Dynamic footprint for stabilising a hygiene chair

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MASTER THESIS

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A master's thesis pre-study investigating a dynamic chassis design for future Arjo hygiene chairs

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Abstract

The purpose of this thesis work is to investigate whether a dynamic chassis can possibly enhance hygiene chairs used in hospitals and elderly care. The problem with a lot of today's products is the difficulty of manoeuvring the hygiene chair in tight spaces, and to allow for a high enough seating position to contribute to a more ergonomic working position for caregivers during showering. Thereof it is interesting to investigate if one can decrease the chassis size of the hygiene chair in tight spaces, but also to increase the chassis size in a raised chair position for increased stability.

The project is seen as a pre-study for coming development work regarding the company's hygiene chairs. The project has followed a development process inspired by methodology described by Ulrich and Eppinger in their book *Product Design and Development,* combined with elements of agile development methodology. The goal was to develop a wide range of concept ideas which acts as a foundation for further development, where also one or a couple of alternatives could be further developed with prototyping.

Many interesting concept suggestions of dynamic chassis have been generated and evaluated. The most suitable concept has been further developed and tested physically through the making of a full-scale prototype.

To summarise, this thesis work has shown concept suggestions with good potential to increase the stability of hygiene chairs by utilising a dynamic chassis, which can decrease its occupied space at low seating positions and increase the footprint in raised seating positions.

Keywords: Elderly care, Hygiene, Mechanical design, Concept development, Stability

Sammanfattning

Syftet med detta examensarbete är att undersöka huruvida ett dynamiskt chassi möjligen kan förbättra hygienstolar som används inom sjuk- och äldrevården. Problemet med många av dagens produkter är svårigheten att manövrera hygienstolen i trånga utrymmen, och att möjliggöra en tillräckligt hög sitsposition för att bidra till en mer ergonomisk arbetsställning för vårdgivare under duschning. Därav är det intressant att undersöka om man kan minska chassits upptagna yta i trånga utrymmen, men även öka chassits storlek i upphöjt stolsläge för ökad stabilitet.

Projektet ses som en förstudie inför kommande utvecklingsarbeten gällande företagets hygienstolar. Projektet har följt en utvecklingsprocess inspirerad av metodik beskriven av Ulrich och Eppinger i deras bok *Product Design and Development*, kombinerat med inslag från agil utvecklingsmetodik. Målet var att ta fram ett brett urval konceptidéer som utgör underlag för vidare utveckling, där även ett eller ett fåtal alternativ kunde vidareutvecklas med prototyptillverkning.

Många intressanta konceptförslag av dynamiska chassin har generats och utvärderats. Det mest lämpade konceptet har vidareutvecklats och testats fysiskt genom tillverkning av en fullskalig prototyp.

Sammanfattningsvis har detta examensarbete visat konceptförslag med goda möjligheter att förbättra stabiliteten hos hygienstolar genom att utnyttja ett dynamiskt chassi, som kan minska sin upptagna yta vid låga sitspositioner och öka sitt fotavtryck i upphöjda sitspositioner.

Nyckelord: Äldrevård, Hygien, Mekanisk design, Konceptutveckling, Stabilitet

Acknowledgments

This report is the result of a master’s thesis in Mechanical Engineering conducted at the Division of Product Development, Faculty of Engineering LTH, Lund University in collaboration with Arjo.

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Martin Olsson and Elias Åberg

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List of acronyms and abbreviations

bin.	binary
CAD	computer aided design
CoM	centre of mass
deg.	degrees
dir.	direction
i.	importance
MRS	market requirement specification
N/A	not applicable
nbr.	number
N.T	not tested
N.T.P	not tested physically
POM	polyoxymethylene
pos.	position
SD	safe distance
subj.	subjective
SWL	safe working load
TDD	test-driven development
U&E	Ulrich and Eppinger
w/o	without
yrs.	years

1 Introduction

This chapter presents the problem background and description, as well as the main goals and purposes of this master's thesis.

1.1 Arjo

Arjo is a Swedish company founded in 1957 by Arne Johansson. He was one of the first to understand the need for bathing and transfer equipment in healthcare and elderly care as well as for improved ergonomics for healthcare professionals. He developed a series of innovative products that could meet these needs in Sweden, and shortly after, Arjo started expanding globally. At the end of the 1960s, Arjo products were for example sold in the UK, Germany, France, Belgium, and the US. In the 1980s, Arjo strengthened its position in the international market with the acquisitions of several similar companies from these countries and Arjo soon became a global player in products and equipment for hygiene and resident handling. The development of innovative technology continued in the 1990s, focusing on product development in hygiene and resident handling systems.

In 1995, Arjo was acquired by Getinge and became the foundation of Getinge's Extended Care business area. Further expansion happened in the 2000s where several corporate acquisitions were implemented to continue to strengthen the hygiene and resident handling offering. In 2016, the Board of Directors of Getinge announced its intention to divide Getinge into two operations, Getinge and Arjo, to give each company the best conditions for developing and realizing their potential.

Today, available in over 100 countries with over 6000 employees worldwide, Arjo is a market-leading supplier of medical devices and solutions that improve quality of life for people with reduced mobility and age-related health challenges. [1]

1.2 Background

Hygiene chairs are widely used for moving residents safely between rooms, while allowing a single caretaker to perform most hygienic caretaking tasks without further assistance [2]. One fundamental requirement for such chairs is to ensure the stability of the chair for it not to tip over when under load. This minimum requirement is well described in the product standard ISO 10535 for patient lifters [3]. This requirement gets more and more critical in the world of patient lifters as the demand for higher and higher allowed resident weights increases [4] and the available space by the users is constant and often too small to fit such lifters. Here, the term "patient lifter" describes equipment used to transfer patients, which also covers hygiene chairs, and the term "resident" is furthermore used throughout this report instead of patient or caretaker. One case where the problem related to the available space is critical is in bathrooms intended to be used by only one resident. These bathrooms of interest can be in either hospitals, health care facilities, or resident homes, and are often too small to fit both assistive products needed as well as workspace for the assisting personnel.

The facilities that purchase this kind of assistive products often have a buying criterion that the equipment should be able to carry a Safe Working Load, hereinafter "SWL" of at least 150 kg. The SWL is the maximum resident weight allowed for the hygiene chair. This buying criterion is not because many of their residents weigh this much, but rather set as a safety factor if they were to get a resident of that weight and partly to assure that the product has "some margin" when it comes to stability and rigidity. The contradiction in this situation is that most residents, specifically living in elderly care facilities, typically have a weight in the span between 50-90 kg due to weight loss as a consequence of aging. The SWL has also become an increasingly important competitive factor between different manufacturers of such products.

As a summary this type of assistive products, which are intended to be used in both hospitals and elderly care homes, tend to represent a big footprint, which is the area of the floor covered by the hygiene chair. They also tend to have a high product weight and are often associated with high cost due to the amount of material and design solutions needed.

1.3 Problem description

Based on the background, the thesis group is left with contradicting requirements to both fulfil the stability requirements (according to the product standard) for a high SWL and offer a product design that has a small enough footprint to fit in a typical bathroom. Therefore, this master's thesis mainly investigates new concepts regarding the functional design of the product, rather than focusing on aesthetics.

Currently, Arjo and most other manufacturers set a target SWL for the product, and then stretch the outer dimensions of the chassis (the actual product footprint) until the stability requirements are met. For products that have a movement where the centre of gravity (when loaded) moves, their range of movement or length of lever arms or booms can be restricted to pass the standard. The design intent used today is basically quite traditional where the chassis outer dimensions are adjusted until the stability requirements are met.

1.4 Project description

The overall purpose of the master's thesis is to provide Arjo with technical assistance and knowledge on a new design of a hygiene chair, with focus on a design that fulfils a sufficiently small footprint suitable for a bathroom environment and resident weight, which also meet the stability requirement according to the ISO 10535 standard for patient lifters. The importance and weight requirement of SWL have become an increasingly competitive factor for hygiene chairs, and therefore a dynamic footprint design which may carry increasingly heavier resident loads is desired, without contributing to an unnecessarily heavy lifter design when aiding lighter residents. Therefore, the aim was to produce a concept solution which may adapt to the change in centre of mass location depending on the weight of both lightweight as well as increasingly heavier resident loads. The idea is to solve this using a dynamic footprint, meaning a footprint that can be resized depending on the required stability during different use cases of the hygiene chair.

1.4.1 **Research questions**

In summary, this master thesis aims to answer the following research questions:

1. How can the chassis of a hygiene chair be dynamically designed to minimise occupied space, depending on the current resident weight and the change of centre of mass of the lifter device?
2. Which chassis design(s) is most suitable to meet the product requirements and industry standards?

1.5 Delimitations

Although the product planned to be developed is a medical device, several project delimitations are planned to limit the scope of the project and allow more focus on specific parts of the project. The development work does not have to follow design control procedures according to Arjo’s general guidelines, since the project is focused on explorative early concept work. The business models do not have to cover general product liability issues since they often differ from market to market. Also, strictly commercial terms concerning orders, price agreements, logistics etc. are not in the core scope of the project but can be incorporated if there is time available.

2 Methodology

This section describes the development process methodology used for this master's thesis project, which may be seen as a combination of a widely used product development process described by Ulrich and Eppinger and elements from an agile project approach.

2.1 The overall process

Product development is the complete process of delivering a new product or improving an existing one. It's a vast engineering subject with a lot of different methods and procedures available to be inspired by. The plan for a methodology that would be optimal for the concept development phase of this thesis project was outlined in the early stages of the project. The planned methodology process may be described according to the following three stages:

1. Initiate according to Ulrich & Eppinger's (hereinafter "U&E") product development process, where one will think broad and generate a large number of concept ideas.
2. Conduct a concept selection according to the methods described by U&E, where a handful of concepts are chosen.
3. Begin to work according to an agile work process, where new designs and physical tests are continually iterated to find suitable proof of concept solutions.

The methodology may therefore be seen as a combination of the development process described by U&E, with elements inspired by agile development. The U&E process can in other terms be seen as the backbone structure of the entire project process, where agile elements are merged into different stages along the way. The Agile planning adopted includes for example weekly sprint meetings and a project task board.

2.2 Ulrich and Eppinger's Product Development Process

A well-known methodology is the one described by U&E in their book "Product Design and Development". This methodology was used to an extent where it was found to fit well with the development process of the project. The parts of the development process that didn't fit the methodology as well have instead been replaced with other methods.

According to U&E [5], the generic product development process consists of six phases. These are:

1. Planning
2. Concept Development
3. System-Level Design
4. Detail Design
5. Testing and Refinement
6. Production Ramp-Up

This thesis project covers the development of new concepts and prototypes for a hygiene chair chassis that can dynamically adapt to allow a heavier SWL while maintaining stability according to the industry standard for such products. Based on the six phases of the development process, the starting point of the project may therefore be seen as placed in the concept development phase. The concept development phase further contains seven steps. These are:

1. Identify Customer Needs
2. Establish Target Specifications
3. Generate Product Concepts
4. Select Product Concept(s)
5. Test Product Concept(s)
6. Set Final Specifications
7. Plan Downstream Development

While these steps might appear in a sequential fashion, the process should rather be seen as iterative, with activities often repeated once new obstacles and insights arise along the way.

To summarise, the generic product development process together with the steps contained within the concept development phase is illustrated in Figure 1. The green box shows the process steps covered within this project. [5]

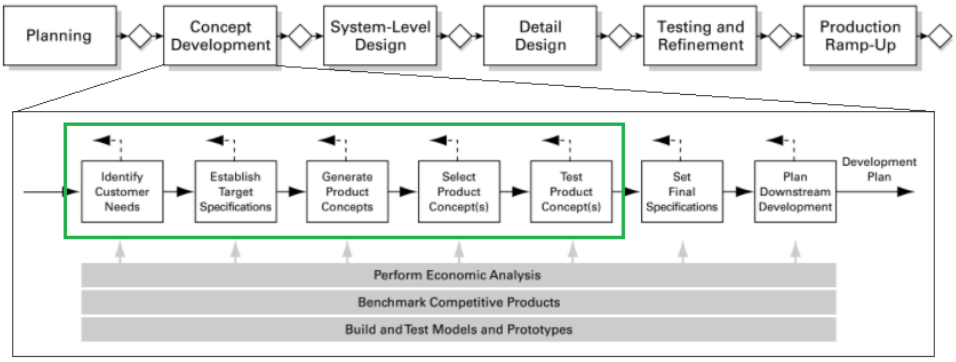

Figure 1. The six phases of the generic product development process according to U&E, along with a detailed view of the concept development phase. The green box encapsulates the process steps included in this master's thesis. [5]

As seen in Figure 1, three grey bars are present during all seven steps of the concept development process. These are "Perform Economic Analysis", "Benchmark Competitive Products", and "Build and Test Models and Prototypes". All these activities can be utilised during the whole concept development process. The economic analysis will not be prioritised in the scope of this thesis but benchmarking of competitive products and building and testing models as well as prototypes will be used extensively to understand the current market situation and to verify various concepts in terms of functional feasibility.

2.2.1 Customer needs

The initial step of the concept development phase described by U&E, is to identify and define the needs of the users and the market segment(s). This includes gathering consumer data from an identified target segment with the use of different market research methods and interpreting costumer statements into actual needs. A need is here defined as what the product must do based on the research input data. Therefore, a need statement does not (and must not) explain how an issue may be solved, instead this is described during later stages of the development process.

After the interpretation of the established needs, they are organised in a hierarchical order and then prioritised by relative importance into a comprehensive list. [5]

In summary, the step of identifying customer needs may be listed into the following 5 steps:

1. Gather raw customer data.
2. Interpret the gathered data into needs.
3. Organize the needs into a hierarchy.
4. Sort the needs based on relative importance.
5. Reflect on the result and process.

2.2.2 Target specifications

Once the customer needs have been documented in the previous step, the development of product target specifications may begin. While customer needs explain what the product must do from the customer's perspective, often in a subjective manner, the product specifications are meant to describe in precise, measurable detail what the product must do based on the customer needs. This is achieved by giving each specification a *metric* and a *value*. Fulfilling the product specifications should satisfy the customer needs, but some specifications might not be technically achievable. These specifications are subject to change once new knowledge is gained during later stages of the development process. As previously seen in Figure 1, the final specifications are set once concept testing has taken place. [5]

The process of establishing target specifications follows four steps according to U&E:

1. Prepare the list of metrics.
2. Collect competitive benchmarking information.
3. Set ideal and marginally acceptable target values.
4. Reflect on the results and the process.

Not all steps will however be followed to a full extent. Instead, a simplified version of the process will be used.

2.2.3 Concept generation

During the concept generation phase, the aim is to systematically explore and design different product concepts that fit the customer needs based on the previously mentioned steps of identifying needs and defining target specifications. The process includes internal and external search in an explorative manner, where concept solutions often are generated during work in team. Here, a concept can be presented as a principial sketch or 3D-model and is often supplemented with brief descriptions in order to describe for example a working principle or choices regarding the design. [5]

According to U&E the concept generation phase can be summarised into a five-step method, which includes the following stages:

1. Clarify the problem.
2. Search externally
3. Search internally
4. Explore systematically
5. Reflect on the solutions and the process

2.2.4 **Concept selection**

Once a fair number of concepts have been generated, the concept selection may begin. This process involves evaluating the generated concepts with respect to the criteria set by the customer needs and target specifications to determine the most promising concept(s). As previously stated, this process usually requires several iterations and could spark new concept generation ideas and refinements to already generated concepts. U&E recommends a two-stage process for concept selection, using concept screening and concept scoring. The concept screening stage are used to narrow down the number of concepts coarsely by using a reference concept to evaluate other concepts against, while the concept scoring stage utilises more detailed analyses and finer quantitative evaluation of the remaining concepts to further eliminate unfeasible concepts. [5]

Both the stages of concept screening and scoring utilises the same six-step process to guide the selection of the optimal concept(s). According to U&E, these steps are:

1. Prepare the selection matrix.
2. Rate the concepts.
3. Rank the concepts.
4. Combine and improve the concepts.
5. Select one or more concepts.
6. Reflect on the results and the process.

2.2.5 **Concept testing**

Concept testing can be done in various ways depending on the type of product that is being developed. The method described by U&E is mainly focused on gathering responses from potential customers in the target market of a product by using customer surveys. This method can verify that customer needs have been met by the concept, give an indication of how well the product might sell on the market, and gather new input for refining the product concept. [5]

U&E recommends the following seven-step method for testing product concepts using surveys:

1. Define the purpose of the concept test.
2. Choose a survey population.
3. Choose a survey format.
4. Communicate the concept.
5. Measure customer response.
6. Interpret the results.
7. Reflect on the results and the process.

However, this method does not fit very well for testing the type of concepts developed in this thesis. Another more agile approach for testing the concepts have been planned and is further discussed below.

2.3 Agile development process

The intention with a mixed methodology is to try new ways of producing ideas and concepts, as well as testing at a faster rate. As agile methods are not widely used for hardware development projects in general, the aim is to explore this topic further for gained knowledge both regarding its benefits and limitations in certain project stages.

2.3.1 **Applying agile elements for hardware development**

As the agile framework initially was intended for software development processes and not entire hardware development projects, some core ideas have instead been adopted for certain steps within the thesis project process where agile methods are applicable.

2.3.1.1 Test-driven development

One core idea used for this project is the concept of so-called test-driven development (TDD). The principle is originally rooted in agile software development, where code is iteratively designed based on sets of pre-defined test cases. A test case is produced to validate a required behaviour. This test case must fail at first. Frome here, new code is added until the test case passes. Once the newly added code makes the test case pass, the developer is not allowed to work further on that block of code unless to eliminate unnecessary code such as duplicates. Instead, a new test case is produced to test another required behaviour, and the cycle continues. [6]

For this project, the concept of TDD will not be used for software development, but instead for hardware design changes for the chassis in a similar iterative fashion. The test cases used in this thesis may be seen as a collection of several ways of verifying design aspects of concepts and later early prototypes. New tests of different character are constructed along the design process and are based on target requirements and industry standards. Design changes are engineered and tested against the selected test method, in a manner inspired by the TDD method. The test methods used during the process are of different character depending on the specification(s) in focus and phase in the overall project timeline. The tests can be summarised as follows:

1. Sketches and 3D-models, which primarily validates early proof of concept and ideas.

2. Simulations in CAD including centre of gravity estimations for validating new concepts solutions and refinements.

3. Physical prototypes, both smaller and full-scale models to test physical principles and dimensions.

4. Physical testing by applying different loads and measure forces using various sensors, depending on the prototype design.

5. Validation through expert reviews at the company.

2.3.1.2 Kanban board

Another agile-related method adopted in this thesis work is a so-called Kanban board, which is used for organising project related tasks. The Kanban board visually describes the overall project, structured in different columns that represents different project stages. Each column has a headline describing the name of a particular stage, and tasks are sorted based on priority within each column, where activities with the highest priority are placed at the top of the column. A Kanban card, carrying the information related to a specific task, essentially moves from the left side of the board to the right as work progresses. Each card generally goes through three major steps; *Requested tasks*, *In progress tasks* and *Completed tasks,* along its way. [7]

In this thesis, an online Kanban task board called "Trello" has been used, and functions as previously described. Figure 2 presents a capture of the online Kanban board during the beginning of the concept generation phase in this project.

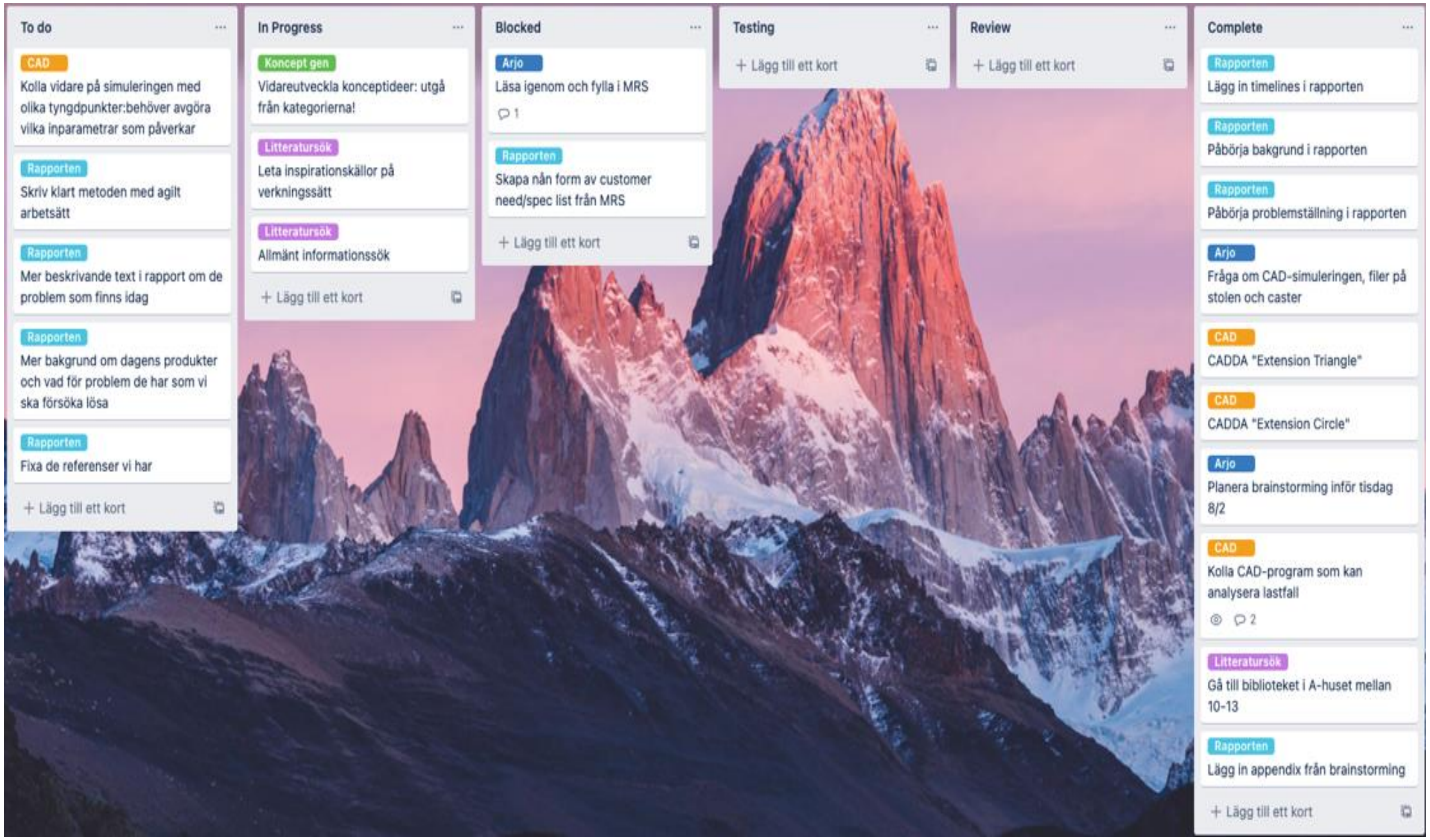

Figure 2. Kanban board for project related tasks.

