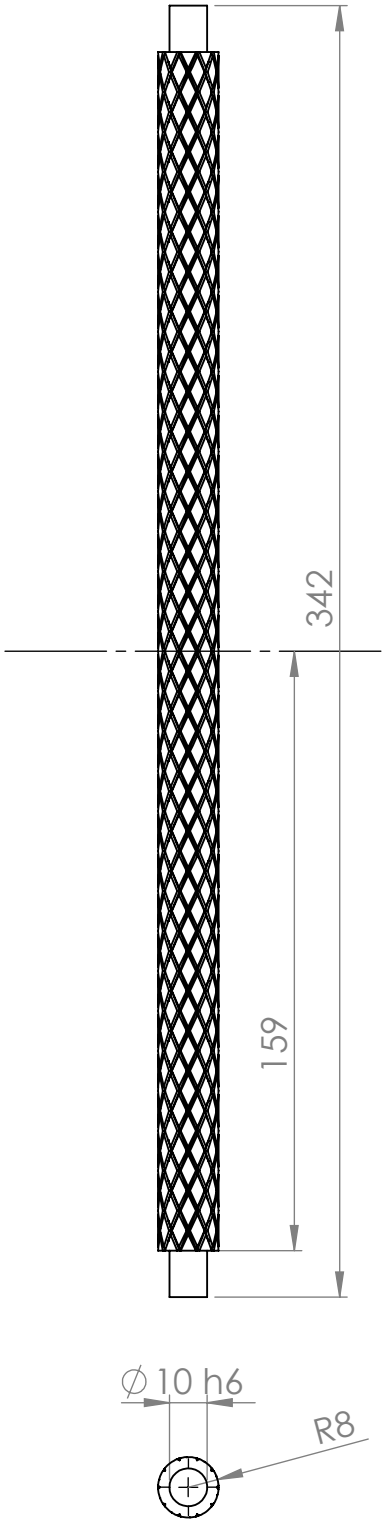
BILL OF MATERIALS

Nr.	Title	Qty	Material	Production	Surface treatment
1.	ISO 7040-M3-N	8	-	-	-
2.	Bracket for AC adapter	2	Sheet metal (steel)	Cutting & bending	-
3.	AC adapter + radio frequency receiver	1	-	-	-
4.	ISO 7045-M3x8-Z-8N	4	-	-	-
5.	ISO 4026-M4x-3-N	4	-	-	-
6.	Roller 1.	4	Stainless steel rod	Cutting & turning	-
7.	ISO 15 ABB-4810-14, SI, NC, 14_68	12	-	-	-
8.	Roller support	4	Stainless steel bar	Cutting & milling	-
9.	ISO 4026-M3x2-N	12	-	-	-
10.	Roller 2.	1	Stainless steel rod	Cutting & turning	-
11.	Roller connecter	1	Steel pipe	Cutting & milling	-
12.	Roller 3.	1	Stainless steel rod	Cutting & turning	-
13.	ISO - Straight miter gear IM16T 20PA 3FW --- 16O14H20MD10.0N	1	-	-	-
14.	Motor bracket	1	Sheet metal (steel)	Cutting & bending	-
15.	ISO - Straight miter gear IM16T 20PA 3FW --- 16O14H20MD6.0N	1	-	-	-
16	Motor	1	-	-	-

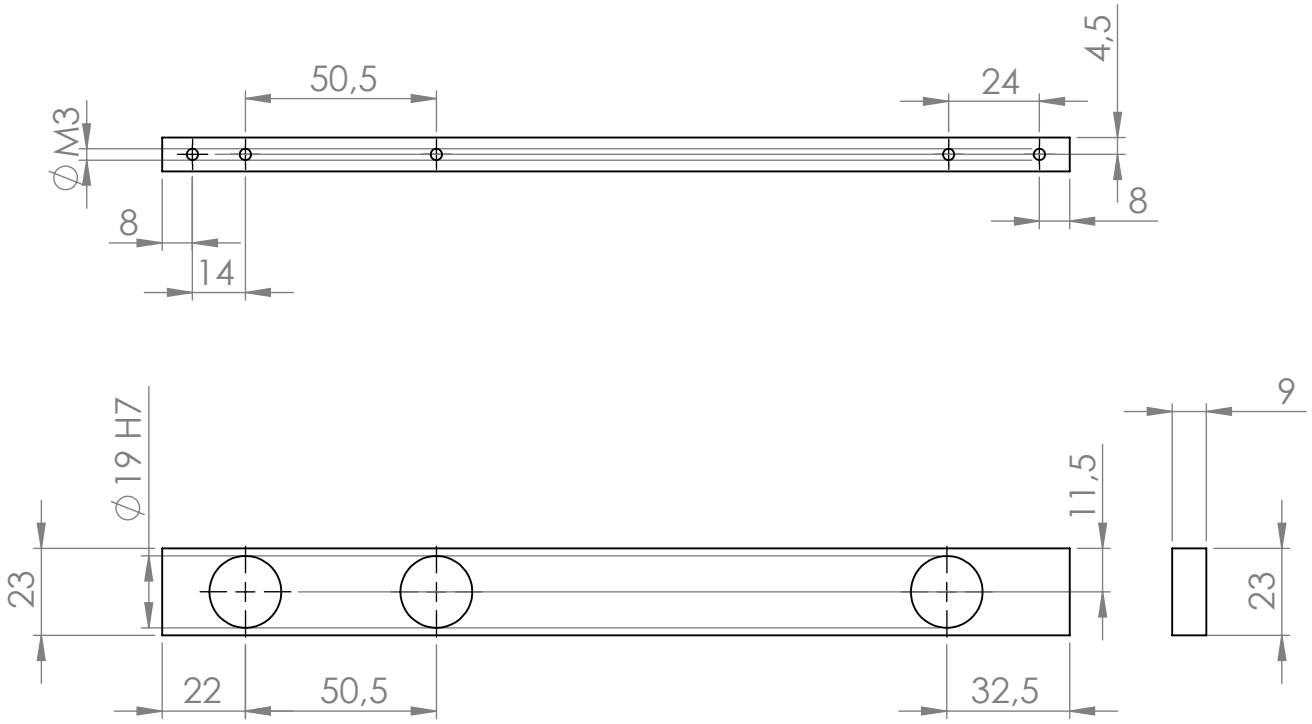




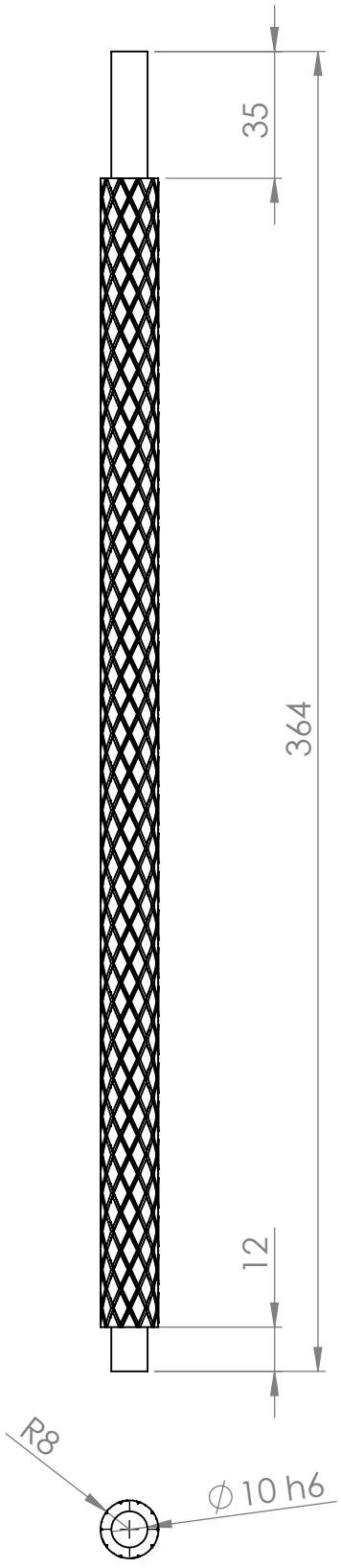
Titel: Bracket for AC adapter		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 2 (Assembly 1B)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Sheet metal		DATE: 10/5/2022	Scale: 2:1



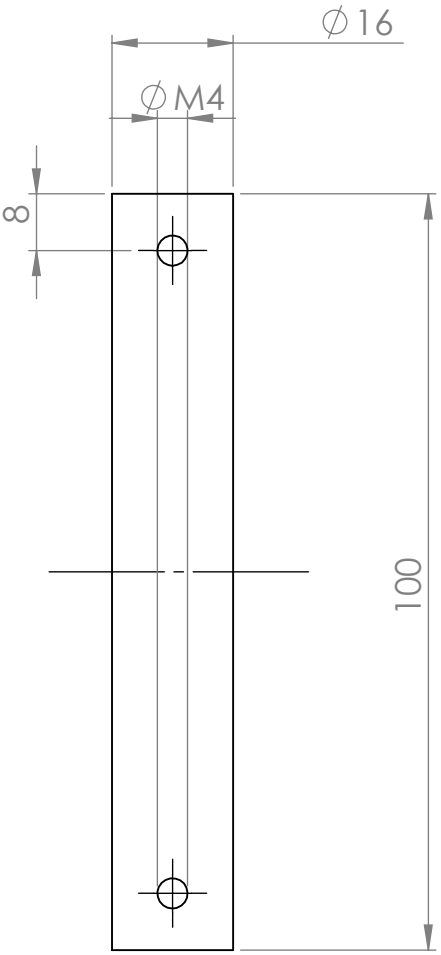
Titel: Roller 1.		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 6 (Assembly 1B)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Stainless steel		DATE: 10/5/2022	Scale: 1:2

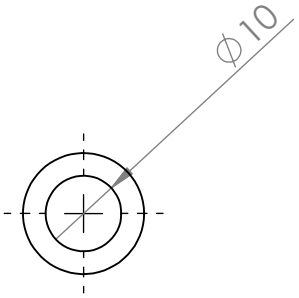


Titel: Roller support		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 8 (Assembly 1B)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Stainless steel		DATE: 10/5/2022	Scale: 1:2

