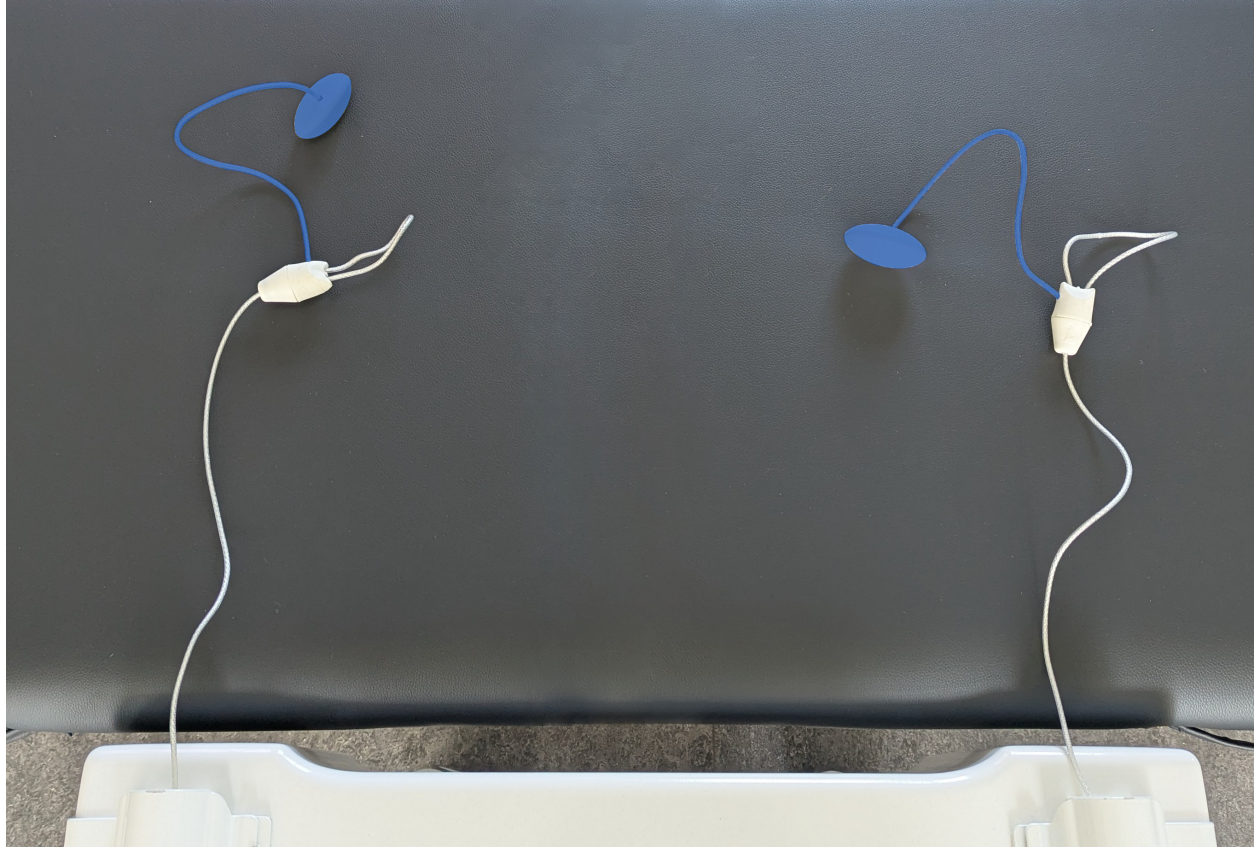




CHALMERS
UNIVERSITY OF TECHNOLOGY



Development of new attachment solution for patient transfer device

Master's thesis in Industrial Design Engineering

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DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2026
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MASTER'S THESIS 2026

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Abstract

Patient handling is a common task in healthcare associated with physical strain and risk of work-related injuries. Assistive devices for patient transfer have therefore become important tools for improving working conditions and reducing manual handling. Atle® 180, developed by Njord Medtech, is a patient transfer device designed to perform lateral transfers by sliding patients between surfaces. However, the current attachment solution presents challenges related to usability, time efficiency and risk of detachment during use.

The aim of this project was to explore, develop and evaluate concepts for the attachment solution in Atle® 180. The focus of the work was on developing a solution that is easier to attach, more secure and time-efficient during use. The project followed an iterative product development process consisting of six main phases: *Pre-study*, *User research*, *Problem analysis*, *Ideation*, *Evaluation* and *Development*. User needs and contextual constraints were identified through a literature study, observations and interviews with healthcare workers at Sahlgrenska University Hospital. Identified needs were translated into design guidelines and requirements that formed the basis for the concept development and evaluation.

Several concepts were developed iteratively using structured ideation methods, and evaluated through mockups and Pugh matrix evaluation. The selected concept was further refined through CAD modelling, prototyping and ergonomic validation. The final design solution presents an alternative attachment solution intended to reduce handling problems while maintaining functionality and compatibility with Atle®.

The project has shown how an iterative development approach can support improvements in the attachment system of a patient transfer device by addressing both technical performance and user needs in healthcare environments.

Keywords: product development, patient transfer, prototyping, industrial design, concept evaluation, patient transfer device.

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Hanna Birgersson & Deborah Sjöberg
Gothenburg, June 17, 2026

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1. Introduction

This chapter presents the background and aim of this project where a new design suggestion for the attachment solution in a patient transfer device was developed. The limitations of this project and structure of the report are also presented.

1.1 Background

Patient handling is among the common tasks that healthcare workers do in their daily work in hospitals, radiology departments and emergency care. Many patients are unable to move independently due to illness or injury. Therefore, workers must assist with patient handling frequently. Activities such as lifting, repositioning or transferring patients can lead to work-related injuries (Nelson & Baptiste, 2004). As a result of this, ergonomic interventions are increasing and helping aids are being introduced to improve the working conditions.