3 Pre-study and background research

This chapter covers background information required to understand the users, the current hygiene chairs provided by Arjo, competing products on the market, as well as design standards related to hygiene chairs. The findings from this chapter form the basis for further development of concepts.

3.1 The Arjo Mobility Gallery

To provide the right care for every resident, Arjo have identified five personas with different levels of mobility and needs. These resident types are ordered by degree of mobility with personas whose names start with letters A to E. These can be described according to the Arjo Mobility Gallery booklet as follows [8]:

Albert - has the most mobility and can be described as independent, who can clean and dress himself. He can walk with minimal aid, for instance by using a walking cane. Physical motion is important for him, although he can tire quickly.

Barbara - can support herself to some degree and uses a walking frame or similar equipment to walk. She is dependent on a caregiver in challenging situations and stimulating the physical abilities she can perform is important. The tasks performed by caregivers to aid Barbara is not very physically demanding.

Carl - sits in a wheelchair and can put weight on at least one leg to a limited degree. He has some trunk stability but is dependent on help from caregiver in most situations. Carl is often physically demanding for the caregiver(s). Stimulation of remaining abilities is very important for him.

Doris - sits in a wheelchair and has no capacity to support herself. She can neither stand upright unsupported nor bear any weight on her legs. She is dependent on a caregiver in most situations and is physically demanding to handle for caregivers. Stimulation of remaining physical abilities is very important.

Emma - is passive and completely dependent on help from caregivers. She mostly spends time in a bed which may result in bedsores and has stiff contracted joints. She is physically demanding for caregivers, and stimulation for increased mobility is not a primary goal.

The personas described above are presented in Figure 3 to give a visual representation of the different caretaker types.

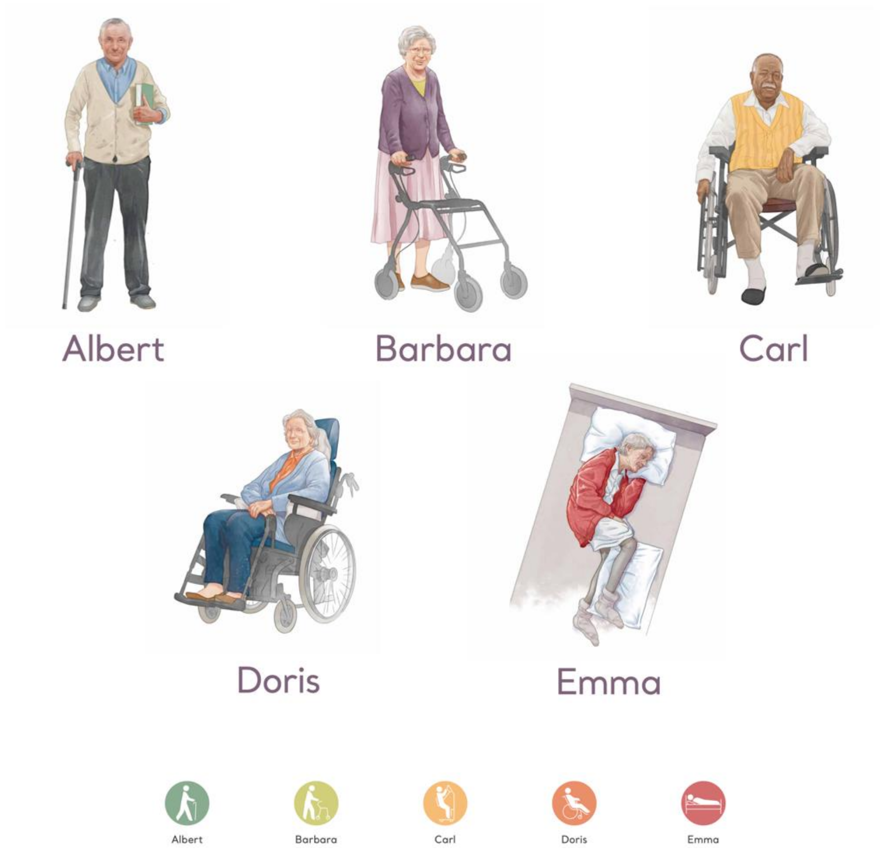

Figure 3. The Arjo Mobility Gallery for long-term care. [9]

Based on the Mobility Gallery model, the personas targeted for this development project is primarily Carl and Doris. Both need assistance in most situations, where the focus area for this master’s thesis is in the bathroom environment. In these situations, resident handling in narrow spaces, toilet visits, and showering are important care scenarios to address.

3.2 Breakdown of hygiene chairs

To get a basic understanding of how the current hygiene chairs work, a further explanation of how they generally function is necessary. Hygiene chairs can be described as a type of equipment used by caregivers to facilitate care for residents. They typically allow transferring, toileting, and showering of residents. Different terms can be used to describe hygiene chairs, such as commode chair or shower chair, but the term hygiene chair is used throughout this report.

The lower part of a typical hygiene chair consists of a steel frame, hereinafter called chassis, with four caster wheels attached to it. The chassis is intended to provide stability to the chair. An important aspect to consider during the development of the chassis is the intended use-cases of the chair. To use the hygiene chair for toileting purposes, the chair is situated above a toilet. The seat of the chair has a commode hole which lines up with the toilet bowl, which allows the resident to fulfil their toileting needs. To be able to situate the chair above a toilet, the chair must have sufficient free space underneath the seat. This forces the chassis to have a certain width and length. The chassis must also neither be too long nor wide, since this would make it hard to manoeuvre through narrow doorways, while also limiting the number of bathrooms where the chair can fit.

The chair typically has a backrest to allow the resident to sit comfortably, and most models also features a footrest to further facilitate comfortable seating for the resident. To make showering of residents easier for the caregiver, some models allow the chair to be raised, which puts less strain on the caregiver when washing the resident [10]. In some cases, the backrest has a fixed angle to the seat, while other models allow reclination of the backrest. A chair with a reclinable backrest provides even better ergonomics for the caregiver during the washing activity [11].

Since showering drenches the chair, it must also be designed with water resistance in mind.

3.2.1 Nomenclature of hygiene chairs

To summarise the breakdown of hygiene chairs, Figure 4 shows the main parts of a general hygiene chair and what those parts are called in this thesis work. Note that this is a very generalised view of the hygiene chair structure. The link, which is the part between the chassis and the seat, often varies greatly in design and function between different models and manufacturers.

Figure 4. A general hygiene chair with numbers indicating the name of the part.

3.3 Understanding the Arjo hygiene chairs

To better explain how the conclusions of this thesis work can help Arjo make better products, a further look into how the products currently offered by Arjo works is necessary. This will also cover some limitations of the current designs.

The specific products currently offered by Arjo that best corresponds to the type of product developed in this thesis work are the Carino and Carendo shower systems.

3.3.1 **Carino**

One of Arjo's current products, Carino, is a versatile height-adjustable shower and hygiene chair [12]. The chair can be seen in Figure 5. The chair is designed to reduce the number of transfers required for assisted showering and hygiene, enabling a single caregiver to perform everyday hygiene tasks such as washing, toileting, and foot care while the resident remains seated, which can be seen in Figure 7.

The Carino chair is designed with resident categories Barbara and Carl in mind from the Arjo Mobility Gallery. This corresponds to residents who are at least semi-active i.e., able to sit upright self-supported on the side of bed or toilet.

Instead of a typical link between the chassis and the seat, Carino utilises a curved frame which lifts the seat by pulling it up using a lifting strap, which can be seen in Figure 6. This also tilts the whole seat backwards, giving the resident a more comfortable seating position.

One limitation of this design is that the angle between the seat and backrest is fixed, limiting the flexibility of the chair. The chassis of the chair is also fixed, which equates to a minimum footprint of 881 by 624 mm with no ability to make it smaller. Another limitation is the SWL of 140 kg, a metric which the facilities that purchase this kind of assistive products often compares to competing products. [13]

Figure 5. Carino Hygiene Chair. [12]

Figure 6. Lifting strap of the Carino chair. [12]

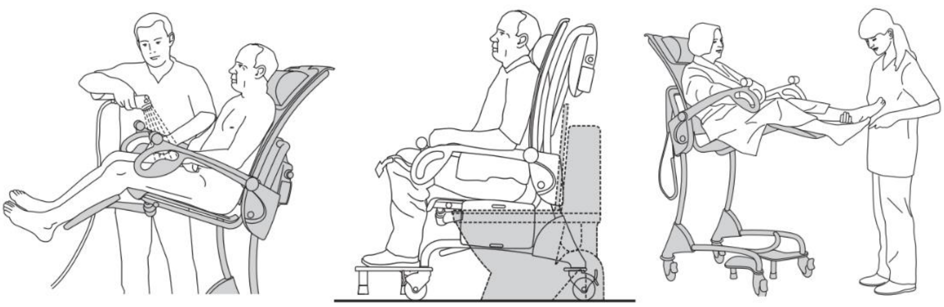

Figure 7. The Carino chair during washing, toileting, and foot care. [12]

3.3.2 **Carendo**

Carendo is another height-adjustable shower and hygiene chair offered by Arjo which can be seen in Figure 8 [14]. Just like Carino, this hygiene chair is also designed to enable a single caregiver to perform the full hygienic routine within a single transfer, which can be seen in Figure 10.

Figure 8. Carendo Hygiene Chair. [14]

The Carendo chair is designed with resident categories Carl and Doris in mind from the Arjo Mobility Gallery. This allows the chair to be used by residents who can't support themselves.

The chair features a parallelogram link between the chassis and the seat, which allows a linear actuator driven by an electric motor to raise or lower the seat. Carendo also features a reclining function, which lowers the backrest and raises the footrest simultaneously which makes hygienic care of residents easier. Another feature which is not present in Carino is the so called "Care Raiser" function, which raises the posterior parts of the resident at the same time as the backrest is lowered. This makes undressing, washing, and dressing the resident easier, and can be seen in Figure 9.

Figure 9. Care Raiser function activated during dressing. [14]

Carendo shares a couple of limitations with Carino, as the chassis is fixed with a minimum footprint of 875 by 640 mm. The SWL of Carendo is also set relatively low at 136 kg. Since the linear actuator for raising the seat is situated in the middle of the chassis, some toilets can cause problems when aligning the commode hole with the toilet.

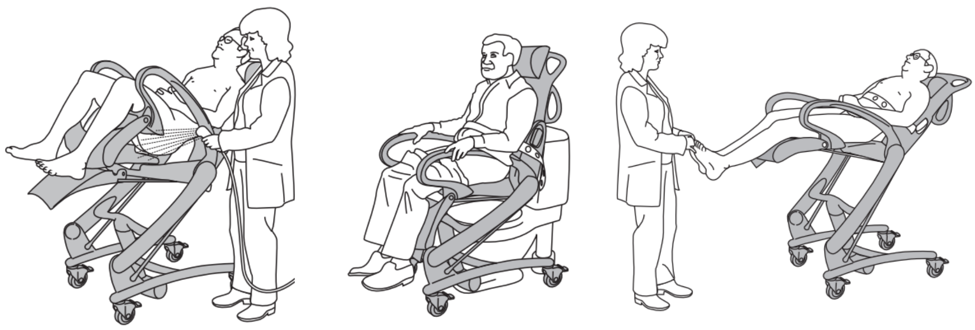

Figure 10. The Carendo chair during washing, toileting, and foot care. [14]

3.4 Market competitors

To set the Arjo hygiene chairs Carino and Carendo in perspective relative to other products on the market, a benchmarking comparing similar products have been conducted. The goal with this comparison is also to highlight how competing companies have solved problems related to the change of centre of mass, such as how the articulation range of the hygiene chair is limited by the SWL criterion. Some competing products with similar functionality have thereby been analysed regarding requirements such as footprint size, design principles used, and articulation adjustments.

3.4.1 **Invacare Aquatec** Ocean E-VIP

The Aquatec Ocean E-VIP is an electrically controlled hygiene chair produced by Invacare. The seat height is electronically controlled with a height ranging from 500 to 1050 mm above the floor level. The backrest of the chair is connected to the seat in a fixed relation, with a seat tilt function that can rotate the entire seat system between -5 (forward tilt) to 35° into a backward position. [15]

The Aquatec Ocean E-VIP is designed with a static lower chassis construction, and therefore has a permanent footprint size of 730 by 1010 mm. In order to tilt and elevate the SLW of 150 kg, it uses a combination of a parallelogram shaped frame and a pair of actuators mounted on both sides of the chassis. These are connected on a small forward tilted rod, to compensate for the centre of mass as it travels in the backwards direction when elevated and tilted backwards. [16]

3.4.2 **Anatomic SITT Zitzi Starfish Pro**

The Anatomic SITT Zitzi Starfish Pro is another electrically controlled hygiene chair. It comes with an adjustable leg system, to provide an ergonomic sitting position and make the chair adapt to the user size. The back support is height adjustable and may be tilted together with the seat its attached leg supports. [17]

Compared to many other hygiene chairs, Zitzi Starfish Pro comes in three different sizes, based on resident height. Measurements such as the seat height range and toilet clearance are same for all models, whereas the tilt angle range is slightly limited on the largest chair version, named size 3. This top version is according to the company appropriate for resident heights between 170 and 200 centimetres and may be tilted from a hip angle of -10 up to 30° relative to the floor. This stands for a 5° decrease in backward tilt compared to the small and middle versions, size 1 and 2. All versions have a SWL of 150 kg and may be adjusted from 50 to 78 centimetres in seat height position. [18]

3.4.3 **Raz-ART shower commode chair**

The Raz-ART commode chair is another hygiene product on the market. It comes with a so called attendant rotational tilt (ART), where the tilt is completely controlled manually by the caregiver. In order to safely tilt the resident, the ART mechanism is used. The chair tilt is described by the company themselves as an orbital tilt system that allows for the smallest footprint and at the same time the lowest tilt effort of any chair on the market. [19] The tilt range is set to 40°, and the seat height can be changed manually between 51 to 58.5 cm for the low setting, and 61 to 68.5 cm for the higher setting. Furthermore, the chair has a SWL capacity of 160 kg, a total length of 89 cm in the upright position, and an overall width of 57 cm. [20]

3.4.4 **Comparison of competing products**

The previously mentioned competitors have been compared to Carino and Carendo offered by Arjo, to get an overview of how the products perform relative each other. Specifications such as height articulation range, tilt adjustability, SWL, and occupied footprint area are compared. A summarised comparison is presented in Table 1.

Table 1. Comparison of main functions of current products on the market in relation to the Arjo hygiene chairs.

Features	Tilt Adjustability*	Floor to seat height adjustment	Minimal footprint size	SWL [kg]
Arjo Carino [12]	SA: 0 to 23° LA: N/A BA: N/A	450 – 1050 mm	881 x 624 mm	140
Arjo Carendo [14]	SA: 6° to 25° LA: 67° BA: 0° to 35°	510 – 1050 mm	875 x 640 mm	136
Invacare Aquatec Ocean E-VIP [16]	SA: -5 to 35° LA: N/A BA: N/A	500 – 1050 mm	1010 x 730 mm	150
Anatomic SITT Zitzi Starfish Pro [18]	SA: -5° to 30° LA: 0 to - 90° BA: -10° to 30°	500 – 780 mm	790 x 590 mm	150
Raz-ART shower commode chair [20]	SA: 0° to 40° LA: N/A BA: 0° to 4.5°	510 – 685 mm	890 x 570 mm	160
*** Description of abbreviation for different tilt adjustments:** SA: Seat tilt angle adjustment relative to floor plane LA: Tilt adjust for leg support BA: Backrest tilt adjustment, independently from seat angle				

3.5 ISO standards

Since the product that is being developed is meant to be used to care for and nurse persons with disabilities, several requirements and test methods for such products have been standardised to ensure that the product is safe to use, both for the resident and the caregiver.

3.5.1 ISO 10535:2021

The title of ISO 10535:2021 is *Assistive products – Hoists for the transfer of persons – Requirements and test methods*. The standard specifies requirements and test methods that are relevant to hoists for the transfer of persons with disabilities [3]. Here, the notions of hoist and hygiene chair are synonymous in this context.

The following headings describe some requirements related to the design process of the hygiene chair being developed in this master's thesis.

3.5.1.1 Safety of moving and folding parts

One of the important requirements specified in the standard for assistive products is the "Safe distance between moving parts". It describes which measurements a gap between parts that moves relative to each other should maintain throughout the whole range of movement to be considered safe, i.e., to avoid squeezing. The measurements that are considered safe can be found in Table 2. [3]

Table 2. Safe distances between moving parts according to ISO 10535:2021 [3].

To avoid	Safe distances for adults	Safe distances for children[a]
Finger traps	Less than 8 mm or more than 25 mm	Less than 4 mm or more than 25 mm
Foot traps	Less than 35 mm or more than 120 mm	Less than 25 mm or more than 120 mm
Head traps	Less than 120 mm or more than 300 mm	Less than 60 mm or more than 300 mm
Genitalia traps	Less than 8 mm or more than 75 mm	Less than 8 mm or more than 75 mm
[a] Also including adults with a height less than 146 cm, or a mass less than 40 kg, or a Body Mass Index (BMI) less than 17.		

Since the target users of the hygiene chair being developed is intended to be adults, the safe distances for adults in the table above will be considered during development of the concepts.

3.5.1.2 Requirements for static stability

Another important requirement concerns the static stability of the hygiene chair. According to the standard, both unloaded and under maximum load, the hygiene chair shall not lose its equilibrium (balance) at the following angles: [3]

a) Forwards and backwards directions 10° with the base in the intended travelling position.
b) Forwards and backwards directions 7° with the base in the most adverse condition.
c) Any other direction, 5°.

To make it easier to understand the above stated requirement, the following explanation exemplifies the 10° requirement. Consider Figure 11, it shows two lines extending from the contact area between each wheel and the ground. One line is completely vertical, as indicated by the 90° measurement. The other line is angled by 10° relative to the vertical line. This angled line shows where the vertical line would be if the hygiene chair were tilted 10° in either forwards or backwards direction. Figure 11 also contains the centre of mass for the chair, which is indicated by the black and white circle in the middle of the figure. Imagine that both angled lines create a triangle which can be considered a safe area for the centre of mass. If the centre of mass were to be placed outside this triangle, a tilt of 10° in either forwards or backwards direction would result in the hygiene chair losing its equilibrium and would therefore not pass the requirement for static stability. If the centre of mass is located within the triangle, the hygiene chair will theoretically pass the static stability requirement.

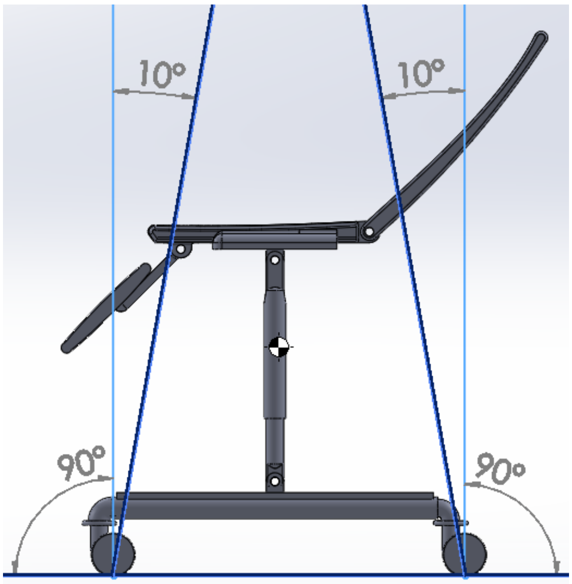

Figure 11. Static stability limits illustrated using a chair model.

3.5.2 **ISO 7176-11:2012**

The title of ISO 7176-11:2012 is *Wheelchairs – Part 11: Test dummies*. The standard specifies the requirements for test dummies used in the evaluation of wheelchairs [21]. Since the products that Arjo develops are similar to wheelchairs in some respects, they also use these test dummies for evaluation of some of their products.

The test dummy consists of three segments: the torso segment, thigh segment and lower leg segment. Depending on the desired total weight of the test dummy, these segments have different weights according to Table 3.

Table 3. Masses of segments, in kilograms [21].

Dummy mass range	m_{torso}	m_{thigh}	m_{leg}
$25 \leq m_{dummy} < 50$	$(0{,}66\ m_{dummy} - 3) \pm 3$	$(0{,}34\ m_{dummy} - 2) \pm 3$	5 ± 1
$50 \leq m_{dummy} < 100$	$(0{,}66\ m_{dummy} - 5) \pm 3$	$(0{,}34\ m_{dummy} - 3) \pm 3$	8 ± 1
$100 \leq m_{dummy}$	61 ± 3	$(m_{dummy} - 69) \pm 3$	8 ± 1
Definitions of abbreviated terms: m_{torso} – mass of the torso segment m_{thigh} – mass of the thigh segment m_{leg} – mass of the lower leg segment m_{dummy} – nominal mass of the test dummy			

The torso and thigh segment are connected by hip pivots, and the thigh and lower leg segment are connected by knee pivots. These pivots shall provide a range of rotation that accommodates all postures likely during use.

According to the standard, the location of the overall centre of mass shall be as specified in Table 4.

Table 4. Location of overall centre of mass [21].