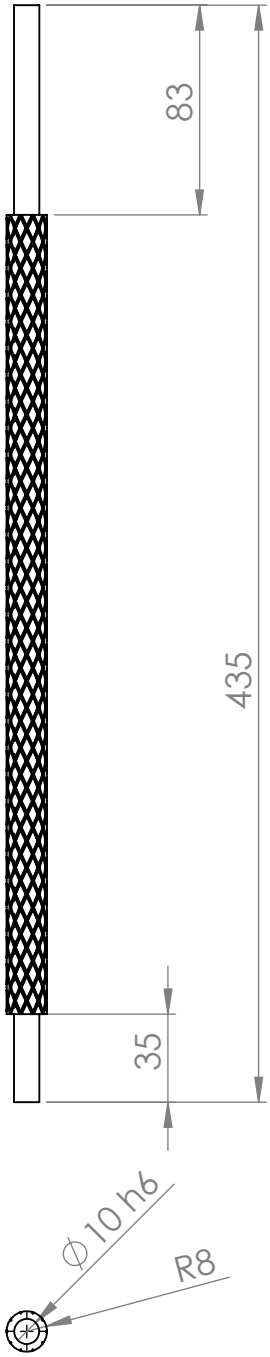


Titel: Roller 2.		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 10 (Assembly 1B)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Stainless steel		DATE: 10/5/2022	Scale: 1:2

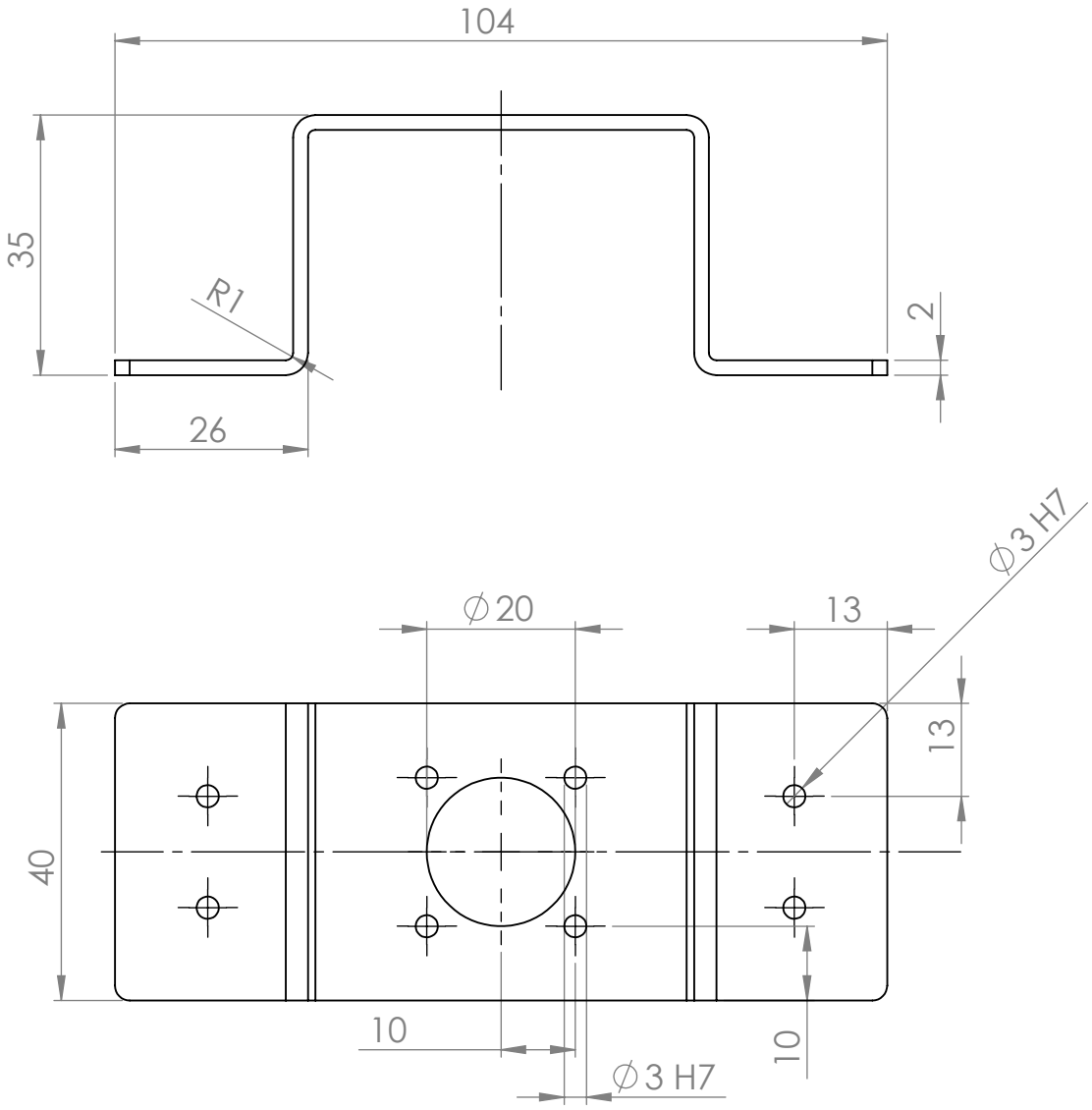




Titel: Roller connecter		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 11 (Assembly 1B)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Steel		DATE: 10/5/2022	Scale: 1:1

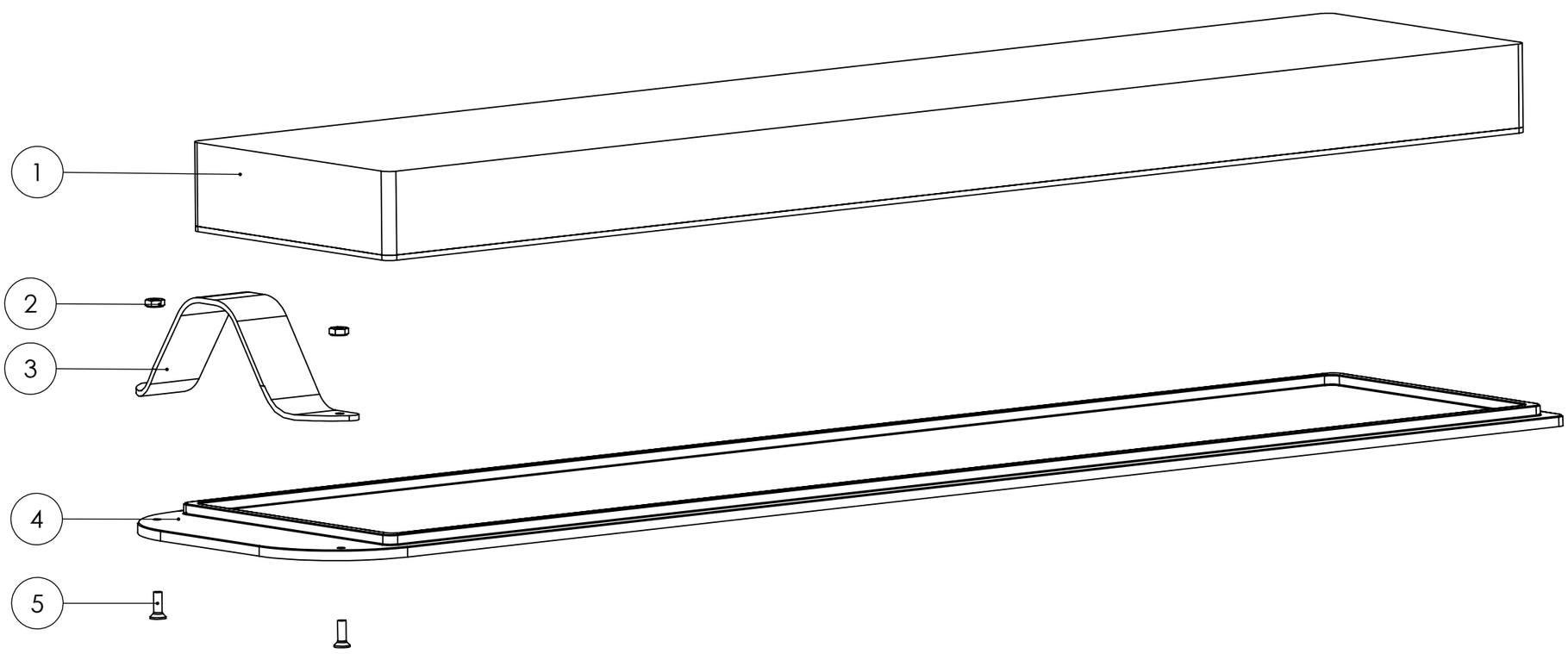


Titel: Roller 3.		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 12 (Assembly 1B)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Stainless steel		DATE: 10/5/2022	Scale: 1:3



Titel: Motor bracket		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 14 (Assembly 1B)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Sheet metal		DATE: 10/5/2022	Scale: 1:1