The different types of ergonomic interventions and assistive devices aim to support safer patient transfers and reduce the need for manual lifting that can cause physical injuries. Mechanical transfer devices can assist healthcare workers by taking over part of the physical workload during the transfer process. However, even when assistive devices are available, the practical usability of them can influence if they are used and how frequently they are used.

Njord Medtech is a company that has developed a solution for transferring patients in healthcare in a safer and more ergonomic way. Their product, *Atle*[®] 180, was created to improve the working environment for healthcare workers and quality of care for patients (Njord Medtech, n.d.-b). It works by transferring a patient from one surface to another by pulling them over using the sheet instead of performing any lifting. This solution allows the patient to be moved with less physical effort from the caregiver while maintaining stability during the transfer.

Atle[®] works by attaching to the bed sheet, or another compatible surface the patient is laying on, and pulling it to the receiving bed or table. The current attachment solution uses a transfer bar wrapped in the sheet together with lines that are fastened around the wrapped bar. Although this solution enables the device to perform the transfer, it has some limitations regarding workflow and time efficiency during use. If the attachment process is perceived as complicated or time-consuming, it may affect how convenient the device is to use during patient transfers. Therefore, there is a need to explore alternative attachment solutions that can simplify the handling of the system while maintaining safety and reliability during use.

This has raised a few questions regarding the development of a new attachment solution and what to focus on. Hence, the work should be guided by clearly defined

design requirements aimed at addressing the identified usability and efficiency issues. In particular, the design of the attachment between the sheet and the patient transfer device should be improved to enhance and/or maintain usability, efficiency and safety during repetitive use. Furthermore, different concepts should be evaluated and compared with respect to their usability, structural stability and time efficiency in practical application.

1.2 Aim

The aim of this project was to explore, develop and evaluate concepts for the attachment solution in Atle[®] 180, a patient transfer device. The focus of the work was on developing a solution that is easier to attach, more secure and time-efficient during use.

1.3 Limitations

The project's limitations are summarised as follows:

- This work did not include specific cost calculations.
- One working prototype was created in this project.
- No real hospital patients were involved in the prototype testing.

1.4 Report structure

This report consists of 13 chapters in total, illustrated by Figure 1.1. *Introduction* (Chapter 1) and *Clinical context & product overview* (Chapter 2) are both chapters that give the reader context about the project and the product it is about. *Methods* (Chapter 3) and *Procedure* (Chapter 4) explains what has been done in the project and how it has been done. Chapters 5-10 presents the results of the work. Lastly, the final design solution is presented and discussed in Chapters 11-13.

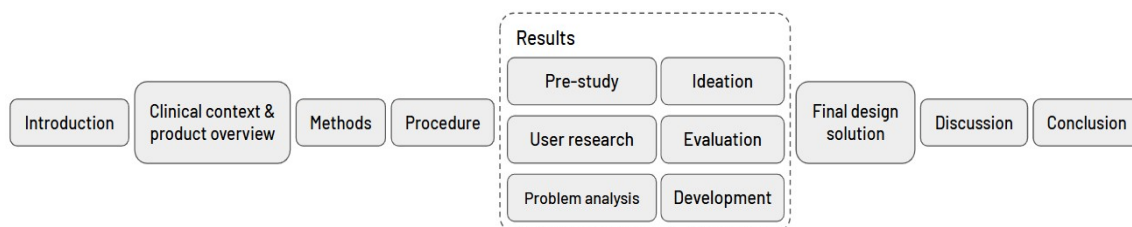


Figure 1.1. Overview of report structure presenting the main chapters.

2. Clinical context & product overview

In this chapter, an overview of the project prerequisites is presented. This includes a description of patient transferring practices in healthcare and of the product Atle® 180 with the focus on the current attachment solution. Furthermore, a description of the main patient transfer situations for using the product is included in this chapter.

2.1 Patient transfer

Patient transfers are performed frequently in healthcare settings and are essential for maintaining patient comfort and safety. Often patients need to be transferred with help of caregivers if they are unable to move themselves. This could be from chair to wheelchair, from floor after a fall or laying down. These tasks are among the most physically demanding tasks for healthcare workers and pose risk to both the staff and the patients. Factors such as transfer distance, patient's weight, workspace, patient behaviour and body positioning contribute to the risk of performing patient handling tasks (Nelson & Baptiste, 2004). Depending on the setting of the patient transfer, the risks associated with the task vary.

One way of patient transfer in a laying down position is moving the patient from a bed to a stretcher (Reifeldt, 2023). When doing this manually without lifting aid, at least two nurses are required. At first, they will put a draw sheet over the bed to cover the area of the patient's head, shoulder and hips. One or more sliding boards are used as aid between the surfaces. Both bed surfaces need to be the same height to make transferring the patient across possible. The nurses will stand on each side of the surfaces, with the patient between them. The nurse at the receiving end of the transfer will drag the sheet slowly toward themselves (Reifeldt, 2023). The nurse on the other side will also hold the sheet and make sure the patient's legs are bent and guide them during the transfer. When the transfer is complete, the sliding board is removed and the patient's position is corrected using the draw sheet.

To reduce the risk of injury during patient handling, World Health Organization (n.d.) provide preventive guidelines. These include ensuring that at least two people perform manual lifts and that mechanical lifting aids are used whenever available. The guidelines emphasise to minimise unnecessary manual handling and promoting safer working techniques. Despite these recommendations, manual patient handling still occurs in clinical practice, partly due to time constraints, staffing limitations and situational factors (Arbetsmiljöverket, 2026). As a result of this, there remains a need for technical solutions that can support safer and more efficient patient transfers in clinical environments.