Dummy mass range kg	x_{dummy}[a] mm	y_{dummy}[a] mm
$25 \leq m_{dummy} < 100$	$(0{,}62\ m_{dummy} + 173) \pm 25$	$(0{,}77\ m_{dummy} + 159) \pm 25$
$100 \leq m_{dummy}$	$(0{,}62\ m_{dummy} + 173) \pm 25$	$(-0{,}28\ m_{dummy} + 264) \pm 25$
[a] These formulae relate the numerical value of linear dimensions, expressed in millimetres, to the numerical value of dummy mass, expressed in kilograms.		

Arjo has built a test dummy called *Flatman* according to this standard, with a nominal mass of 200 kg, and provided drawings of the test dummy. A CAD model of the test dummy was constructed to be used for simulating the centre of mass of a resident in future concepts constructed in CAD, see Figure 12. The segments of the test dummy were given weights according to Table 3 above with $m_{dummy} = 200$ kg, resulting in $m_{torso} = 61$ kg, $m_{thigh} = 131$ kg, and $m_{leg} = 8$ kg.

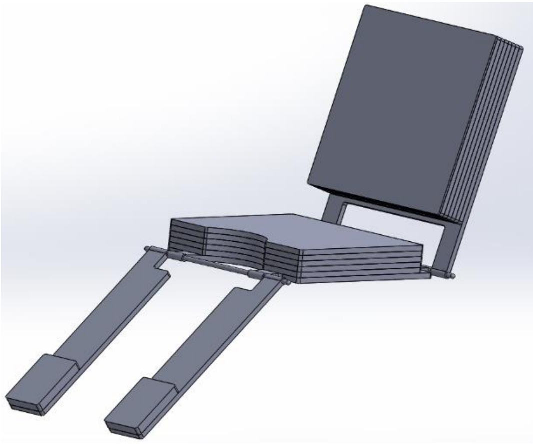

Figure 12. The *Flatman* test dummy CAD model.

According to Table 4, the overall centre of mass of the test dummy shall be positioned at x_{dummy} = 297 mm and y_{dummy} = 208 mm, where x_{dummy} and y_{dummy} can be found in Figure 13. The actual centre of mass of the *Flatman* CAD model can be seen in Figure 14, positioned at $x_{\text{dummy, CAD}}$ = 201.44 mm and $y_{\text{dummy, CAD}}$ = 106.24 mm.

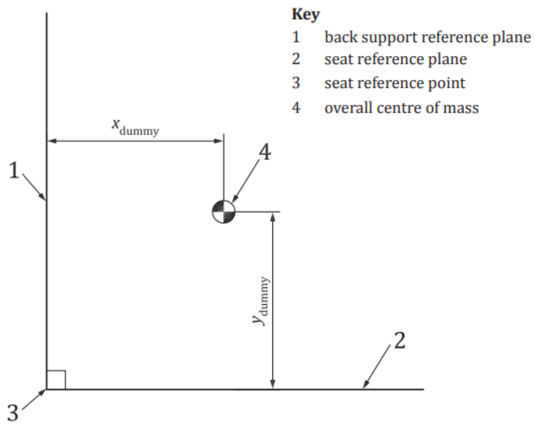

Figure 13. Location of overall centre of mass. [21]

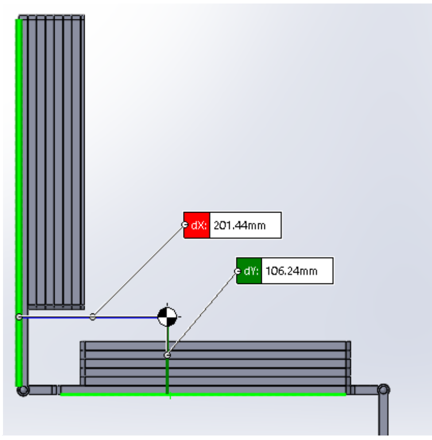

Figure 14. Location of actual centre of mass for the *Flatman* CAD model.

To adjust the centre of mass position of the *Flatman* CAD model to comply with the standard, additional low weight “spacer” supports are used. A support of 297 – 201.44 mm = 95.56 mm between the seat and the *Flatman* thigh segment, along with a support of 208 – 106.24 mm = 101.76 mm between the back support and the *Flatman* torso segment, will place the centre of mass in the correct location.

3.6 Patent search

According to U&E, patent searches are valuable resources in order to see which concept solutions that are already protected and must be avoided [5]. But a patent search can also be a source of inspiration and can tell if the own design is unique on a potential market. As patents expires at most 20 years after the official filing date [22], old patents with outdated licencing can be worth investigating and provide sources of inspiration.

A patent search for both old and newer patents have been conducted in this master thesis, focusing on medical chairs, but also investigating technical principles used in other industry applications. This includes for example telescopic motion in cranes and slide systems used in cars. However, nothing of significant interest was found during the patent search and therefore material from this investigation have been excluded from the report.

3.7 The CAD Testing Model

As stated in Chapter 3.5.1, the ISO 10535:2021 standard specifies requirements and test methods for the type of product being developed in this master's thesis. To verify that the concepts being developed fulfils these requirements, a simple model chair was made in SolidWorks. The model is built as general as possible, where different parameters can be changed to simulate different articulations for the chassis, the link, and the seat. Figure 15 shows what the chair model looks like.

Figure 15. A general view of the chair testing model made in CAD.

The parameters that are possible to change are the following:

1. Extension range of chassis
2. Translation range of connection between link and chassis
3. Angular movement range between link and chassis
4. Extension range of link
5. Translation range of connection between link and seat
6. Angular movement range between link and seat
7. Angular movement range between seat and backrest
8. Angular movement range between seat and footrest

All ranges of motion can be seen in Appendix B.

The dimensions and weights of the components are based on the Carino and Carendo hygiene chairs offered by Arjo. The most important dimensions to keep in mind are the width of the chassis, as well as the available space underneath the seat, to allow the chair to be able to function for toileting purposes.

The main objective of the test chair is to be able to see how the centre of mass varies depending on changes to the parameters for the model. To get as realistic measurements of the centre of mass position as possible, each component of the test chair has been given weights according to approximatively how much their counterparts in similar products weigh. In total, the test chair has been given an approximated total weight of 70 kg.

3.7.1 The toilet model

To be able to test and verify different concepts against standard bathroom environments, a test model of a standard toilet has been designed in CAD. The toilet is based on an American standard toilet [23] which can be seen as “more difficult” regarding the accessibility for a hygiene chair. These toilets often have a lower seat height and a deeper neck design. They are also placed very close or directly mounted onto the wall. For current hygiene chairs, this is not an ideal situation as it is difficult to dock the chair sufficiently close to the toilet hole. This happens as the back legs of the chassis hit the wall before the toilet hole is aligned with the commode hole of hygiene chair seat. Such a low toilet design also makes it difficult to lower the hygiene seat close to the toilet seat, resulting in splashing of faeces outside to toilet hole perimeter.

The CAD test toilet is a wall mounted version and have been given a width of 365 mm, a seat height of 400 mm and a total depth of 545 mm according to the measurements taken from the referred American toilet. A picture showing the test toilet is presented in Figure 16.

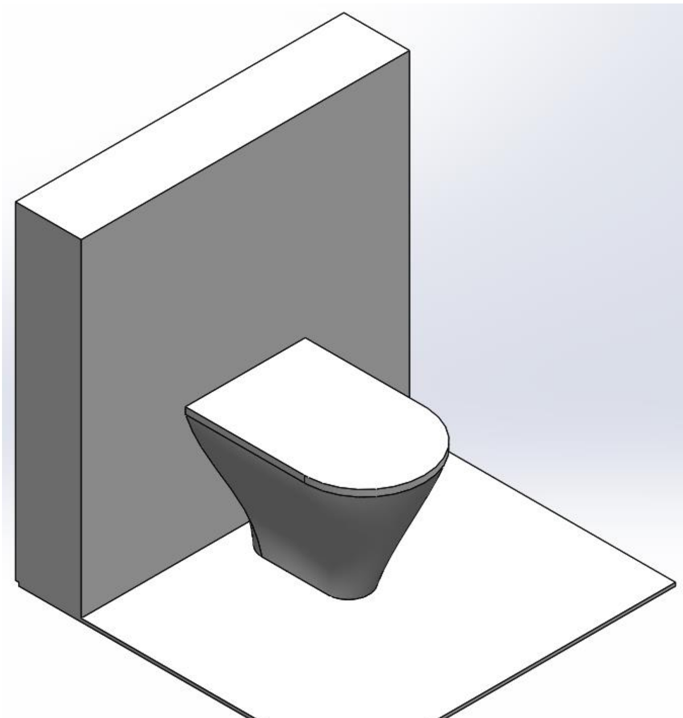

Figure 16. A reference toilet made in CAD to represent a "difficult" toilet scenario.

4 Customer needs

This chapter covers information related to customer needs for the usage of hygiene chairs based on data provided by Arjo, together with discussions with engineers at the company.

4.1 Provided data

As described in the methodology, identifying and defining customer needs are the initial steps of the concept development phase according to U&E. As this project focuses on new concept development for already existing products, Arjo has provided a so-called Market Requirement Specification list (MRS). This list explains what the product must do based on wide market research and industry standards, laying the groundwork for the customer needs and target specifications. The data contained within the MRS represents already gathered customer data, which corresponds to the first step of identifying customer needs according to the summary of steps presented in the methodology. To this end, no further data gathering from customers have been conducted.

The MRS document contained a broad range of unrefined market input where needs and target specifications were not fully separated. The data in the MRS were interpreted and broken down further into one list of customer needs and one list of target specifications. This interpretation corresponds to the second step of the methodology described by U&E.

4.2 Discussion with engineers

While the MRS laid the groundwork for the customer needs, some additional needs were discussed together with experienced engineers from Arjo. These needs mostly relate to how the hygiene chair functions regarding articulations and actual usage. A latent need was also found concerning the flexibility of the chassis. Latent needs are needs that many customers recognise as important in the final product but do not or cannot articulate in advance [5]. A chassis that can flex during transportation over doorsteps generally provides a more pleasant experience for both residents and caregivers.

4.3 Compilation of customer needs

The third step of the methodology is to organise the interpreted needs into a hierarchy of primary and secondary needs. Here, the primary needs are general need statements, while secondary needs are linked to a primary need with similar characteristics and provide more details to the primary need.

Once the needs had been organised into primary and secondary needs, they were ranked based on relative importance according to the fourth step of the process. The ranking was done according to how important the needs are to achieve the envisioned product. Latent needs have been denoted with an exclamation mark. The source of each need has also been indicated. The final customer needs list can be found in Table 5.

Table 5. Customer needs sorted into primary needs stated in bold, grouped together with each primary need's respective secondary needs. The source ("Src.") indicates if the need comes from the MRS (M) or from discussions with engineers (E). The abbreviation "Imp." is the relative importance.

No.	Src.	Customer Needs	Imp.
1		**The chair is space efficient**	
1.1	M	The chair integrates well with both floor-mounted and wall-hung toilets	3
1.2	M	The chair can be manoeuvred through small bathroom door openings	2
1.3	M	The chair provides optimal footprint size for the whole articulation range	2
1.4	M	The chair is perceived to be just the right size	1
1.5	M	The chair integrates well with resident transfers from/to other Arjo lifters	1
2		**The chair provides easy resident handling**	
2.1	M	The chair is suitable for B-D residents according to Resident Gallery	3
2.2	E	The chair only requires a single caregiver to perform the entire hygiene routine	3
2.3	M	The chair is intuitive to understand regarding how it interacts with the user	1
2.4	M	The chair can be manoeuvred regarding position and direction by foot	1
2.5	E	The chair chassis can flex with a small degree	1 **!**
3		**The chair is safe to handle**	
3.1	M	The chair conforms to the ISO 10535:2021 standard	3
3.2	M	The chair is safe to operate for caregivers	3
3.3	M	The chair is stable within the articulation range	3
3.4	M	The chair can be used on inclined floor surfaces to a certain degree	3
3.5	M	The chair provides handling without risk of squeezing	2
3.6	M	The chair is designed with no risk of stumbling or tripping	2
3.7	E	The chair has a safe working load (SWL) of 150-200 kg	1
3.8	M	The chair can be serviced safely by one service engineer	1
4		**The chair has a wide range of articulations**	
4.1	E	The chair backrest can be tilted fully backwards in an elevated position	3
4.2	E	The chair can be raised to provide good posture for caregivers	2
4.3	E	The chair can be lowered to provide a comfortable seat entry height	2
4.4	M	The chair is intuitive in regard to its articulation	1
4.5	E	The chair seat can be tilted forwards for easy entry for residents	1
5		**The chair allows for hygienic resident care**	
5.1	M	The chair is easy to clean and disinfect	2
5.2	M	The chair is designed with infection control in mind	2
6		**The chair is designed with durability in mind**	
6.1	M	The chair's steel frame has a lifetime of 10 years	2
6.2	M	The chair's soft parts have a lifetime of 2 years	2
6.3	E	The chair can be handled roughly	2

5 Target specifications

This chapter covers the target specifications derived from the MRS document and the customer needs. Also, use studies where similar products have been analysed at the company R&D facilities are treated here.

5.1 Gathering data for the specifications

With the customer needs identified and documented, the development of target specifications could proceed. As previously stated, the data from the MRS were broken down into customer needs and target specifications. Every target specification identified had a correlating customer need, but every customer need did not have a correlating target specification. Since the goal of the target specifications are to give the development team measurable specifications to satisfy the customer needs, each identified customer need was given at least one target specification. This way, satisfying every target specification will also satisfy every customer need.

Each target specification has a *metric* and a *value*. The metrics were generated by analysing each need and considering what measurable characteristic of the product could fulfil said need. The metric is then given a *target value*, expressed in a relevant *unit*. Some values were taken from the MRS when available, and others were generated both from discussions with experienced engineers at Arjo and from studying similar products available at the company R&D facilities. The *importance* of each target specification is based on the importance of the correlating customer need(s).

These target specifications are not intended to represent the final specifications of a future hygiene chair, but rather serve as a guideline for the development of the concepts within this thesis work.

5.2 Target specifications list

The target specifications with metrics and values can be seen in Table 6, along with descriptions of abbreviations and acronyms used.

Table 6. Target specifications listed with metrics and target values. "Need Nos." indicates which customer need(s) the specification correlates to. "I." is the relative importance, based on the importance of the correlating customer need(s).

No.	Need Nos.	Metric	Target Value	Unit	I.
1	1.1	Free height under seat	400	mm	3
2	1.1	Commodity hole width	145	mm	3
3	1.1	Backrest depth in length direction (bird's eye view)	80	mm	1
4	1.1-1.5	Chassis length	750-1050	mm	3
5	1.1, 1.5	Free length under seat	500-700	mm	3
6	1.1, 1.5	Free width under seat	450	mm	3
7	1.2, 1.4	Minimum door width for passing through	750	mm	3
8	1.5	Chassis free height, floor to frame	120	mm	1
9	2.1	The lifter is designed to address B-D residents	Yes	Bin.	3
10	2.2	One single caregiver for all intended operations	Yes	Bin.	3
11	2.3, 4.4	Easy to understand the possible articulations	Yes	Subj.	1
12	2.3, 4.4	Easy to understand reaction to different weights	Yes	Subj.	1
13	2.4, 6.3	Chassis rigid enough to be pushed around by foot	Yes	Bin.	2
14.	2.4	May be pushed around with ease while fully loaded	Yes	Bin.	1
15	3.1-3.4	Tilt w/o tipping, forward dir., intended wheel pos.	10	Deg.	3
16	3.1-3.4	Tilt w/o tipping, forward dir., most adverse condition	7	Deg.	3
17	3.1-3.4	Tilt w/o tipping, any other direction than forward.	5	Deg.	3
18	3.1, 3.5	Safe distance between moving parts, finger traps	SD < 8 SD > 25	mm	2
19	3.1, 3.5	Safe distance between moving parts, foot traps	SD < 35 SD > 120	mm	2
20	3.1, 3.5	Safe distance between moving parts, head traps	SD < 120 SD > 300	mm	2
21	3.1, 3.5	Safe distance between moving parts, genitalia traps	SD < 8 SD > 75	mm	2
22	3.4, 2.5	Can be used on slightly uneven floor surfaces	Yes	Bin.	3
23	3.6	Protruding parts with risk of tripping/stumbling	0	Nbr.	2
24	3.7	Safe working load	150-200	kg	1
25	3.8	Maximum hands required to perform service	2	Nbr.	1
26	4.1	Angle between seat and backrest in raised position	180	Deg.	3
27.	4.2	Maximum height floor to top seat surface	1000	mm	2
28	4.3	Minimum height floor to top seat surface	500	mm	2
29	4.5	Seat tilt angle from horizontal plane, forward dir.	35	Deg.	1
30	5.1, 5.2	Avoid indents and pockets for exterior parts	Yes	Bin.	2
31	6.1	Lifetime of steel frame	10	Yrs.	2
32	6.2	Lifetime of soft parts	2	Yrs.	2

Descriptions of abbreviations and acronyms used in table:
Bin. – binary Deg. – degrees Dir. – direction I. – importance Nbr. – number
Pos. – position SD – safe distance Subj. – subjective w/o – without Yrs. - years

6 Concept generation

This chapter covers the problem clarification derived from the information in Chapter 3, as well as the process of generating concepts during the project.

6.1 Clarify the problem

As stated in Chapter 3, a hygiene chair must fulfil the stability requirements according to the product standard, while having a small enough footprint to fulfil the intended use cases. To make it easier to understand how different parts of the chair relates to these requirements, the hygiene chair has been broken down into subsystems. Based on the CAD testing model, three main subsystems have been identified. These are the chassis, the link, and the seat subsystems. Furthermore, each possible adjustment earlier identified in the CAD testing model has been paired with a corresponding subsystem. The breakdown of the hygiene chair system into subsystems is presented in Figure 17.

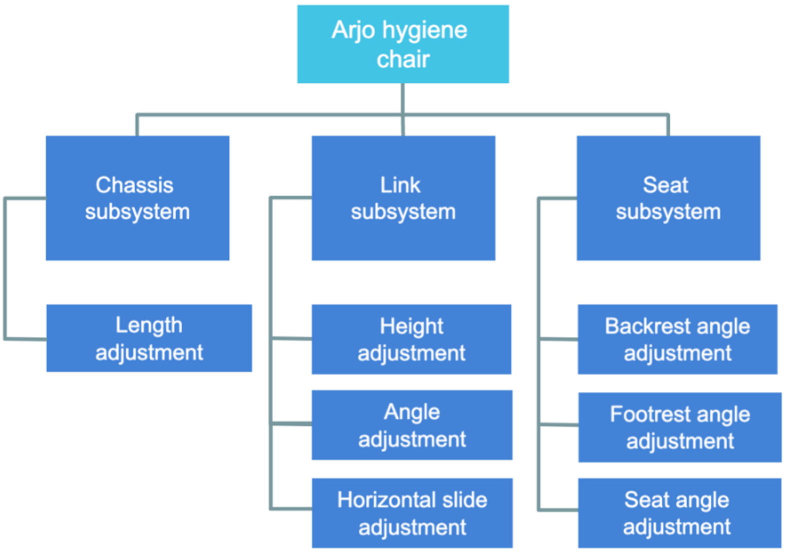

Figure 17. Diagram showing the breakdown of the hygiene chair into the subsystem's chassis, link, and seat, along with the available adjustments paired to each subsystem.

Based on the CAD test model and the diagram of subsystems, several adjustments of parameters were tested against the 10° tilt requirement from the ISO 10535 standard. An extension of the chassis proved to be an effective and relatively simple way of increasing the safe area for the centre of mass, as can be seen in Figure 18. The figure shows a centre-to-centre distance between the wheels from 810 mm, increased by 100 mm thrice. A larger safe area for the centre of mass is beneficial during the showering of residents since the seat gets raised to provide a better working position for the caregiver. This adjustment also allows the chassis to retract into a smaller footprint size during toileting and transportation, which increases ease of handling during these situations.

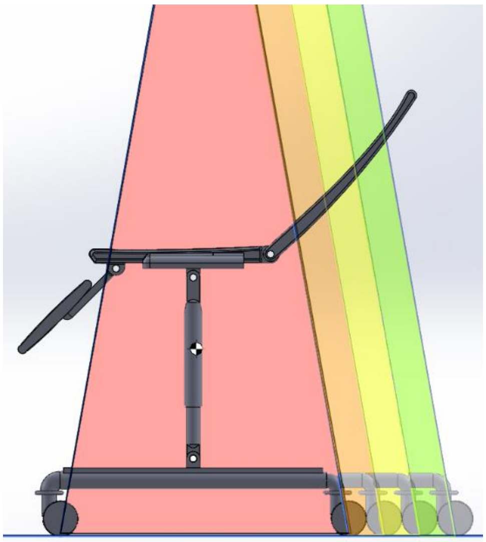

Figure 18. An extension of the chassis provides a larger safe area for the centre of mass. Extension shown in 100 mm increments.

The method of extending the chassis length was compared to the adjustments related to the link subsystem. One of the tested adjustments was to translate the link along the chassis, or similarly along the seat connection. This adjustment aims to solve the 10° tilt requirement by moving the centre of mass through horizontal translation. Another adjustment tested was to rotate the link about its attachment to the chassis, which would also change the position of the centre of mass. These adjustments did however seem to require more complex technical solutions compared to an extending chassis. Therefore, in order to solve the 10° tilt requirement as feasibly as possible, an extending chassis design was decided to be primarily focused on. However, this does not exclude other methods completely as combinations of adjustments related to different subsystems can integrate with each other to achieve a better overall solution.

The seat subsystem and its related adjustments were also examined regarding solving the 10° tilt requirement. Testing showed limited possibilities for adjusting the centre of mass location compared to an extending chassis. However, a tilting seat is desirable for other reasons, such as providing a more relaxing experience for residents and better working ergonomics for caregivers.

To summarise, the concepts generated will mainly focus on extending the chassis. Being able to adjust the seat regarding the identified adjustments in the seat subsystem is desirable in the final product regardless of the design and function of the rest of the hygiene chair, but due to time constraints the functions of the seat subsystem won't be explored further.