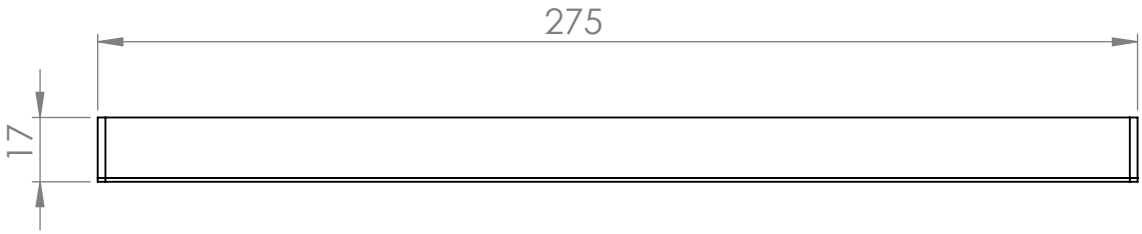
2



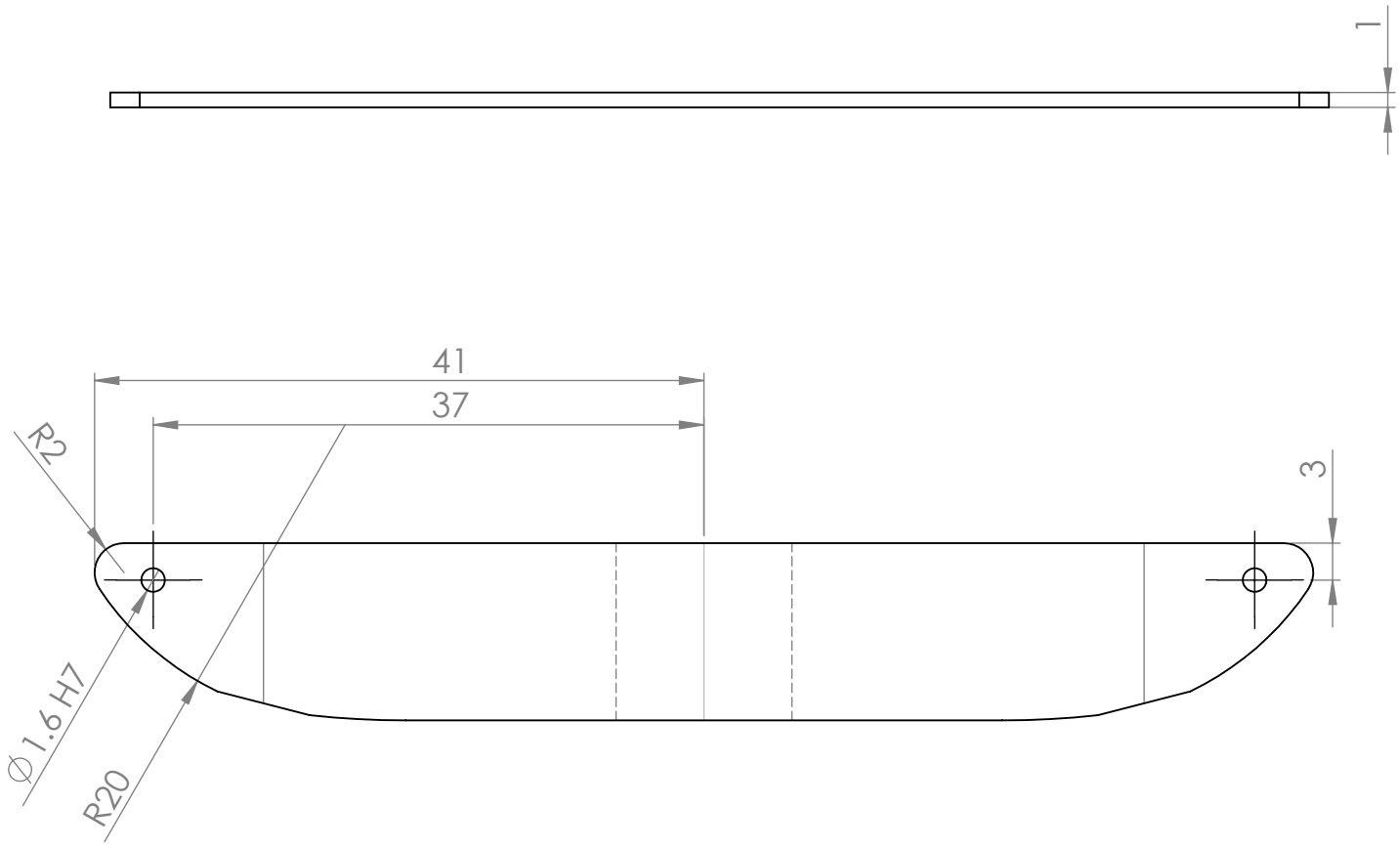
Exploded view	Brush
MSC-ID4 GR. 5	Size A3
Date: 10/5/2022	Scale: 1:1

BILL OF MATERIALS

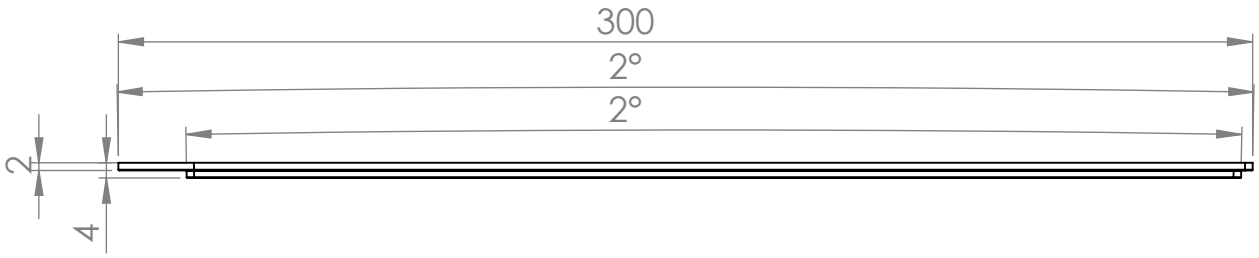
Nr.	Title	Qty	Material	Production	Surface treatment
1.	Brush hair	2	Hard brush (ABS)	-	-
2.	ISO-4032-M1.6-W-N	4	-	-	-
3.	Brush handle	2	Rubber	Cutting	-
4.	Brush plate	2	ABS	Injection moulding	-
5.	ISO 7046-1-M1.6x5-Z-5N	4	-	-	-

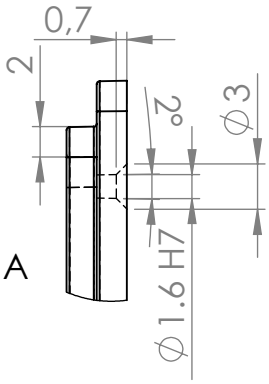


Titel: Brush hair		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 1 (Assembly 2)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Hard brush (ABS)		DATE: 10/5/2022	Scale: 1:2



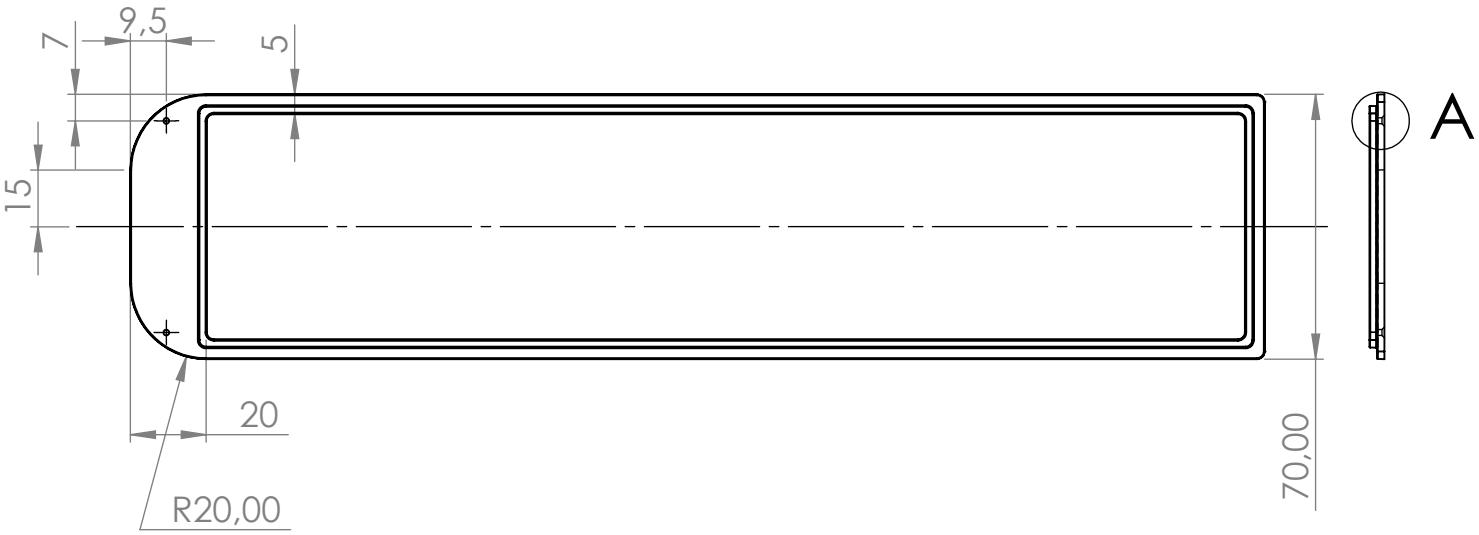
Titel: Brush handle		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 3 (Assembly 2)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Rubber		DATE: 10/5/2022	Scale: 2:1