2.1.1 Lifting ergonomics

Manual lifts of objects or people can cause injuries. There are several risks associated with performing lifts, for example frequency, lack of rest between lifts or lifting in awkward body positions (Arbetsmiljöverket, 2025). Examples of awkward body positions when lifting include: *being bended and twisted, holding the load in or below knee-level and holding the load in or above shoulder-level*. Lifting ergonomics are a crucial part of healthcare work, as caregivers often need to assist patients during transfers or repositioning. Patient handling is more complex than lifting inanimate objects since it involves unexpected movement, shifting weights and people that might be in pain. This highlights the importance of understanding the biomechanical demands placed on healthcare workers.

In an experimental research study, Skotte and Fallentin (2008) biomechanically evaluated manual patient repositioning tasks in bed in order to assess the physical load on caregivers. Lumbar spine loading was calculated using biomechanical modelling, with compression force at the L4/L5 vertebrae segment as the primary outcome measure. A reference value of 3400 N for lumbar compression was applied in the analysis.

Six common in-bed repositioning tasks were examined and a total of 443 measurements were conducted across different patient weights and disability levels (Skotte & Fallentin, 2008). The results showed a variety in lumbar compression within the tasks. Apart from turning patients in bed, between 19% and 51% of the measurements exceeded the 3400 N depending on the task performed. The results exceeded this level in 33% of the cases where participants were repositioning patients laterally in bed and 19% of the cases when moving them up in bed.

Skotte and Fallentin (2008) conclude that most manual in-bed repositioning present high-risk situations with respect to lumbar loading. The variability of the results makes it difficult to predict whether a certain transfer will remain below the recommended values. The findings of the study illustrate the mechanical demands associated with manual patient handling and highlights the need for technical solutions that can reduce the risks for injuries of healthcare workers.

2.2 Atle[®] 180

The device for which the attachment solution has been developed is the *Atle[®] 180*, shown in Figure 2.1. It has four wheels at the bottom with brakes, and a handle on top that make it easy to move around. The product itself weighs 50 kg and the maximum weight it can pull is 180 kg (Njord Medtech, n.d.-b). Atle[®] is an assistive device designed to support healthcare workers while handling patients, particularly when moving the patients between surfaces in a clinical setting at hospitals and in radiology (Njord Medtech, n.d.-a). By automating this process, Atle[®] can significantly reduce the physical effort needed, which reduce risk for injuries associated with patient handling.



Figure 2.1. *Picture of the product, Atle[®] 180. Reprinted with permission.*

The device is battery-driven and can be operated using a handheld control. One charge will last for around 50 cycles depending on the weights (Njord Medtech, 2021). The compact and mobile design ensures that it can be easily positioned around a patient's bed without being in the way. During a transfer, Atle[®] will perform a lateral transfer of the patient while maintaining their comfort and stability. The transfer takes only 15 seconds from starting the transfer (Njord Medtech, n.d.-b). The overall purpose of the product is to ensure safe and efficient patient transfer without the risk of injuring the healthcare workers or patients.

2.2.1 Current attachment solution

The current solution for attaching the device to the bed sheet is based on a transfer bar and two line loops with line holders that adjust the loop sizes to fit tightly around the bar. The line ends and the transfer bar can be seen in Figure 2.2. The lines are connected to the device and they get stretched when the handheld control is used to start the pulling. Inside the device the lines get rolled up as the transfer is being complete.

2. Clinical context & product overview



Figure 2.2. *Overview of the transfer bar and the line ends.*

Figure 2.3 illustrates how the line loops are attached to the bed sheet using the transfer bar. It works by wrapping the sheet around the ends of the bar and fastening the loops tightly with the line holders that run on the lines. This is done on both ends of the bar.