6.1.1 Calculating chassis extension based on the ISO 10535 standard

Since the chassis extension was shown to be the most feasible subsystem to further develop, an exploration of how the chassis extended length affects the centre of mass safe area was carried out. Table 7 gives an overview of how long the chassis must be (X_1) when fully extended, specified by a chosen input height (Y), and allowed horizontal range (X_2) of the total centre of mass (CoM). See Figure 19 for an illustration of the dimensions. The length of X_2 is based on the geometry of the 10° tilt requirement from the ISO 10535 standard.

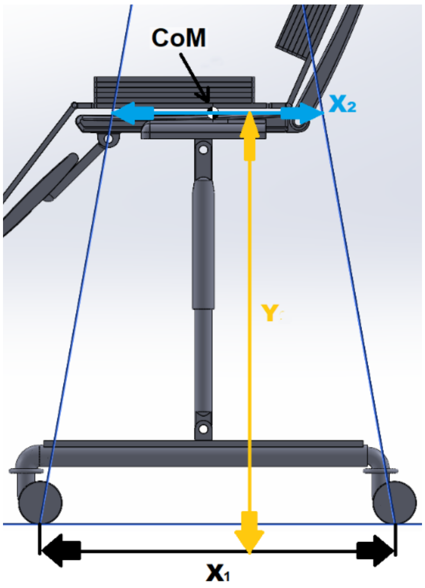

Figure 19 – Illustration of dimensions X_1, Y, and X_2, along with approximate location of CoM.

Studies of the CAD testing model has shown that heavy residents (200 kg) in a fully raised chair position results in a total CoM height close to the seat height, while lower resident weights result in lower total CoM heights. To provide an ergonomic posture for caregivers during showering of residents, the seat height, and therefore CoM height, should be around 100 cm [13].

The horizontal range X_2, which is chosen during the development process, should be long enough to provide some leeway for the CoM. However, a longer length of the safe area also results in a longer extended chassis, which should be kept as small as possible while still providing enough support. A smaller chassis overall results in better handling of the hygiene chair.

Table 7. Extended chassis length X_1 for a specified height of CoM Y and chosen length of horizontal range X_2 for CoM at specified height. All lengths given in cm.

		X_2 - Length of safe area for CoM at height Y, in cm								
		40	42.5	45	47.5	50	52.5	55	57.5	60
Y - Height of CoM when fully raised, in cm	95	73.5	76.0	78.5	81.0	83.5	86.0	88.5	91.0	93.5
	97.5	74.4	76.9	79.4	81.9	84.4	86.9	89.4	91.9	94.4
	100	75.3	77.8	80.3	82.8	85.3	87.8	90.3	92.8	95.3
	102.5	76.1	78.6	81.1	83.6	86.1	88.6	91.1	93.6	96.1
	105	77.0	79.5	82.0	84.5	87.0	89.5	92.0	94.5	97.0

6.2 Search externally

6.2.1 **Mechanical principles**

6.2.1.1 Linear actuators

A linear actuator is a device that converts input energy and signals into a linear mechanical motion. The actuator can be of electrical, hydraulic, or pneumatic type depending on the intended usage and system requirements [24].

For medical applications, electrical actuators that utilises a rotating screw are common. The principle is based on converting electrical energy into linear motion by rotating a screw driven by an electrical motor, often converted via an appropriate gear transmission. The screw is further connected to a threaded nut which moves in the axial direction, up or down depending on the direction of rotation [25]. In Figure 20, the cross-section area of an electrical screw-based actuator is shown.

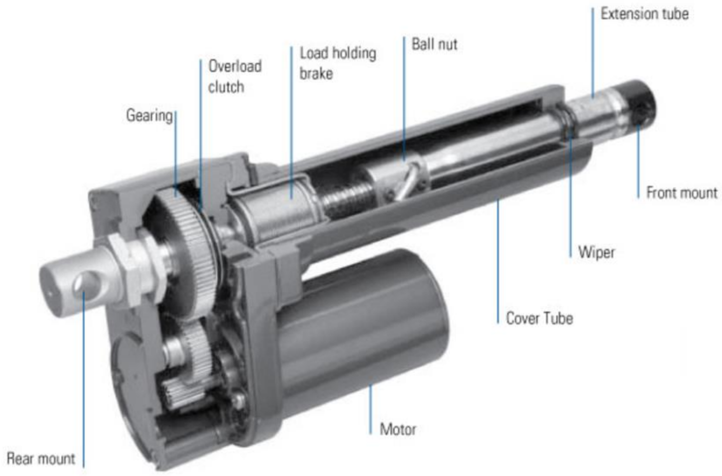

Figure 20. An electrical linear actuator and its overall components. [26]

6.2.1.2 Linear motion bearings

A linear motion bearing, or linear guide, is a bearing designed to provide free motion in one dimension. There are several different types of linear motion bearings on the market used for different applications. The simplest and cheapest type is the sliding contact linear motion bearing, which consists of two surfaces that slide relative to each other. This type of linear guide has a relatively high friction coefficient. Another option is the rolling element linear motion bearing, where rolling elements such as balls or rollers are used to create a rolling contact between two relatively moving objects. This rolling contact generally features much lower friction compared to the sliding contact. A common material for rollers are POM (polyoxymethylene) plastic, which is a plastic with excellent friction and wear properties [27]. Other examples of linear guides are hydrostatic and magnetic linear motion bearings, which has no mechanical contact between the contact surfaces. These types of linear guides are often costly, difficult to manufacture, and are mostly used for limited applications where ultra-precision is required. [28]

6.2.1.3 Belt pulleys

Belt pulleys, or belt drives, generally consist of a belt wrapped around a set of pulley wheels, which can be seen in Figure 21. The belt can have either a rectangular or a V-shaped cross section, and both grooved and flat inner surfaces are present on the market. Many belts are made of vulcanized rubber, which is a strong, elastic rubber providing high friction coefficients as well as durability [29].

A V-shaped cross section reduces belt tension and sideway slip, making this alternative suitable for fast moving belt transmissions. V-shaped belts also increase the friction against the pulley as the side provides an increased surface area. Flat belts provide a slight increase in energy efficiency compared to V-belts, due to reduced losses from bending as thinner cross sections are possible. A drawback of flat belts is instead the increased risk of misalignment of the belt around the pulley. [30]

Figure 21. A view of a belt pulley system with grooved pulleys and belt. The belts in this picture have a grooved, rectangular cross-section. [31]

6.2.1.4 Rack and pinion

A rack and pinion system consists of a grooved bar with rectangular cross section called a rack, and a grooved gear which can have straight or helical teeth and is called pinion. Figure 22 shows a rack and pinion system with straight teeth. The teeth on the pinon meshes with the teeth of the rack. Assuming a fixed pinon axis, the system can act in two ways. The first alternative is to translate the rack linearly by rotating the pinion. The second alternative is to rotate the pinion by translating the rack, where the direction of linear movement directly decides the direction of rotation. [32]

Figure 22. A rack and pinion gear with straight teeth. [33]

6.2.1.5 Springs

Springs are flexible elements able to store or release energy as mechanical work. A spring is commonly made of circular or rectangular bent wire and can exert force as either a linear push or pull motion, alternatively in the radial direction. There are also types of springs on the market that can produce torque. Energy is generally stored when to spring have been deformed and released when the mechanical tension is being released. Springs are designed with various specifications such as minimum and maximum length, allowable stress, spring index and more. [34]

6.3 Search internally

The process of Search internally have mainly focused on iterative concept generation conducted by the authors. Weekly sprints and two brainstorming meetings have been held to support this continuous concept generation. These complementary activities are further described below.

6.3.1 **Brainstorming 1**

A brainstorming session was performed in the fourth week of the thesis project. The session was held at the Arjo office together with experienced engineers who understand the problem related to the thesis project. The starting point of the session was to visualise and keep the problem in mind, which mainly concerns elevating a resident chair while maintaining the stability criteria. One important ground rule for the session was established, namely to avoid any negative criticism of ideas. The session procedure was then conducted as follows:

1. All members of the session were handed a simple illustration of the problem.

2. Every member contemplated the problem individually and produced conceptual solutions including drawings and short descriptions.

3. Each member took turns to present their solutions in front of the group. The other members could ask questions about a solution(s), without criticising.

4. All concept solutions presented were put on a whiteboard to get an overview, and further discussions arose on different concept combinations.

The results from the brainstorming session were compiled and sorted into clusters based on design similarities. These clusters were: enlargement of the chassis, moving of the centre of mass, weight-dependent chassis, and stand-alone concepts. A summary of the results can be found in Appendix C.

6.3.2 **Brainstorming 2**

A second brainstorming session was performed in the eighth week of the thesis project. At this stage, the goal was to widen the available number of concepts, with focus on the principle of moving the position of the centre of mass. The participants were the same as during the last brainstorming session. The session resulted in several new concept ideas, solving the centre of mass problem in different ways. A summary of the resulting concepts can be found in Appendix D.

6.3.3 Weekly sprint meetings

Along the entire project, sprint meetings according to the Agile project methodology have been conducted at the Arjo office facilities in Malmö each week. This can be seen as an opportunity to show the work progress and discuss topics related to the development activities, together with experienced engineers at the company. This provided valuable knowledge and input for the project work, which can be seen as part of the internal knowledge search.

6.4 Explore systematically

According to U&E [5], a systematic exploration should be conducted where subcomponents of each concept are extracted to be combined with subcomponents from other concepts. However, such a thorough investigation of concepts on a detailed level was not seen as realistic given the project timeline. Due to this, a systematic exploration was not fully conducted, but have instead been used as inspiration where concepts have been combined on a broader level during the development stage.

In addition to this, a continuation of iterative development according to the agile methodology have been adopted in parallel with the concept screening and selection stages described by U&E.

6.5 Generated concepts

Based on the ideas sorted into clusters from brainstorming 1, further development of selected concept solutions was conducted. The development initially took inspiration from each cluster separately, while later designs merged concepts from different clusters to find new concept combinations. The concepts in this chapter will therefore be presented in groups based on common design characteristics.

6.5.1 Concept type A - Linear chassis extension

The concepts of type A includes different variants of chassis designs that extends linearly to increase the chassis length, which in turn increases stability. All concepts of this type share the principle of extending the chassis, but they vary by being driven by different technical principles.

6.5.1.1 Concept A.1 - *The Double Actuator System*

The Double Actuator System, shown in Figure 23, features a linearly extending chassis driven directly by one linear actuator for each leg. The actuators can push and pull both legs back and forth depending on the required chassis length. The “inner legs” are sliding inside the outer leg chassis with linear motion bearings. These bearings can either be the simple sliding bearings where POM plastics can be utilized to reduce friction, or roller bearings if the friction needs to be further reduced.

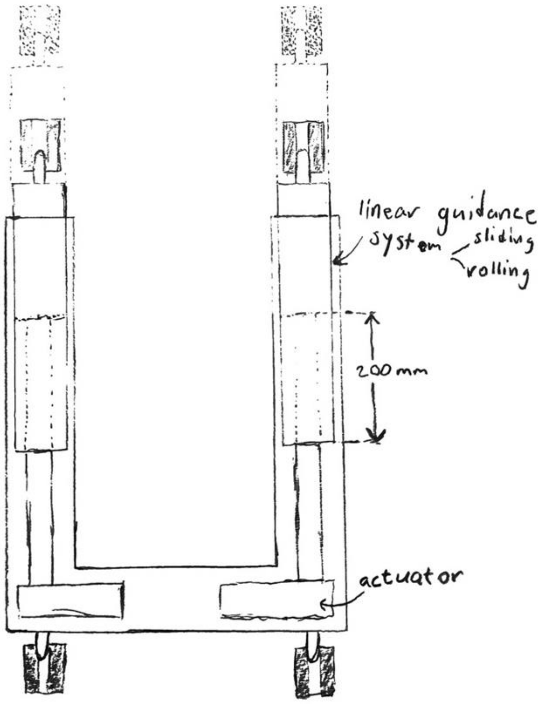

Figure 23. Concept A.1 - *The Double Actuator System.*

6.5.1.2 Concept A.2 - *The Rack and Pinion System*

The Rack and Pinion System relies on a centralised motion which rotates an axle with pinions at each end. These pinions drive a gear rack mounted on each extending leg, which results in simultaneous extension on both sides. The rotating motion could for example be driven by either a belt, a bevel gear drive, or using direct electric drive with a DC-motor. In Figure 24, an example of the rack and pinion system is shown with a bevel gear drive, only illustrating the interior parts to be placed inside the outer chassis.

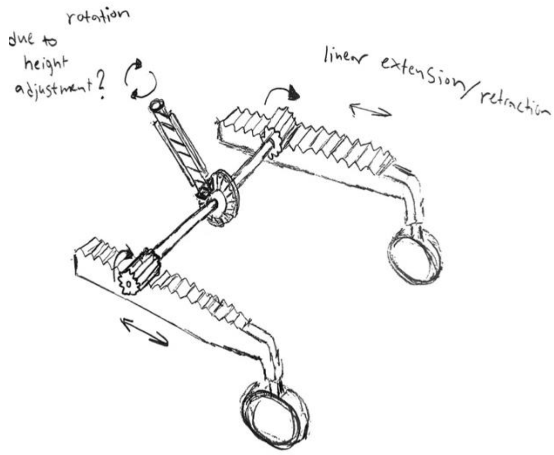

Figure 24. Concept A.2 - *The Rack and Pinion System.*

6.5.1.3 Concept A.3 - *The Pulley System*

The Pulley System uses the principle of pulleys and a belt to drive the linear extension motion. Two pulley wheels are located on each side of the chassis, connected with a belt. A pin is located on the bottom outer surface of the belt, which attaches to the inner sliding leg. The pulley system is driven by turning the axle which interlinks the two chassis sides. This axle can for example be driven by either a belt connected to the seat subsystem, or an electric motor driving the rotation motion directly. As the pulleys and belt turn, the pin attached to the leg is moving horizontally following a slot path. This motion extends or retracts the inner legs depending on the direction of rotation. A view of the concept can be seen in Figure 25.

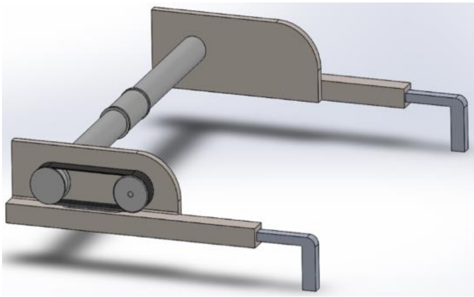

Figure 25. Concept A.3 - *The Pulley System.*

6.5.1.4 Concept A.4 - *The Arc-Guided Push System*

The Arc-Guided Push System features linearly guided legs that connects to an arc shaped slot on each side of the chassis, which can be seen in Figure 26. Two stiff arms are interconnected by a rod which slides along the arc shaped slot. As the rod gets pushed lower in the slot, the arms push the two legs simultaneously on both sides of the chassis, which extends the legs. The motion driving the rod's path can for example be a belt drive or actuator connected to the remaining subsystems.

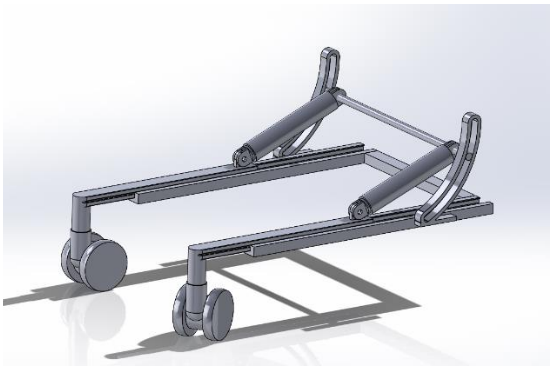

Figure 26. Concept A.4 - *The Arc Guided Push System.*

6.5.1.5 Concept A.5 - *The Perpendicular Linkage System*

Another concept for linear chassis extension is *The Perpendicular Linkage System*, which is based on the “Scott Russell linkage” [35]. A view of the concept at a half-way extended position is shown in Figure 27. The linkage system consists of two links, one longer and one shorter. When one end of the longer link moves in one direction, the other end moves perpendicular to this direction. A linear actuator placed within the front beam of the chassis moves one end of the longer link. The other end of the link then pushes a rod, which connects the moving legs and allows simultaneous extension. The slide mechanism for the legs is based on linear guides similar to the previously mentioned concepts based on linear extension.

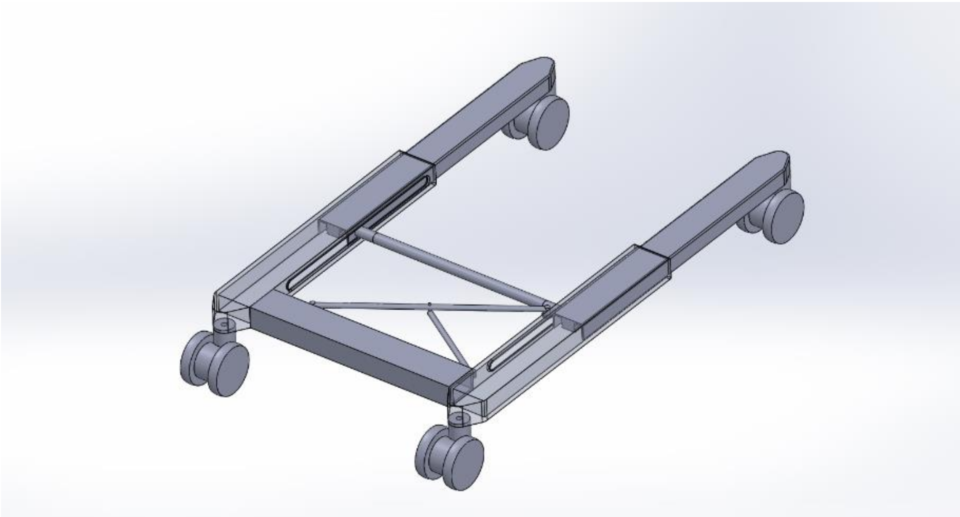

Figure 27. Concept A.5 - *The Perpendicular Linkage System.*

6.5.2 **Concept type B - Rotating chassis support legs**

Concepts of type B uses rotating support legs in addition the ordinary chassis back wheels. These support legs expand the safe triangle area according to the 10° tilt requirement when the resident is sitting in an elevated seat position. Two different concepts have been generated and are shown below.

6.5.2.1 Concept B.1 - *The Side-mounted Rotating Support Legs*

The Side-mounted Rotating Support Legs concept features support legs mounted on the outer sides of the chassis. These legs are extended by a wire and pulley system. This system allows the support legs to be folded outwards when the wires are pulled in one direction and folded back in when the wires are pulled in the opposite direction. The pulling mechanism of the wires could for example be driven either by a mechanical pedal or a DC-motor. The concept is illustrated in Figure 28.

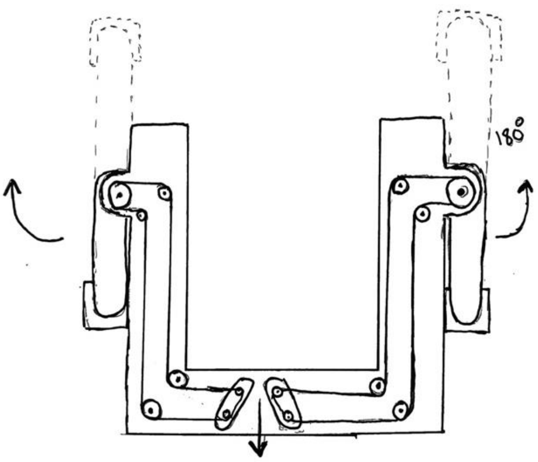

Figure 28. Concept B.1 - The Side-mounted Rotation Support Legs.

6.5.2.2 Concept B.2 - *The Top-mounted Rotating Support Legs*

The Top-mounted Rotating Support Legs is a variant of the rotating chassis support. This design features support legs which are mounted on top of the chassis instead of on the sides. The plane of rotation is angled towards the ground, as shown in Figure 29. This angled plane of rotation results in the legs touching the ground when fully extended, which enlarges the footprint and increases stability according to the 10° tilt requirement. The rotation could for example be driven by a DC-motor.

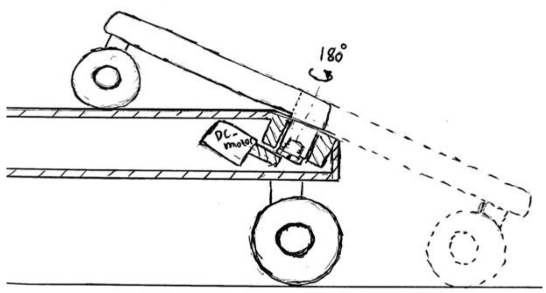

Figure 29. Concept B.2 - *The Top-mounted Rotating Support Legs.*

6.5.3 Concept type C - *The Sliding Link*

The Sliding Link concept is based on similar sliding functionality as the concepts related to linear chassis extension, but the moving parts are instead connected to the link and seat subsystems. Two linear actuators push the link base along both sides of the chassis in linear guide tracks with relatively low friction. The idea of this concept is to solve the stability requirement by adjusting the position of the centre of mass by moving the link base. A view of the sliding link concept is shown in Figure 30.

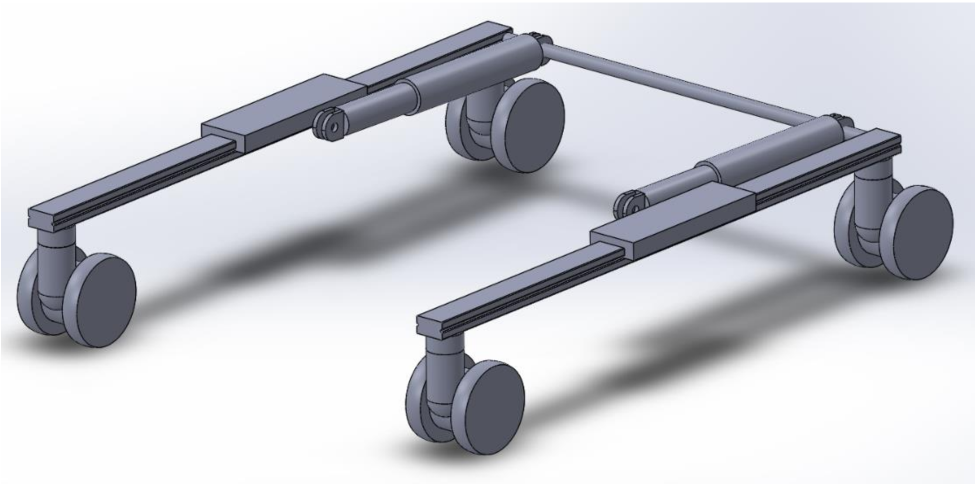

Figure 30. Concept C - *The Sliding Link.*

6.5.4 **Concept type D - Rotating back wheels**

Two concepts based on rotating back wheels were also generated. These are similar to the ones described in concept type B, *Rotating Chassis Support Legs*, but instead of adding support legs to the existing chassis, the back wheels themselves can be rotated. With this design, the chassis length can be minimized during toileting and still provide sufficient chassis length when the back wheels are rotated back to their nominal position.