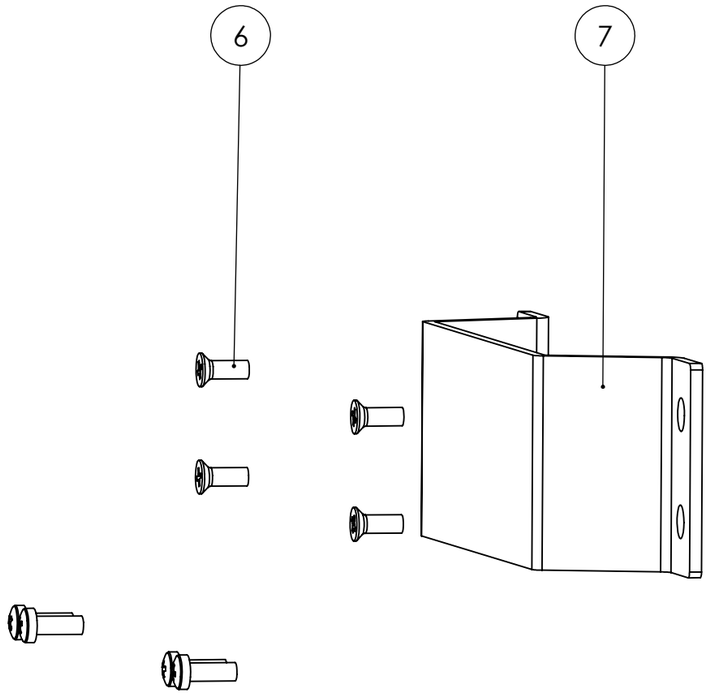
DETAIL A

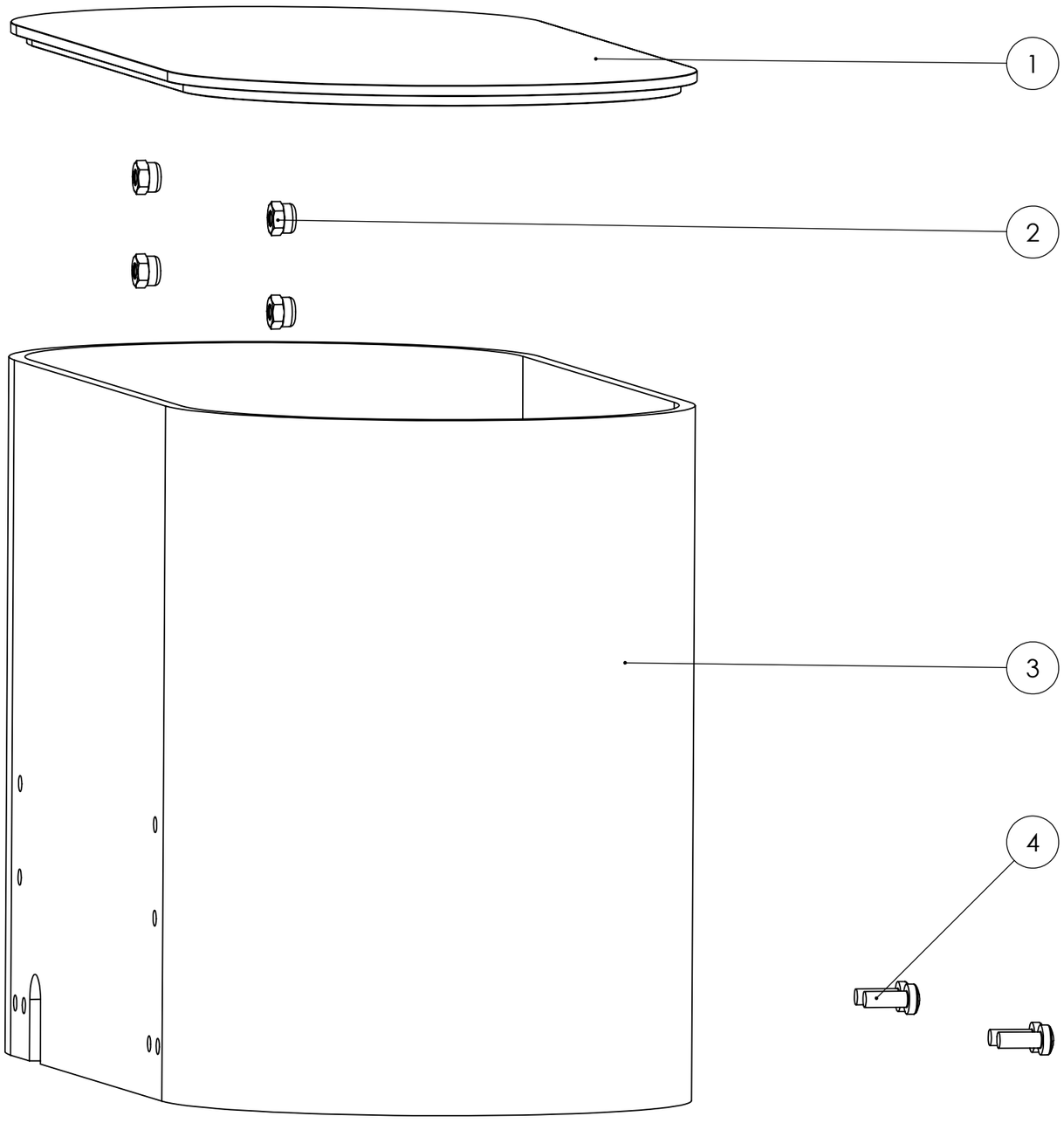
SCALE 2 : 1

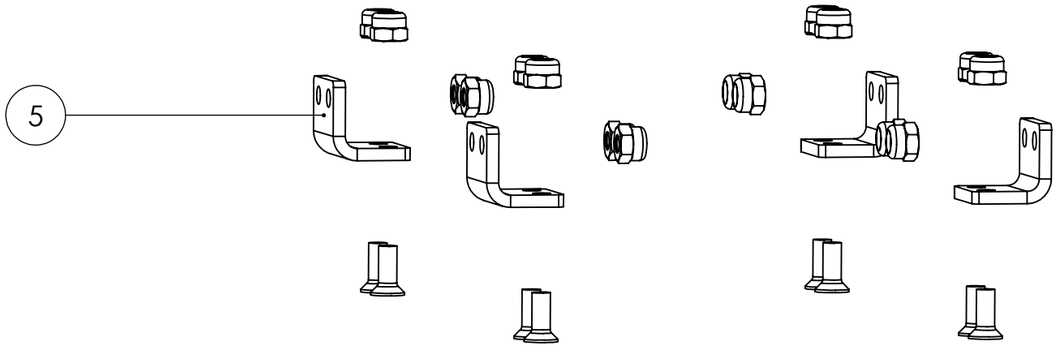


Titel: Brush plate		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 4 (Assembly 2)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: ABS		DATE: 10/5/2022	Scale: 1:2

3



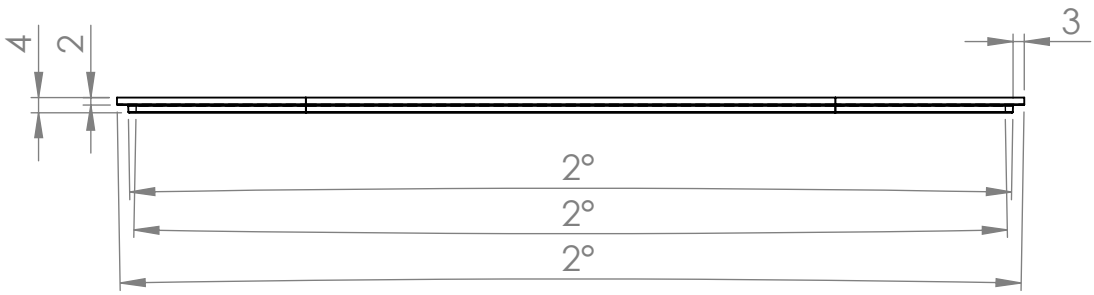




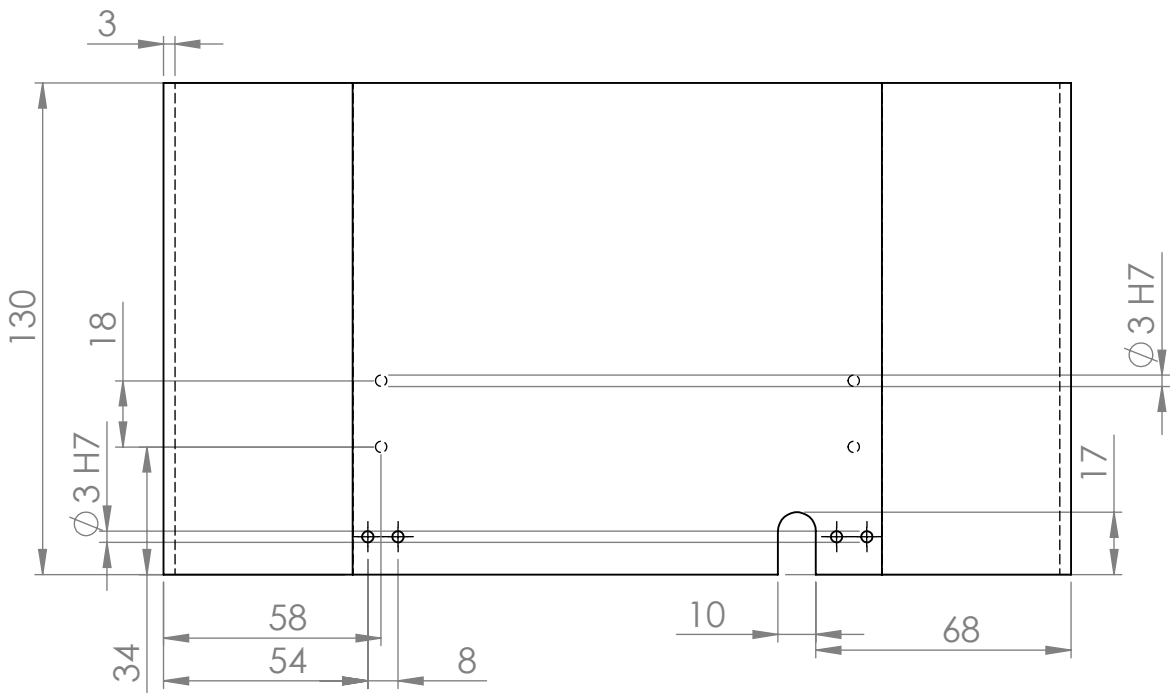
Exploded view	Motor housing
MSC-ID4 GR. 5	Size A3
Date: 10/5/2022	Scale: 1:1