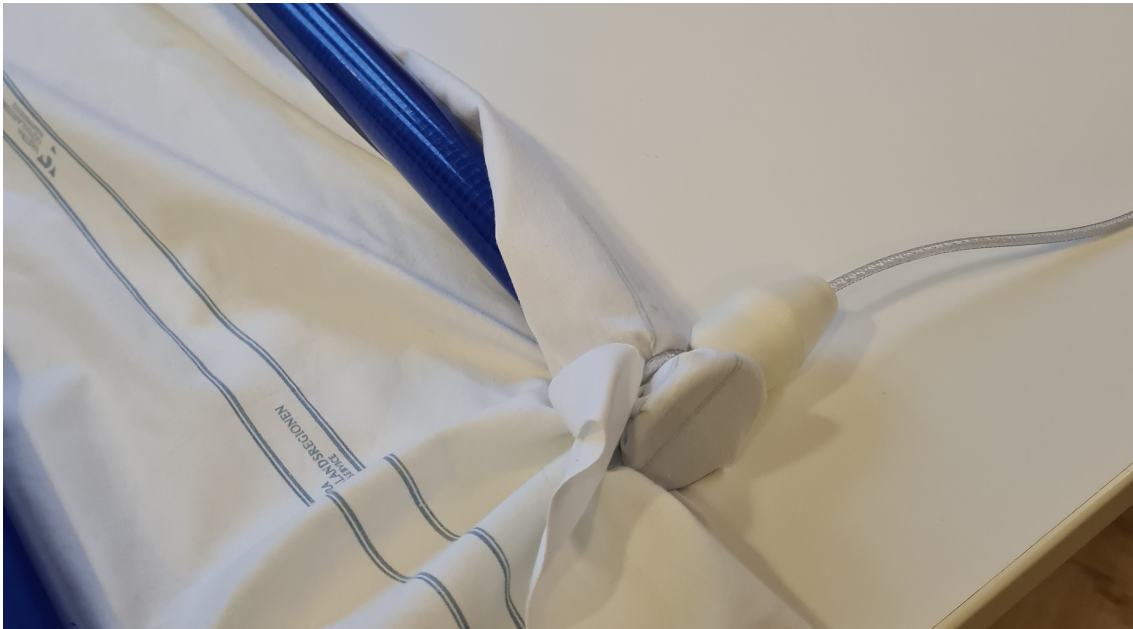


Figure 2.3. *The attachment between the bed sheet and the transfer bar.*

2.2.2 Transfer situations

The patient transfer device can be used in different situations and the three most common ways to use it is with bed sheets, trauma mattress and scoop stretcher, illustrated in Figure 2.4. In the scenario of using a sheet to transfer the patient, the attachment to the sheet is done by wrapping the bar and looping the lines around it. The sheet is attached and then the machine does the pulling. When a trauma mattress is used, a carabiner is attached in each of the line loops and in the handles of the mattress. Another alternative to bed sheets is the scoop stretcher which is made of thick hard plastic or metal. Both the trauma mattress and the scoop stretcher put demands on the attachment solution of Atle[®], and it should be compatible for all transfer situations.

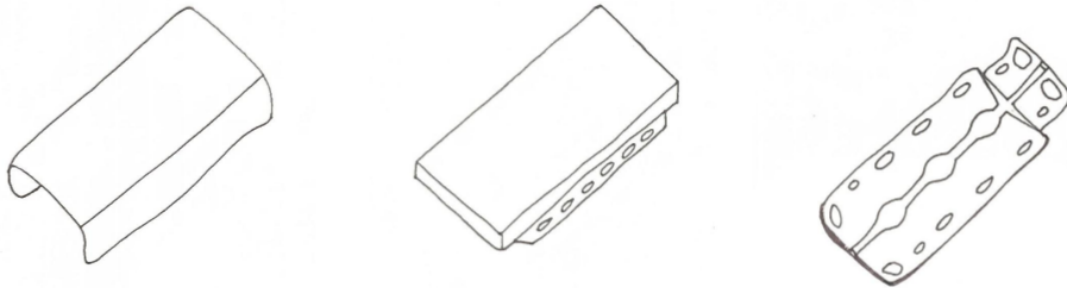


Figure 2.4. *Illustration of the three main objects that Atle[®] can attach to. From left to right: bed sheet, trauma mattress and scoop stretcher.*

2.3 Hygiene in healthcare

In healthcare settings, there are certain hygiene requirements that must be met for both the personnel and equipment used. When designing a product for a clinical environment, it has to meet the criterion of microbial cleanness. There are two main categories of what is considered microbial cleanness: *single-use sterile products* and *reusable disinfected products* (Edman Wallér, 2025). Either the product has to be sterilised in production and only used one time and then discarded, or it has to be made from a material that is compatible with disinfection procedures after every use. This also applies for components of Atle[®], and is a constraint that need to be considered in the development of the attachment solution.

2.4 Summary

This chapter outlines the prerequisites for the project, focusing on patient transfer practices, ergonomic risks and technical solutions that aid patient transfers. Manual patient handling remains common, despite being associated with physical strain and risk of injury, which emphasises the need for assistive devices. Atle® 180 is a device that enhances safety and efficiency by automating patient transfers. However, its current attachment system has potential to be improved in order to encourage and ease use of the aid. In addition, strict hygiene requirements impose important constraints on the design. Overall, this chapter highlights the need for a safer practice for the healthcare workers, time efficiency and an attachment solution that recognises these contextual constraints. The main takeaways of this chapter can be summarised to:

- Patient transfers are frequent in healthcare and essential for patient safety and comfort, but they are physically demanding and risk injury to caregivers.
- Manual handling is still common despite guidelines recommending multiple caregivers and the use of mechanical aids, creating a need for improved technical solutions.
- Risk factors in patient handling include patient weight, movement, posture, workspace conditions and transfer distance.
- Ergonomic studies show that manual patient handling often leads to high spinal loads, frequently exceeding recommended safety limits, which highlights the injury risks.
- Atle® 180 is a mobile, battery-driven device designed to aid lateral patient transfers, reducing physical strain and improving the work environment for the healthcare workers.
- The device's current attachment system (transfer bar and line loops) works for bed sheets, trauma mattress and scoop stretcher, but has limitations in functionality and usability.
- Hygiene requirements in healthcare enforce strict constraints, requiring either single-use sterile components or materials that withstand repeated disinfection.

3. Methods

In this chapter the methods used in this project and detailed descriptions of them are presented. The aim is to give a clear understanding of the theoretical and practical approaches that this work is based on. By outlining each included method, this chapter establishes a foundation for the selected methods and ensures they are clearly defined and understood.

3.1 Background research methods

This section presents the methods used to conduct background research to gain a better understanding of the current system and context. The methods included are *Literature study*, *System model* and *User profiles*.

3.1.1 Literature study

To gain an understanding of the product usage and the context, a review of existing literature and relevant information was conducted. Sources included articles, technical reports, product manuals and design guidelines related to the device and its application. The current attachment solution of the device was studied to define the starting point of the development. The insights gained from this study provided a foundation for identifying potential improvement areas and defined important design considerations in the project. The results from this research is presented in Chapter 2.

3.1.2 System model

A system can be defined as a situation that is represented by an organised whole made up by elements (Flood & Carson, 1993). The system model is a breakdown of the system and its elements using boxes to represent boundaries. Relations between systems and/or sub-system are marked using arrows to represent information or energy. Some boxes can be presented using black frames, which are systems with mechanisms that will not be explored further (Flood & Carson, 1993). This can be done in order to define the included objects and sub-systems within the product that are out of the scope or where details are considered irrelevant.