6.5.4.1 Concept D.1 - *The Parallelogram Linkage System*

One of the concepts generated in order to rotate the back wheels is called *The Parallelogram Linkage System* and is based on a parallelogram linkage mechanism. The linkage system, which can be seen in Figure 31, allows the back wheels on both sides of the chassis to rotate when the discs seen in the figure rotates. These discs are forced to be rotated within a certain degree due to a simple slot that is connected via pins to each disc. This rotation could be driven either by a DC-motor or manually with foot pedals.

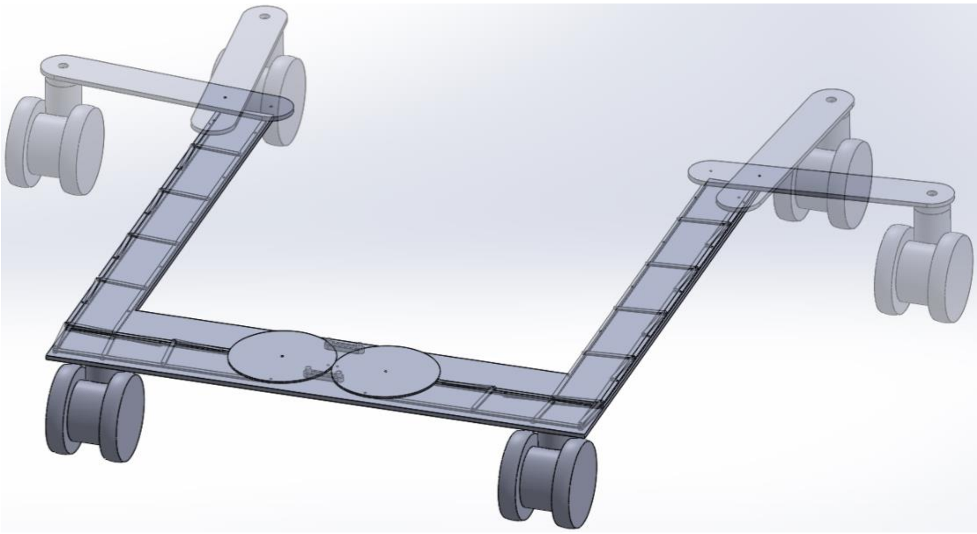

Figure 31. Concept D.1 - *The Parallelogram Linkage System*.

6.5.4.2 Concept D.2 - *The Wire and Spring Leg Rotation*

The second concept for rotating the back wheels is called *The Wire and Spring Leg Rotation* and is based on a wire and spring system, driven by a DC-motor placed inside the front chassis bridge. The initial position of the back wheels is at maximal chassis length, where a spring keeps the wire stretched with a certain force. To rotate the legs and shorten the chassis, the DC-motor rotates a spool on which the wire is wound up, stretching the wire further and with a force greater than the loaded spring force, which forces the back leg and wheel to rotate. A conceptual sketch showing the principle on one leg is presented in Figure 32.

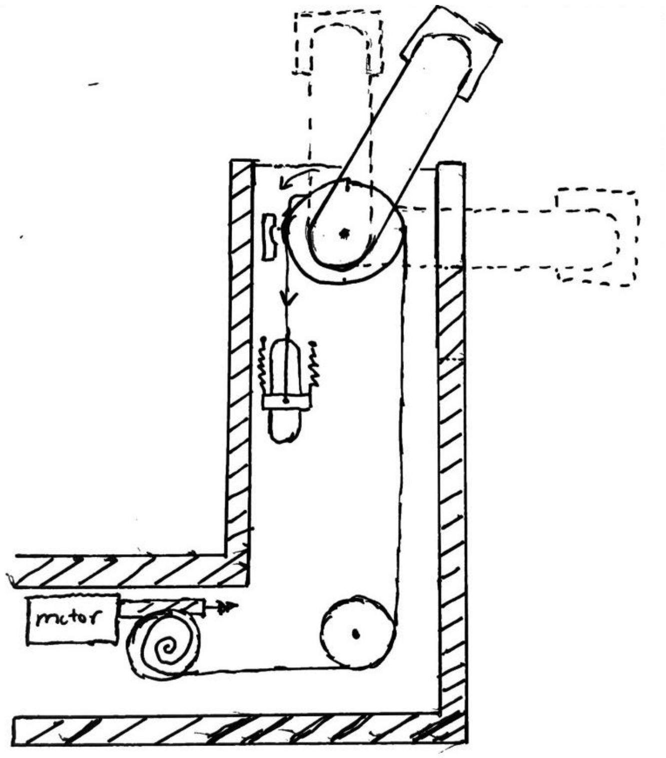

Figure 32. Concept D.2 - ***"The Wire and Spring Leg Rotation".***

6.5.5 **Concept type E - *The Combined Extend and Raise System***

The Combined Extend and Raise System can be seen as a combination of a linear chassis extension together with a rotating and raising mechanism. The intention was to change adjustments related to different subsystems simultaneously in one single motion. Therefore, this concept takes both the chassis and the link subsystems into account, instead of solely focusing on the chassis design. By pushing the inner legs on each side outwards using linear actuators, as well as connecting the longer link arms to the inner legs, a motion of leg extension and height adjustment of the chair can be done simultaneously. Both the attachment of the longer arms and the actuators can be seen in Figure 33.

Figure 33. Concept E - *The Combined Extend and Raise System*

7 Concept selection

This chapter covers the evaluation and selection of the generated concepts.

7.1 Concept screening

After the first iteration of concept development, a concept screening was conducted according to the methodology described by U&E. The concepts previously described in Chapter 6 were inserted in a screening matrix to compare their relative strengths and weaknesses, and thereby remove lower rated alternatives. The comparison is based on chosen criteria which take several aspects relevant for a future hygiene chair into account. The following criteria were chosen:

- Technical Feasibility
  - How realisable the concept is to further develop and produce.
- Space Efficiency
  - How well the concept uses its available space.
- Durability
  - How well the concept can withstand use and abuse.
- Integration Capability
  - How well the concept enables integration with the remaining product (seat etc.).
- Hygiene
  - How easy the concept is to keep clean.
- Cost Efficiency
  - How cheap the concept is to manufacture.

The rating used to rank each concept in the screening matrix is based on a relative score compared to a chosen reference concept. The reference concept is given a neutral rating "0" for each criterion, giving this concept a total summarised score of zero. The remaining concepts are evaluated relative to the reference, where each criterion can, in addition to the neutral score of "0", also receive a plus ("+") if it is performing better or a minus ("-") if worse. The total score of each concept is then summarised and compared to evaluate and remove low scoring alternatives. The resulting concept screening matrix is presented in Table 8.

To summarise, the generated concepts together with their assigned indexing are shown below.

- A.1 – *The Double Actuator System (reference)*
- A.2 – *The Rack and Pinion System*
- A.3 – *The Pulley System*
- A.4 – *The Arc-Guided Push system*
- A.5 – *The Perpendicular Linkage System*
- B.1 – *The Side-mounted Rotating Support Legs*
- B.2 – *The Top-mounted Rotating Support Legs*
- C – *The Sliding Link*
- D.1 – *The Parallelogram Linkage System*
- D.2 – *The Wire and Spring Leg Rotation*
- E – *The Combined Extend and Raise System*

Table 8. The Concept screening matrix.

	A.1 (ref)	**A.2**	**A.3**	**A.4**	**A.5**	**B.1**	**B.2**	**C**	**D.1**	**D.2**	**E**
Technical Feasibility	0	0	-	-	-	0	0	0	-	-	0
Space Efficiency	0	0	0	0	0	-	0	0	-	-	0
Durability	0	0	-	0	-	-	-	0	-	-	0
Integration Capability	0	+	+	+	0	0	0	0	0	0	+
Hygiene	0	0	0	-	-	0	0	-	0	0	-
Cost Efficiency	0	-	+	0	0	+	+	0	+	+	+
Sum +'s	0	1	2	1	0	1	1	0	1	1	2
Sum 0's	6	4	2	3	3	3	4	5	2	2	3
Sum – 's	0	1	2	2	3	2	1	1	3	3	1
Net Score	0	0	0	-1	-3	-1	0	-1	-2	-2	1
Rank	2	2	2	3	5	3	2	3	4	4	1
Continue?	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes

7.2 Further development

Based on the concept screening matrix, the lowest scoring concepts were excluded to narrow down the broad selection of concepts. The excluded concepts were ranked at either place 4 or 5, and includes both concepts of rotating back wheels, as well as *The Perpendicular Linkage System*.

The highest ranked concept, *The Combined Extend and Raise System*, was chosen to be further developed which led to a new concept. The new concept was therefore indexed as concept E.2, and its predecessor concept E.1 instead of E.

7.2.1 **Concept E.2 - *The Combined Extend and Raise System, Forwards Extension***

During this further development, based on the concept E.1, both the direction of the chassis extension as well as the location of the linear actuators were changed. While the previous concept used the linear actuators to push the inner legs horizontally to extend them, the actuators in the redesigned concept are instead placed under the upper arms holding the seat. A pair of lower arms are connected between the upper arms and the inner legs. When the actuators push and raise the upper arms, they rotate forwards which in turn allows the lower arms to pull the inner legs forwards to extend the chassis. The forward extension showed to provide a safer centre of mass position while testing the articulation against the 10° tilt requirement. Concept E.2 is presented in Figure 34.

Figure 34. Concept E.2 - *The Combined Extend and Raise System, Forwards Extension.*

7.3 Concept scoring

After the iterative development of concept E.2, a concept scoring was conducted. The scoring matrix shares similarities with the screening matrix but uses a rating between 1 and 4 for each evaluated criterion. No reference concept was used in the scoring matrix, as each criterion were instead rated from 1-4. The rating alternatives can be described accordingly:

- A rating of 4: The concept fulfils the criterion ***very well***.
- A rating of 3: The concept fulfils the criterion ***well***.
- A rating of 2: The concept fulfils the criterion ***neither well nor poorly***.
- A rating of 1: The concept fulfils the criterion ***poorly.***

Each criterion also received a relative weight in percent. The most important criteria were deemed to be *Space Efficiency*, *Durability*, and *Hygiene*, which received a weight of 20% each. *Technical Feasibility* and *Integration Capability* were both deemed to be the second most important criteria and received a weight of 15% each. *Cost Efficiency* received a weight of 10%, resulting in a total weight for all criteria of 100%.

The score of each concept was summarised and compared against each other. The concept scoring matrix is presented in Table 9.

Table 9. Concept scoring matrix with indication for each concept whether they should be further developed, discontinued, or kept in mind.

	Rel. Weight	**A.1**	**A.2**	**A.3**	**A.4**	**B.1**	**B.2**	**C**	**E.1**	**E.2**
Technical Feasibility	0.15	4	3	2	1	2	3	4	3	3
Space Efficiency	0.2	3	2	3	2	1	2	3	3	4
Durability	0.2	3	4	2	3	2	2	3	3	3
Integration Capability	0.15	1	3	3	2	1	1	1	4	4
Hygiene	0.2	3	2	2	1	3	3	2	2	2
Cost Efficiency	0.1	2	2	3	3	3	3	2	3	3
Net Score	1	2.75	2.7	2.45	1.95	1.95	2.3	2.55	2.95	3.15
Rank	-	3	4	6	8	8	7	5	2	1
Continue?	-	DSC	KIM	KIM	No	No	KIM	KIM	KIM	Yes
Descriptions of acronyms used in table: DSC – Develop similar concepts instead KIM – Keep in mind										

8 Prototyping and physical testing

This chapter covers the process of prototyping and conducting tests to evaluate desired criteria for a prototype, and later a fully functioning hygiene chair chassis.

8.1 The purpose of making a prototype

Based on the concept scoring, the new concept *The Combined Extend and Raise System, Forwards Extension* was chosen to be developed and built as a full-scale physical prototype. The aim of producing a physical prototype was mainly to test whether the principial design functions as intended when real forces and friction are present, but also to get a sense of the actual size of the physical concept. Regarding the mechanical principles of the concept, two aspects were interesting to test. The first was to see how much force would be required to extend the chassis under a real load case with approximately 100 kg load on each side of the chassis, which equates to about 200 kg in SWL. The second aspect was to test out a reasonable linkage geometry regarding available actuators and at the same time find the desired seat height adjustment relative to chassis length extension.

8.2 Building the prototype

In order to produce a physical prototype, brief drawings based on the concept CAD model were presented to the personnel working in a R&D workshop, located at the Arjo headquarters in Malmö. The workshop provided all the resources needed to be able to build and test the physical version. Here, iterative design changes were made based on trial and error, and some initial concept design choices were changed in consultation with personnel from the workshop. The available linear actuators also affected the prototype design. The CAD drawings can be found in Appendix E, where both the first version and a redesigned version is presented. From there, a physical test prototype was produced with several adjustment plates with holes at linkage intersections, to be able to test different configurations for the geometry. Only one of the two chassis sides of the chosen concept was produced as a prototype since it was seen as sufficient to perform the planned tests. The final prototype can be seen in Figure 35.

Figure 35. The final prototype produced in the company workshop.

8.2.1 Available adjustments for the prototype

The CAD drawings for the prototype were conceptual and didn't have any final measurements of the attachment points for the linear actuators and arm. Holes have therefore been drilled to test different configurations of the attachments. The attachments with adjustment holes can be seen in Figure 36.

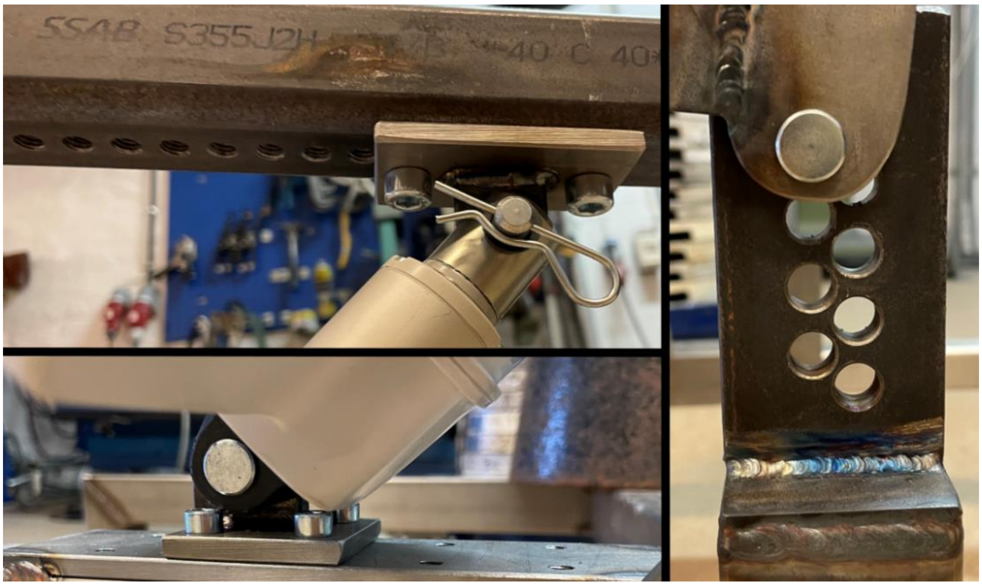

Figure 36. Close up pictures of the available adjustment holes for the prototype.

The attachments can be moved according to the lengths described in Figure 37. Here, the adjustable lengths A, B, and C have the following descriptions and available measurements, all given in millimetres:

A - Measurement between the front of the chassis and the centre point of the lower attachment for the actuator:

340, 355, 370, 385, 400, 415, 430, 445, 460

B - Measurement between the centreline perpendicular to the arm and the centre point of the upper attachment for the actuator:

177, 189.5, 202, 214.5, 227, 239.5, 252, 264.5, 277

C - Measurement between the bottom of the chassis and the centre of the attachment point for the arm:

165, 172.5, 180, 187.5, 195, 202.5, 210, 217.5, 225, 232.5

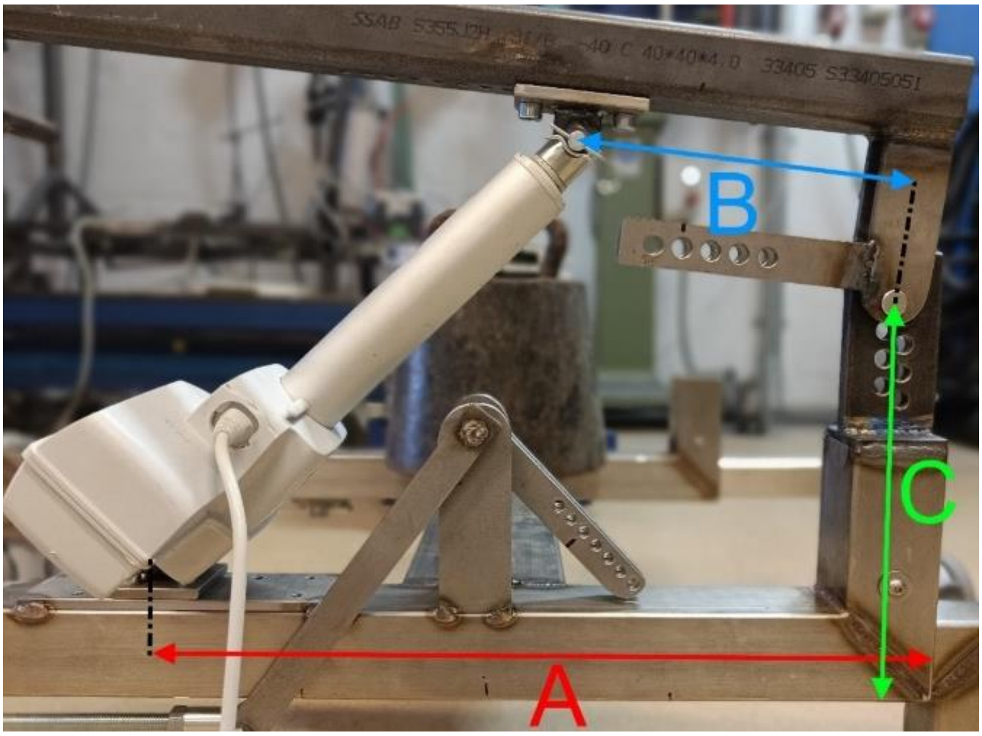

Figure 37. Three parameters, A, B, and C are available for adjusting the location of the attachment points for the linear actuator and the pivot point of the arm.

8.3 CAD testing for finding suitable configurations

Since there are 9 different available configurations each for parameters A and B, and 10 different available configurations for parameter C, the total number of available combinations amounts to 810. To narrow down the search for a suitable configuration and avoid having to test every possible combination, a simple CAD model was made. This model had the same measurements as the physical prototype, both regarding attachment point adjustments and linear actuator stroke length. The CAD model can be seen in Figure 38.

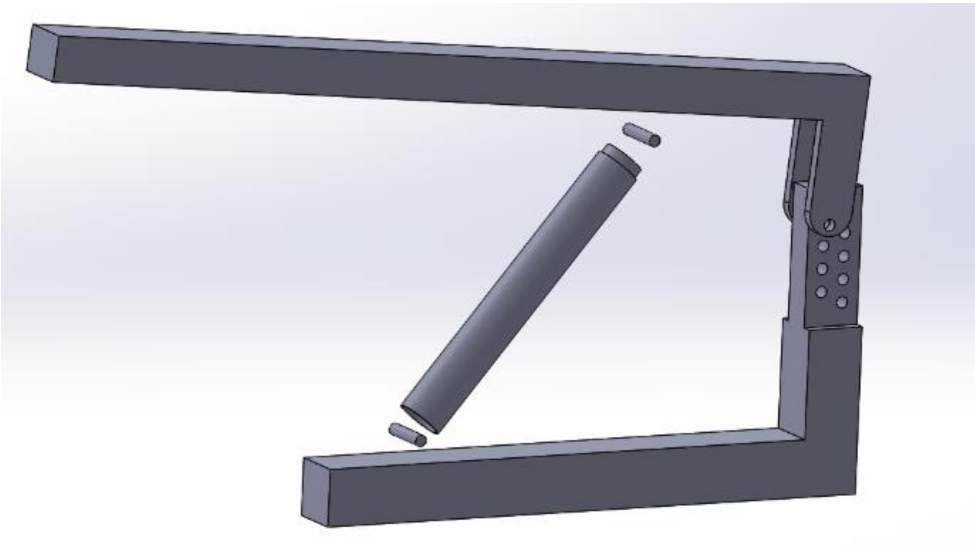

Figure 38. CAD model used to find suitable configurations for the prototype.

The target specifications presented earlier were used to find suitable configurations for the prototype. Target specifications No. 27 and 28 show a targeted minimum seat height of 500 mm from the floor, and a maximum seat height of 1000 mm from the floor. Since the seat is supposed to be located at the end of the upper arm, different configurations for the attachment points were tested until the end of the upper arm traverses from about 500 mm from the floor to 1000 mm from the floor when the linear actuator extends. This testing resulted in a set of configurations suitable for possible attachment points, which were written down to be verified by the physical prototype.

8.4 Physical testing

With suitable configurations found theoretically through the CAD model, testing these with the physical prototype could begin. Three different loads were tested for each configuration, 20, 60, and 100 kg. During the testing, the required input current for driving the linear actuator was measured during the whole actuator movement. The start current was measured during the first few seconds of activation, and the end current was measured right before reaching the end of the stroke. The supposed seat heights, both during the lowest and highest setting, were also recorded for each configuration. These measurements also gives the stroke height of each configuration, which is the maximum height subtracted by the minimum height. The final results from the physical testing is summarised in Table 10.