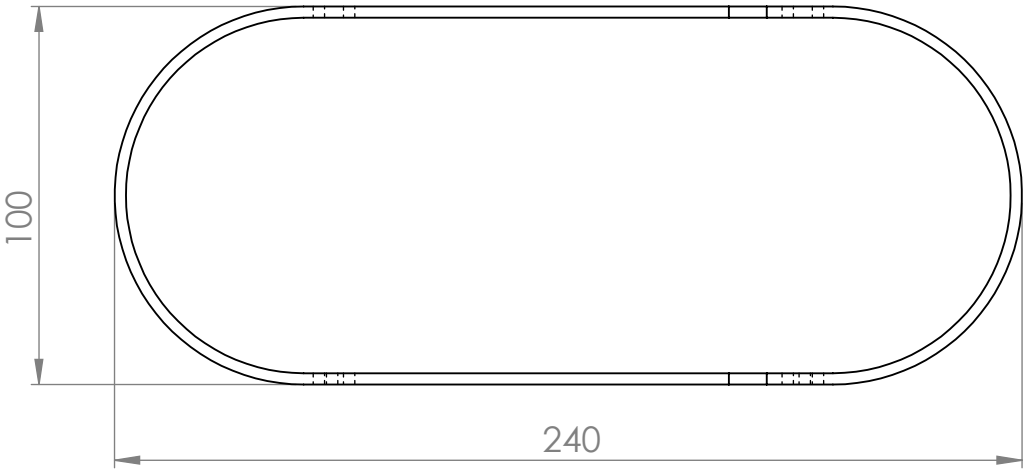
BILL OF MATERIALS

Nr.	Title	Qty	Material	Production	Surface treatment
1.	Top lid	1	ABS	Injection moulding	-
2.	ISO 7040-M3-N	20	-	-	-
3.	Housing	1	ABS	Extrusion & cutting & milling	-
4.	ISO 7045-M3x8-Z-8N	8	-	-	-
5.	L-bracket	4	Sheet metal (steel)	Cutting & bending	-
6.	ISO 7046-1-M3x8-Z-8N	12	-	-	-
7.	Handheld device holder	1	ABS	Injection moulding	-

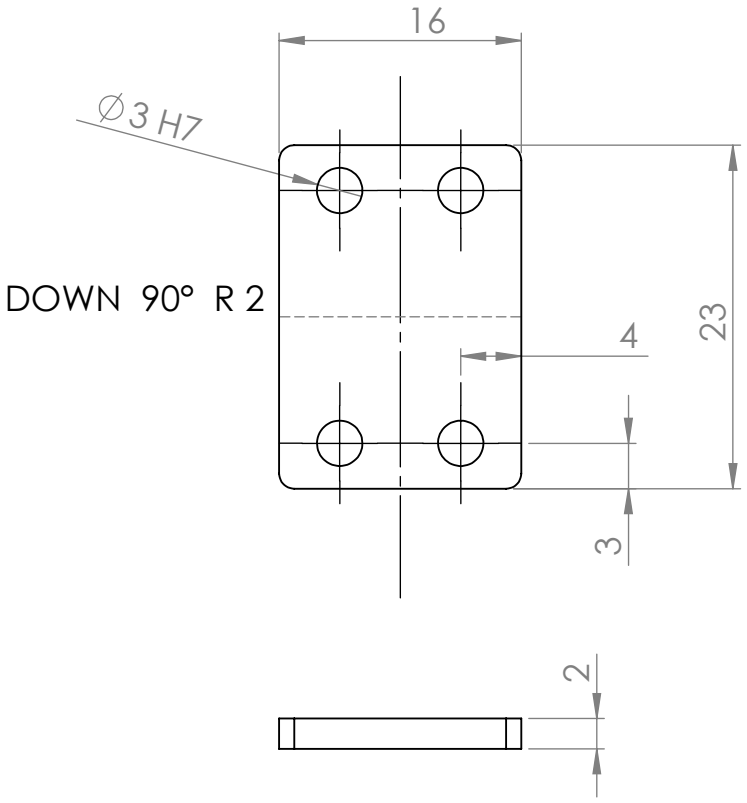


Titel: Top lid		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 1 (Assembly 3)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: ABS		DATE: 10/5/2022	Scale: 1:2

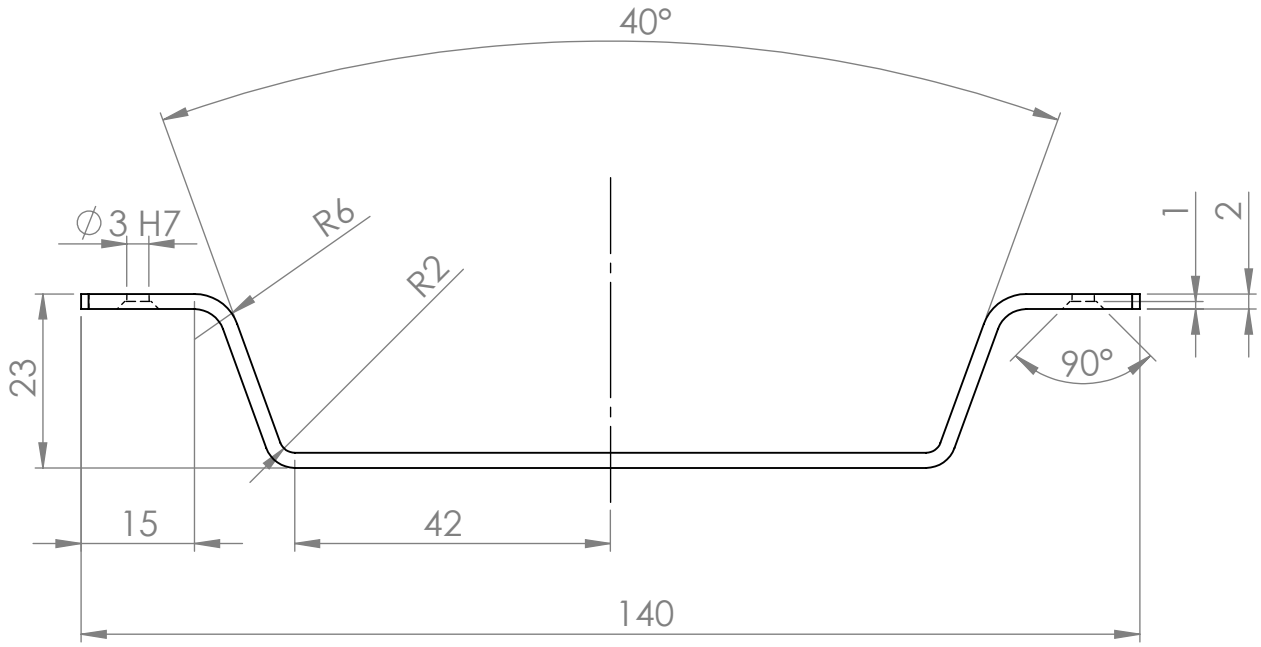


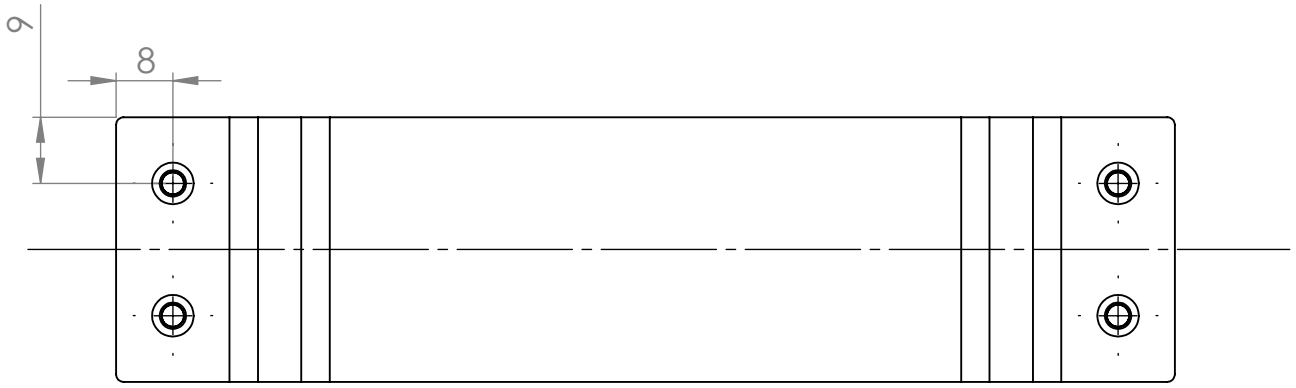


Titel: Housing		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 3 (Assembly 3)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: ABS		DATE: 10/5/2022	Scale: 1:2



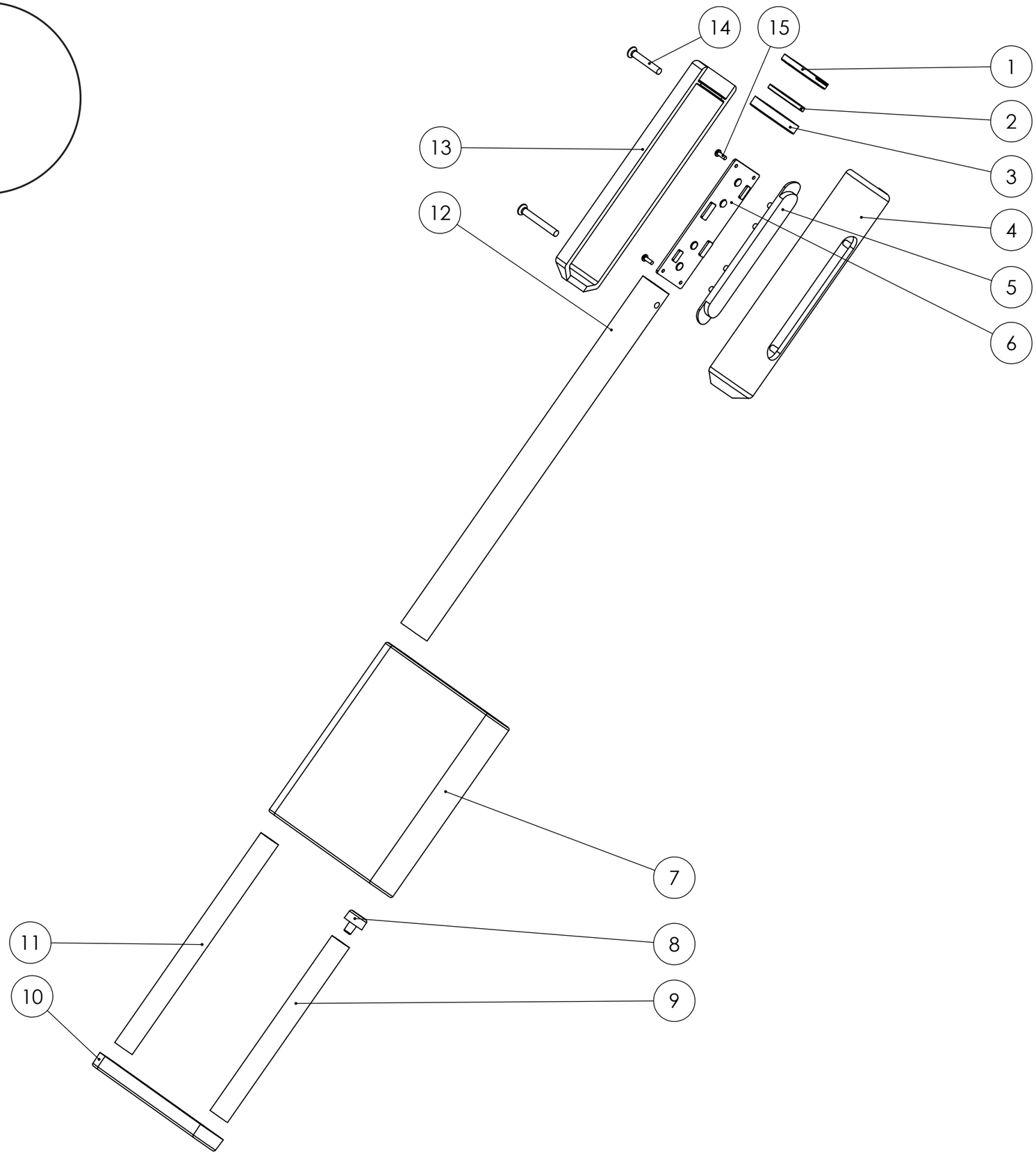
Titel: L-bracket		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 5 (Assembly 3)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Sheet metal		DATE: 10/5/2022	Scale: 2:1