3.1.3 User profiles

A user profile is a breakdown of users' characteristics and experiences relating to the use of a product or service (Bligård, 2025). It includes categories such as what kind of user they are, their level of knowledge and experience, frequency of use and their emotional relationship towards the device. Table 3.1 presents what each category in the user profile represents.

Table 3.1. Explanations of categories in the user profile (Bligård, 2025).

Category	Explanation
<i>Type of user</i>	Defines whether the user is a primary, secondary, co-user or side user.
<i>Education</i>	Minimum educational or training background required for proper use.
<i>Language understanding</i>	Level of reading and comprehension ability needed to understand instructions or interface elements.
<i>Knowledge</i>	Degree of general or technical knowledge related to the device.
<i>Mental model</i>	The user's expected understanding of how the device works and how it should be operated.
<i>Experience</i>	Prior exposure to or familiarity with similar products or technologies.
<i>Frequency of use</i>	How often the device is expected to be used.
Influence on and responsibility of use	Describes the user's level of decision-making power in selecting the device, their control over the usage context and their degree of responsibility and accountability during operation.
Emotional relationship towards the device	Addresses the user's emotional connection to the device, including aspects of ownership, social visibility and the potential impact on self-perception, confidence and overall user experience.

3.2 Data collection & needs identification

The methods used for data collection and needs identification are presented in this section. The data collection consisted of *Observations & contextual inquiry* and *Interviews*. The data was compiled and translated into design *Requirements & guidelines* using the *KJ method*.

3.2.1 Observations & contextual inquiry

Observations are a field study method where the observer watches a user from distance (Baxter et al., 2015). The participants of an observation study can either know they are being observed or not. The data that can be collected could be in the form of facial expressions, comments or behaviours that get documented in text, video, notes or pictures.

Contextual inquiry is an observation-based method consisting of four main elements: *context*, *partnership*, *interpretation* and *focus*. The contextual aspect relates to conducting the observation in the user's environment to better understand them (Baxter et al., 2015). Partnership means to immerse in the participant's work or task and do as they do. Interpretation represents that the observational conclusions are verified by the user. To achieve focus during the observations, an observation guide should be used.

3.2.2 Interviews

An interview is a data collection method commonly used in user studies. Baxter et al. (2015) states that an interview is a guided conversation in which one person seeks information from another. An interview may be structured by asking pre-defined questions or spontaneous and fluent by asking questions based on answers given in the moment. The questions are aimed at retrieving information that in other ways may be difficult to retrieve or to gain first-hand knowledge from the user.

3.2.3 KJ method

Identified needs can be categorised into groups based on themes using the KJ method. The KJ method consists of four steps: *label making*, *label grouping*, *chart making* and *explanation* (Scupin, 1997). In the first step, *label making*, information based on observations from a relevant problem is written down on paper notes. After this, during the *label grouping*, the notes are grouped in broader titles or categories for needs that relate to the same theme. In the third step, *chart making*, the groups are placed on a bigger paper to create an overview of the categories. In the last step, *explanation*, the chart is discussed to ensure which areas are relevant.

3.2.4 Requirements & guidelines

A set of design guidelines and requirements can be established by specifying them in a list (Österlin, 2016). The criteria can be listed as a translation of identified user needs, functional and contextual goals, and it is important to find a balance between strict, technical constraints and loosely formulated needs. The purpose of making a requirement specification is to create an overview of the product goals (Österlin, 2016). The list of design criteria is a living document that is often revisited to ensure it represents insights gained in later stages of the product development process.

3.3 Ideation methods

The ideation process included two main brainstorming methods for creating concepts: *SCAMPER* and *Round Robin*. This section explains the selected ideation methods in more detail.

3.3.1 SCAMPER

SCAMPER is an ideation method in which a problem or product gets approached through new perspectives with the help of several guiding words (Österlin, 2016). Each guiding word sets the starting point for the brainstorming sessions. By using the guiding words as a driver for the ideation, a broad variety in ideas can be achieved. The guiding words are:

- Substitute
- Combine

- Adapt
- Modify
- Put to another use
- Eliminate
- Reverse

3.3.2 Round Robin

Round Robin is a method in which a potential solution or idea is analysed in what ways it might fail and then ideating ideas on how to solve the issue (LUMA Institute, n.d.). In practice this means that each of the participants start with a piece of paper that is folded into four sections. In one section of the paper, they write down a solution which can be supported by a quick sketch. The paper is passed on to the next person who will write down a way the idea might fail. The paper is then passed on once again and the next person will write down an idea that could prevent it from failing in that way.

3.4 Concept evaluation & selection

To evaluate the different concepts and select one for further development, both *Mockups* and *Pugh matrix* evaluation were conducted. This section presents the selected methods for narrowing down the options.

3.4.1 Mockups

A mockup is a physical model of an idea that is created to get a rough, hands-on feeling of a design solution in full scale (Österlin, 2016). It is a simplified version of a prototype, with the purpose of providing a tangible visualisation of the concept as well as enabling early evaluation of the functionality and usability.

3.4.2 Pugh matrix

The Pugh matrix is a method where pre-defined criteria is used as a mean of measure to compare concepts or ideas with a current solution (Six Sigma, 2024). It works by setting the current solution as a baseline at 0 points, if the new idea is considered to be better it will gain one point, however if it is considered to be worse it will lose one point. This proceeds throughout the whole list of design criteria and the sum determinants if the idea is viable. If the score is negative, the idea will be discarded or reworked. If the score is positive it is considered a viable solution.

3.5 Development & validation methods

The selected final design concept was developed and validated in the last stage of the project. This included *CAD modelling*, *Prototype testing* and *RULA*. This section describes the methods used in the development.