Table 10. Summary of the tested configurations with different adjustable lengths A-C, loads, and measured currents required to drive the linear actuator. The stroke height for each configuration is also presented, based on minimum and maximum measured seat height.

Conf. No.	Length A [mm]	Length B [mm]	Length C [mm]	Load [kg]	Start current [A]	End current [A]	Min. height [mm]	Max. height [mm]	Stroke height [mm]
1.1	415	189.5	232.5	20	0.9	0.7	595	1050	455
1.2	415	189.5	232.5	60	1.5	1.1	595	1050	455
1.3	415	189.5	232.5	100	2.2	1.3	595	1050	455
2.1	415	177	232.5	20	0.8	0.5	570	1060	490
2.2	415	177	232.5	60	1.7	0.7	570	1060	490
2.3	415	177	232.5	100	2.3	1.6	570	1060	490
3.1	430	177	232.5	20	1.1	0.8	525	1030	505
3.2	430	177	232.5	60	1.5	1.1	525	1030	505
3.3	430	177	232.5	100	2.5	1.6	525	1030	505
4.1	430	177	225	20	1.3	0.7	510	1025	515
4.2	430	177	225	60	1.7	1.1	510	1025	515
4.3	430	177	225	100	2.5	1.6	510	1025	515
5.1	430	177	217.5	20	1.3	0.7	555	1040	485
5.2	430	177	217.5	60	1.8	1.1	555	1040	485
5.3	430	177	217.5	100	2.4	1.5	555	1040	485

9 Results

In this chapter, results for the project are presented based on the questions stated in the introductory chapter. This includes various concept alternatives for a dynamic chassis and the final concept design based on the test results given from the physical prototype testing.

9.1 Introduction

Based on the research questions defined in Chapter 1.4.1, the result for this project consists of both concept alternatives generated to make the chassis dynamic, and the final concept design which can be seen as the most suitable alternative at this early stage of development.

9.2 Concept design alternatives

As seen in Chapter 6.5 Generated concepts, there are several ways to design a dynamic chassis and at the same time address the moving centre of mass location. Most concepts solve the problem by using extending chassis legs, which has shown to be a simple and effective solution to provide a safety margin for the centre of mass location.

Different ways of driving an extending leg mechanism have been explored and are not excluded completely for future prototyping activities. Rather, they represent a selection of alternatives to explore further if the mechanisms of the current prototype do not function as intended during further testing. The driving mechanism of choice also depends on for example cost and durability. This topic will be discussed further in Chapter 10 Future Work.

Other concepts used either rotating back legs or supports to minimize the chassis length during toileting and adding length as the seat gets closer to an elevated showering position. These concept solutions may be seen as low-cost alternatives compared to other more complex concept designs, as they are relatively simple and can be made without electronics and software involved.

9.3 Final concept design

The final concept for this thesis project is based on concept E.2 - *The Combined Extend and Raise System*, *Forwards Extension,* with a slightly changed design due to what showed to be realisable from the physical build. Some design changes came directly from the prototyping stage, while others take inspiration from the prototype. The final concept design can be seen in Figure 39, and with an added mock-up of a seat subsystem in Figure 40.

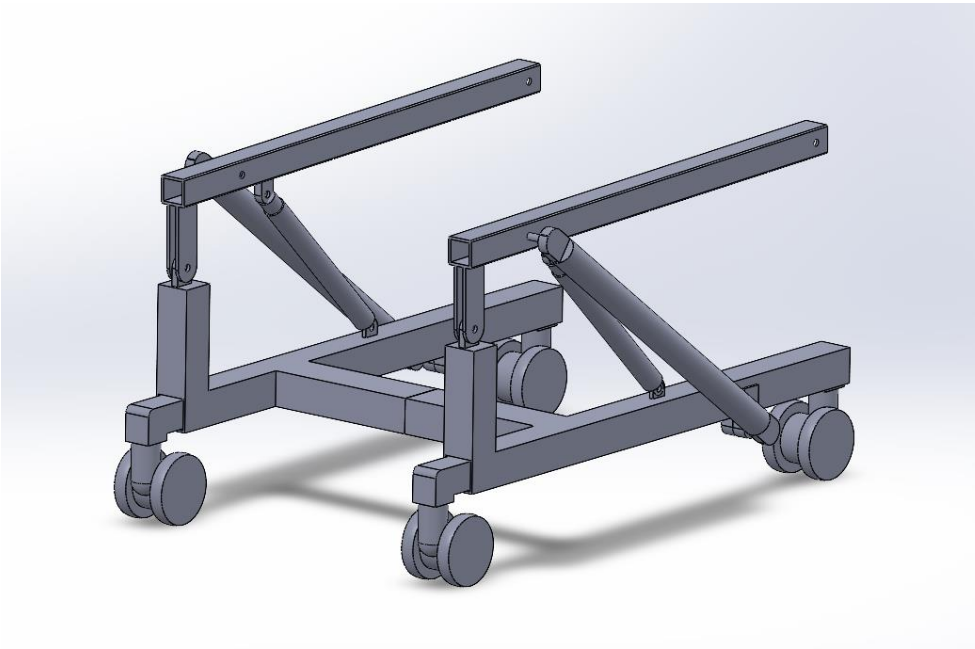

Figure 39. The final concept design of the chassis system, which partially includes the link subsystem.

Figure 40. The final concept design with an added seat system to show the chassis in relation to the entire product.

For the final version, one actuator has been placed on top of each leg of the chassis with an appropriate geometric configuration based on the prototype testing. The leg extensions on both sides are guided with a linear guide system using POM plastics. POM is Inside the front of the chassis, a POM roller wheel is placed on each side, supporting the upper surface of the inner legs which can be seen in Figure 41. Another smaller roller wheel made of the same material is partially inserted inside the end of the inner leg, see Figure 42, providing low friction support against the inner surface of the outer chassis. This linear guide design is a result from the work on the prototype in the workshop and proved to be simple and effective and gave no indication of increased current consumption for the linear actuators during testing.

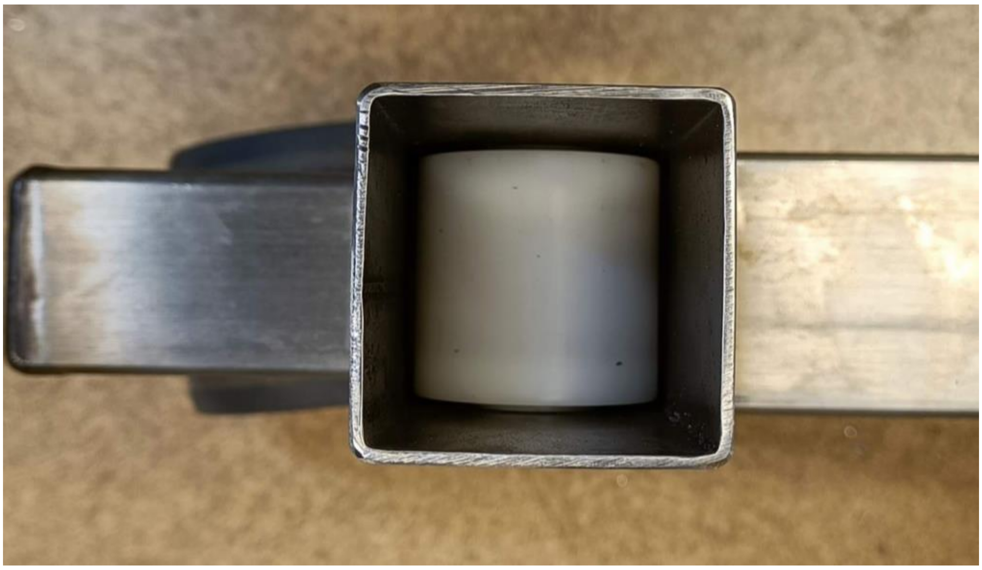

Figure 41. Top view of the POM roller wheel mounted inside the chassis front, supporting the upper surface of the inner leg which can extend linearly.

Figure 42. View of the inner leg and the POM rollers. The larger POM wheel is mounted inside the outer chassis in front, and the smaller wheel is attached to the inner leg sliding inside the outer chassis on the opposite side of the leg.

The linkage mechanism that drives the inner legs in and out will probably have an attachment placed under the chassis legs and not on the sides as in the previous CAD concept. This is mainly due to better hygiene and ease of cleaning. The final concept has therefore been changed to have this placement, which also is a design change inspired by the ideas generated during the prototyping stage in the workshop. The new attachment system connected to the driving linkage arm can be seen in Figure 43.

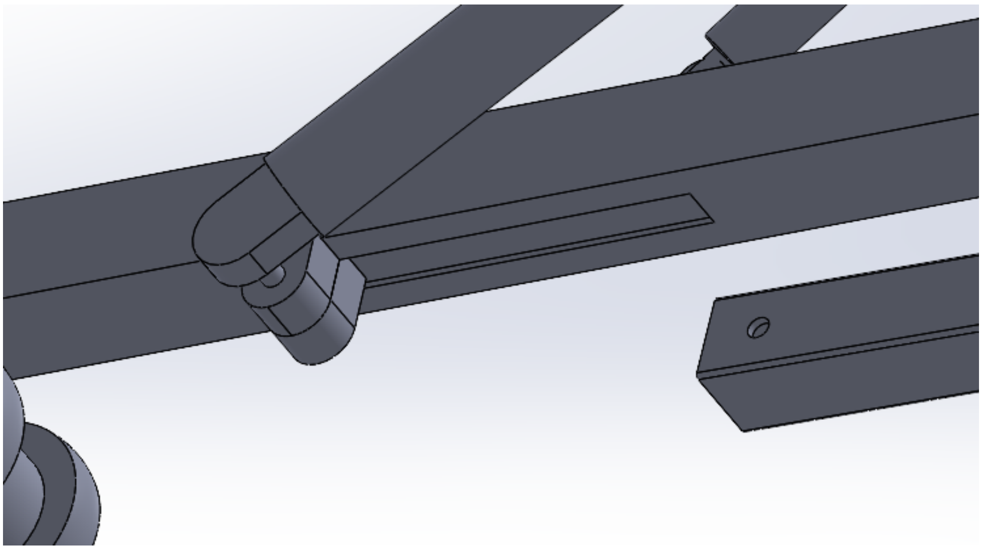

Figure 43. The new attachment system between the linkage arm and the inner leg placed inside the chassis.

9.3.1 Fulfilled specifications

To verify which specifications that have been fulfilled by the final concept design, a new list, shown in Table 11, have been made consisting of the target specifications and a column describing if each metric has been fulfilled or not. Many of the metrics have been fulfilled, but some could not be tested during the timeline of this thesis work.

Table 11. Fulfilled specifications based on the target specifications. The descriptions of abbreviations and acronyms used are found at the end of the table.

No.	Metric	Target Value	Unit	I.	Fulfilled
1	Free height under seat	400	mm	3	Yes
2	Commodity hole width	145	mm	3	Yes
3	Backrest depth in length direction (bird's eye view)	80	mm	1	Yes
4	Chassis length	750-1050	mm	3	Yes
5	Free length under seat	500-700	mm	3	Yes
6	Free width under seat	450	mm	3	Yes
7	Minimum door width for passing through	750	mm	3	Yes
8	Chassis free height, floor to frame	120	mm	1	Yes
9	The lifter is designed to address B-D residents	Yes	Bin.	3	Yes
10	One single caregiver for all intended operations	Yes	Bin.	3	Yes
11	Easy to understand the possible articulations	Yes	Subj.	1	N.T
12	Easy to understand reaction to different weights	Yes	Subj.	1	N.T
13	Chassis rigid enough to be pushed around by foot	Yes	Bin.	2	Yes
14.	May be pushed around with ease while fully loaded	Yes	Bin.	1	Yes
15	Tilt w/o tipping, forward dir., intended wheel pos.	10	Deg.	3	N.T.P
16	Tilt w/o tipping, forward dir., most adverse condition	7	Deg.	3	N.T.P
17	Tilt w/o tipping, any other direction than forward.	5	Deg.	3	N.T.P
18	Safe distance between moving parts, finger traps	SD<8 SD>25	mm	2	No
19	Safe distance between moving parts, foot traps	SD<35 SD>120	mm	2	Yes
20	Safe distance between moving parts, head traps	SD<120 SD>300	mm	2	Yes
21	Safe distance between moving parts, genitalia traps	SD<8 SD>75	mm	2	Yes
22	Can be used on slightly uneven floor surfaces	Yes	Bin.	3	N.T.P
23	Protruding parts with risk of tripping/stumbling	0	Nbr.	2	No
24	Safe working load	150-200	kg	1	N.T.P
25	Maximum hands required to perform service	2	Nbr.	1	N/A
26	Angle between seat and backrest in raised position	180	Deg.	3	N/A
27.	Maximum height floor to top seat surface	1000	mm	2	Yes
28	Minimum height floor to top seat surface	500	mm	2	Yes
29	Seat tilt angle from horizontal plane, forward dir.	35	Deg.	1	N/A
30	Avoid indents and pockets for exterior parts	Yes	Bin.	2	No
31	Lifetime of steel frame	10	Yrs.	2	N.T
32	Lifetime of soft parts	2	Yrs.	2	N.T

Descriptions of abbreviations and acronyms used in table:
Bin. – binary Deg. – degrees Dir. – direction I. – importance Nbr. – number
Pos. – position SD – safe distance Subj. – subjective w/o – without Yrs. – years
N.T – not tested N.T.P – not tested physically N/A – not applicable

To verify that the final concept fulfils the 10° tilt requirement, the *Flatman* test dummy, together with the 10° tilting lines, were added to the CAD model. The *Flatman* dummy was added with a distance from both the seat and the backrest according to the ISO 7176-11 standard for test dummies. The centre of mass position was then tested throughout the entire articulation to verify that the tilt requirement was successfully being fulfilled. The final concept test at the lowest and the highest seat positions are presented in Figure 44 and Figure 45 respectively.

Figure 44. View of the concept at its lowest position in relation to the 10° tilt requirement. The centre of mass is located inside the borders with a relatively large safety margin.

Figure 45. View of the concept at its highest position in relation to the 10° tilt requirement. The centre of mass is located inside the borders with a relatively large safety margin.

As can be seen in Figure 45, if the chassis had not been extended forwards, the centre of mass would be dangerously close to the 10° tilting line.

The final concept was also tested to fit the test toilet made in CAD which is based on demanding toilets. It showed to perform well together with the toilet in the CAD environment, and a view of the chair during toileting is shown in Figure 46.

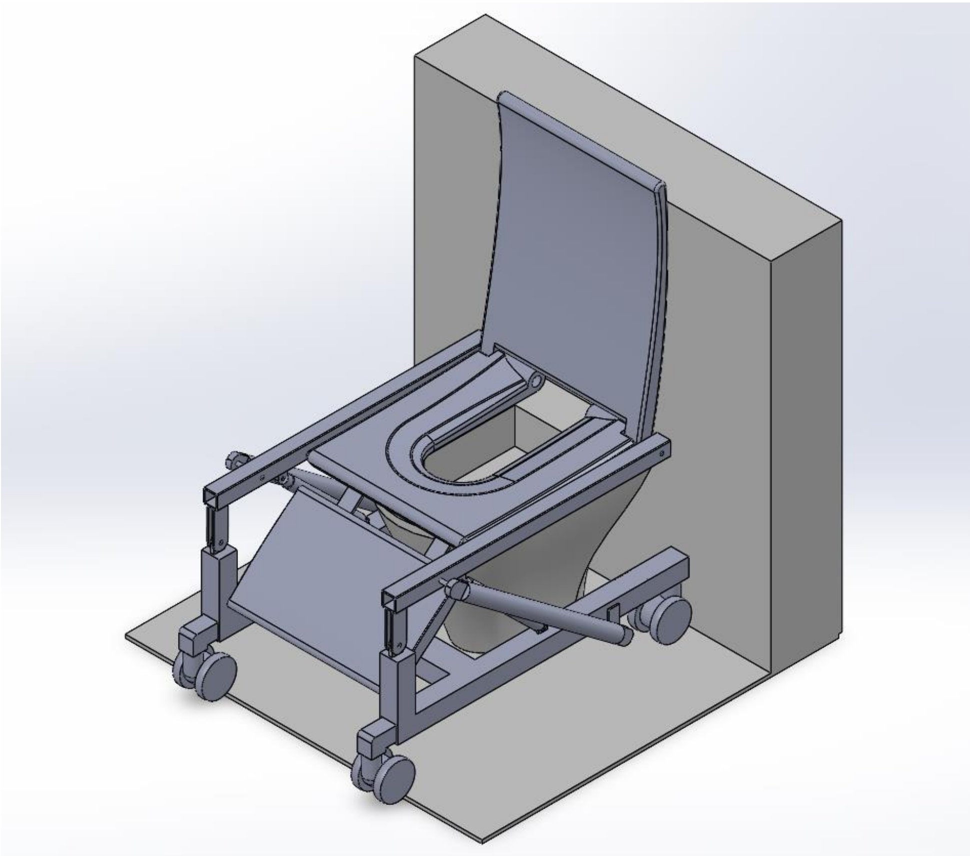

Figure 46. The final concept tested to fit the demanding sized toilet in CAD.

10 Future work

This chapter covers suggested activities that can be done to further develop the concept designs generated in this thesis.

10.1 Introduction

Looking back at the concept ideas offered to Arjo as a whole, several alternatives have been presented that can be further investigated in upcoming development stages. The final concept solution fulfils many of the requirements defined and stated early in the project. However, as the work presented in this thesis is seen as a pre-study for a development project not yet been initialised by the company, the work on final concept design can proceed in different directions depending on upcoming priorities made by Arjo. Such decisions can for example depend on if new physical tests are being passed with acceptable margins or not, or if the design fails toward criteria related to technical feasibility, budget, hygiene etc. The final concept design does also not take the seat subsystem design and integration in consideration which is a crucial part for an upcoming hygiene chair product.

The final concept is the alternative of most interest at this moment, but if it fails, the work here has explored other options which may or may not be relevant to consider instead. Focusing on the final concept for now, several actions can be done by the company in a relatively near future to further investigate and develop the chassis design as well as the remaining subsystems. Below, some potential future actions are presented for the chosen final concept.

10.2 Test the prototype with a dual actuator setup

One crucial factor for the continuation of the final concept design is if a dual actuator setup, one on each side, will be able to extend simultaneously without getting locked or stuck. The tested prototype proved that the measured current required for one actuator was relatively low compared to many other products offered by the company. With a load of 100 kg, the current peaked at 2.5 Ampere which is of no concern according to Arjo. A fully functioning prototype with two actuators, can in theory handle a realistic SWL of 200 kg based on this test result. However, maybe more concerning factor is related to the difficulty of driving two linear actuator synchronous at the same speed. This is a recurring problem for the company and have to be tested before other major design changes are made, if linear actuators are to be used for a further developed version.

10.3 Test actuators with lower build-in dimensions

Another suggestion is to optimise the geometry of the link subsystem in combination with lower build- in dimensions for the linear actuators. This can provide a link and seat system that can give the preferred seat heights with a minimum floor to seat height of 450 mm, and a maximum seat height of 1050 mm relative to the floor. This alternative can be done in conjunction with the speed test of a dual actuator setup described in 10.2, to order actuators with build-in dimension suitable for probable placements of the linkage attachments.

10.4 Rack and pinion drive mechanism instead of linear actuators

One idea to further investigate in the future is to replace the linear actuators of the final concept with a rack and pinion drive mechanism. As seen in the concept selection chapter, the rack and pinion concept received relatively high scores and could become an interesting concept if combined with the overall idea of the chosen final concept. The concept would feature an extending chassis driven by a rack and pinion mechanism. The motor for driving the extending chassis could be placed inside the bridge between the chassis sides, with pinions driving racks simultaneously on both extending legs. The upper arm which holds the seat would still have the linkage arm connected to the extending leg, but this arm would not be used to extend the front legs, but rather to raise the upper arm instead when the rack and pinion mechanism extends the front legs.

A benefit of this solution compared to the one using linear actuators is the guaranteed synchronous speed when extending both chassis legs, which can be challenging with the linear actuator drive. Another potential benefit is reduced cost for a future mass-produced product. However, this require a more thorough cost analysis which is not included in this thesis.

10.5 More alternative designs to test

One interesting alternative to the final concept was generated when building the prototype, which involved not having a fixed attachment for the bottom of the linear actuator. Instead, the bottom attachment for the linear actuator would be connect directly onto the extending legs, which would involve moving the slot on the chassis to the top side rather than the bottom. When the actuator extends it lifts the upper arm, which in turn extends the legs through the existing linkage, which also moves the linear actuator forwards. This would theoretically allow for a linear actuator with a smaller stroke while still being able to raise the upper arm to a desired height.

10.6 Work on remaining subsystems

As this thesis has focused on the chassis subsystem from the subsystems described in Chapter 6.1, more work is necessary regarding the remaining subsystems. Since the final concept did combine both the chassis and link subsystem, most work is required on the seat subsystem.

Some ideas regarding how the seat subsystem should function has been generated during the thesis work. One desired mechanism is inspired by Carendo, where the footrest is connected to the backrest with a linkage, which allows the footrest to fold out simultaneously as the backrest reclines. This motion could either be driven by a separate DC-motor if this function is desired to be controlled individually from the other functions or connected with various linkages to also be controlled by the extend-and-raise mechanism.

Another feature discussed was to be able to tilt the seat forwards to allow easier entry for the resident. This function was added as target specification No. 29.

11 Discussion

This chapter covers discussions regarding the entire project, divided into subheadings based on the structure of the process and the report.