Titel: Handheld device holder		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 7 (Assembly 3)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: ABS		DATE: 10/5/2022	Scale: 1:1

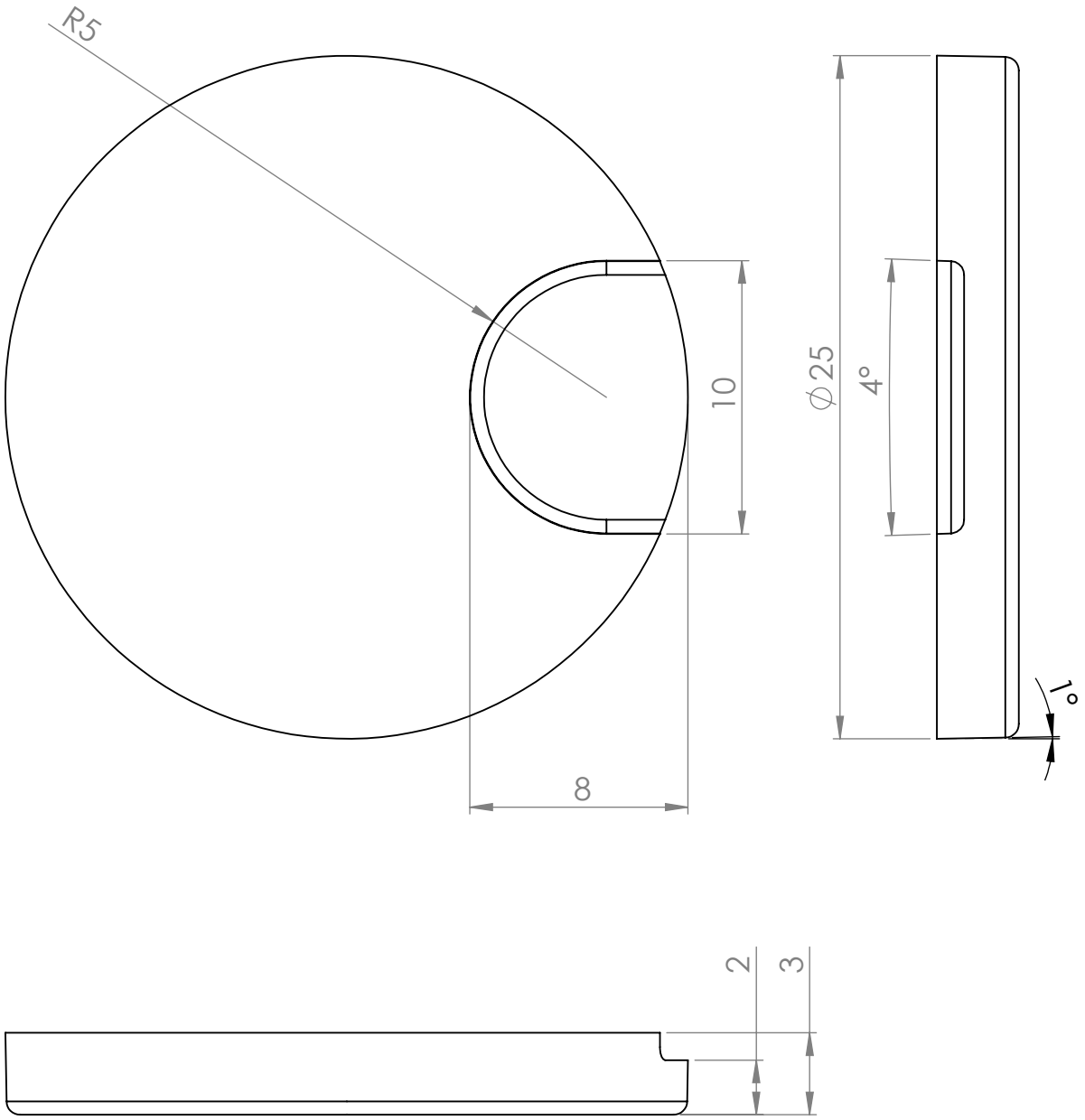
4



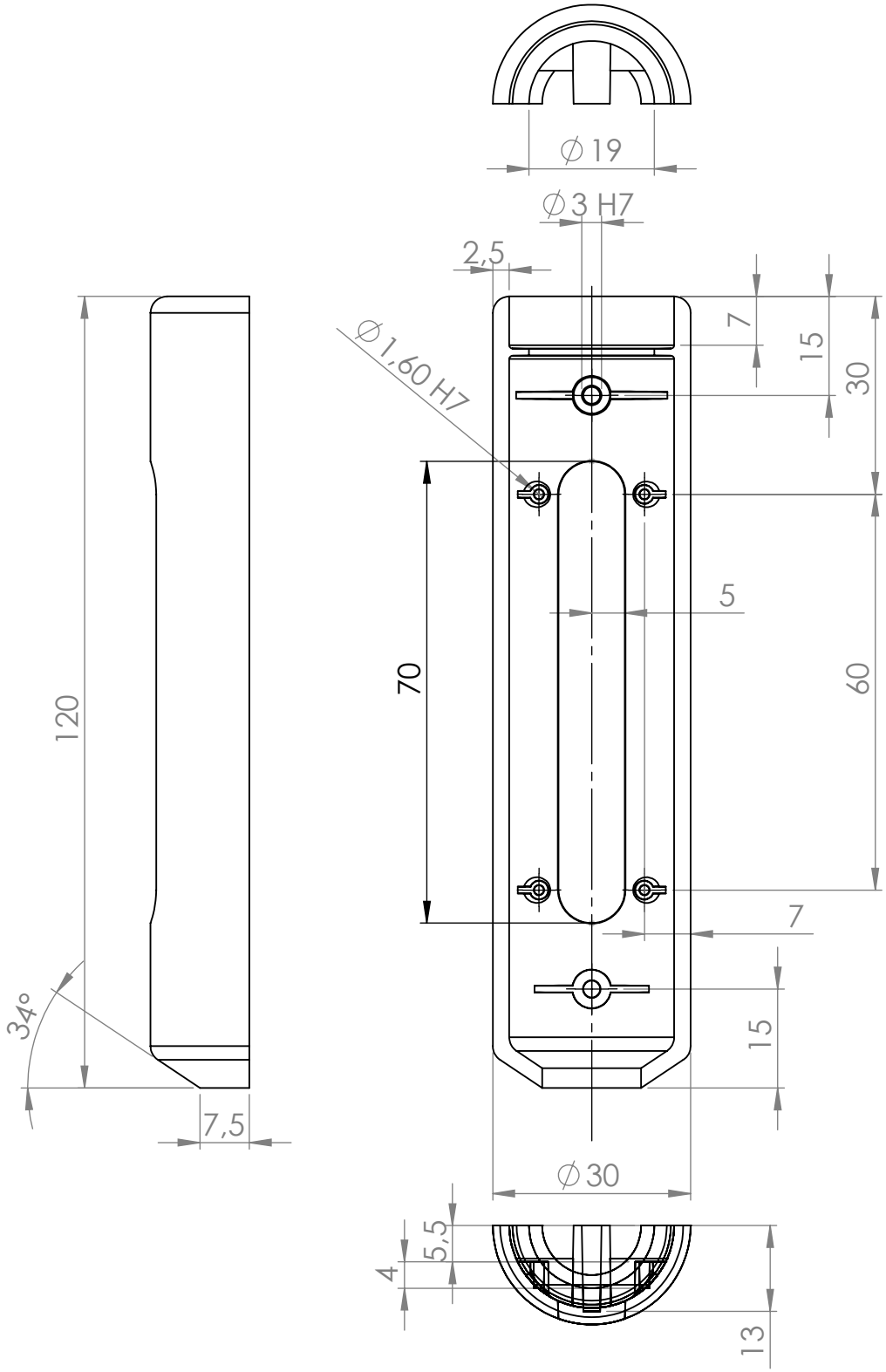
Exploded view	Handheld
MSC-ID4 GR. 5	Size A3
Date: 10/5/2022	Scale: 1:2