3.5.1 CAD modelling

The final concept was modelled in more detail using CAD. The program used for this was CATIA V5. CATIA stands for *Computer-Aided Three-dimensional Interactive Application*, and is widely used for product design and development (Dassault Systèmes, n.d.).

3.5.2 Prototype

A prototype is a model of a design meant to represent a product idea in detail and provide a base for further modifications (Österlin, 2016). The prototype should represent the form, function and material of the planned product in great detail, however the manufacturing method of the prototype may vary from that of the final product.

3.5.3 RULA

Rapid Upper Limb Assessment (RULA) is an ergonomical assessment tool that is used to assess movements in a specific moment in manual work. The RULA tool uses a systematic process to evaluate posture, force and repetition in a task, focusing on the upper body (Middlesworth, n.d.). The scores are added up to give insight in the risk of musculoskeletal disorders (MSD). The total score from the assessment represents the level of risk as:

- 1-2: negligible risk, no action acquired
- 3-4: low risk, change may be needed
- 5-6: medium risk, further investigation, change soon
- 6+ : very high risk, implement change now

4. Procedure

This project consisted of six main phases: *Pre-study*, *User research*, *Problem analysis*, *Ideation*, *Evaluation* and *Development*, illustrated in Figure 4.1. Rather than being a linear process, several of the project phases were approached iteratively, which allowed insights to be revisited and concepts to be progressively refined. The phases that were revisited were the *Problem analysis*, *Ideation* and *Evaluation*. All of the phases included specific methods selected to drive the work, from the initial understanding to the final concept development. This chapter describes how each phase was approached and how the methods were applied. It also presents what parts of the work that were done more than once and how any iteration differed from the previous one.

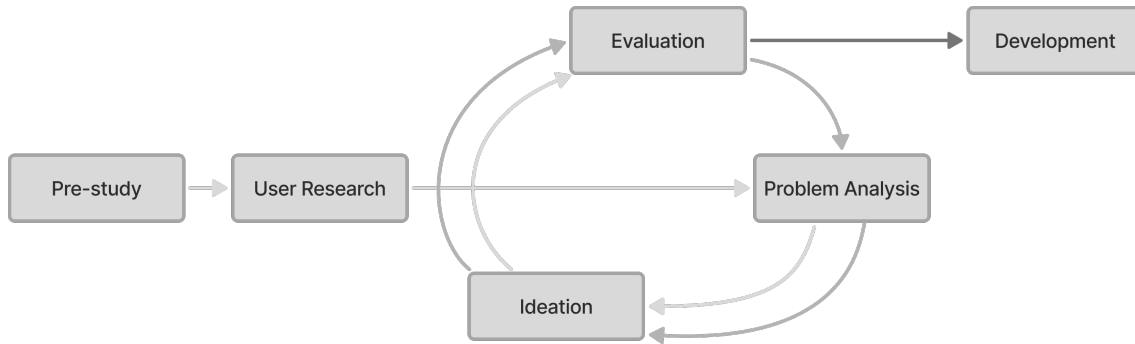


Figure 4.1. *Overview of project phases.*

The pre-study was included to establish a foundational understanding of the current context. This included an understanding of the current attachment solution of Atle®, including both the technical and contextual constraints. This helped set the scope of the project and identifying initial assumptions and constraints. The results of this phase are presented in Chapter 5.

The user research phase was of significant importance for the project. It was conducted to gain insights in behaviour, needs and challenges of the product users. This phase ensured that the project was grounded in a real user perspective rather than just assumptions. The findings, presented in Chapter 6, revealed the user needs and pain points that were the starting point for the problem analysis.

The problem analysis aimed to structure and define the main challenges identified in the previous phases. By summarising insights from both the pre-study and user research, this phase translated user needs and observed issues into clearly defined problem statements that were then formulated as design guidelines and requirements. This step was essential to ensure that the project addressed the right problems and provided a focused direction for the concept development. The outcomes of this phase are presented in Chapter 7.

The ideation phase was included in order to explore a wide range of possible solutions to the defined problems. Through creative and structured ideation methods, multiple concept ideas were created to address both functional and user-centred needs. The focus was on maintaining a broad solution space before narrowing down the options. This approach allowed for innovative ideas to emerge while ensuring alignment with the project constraints. The results of this phase are presented in Chapter 8.

In the evaluation phase, the created concepts were compared and evaluated based on their functionality and the set guidelines and requirements. The evaluation was done both physically and theoretically, using mockups and design requirements respectively. This phase helped identify the most suitable concept to move forward with. The outcomes of this phase are presented in Chapter 9.

The development phase focused on further developing the selected concept into a more final design solution. The concept was refined and adjusted to better meet the requirements and guidelines of the project. The purpose of this phase was to ensure that the final design was feasible and well adapted to its intended use. The results of this phase are presented in Chapter 10.

4.1 Pre-study

The pre-study phase of the project gave a deeper understanding of the product and the current solution for the attachment system. The study consisted of four main methods: *literature study*, *system model* and *user profiles*. This section describes how these methods were applied in this project, including any modifications or adaptations made.

4.1.1 Literature study

In order to gain a better understanding of the prerequisites for this project, an initial literature study was conducted. This was done by reading existing papers on relevant topics. The relevant theory for this work was found both on the internet and also through Chalmers library. The articles and websites that were collected as source material for this research were found using search words like:

- Njord Medtech
- Hygiene in healthcare
- Patient transfers
- Lifting in healthcare work
- Atle® 180
- Patient transfer devices
- Lifting ergonomics

- Manual lifting ergonomics in the work place
- Unsafe patient handling

Some resources were provided by Njord Medtech, for example the report from the study by Skotte and Fallentin (2008), highlighting the risk of injuries when repositioning patients in bed. Some information about Atle[®] 180 and how it is used were also provided by Njord themselves.