11.1 Methodology

In the beginning of the project, when the methodology was chosen, the structure of the project was not known in detail. This made it difficult to adopt a methodology suitable for this type of explorative design project which at the same time is relying on specific standards for the medical technology industry. The challenge was therefore to find a methodology balancing creative idea generation with the possibility to relate to existing requirements set by standards and define new product specific requirements along the development process. Due to these counteractive aspects, a mixed methodology was seen as the most appropriate at the time. The intention with a methodology inspired by agile development was to be able to develop concepts at a high rate, as the project had a very limited time limit. By combining agile development with the methods described by U&E, initial wide search and later narrow concept development could be achieved. But the mixed methodology showed not to be as optimal as thought for several project activities. The TDD method was first seen as a tool to further develop brief concept ideas coming from a broad generation of concepts based on the U&E methodology, but due to the strict time limit, each concept could not be further developed individually with TDD. The TDD method proved instead to be more useful during later development stages where focus was set on a few concept ideas, where the complete iterative design approach became a more natural way of designing a concept.

One agile development method that proved to be useful for the project, and used frequently, was the Kanban task board. It was used to define and structure short term activities related to all project stages including the report writing. Defining and planning new tasks was fast and easy, which made this tool very valuable for the project management as it increased efficiency and defined short term goals accessible for both thesis members when working from remote locations.

The U&E methods could not be adopted completely throughout the project either, especially when it came to the customer needs and specifications, but also the product testing. This is described further in detail below.

11.2 Customer needs and specifications

The process of identifying customer needs took inspiration from the methodology described by U&E, but was not followed strictly. Since Arjo provided an MRS document containing both customer needs and specifications, conducting own user studies were deemed not to be necessary. If a user study had been conducted, it would probably have increased the precision of the customer needs and target specifications but were deemed not to be worth the time investment.

The target specifications were also established in a simplified way compared to the U&E methodology. The goal here was to generate a list of rudimentary metrics that could be used to keep the generated concepts on a realistic level concerning measurements etc. The target values are not final and may depend on different circumstances regarding the generated concepts. That said, they were still useful during the development of various concepts.

11.3 Concept generation

In order to generate a broad selection of concepts, the brainstorming sessions were planned early on together with Arjo. This was a good way to quickly get different concepts based on various mechanical principles. The first session was planned with personal reflection in mind, mixing open discussions with time for individual thinking. This showed to be a successful structure for the session, where every person got the chance to contribute equally.

One clear aspect that all members realised was that it proved to be difficult to generate a holistic design from almost nothing, as the product can be described as relatively complex with several moving parts. Therefore, the problem needed to be further clarified and divided into smaller constituents. The diagram showing the breakdown of a typical hygiene chair was made, which visualised the moving parts grouped in the three subsystems. This made it easier to know how all subcomponents relate to each other, but also what defines the chassis subsystem which was the main focus area. This comparison also kept the project on the right path, avoiding going to deep into other aspects not included in the scope of the thesis. By dividing the larger problem into smaller ones, each subproblem also became more achievable to approach and solve. The initial thought was, as previously described, to solve each subproblem with the TDD method. However, this showed to be time consuming beyond what could be done within the time plan.

Since many concept designs share similar overall working principles, there were early on grouped into what have been named clusters in this report. Multiple concepts can for example utilise the same principles to drive the dynamic chassis movement. Therefore, the principles were chosen to be described separately in the report.

As there are many possible combinations of subcomponents shared between concepts, there was no room to either combine all design fragments during the concept generation phase nor to describe all possible designs in this report. The concepts which are presented here can instead be seen as a foundation of ideas, to further combine with each other or completely new concept ideas in the future. This does not only include the final concept, but also the concepts that did not make it through the stage of concept selection.

It should also be said that the concept generation phase did not end as soon as the concept selection phase initiated. Instead, concepts were generated in parallel with the upcoming activities, which is inspired by the agile development methods earlier mentioned. CAD software was a big part of this continuous idea generation, which was perceived to be a good way to verify mechanical principles with multiple moving components which otherwise could be difficult to visualise only based on hand-drawings.

11.4 Concept selection

The process of selecting concepts took primarily inspiration from the methodology described by U&E. To first use a screening matrix to reduce the number of concepts and later a scoring matrix to further rank the concepts were a concrete and easy-to-use method for selecting concepts. The selection criteria were chosen together with engineers from Arjo to get as good selection as possible for the type of product being developed, since they have a lot of experience in this field.

11.4.1 Concept screening

Concept A.1 – *The Double Actuator System* was chosen as the reference concept for the concept screening. This choice was made because this concept was deemed to be the easiest to understand and therefore the easiest to compare to other concepts. This did lead to some drawbacks which were discovered after the screening process was complete. For the criteria *Technical Feasibility, Space Efficiency, Durability* and *Hygiene,* every concept received either “0” or “–“. This is simply caused by the fact that the reference concept was deemed to be quite good concerning all these criteria, so the other concepts could only be as good (and receive a “0”) or worse (and receive a “–“). The criterion *Integration Capability* had the opposite effect, where the reference concept was deemed to have no integration capability, which caused the other concepts to receive a “0” if they also did not have any integration capability, or a “+” if they did. Even with these identified drawbacks regarding the choice of reference concept, the concept screening was still seen as successful since a relative ranking among the concepts was still achieved.

The concept screening resulted in three concepts receiving worse net scores than the rest. These were A.5 – *The Perpendicular Linkage System*, D.1 – *The Parallelogram Linkage System*, and D.2 – *The Wire and Spring Leg Rotation*. These concepts were further investigated to see if the concept screening results had merit.

Concept A.5 received "–" for the criteria *Technical Feasibility* and *Durability,* which was attributed to uncertainty regarding how well such a linkage system would work, and whether it would be durable. *Hygiene* was also scored as "–" since the concept involved slots on the inner side of the chassis, where dirt can accumulate.

The concepts D.1 and D.2 were both based on the same principle of rotating back wheels. They received the same scores in the screening matrix, which involved "–" for *Technical Feasibility, Space Efficiency,* and *Durability*. The most concerning aspect of these concepts was the requirement of clear space on both sides of toilet, due to the rotating legs. Concern was also raised regarding risk of stumbling on the legs. The concepts would also likely require a very robust design, which was deemed to be hard to achieve.

The investigation of the low scoring concepts from the concept screening resulted in discontinuing their development in favour of the higher scoring concepts.

11.4.2 **Concept scoring**

The relative weight of each criterion during the concept scoring were also discussed together with the engineers from Arjo. Realistically, the *Cost Efficiency* criterion should have been of greater weight than it received, but at the same time determining how cost efficient a specific concept is compared to another is quite hard due to limited experience of the thesis workers. Another benefit of not focusing on the cost efficiency during this early stage of development was that more freedom was granted concerning the idea generation for concepts. Overall, the concept scoring is not an exact science and is based on estimates which was deemed reasonable during consultation with the engineers from Arjo.

The results of the concept scoring matrix were that every concept received a verdict regarding continuation of development. Concept E.2 received the highest score and seemed to be the most promising concept to develop further. Concept A.1 was discontinued in favour of developing the E.2 concept instead, which is similar but deemed to be better. Most concepts with middling scores received a "Keep in mind"-verdict, which means that these concepts might not be the best according to the scoring matrix, but still has merit and could provide inspiration and design features to Arjo and become better concepts if they were further developed. They could also be combined with other concepts as has been discussed in Chapter 10 regarding future work.

11.5 Prototyping and physical testing

The product testing described by U&E was aimed towards end consumer markets rather than conducting physical or structural design tests. Test studies in the form of product tests, for example in focus groups, were therefore not seen as relevant. Also, a final and fully defined prototype was never in the scope of this thesis work. The testing was therefore adapted to fit the project, where physical tests are used to verify the current principal design which is useful for future design work.

Firstly, the linear actuator was planned to have shorter build-in dimensions than what was possible to build in the workshop given the limited timeframe. The one actuator used for the conducted tests was the shortest available in the workshop at the time, and to get new ones would require a delivery time of approximately one month. Therefore, only one side of the chassis linkage system was tested, which still provided some value test results such as the required current to drive one actuator with a realistic load of 100 kg. However, testing both sides would tell if the actuator pair can be run in sync, which can be seen as a bottleneck for the continuation of this actuator driven design.

Based on the CAD drawings handed to the workshop personnel, several design changes were made to simplify the physical prototype. The upper arm that are meant to be attached to the seat subsystem was iteratively redesigned to fit longer actuators. But the new arm design showed to be unnecessarily complicated, and therefore the arm attachment point was instead raised to fit the longer actuator.

The reason to place the actuators normal to the upper arms was to get a better force distribution compared to placing the actuators along the chassis legs. This was a decision made in consultation with the engineers at Arjo, who have several years of experience of this area of design.

By drilling multiple holes to test different geometric configurations, some appropriate configurations were found. However, as the configurations had a fixed number of settings, not all possible alternatives could be tested which could have resulted in even better articulation ranges for the seat height adjustment.

The force required to push the inner legs in and out was measured during the tests and proved that a minimal amount of applied force was required. The force peaked when the caster wheels turned but did not affect the current measured from the actuator significantly. Thereby the extending chassis have been proven to be physically feasible for a potential future product.

11.6 Results

The result of this thesis project includes both the broad range of concept ideas and the final concept which can be seen as the most suitable alternative for further development out of the generated concept ideas. Thereby, both research questions stated in Chapter 1.4.1 have been addressed as planned.

The final concept shares design elements from the further developed CAD concept E.2 and from the physical prototype. From the prototype, the most suitable configuration setting was chosen, which provided the dimensions for the location of attachment points to the final concept. This seemed like a suitable way of suggesting a functioning linkage geometry, as it had been tested physically and proven to be feasible. However, this configuration will most likely be changed during future design steps for a second prototype. Configuration 4 was chosen as it provided a reasonable stroke length of 500 mm, with a minimum and maximum seat height approximately within the targeted range.

Most of the metrics in the target specification list have been set as achieved, but several others could not be verified as they require either physical or use case tests. For example, the width of the final concept should be able to pass through standard sized doors based on the given dimensions, but further testing should be conducted to verify this.

The driving linkage system on the prototype was not chosen for the final concept design, as it was mainly designed to test the geometrical relationship between seat height and leg extension. This mechanism may also be concerning as it probably does not fulfil the criteria described in ISO 10535 related to the *safety of moving and folding parts*. Such a mechanism must probably be completely encapsulated to fulfil the industry requirements. Instead, a simple linkage arm was added, with the sliding attachment mounted on the bottom side of the chassis on both sides. This solution is more likely to fulfil the safety requirements if placed with a safe distance away from other parts, due to the simpler design. The metric related to *safe distance of moving and folding parts, finger traps* have still been set as not fulfilled, as this needs further verification.

Concerning the metric No. 23, *Protruding parts with risk of tripping/stumbling*, this has also been set as not fulfilled as there may be a risk of stumbling on the slightly protruding back legs. These could be shortened when the bird's eye view and dimensions of a future seat subsystem are better known.

With more time, the remaining subsystems could have been developed further, which would provide an overall solution which solves more of the possible adjustments. However, for the given time frame and the scope, the project can be seen as successful and have provided Arjo with a thorough exploration of new design alternatives for their upcoming hygiene chairs.

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Appendix A - Work distribution and time plan

A.1 Work distribution

Both students who have written this thesis are studying at the department of Product Development at LTH. They have studied similar courses and share the same knowledge base within this area of study. Therefore, the work during this thesis have been divided equally throughout the entire process with slight variation depending on weekly planned tasks. All work done by each student have been reviewed by the other and discussed together.

A.2 Project plan and outcome

The actual outcome presented in Figure A.2 corresponds well to the project plan set up during the beginning of the thesis work, seen in Figure A.1. Comparing the project plan and the actual outcome, only the date for the presentation at Arjo was rescheduled.

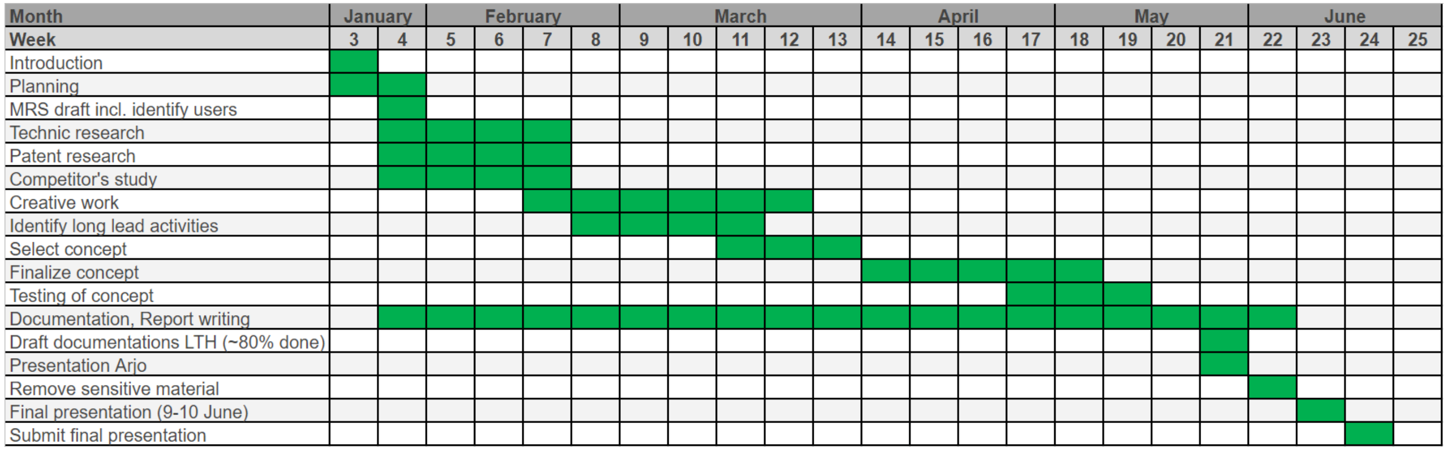

Figure A.1. Project plan.

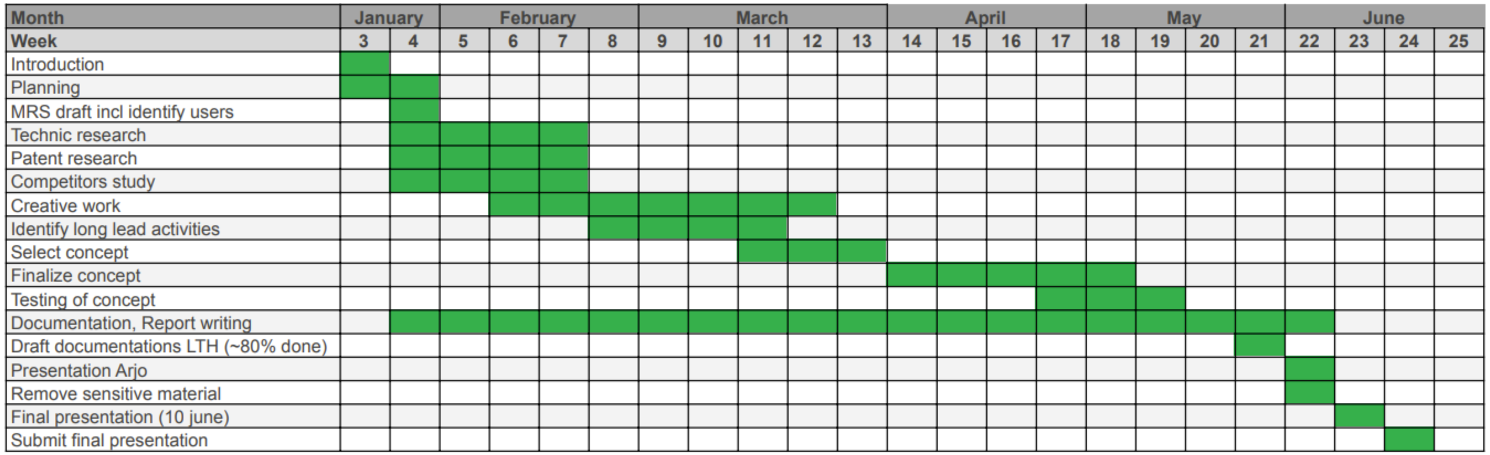

Figure A.2. Actual outcome.

Appendix B - CAD Testing Model

Figure B.1. Extension range of chassis.

Figure B.2. Translation range of connection between link and chassis.

Figure B.3. Angular movement range between link and chassis.

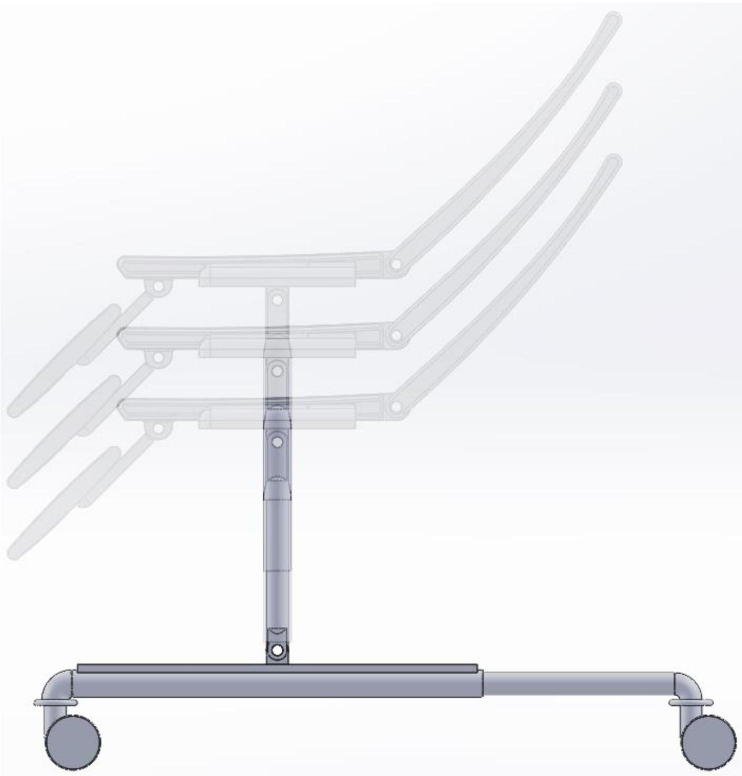

Figure B.4. Extension range of link.

Figure B.5. Translation range of connection between link and seat.

Figure B.6. Angular movement range between link and seat.

Figure B.7. Angular movement range between seat and backrest.

Figure B.8. Angular movement range between seat and footrest.

Appendix C - Brainstorming 1

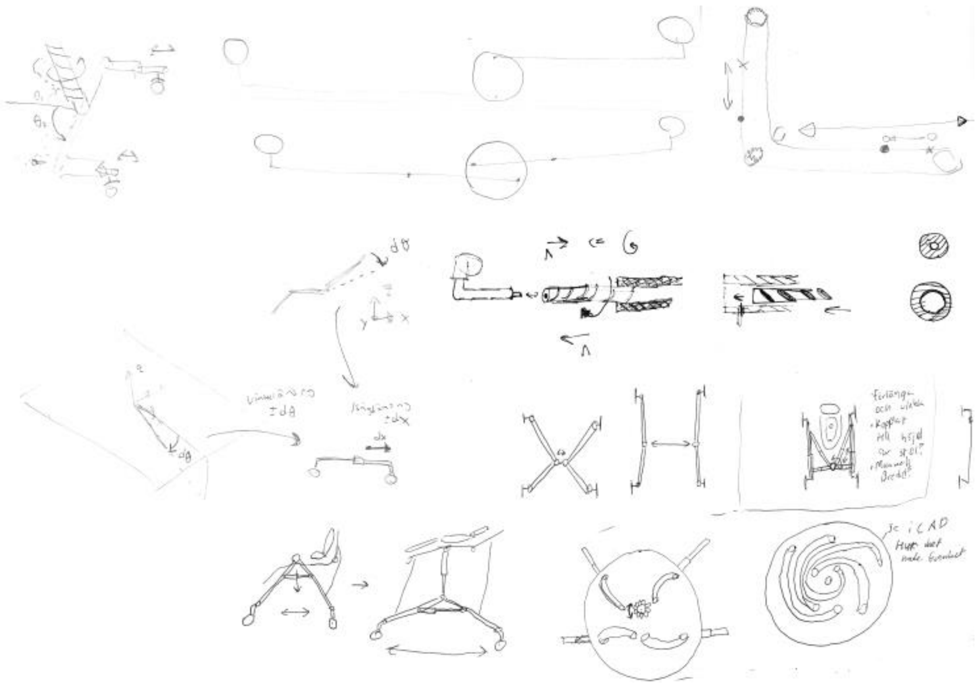

Figure C.1. Enlargement of the footprint 1.

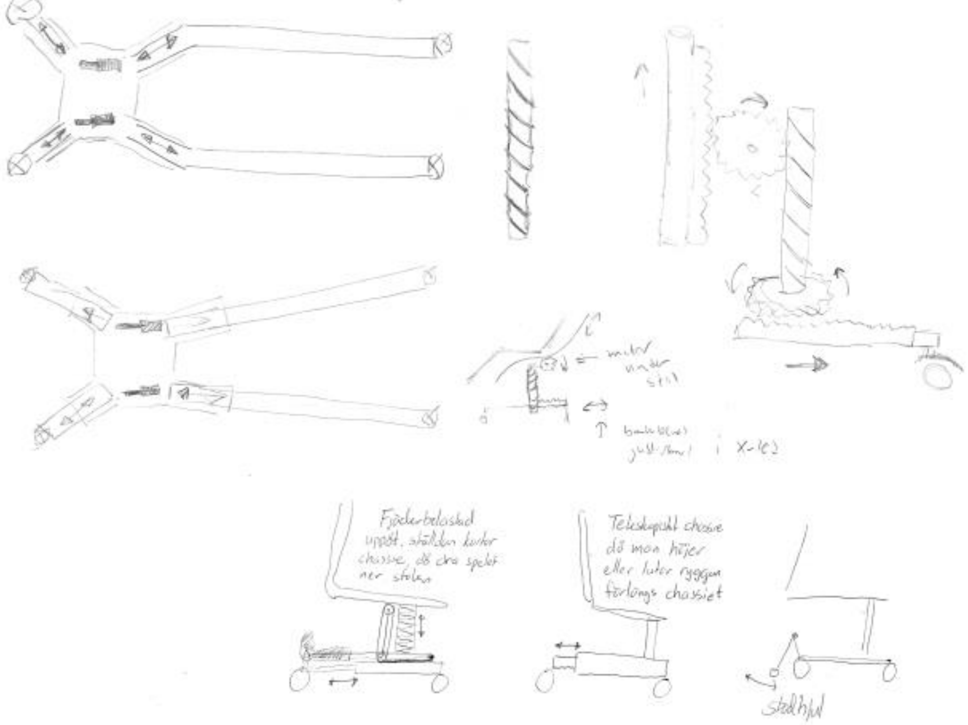

Figure C.2. Enlargement of the footprint 2.