BILL OF MATERIALS

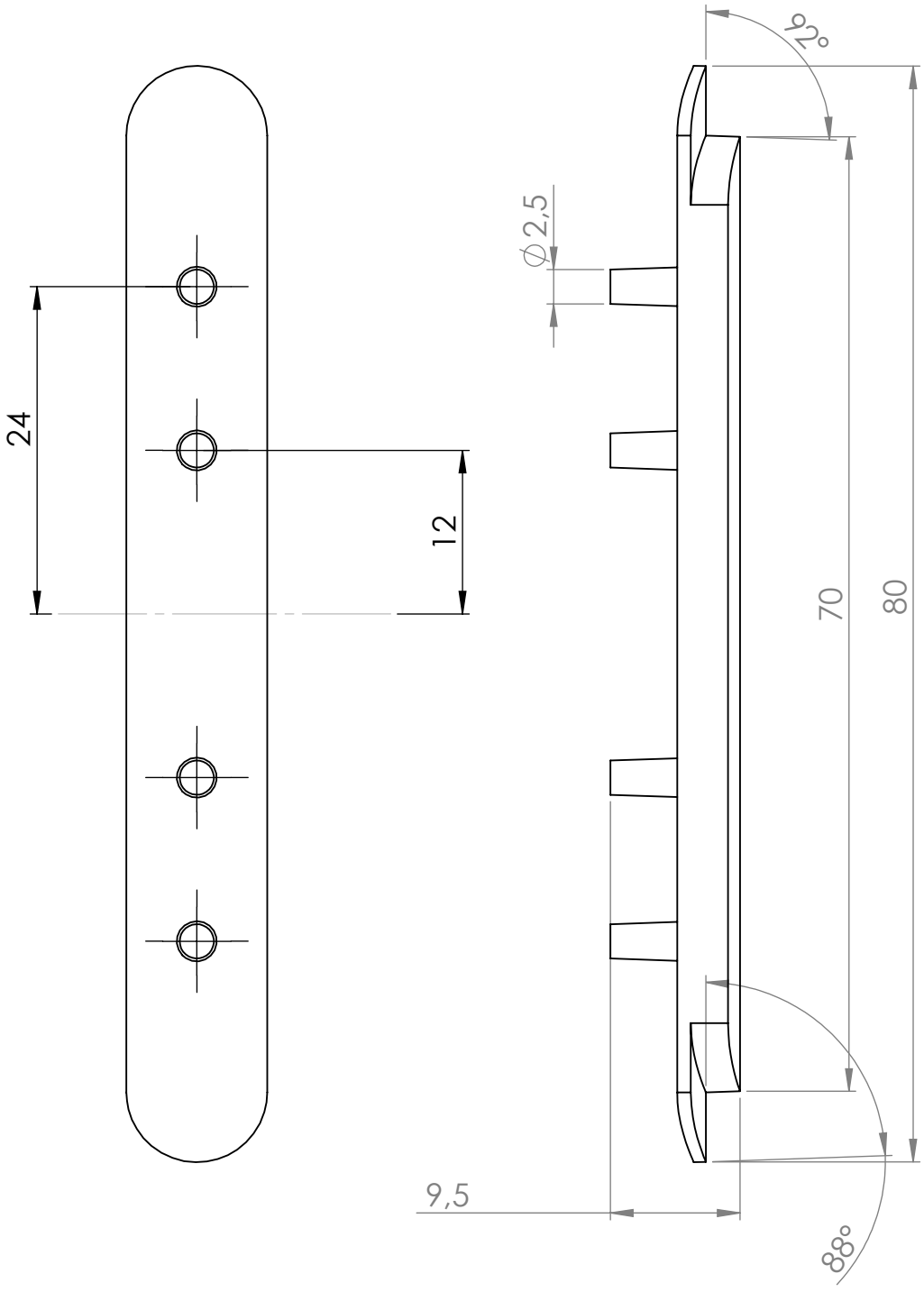
Nr.	Title	Qty	Material	Production	Surface treatment
1.	Handle end cap	1	ABS	Injection moulding	-
2.	Battery	1	-	-	-
3.	Battery mount	1	ABS	Injection moulding	-
4.	Handle part 1.	1	ABS	Injection moulding	-
5.	Push button	1	ABS	Injection moulding	-
6.	PCB & radio frequency	1	-	-	-
7.	Cloth	1	Cotton	-	-
8.	End cap cylinder	1	ABS	Injection moulding	-
9.	Cylinder (small)	1	ABS	Extrusion & cutting	-
10.	Cylinder (connecter)	1	ABS	Injection moulding	-
11.	Cylinder (medium)	1	ABS	Extrusion & cutting	-
12.	Cylinder (big)	1	ABS	Extrusion & cutting & milling	-
13.	Handle part 2.	1	ABS	Injection moulding	-
14.	ISO 7046-1-M3x20-z-20N	2	-	-	-
15.	ISO 7045-M1.6x5-z-5N	4	-	-	-

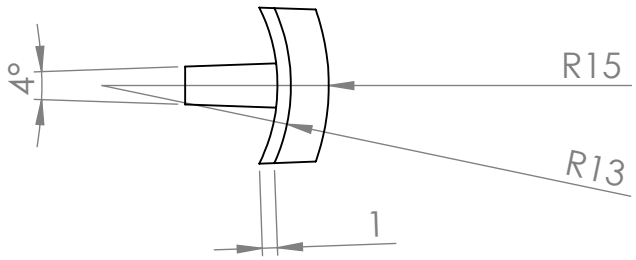


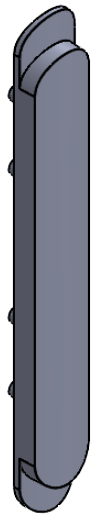
Titel: Handle end cap		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 1(Assemlby 4)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: ABS		DATE: 10/5/2022	Scale: 4:1



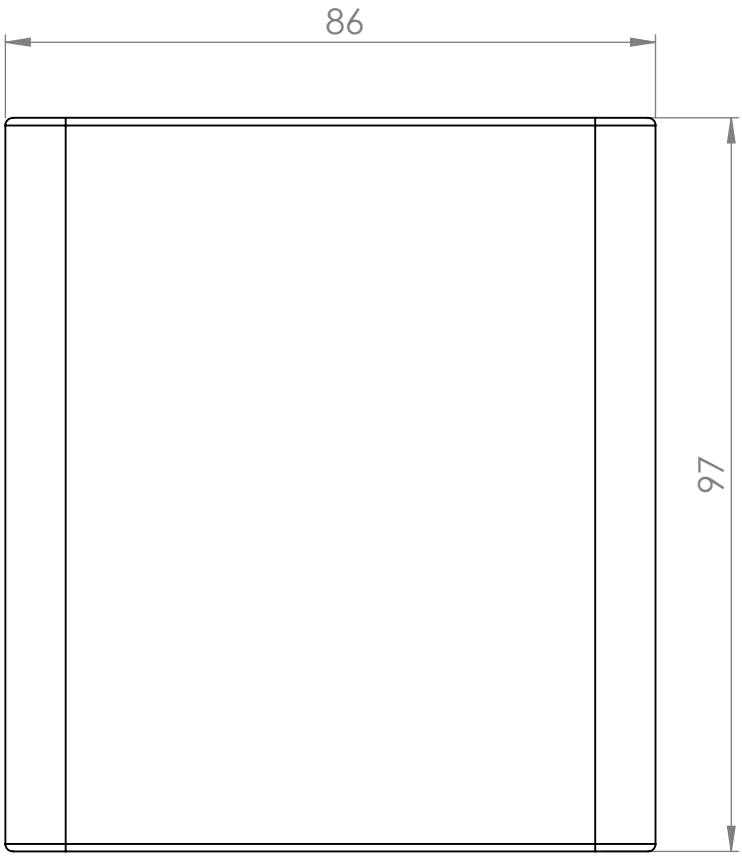
Titel: Handle part 1.		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 4 (Assembly 4)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: ABS		DATE: 10/5/2022	Scale: 1:1

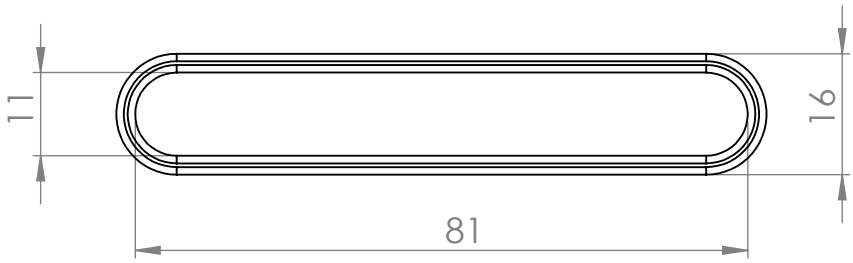




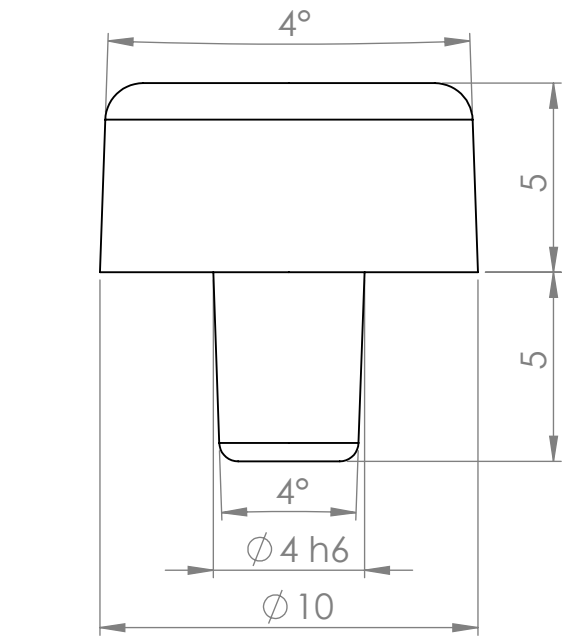


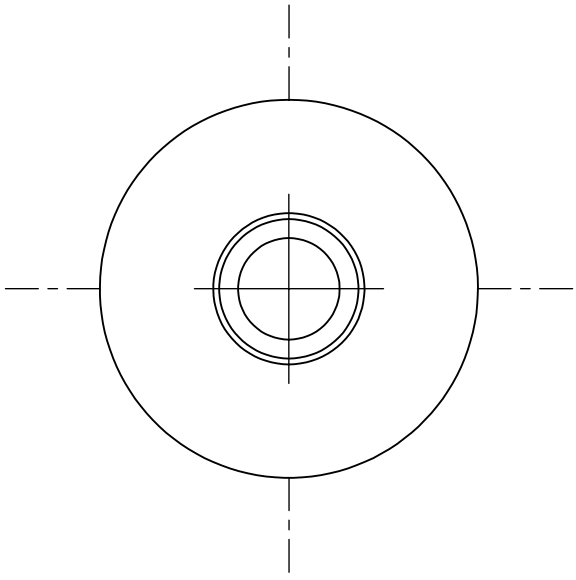
Titel: Push button		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 5 (Assembly 4)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: ABS		DATE: 10/5/2022	Scale: 2:1