4.1.2 System model

The model of the system and its context was created digitally in Figma. In order to differentiate between what is included in a system or sub-system, boundaries outline each system box. Arrows were used to show the relationships between the systems or elements. The reason for creating the system model was to better understand Atle[®]'s context and sub-systems and keep this in mind throughout the development. Figure 4.2 shows the definition for the colours used for each box in the model. Blue boxes with dashed boundaries were used to communicate systems or elements that are considered an indirect part of the attachment system.

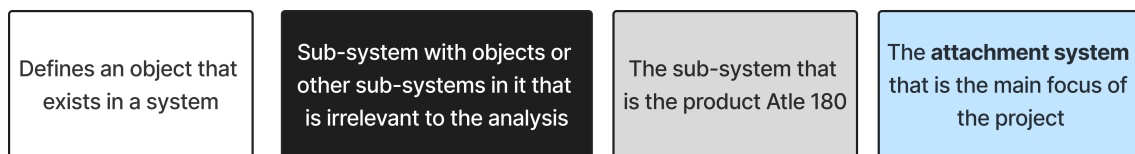


Figure 4.2. *Definitions of box colour coding in the system model.*

4.1.3 User profiles

A definition of the users was done by creating user profiles for both nurses and patients. This was done to define the differences and set the starting point for further identifying user needs. The conclusions drawn about the user groups were based on the insights from the literature study.

4.2 User research

The user research in this project consisted mainly of a visit at Sahlgrenska University Hospital, where observations and spontaneous interviews were conducted. Initially, observations of the current solution and the environment that the product is used in was done. The spontaneous interviews were conducted during the same visit with different workers at the hospital.

4.2.1 Observations & contextual inquiry

The observations were done during a visit at Sahlgrenska University Hospital. Due to hospital regulations, no photography was allowed, so the empirical data was collected in the form of notes, guided by the observational questions in Appendix A.

The main part of the observations was conducted at the radiology department. To gain a deeper understanding of the transfer situation using Atle[®], both authors alternated between assuming the role of patient and observer. While one was transferred using the device, the other documented the procedure through written notes. This approach enabled both experiential insight from the patient perspective and systematic observation of the workflow and handling of the attachment system. During this process, two nurses and the founder of Njord Medtech was present in the roles of caregivers.

4.2.2 Interviews

Spontaneous interviews were conducted during the visit at Sahlgrenska University Hospital to gain insights from healthcare workers in their working environment. The interviews were informal and semi-structured, which allowed for follow-up questions based on observations and responses. This approach enabled the collection of context-specific information about the current attachment system, work routines and experienced problems. The data from the interviews were collected in the form of notes. The prepared interview questions are presented in Appendix A.

The participating healthcare workers were approached in their working environment and asked to share their experiences regarding the use of Atle[®]. In total, approximately 10 caregivers participated in the discussions. Although the interviews were informal, they provided valuable user insights of daily workflows, practical challenges and user behaviours that may not have been captured through other methods. Conducting the interviews during work hours was beneficial, as the participants were already in a work-oriented mindset.

4.3 First round of phase sequence

Some phases of this project were conducted iteratively in a sequence, where the previous phase informed the next. Figure 4.3 presents the three phases that were included in this sequence: *Problem analysis*, *Ideation* and *Evaluation*. This section describes the procedure of the first round of this sequence.

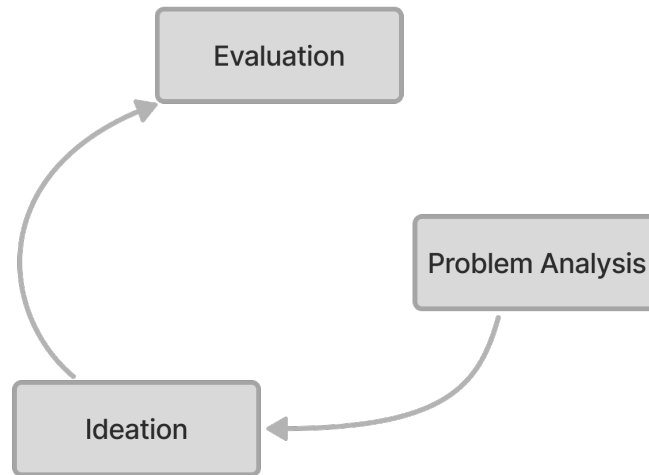


Figure 4.3. *The phases included in the iteration sequence.*

4.3.1 Problem analysis

The problem analysis consisted mainly of three main parts: *the breakdown of current problems, the sorting of identified needs using the KJ method and the translation of these identified needs into design requirements and guidelines*. Initially, the problems of the current solution were defined and further analysed to give a starting point for the development ahead. This was done by breaking down the problems into problem statements. To break down the problems, a mind map was created to highlight the main problem areas. The problems that were identified were based on the user feedback from interviews and observations.

Once the breakdown of the problems was done, identified needs were categorised into groups using the KJ method. The sorting of needs was done on paper, making it easy to change or move around the pieces until the categories were considered to represent an accurate picture.

Based on both the problem mind map and the KJ map, a set of design requirements and guidelines were listed. Each need or problem were translated to either guide development or be a measurable requirement. The guidelines and requirements were classified as either a *need* (N) or a *want* (W). A *need* represents a critical aspect that the product must fulfil in order to function, whereas a *want* represents a desirable characteristic that improves the solution but is not strictly essential. The *wants* were given a priority value 1-5 to mark how important they were considered. A value of 5 represents high priority and a value of 1 represents the lowest priority.