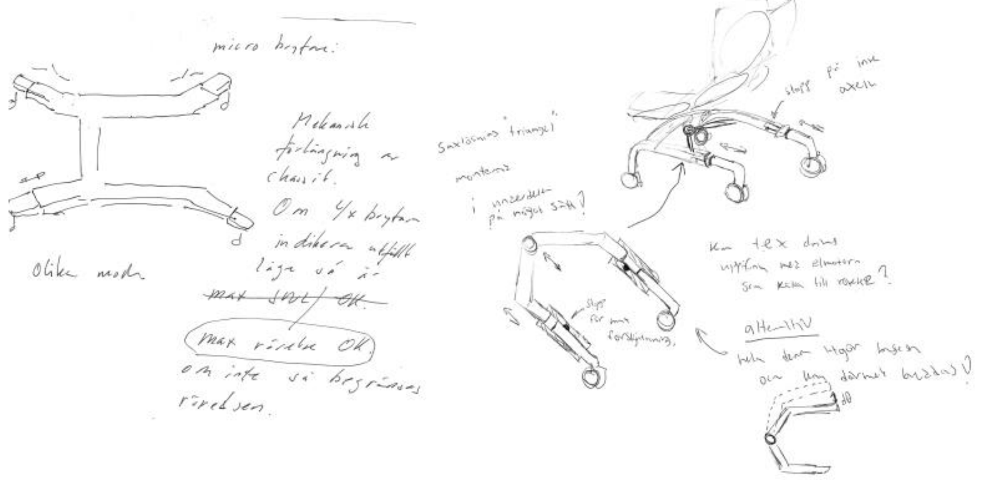

Figure C.3. Enlargement of the footprint 3.

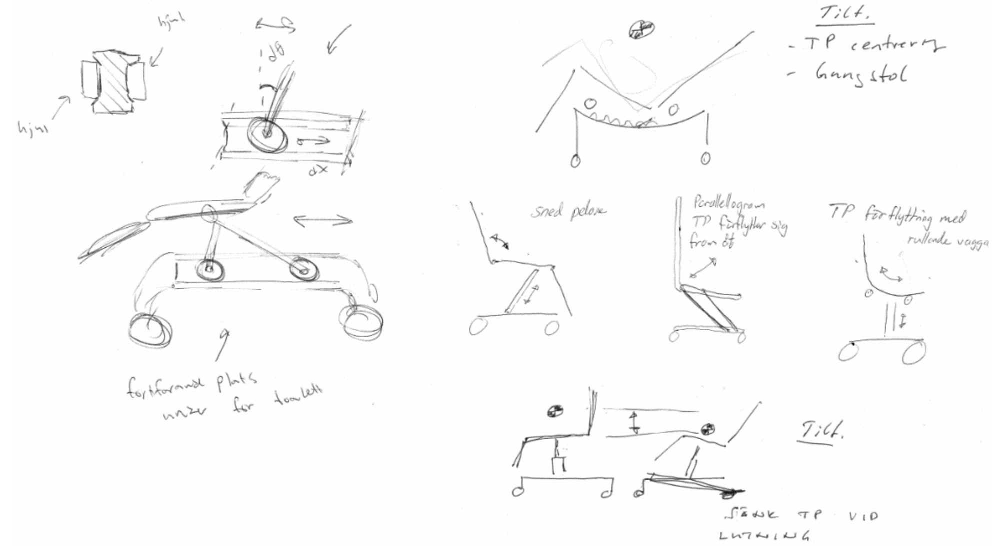

Figure C.4. Moving of the centre of mass.

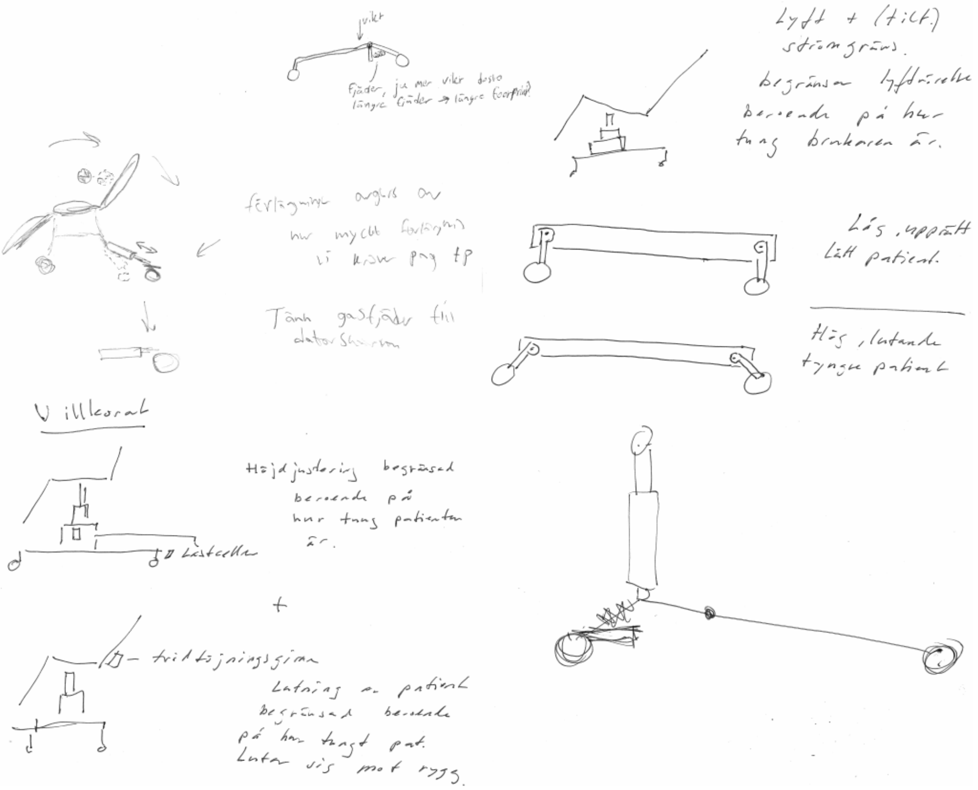

Figure C.5. Weight-dependent footprint.

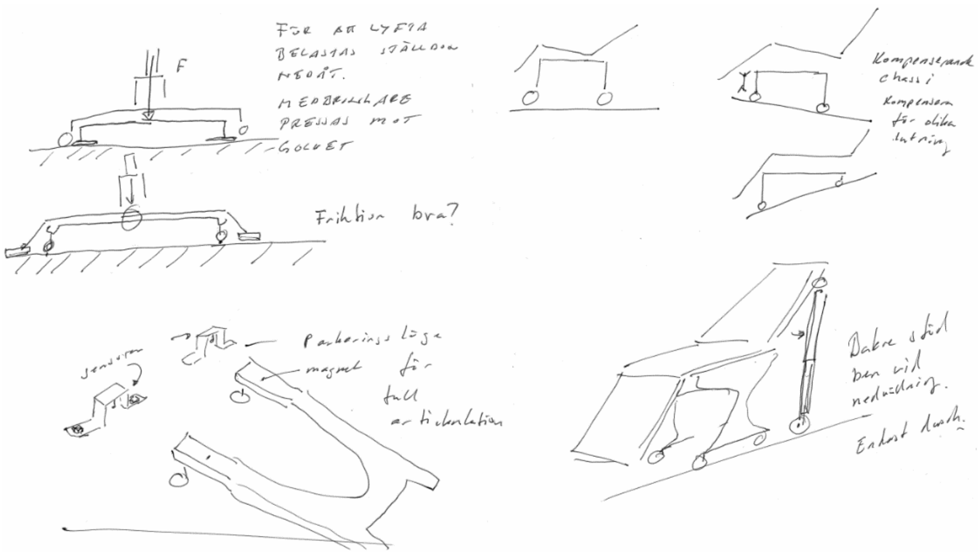

Figure C.6. Stand-alone concepts.

Appendix D - Brainstorming 2

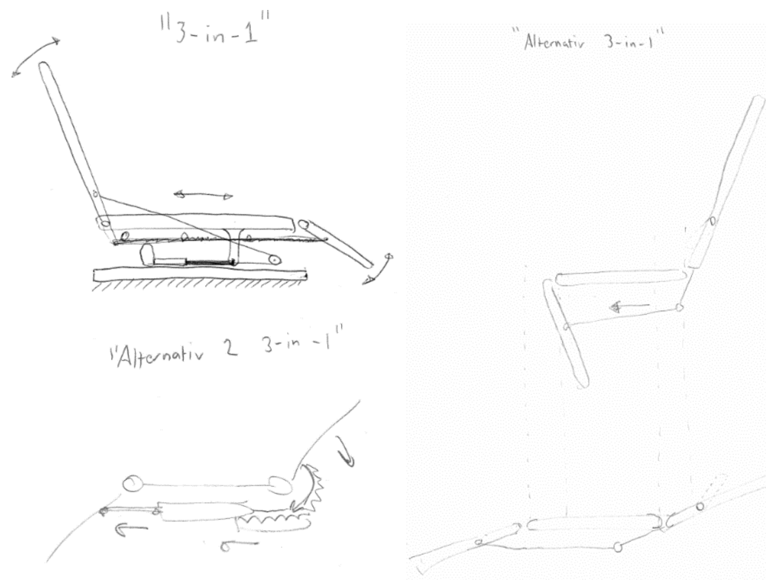

Figure D.1. Concept “3-in-1”.

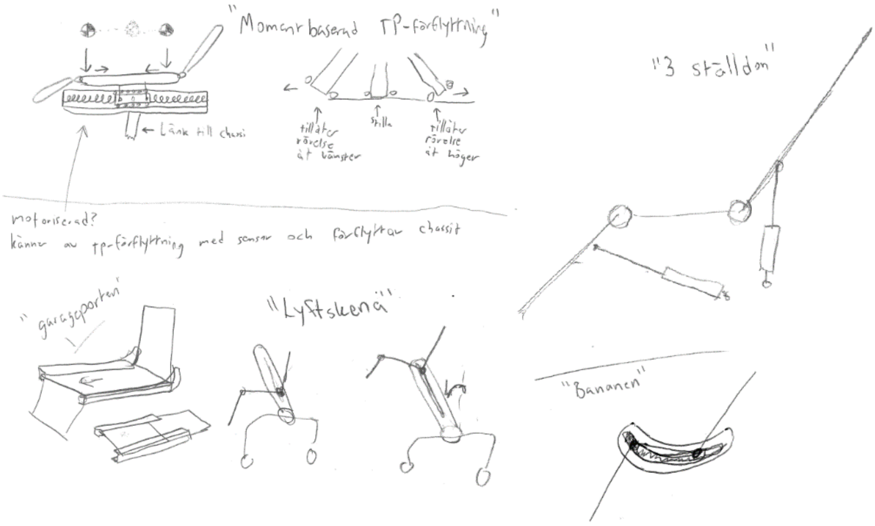

Figure D.2. Concepts “Momentbaserad TP-förflyttning”, “3 ställdon”, “Garageporten”, “Lyftskena” and “Bananen”.

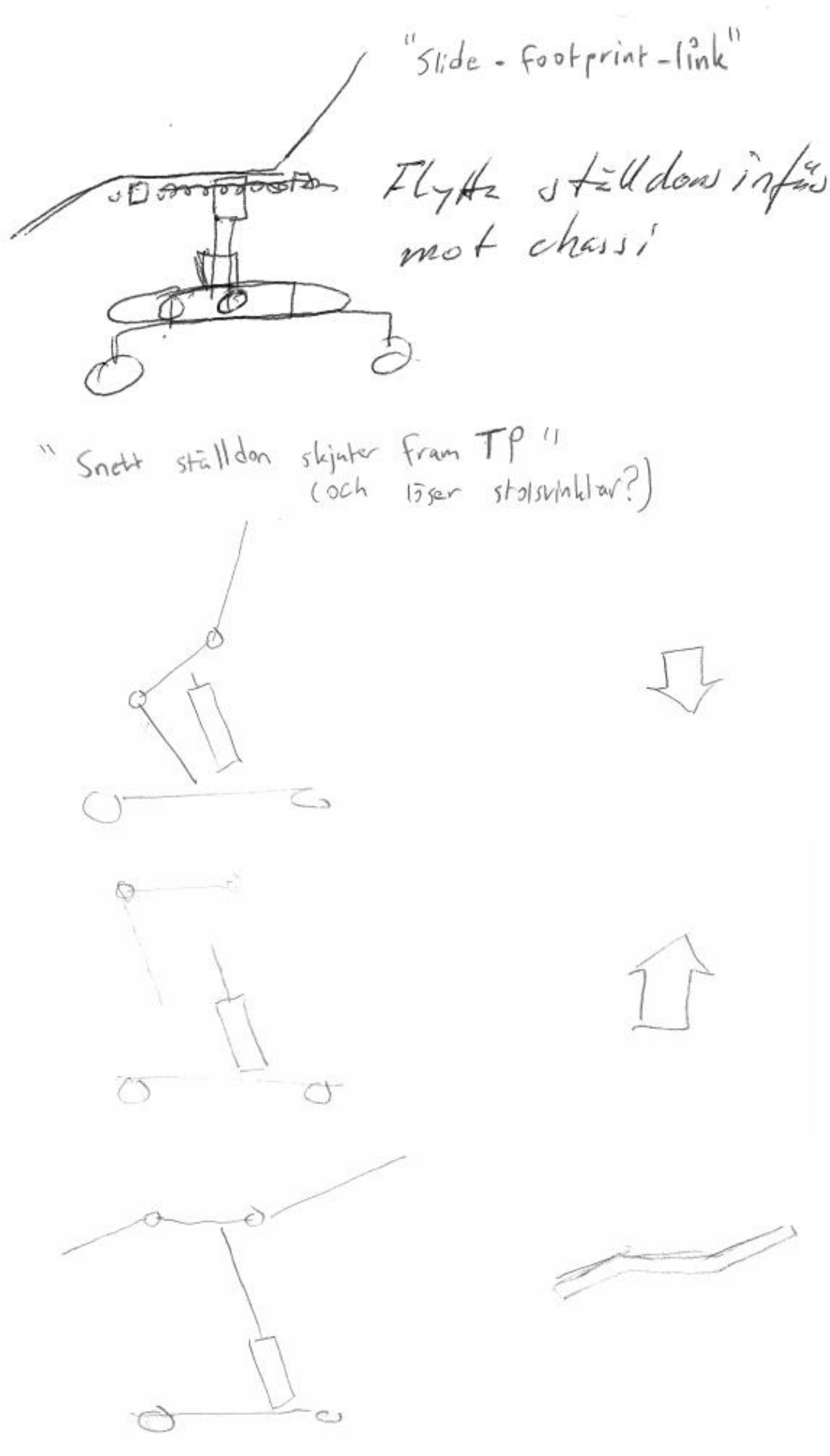

Figure D.3. Concepts "Slide-footprint-link" and "Snett ställdon".

Appendix E - Prototype drawings

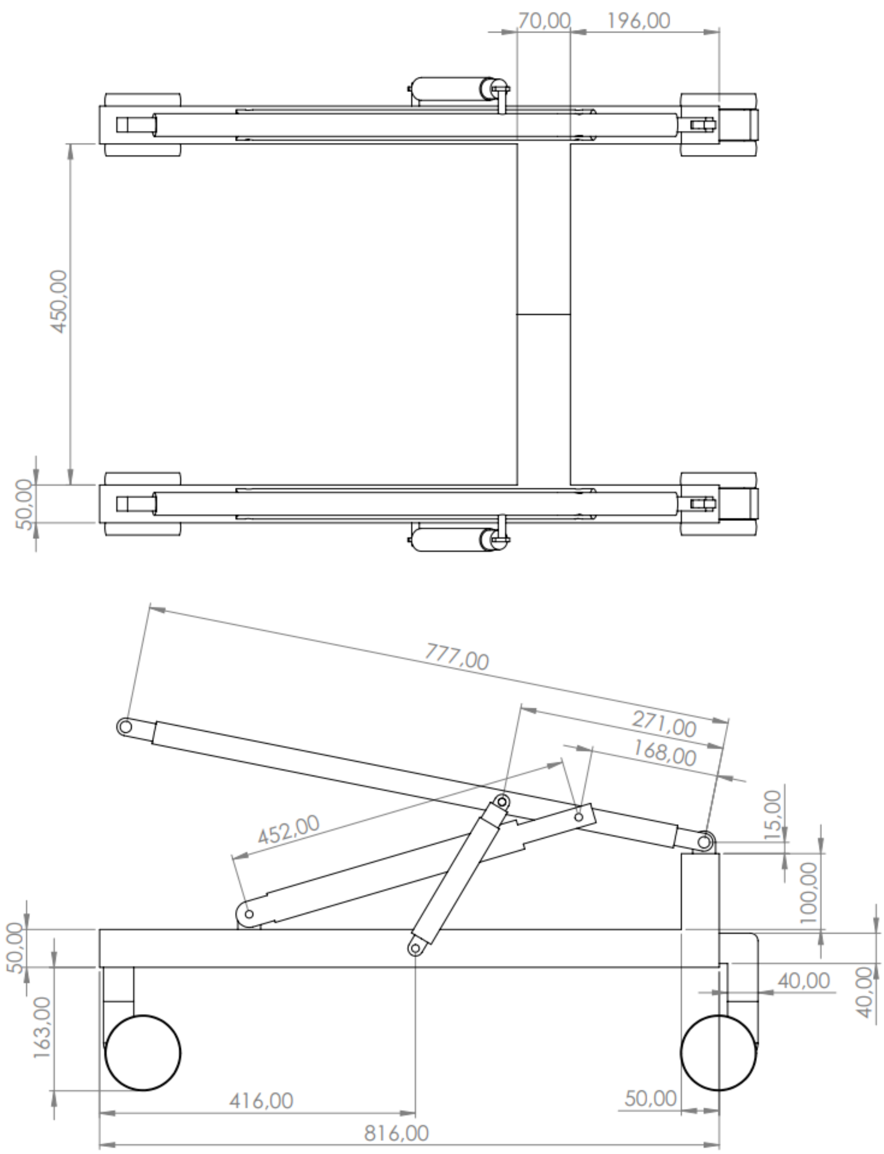

Figure E.1. First CAD drawings sent to workshop personnel.

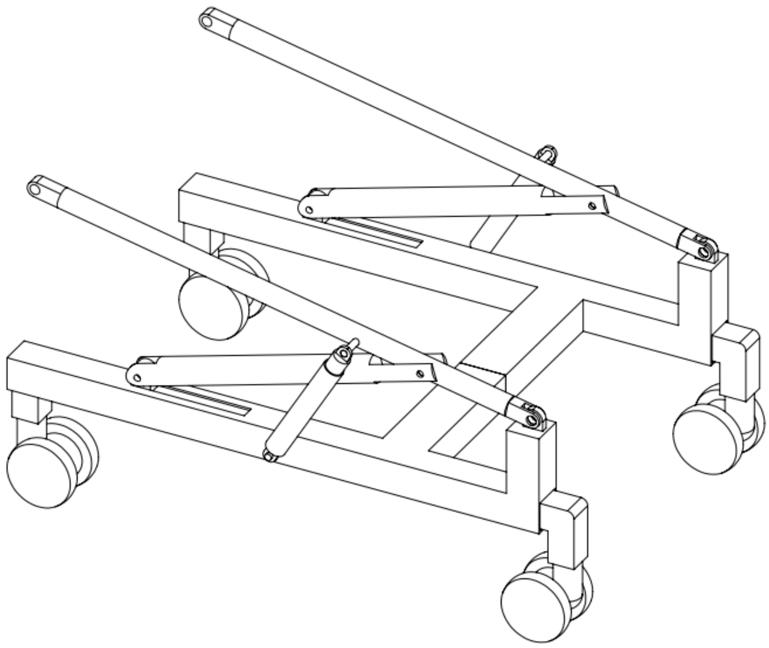

Figure E.2. Overview of first CAD drawings sent to workshop personnel.

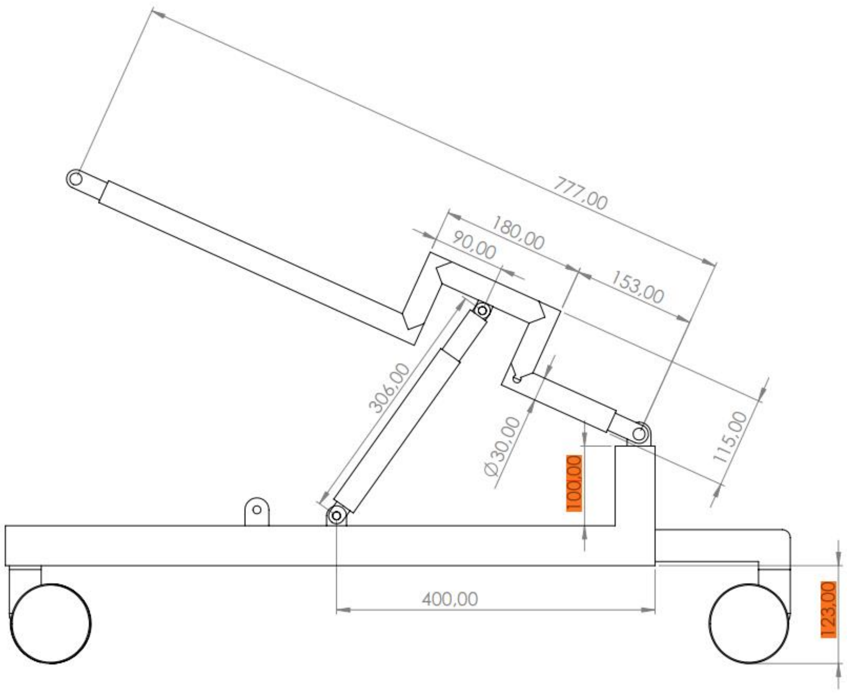

Figure E.3. Redesign of prototype CAD drawings to accommodate longer linear actuator.