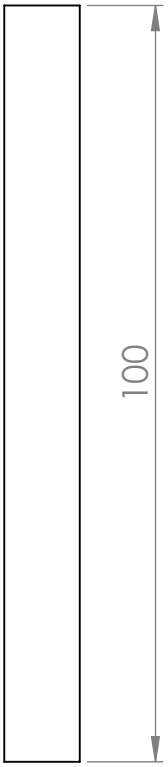


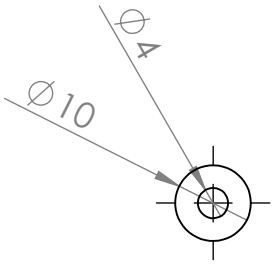
Titel: Cloth		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 7 (Assembly 4)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: Cotton		DATE: 10/5/2022	Scale: 1:1



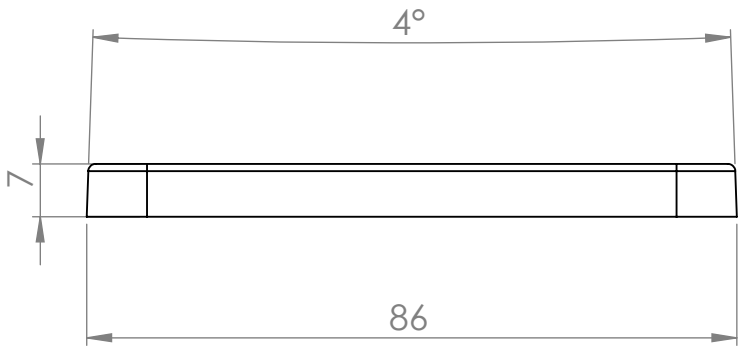


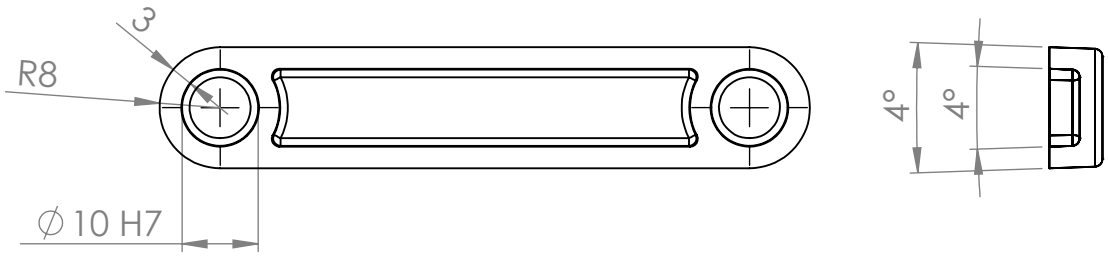
Titel: End cap cylinder		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 8 (Assembly 4)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: ABS		DATE: 10/5/2022	Scale: 5:1

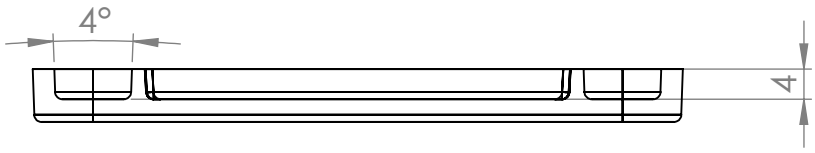




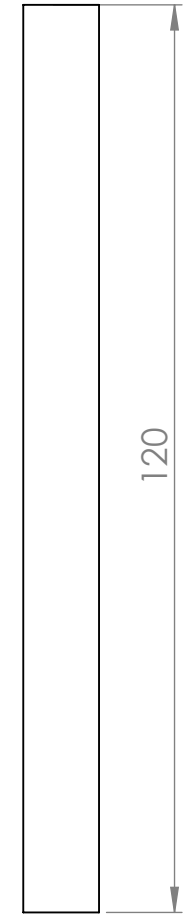
Titel: Cylinder (small)		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 9 (Assembly 4)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: ABS		DATE: 10/5/2022	Scale: 1:1

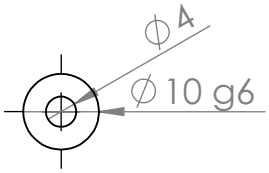




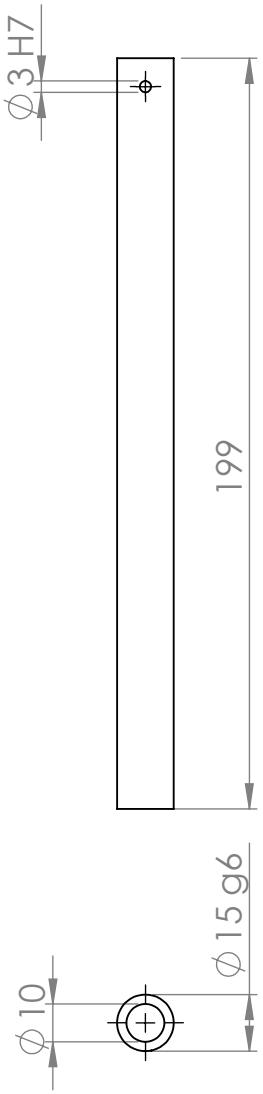


Titel: Cylinder connecter		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 10 (Assembly 4)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: ABS		DATE: 10/5/2022	Scale: 1:1

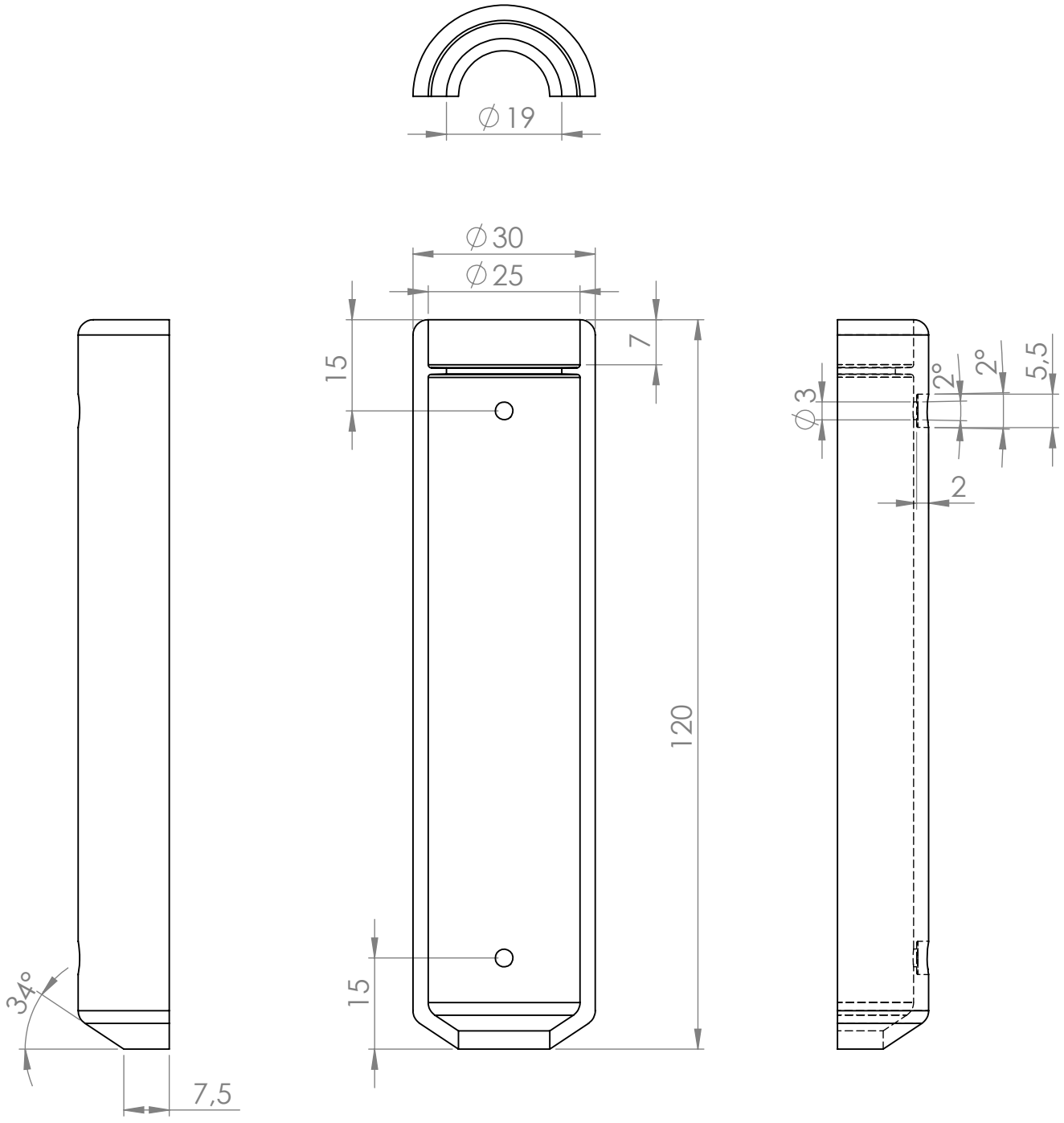




Titel: Cylinder (medium)		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 11 (Assembly 4)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: ABS		DATE: 10/5/2022	Scale: 1:1



Titel: Cylinder (big)		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 12 (Assembly 4)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: ABS		DATE: 10/5/2022	Scale: 1:2



Titel: Handle part 2.		NON-TOLERANCE MEASURES ACCORDING TO: DS/ISO 2768-m	
Drawing nr.: 13 (Assembly 4)	Third angle projection	MSC-ID4 GR. 5	Size: A4
Material: ABS		DATE: 10/5/2022	Scale: 1:1