4.3.2 Ideation

The first round of ideation consisted of sessions of SCAMPER and Round Robin. Ideas from the brainstorming methods were sketched out on paper and parts of the sessions were controlled by a timer that indicated when to switch papers or stop. The first method that was used was SCAMPER, where each of the guiding words were used in one session. This means that seven sessions were conducted. This method was used in order to create a broad variety of ideas early in the ideation process.

After the SCAMPER sessions were complete, some of the ideas that were considered interesting were put through a session of Round Robin. This meant that two perspectives were given to the same idea, both to highlight risks and possibilities with each idea. The Round Robin sessions started with one idea that was evaluated and improved by one person. After five minutes, each person switched papers and tried to modify or identify new risks that would be improved again. The Round Robin rotations were done after four swaps.

4.3.3 Evaluation

In the first round of evaluation, the first group of concepts were created using low fidelity mockups to test their overall functionality. The mockups were made with materials such as cardboard, tape, paper, cords and smaller existing components. The created mockups were then attached to a bed sheet to see how well they could attach to it. The mockups were created again with more detail after they were considered to fulfil the general function of attaching to the bed sheet properly. Based on the testing with the first mockups, smaller modifications were made to the concepts.

After creating the mockups, the concepts were checked against the design criteria using a Pugh matrix to confirm whether they fulfil them better or worse than the current attachment solution on Atle[®]. There were three possible scores that the concept could be given on each criteria: *same* (0), *better* (1) or *worse* (-1) than the current solution. The basis for how the criteria were assessed or tested differed depending on the criteria. Some criteria were not included in this phase of the project and would not be assessed in the selection process. An example of this is the criteria regarding material selection, as no concept had been given a specific material at this stage. There were four alternative verifications based on the criteria:

- Testing with mockups (Included all concepts)
- Testing with prototype of final concept (Only for the final concept)
- Evaluation based on design and testing (Included all concepts)
- Evaluation based on design and material selection (Only for the final concept)

Which criteria got what assessment is presented in Appendix B. The total scores for each concept were added up to see which concept got the highest score. From this round, the concepts that got negative scores were eliminated from following phases.

4.4 Second round of phase sequence

Following the first round of evaluation, the phase sequence was revisited consisting of *Problem analysis*, *Ideation* and *Evaluation*, illustrated by the black arrows in Figure 4.4. The second round of the sequence built upon the findings and outcomes of the first round, refining both the understanding of the problem and the developed concepts. This section describes the procedure of the second rounds of the phases.

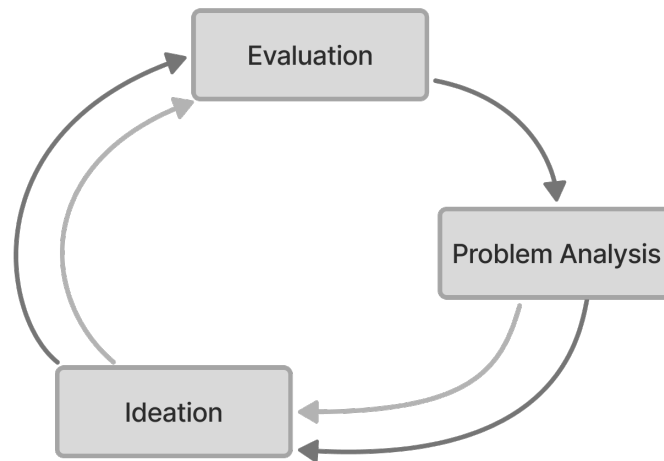


Figure 4.4. *The phases included in the iteration sequence.*

4.4.1 Problem analysis

In the second round of this phase, the requirements and guidelines were updated with new information found during the first rounds of the ideation and evaluation phases. By revisiting this phase, it was possible to make sure the requirements and guidelines represented the solution.

4.4.2 Ideation

During the second round of ideation, mainly parts of the SCAMPER guiding words were used. The focus was on *Substitute*, *Modify* and *Eliminate*. The reason for this was that the concepts of the first round were used as starting points in the sessions. In order to develop or improve the concepts, they were either modified or parts were eliminated and substituted to reduce and maximise the existing ideas. During this round, the existing concepts and new ideas were discussed and merged in different ways to ensure no concept variation were missed.

4.4.3 Evaluation

The second round of evaluation followed a similar procedure to the first round. However, this round focused on the more refined concepts created in the second round of ideation. In contrast to the first round of evaluation, which aimed to explore and test a broad variety of concepts, this round emphasised comparison and

selection between more developed concepts. Each mockup, including any new concept additions, was tested again and more weight was put on the sheet in these tests.

In addition to the mockup evaluation, a second round of the Pugh matrix evaluation was done to check how well the requirements and guidelines were met by the second concept group. Because some modifications had been made to some of the concept, the matrix evaluation was updated. This allowed for honest judgement and a new perspective that was not influenced by previous scores. This time, the selection was more strict since only one concept was considered for further and final development.

After conducting both the mockup testing and Pugh matrix comparison, the results were discussed before making the final decision on which concept to move forward with. Because not all criteria had been evaluated at this stage, these were also discussed to see if they could affect the concepts' performance. After careful consideration, the decision was made and one of the concepts was selected to be further developed.

4.5 Development

The selected concept was refined and improved in the development phase. This section presents how this was approached and what was done to validate how the final prototype performed.

4.5.1 CAD modelling

The selected concept was modelled in CATIA V5 and made to scale 1:1 for 3D-printing. When modelling the concept digitally, the main focus was on the two blobs. Two parts were created in order to enable printing on flat surfaces. The bottom half was modelled with a hole going through it. This way, the line connecting it to the holder could go through and a knot would hold the bottom piece in place. The top part had to have a cavity that allowed the knot to not hinder the connection between the parts.

4.5.2 Prototype

The prototype was made using the digital model and the current lines of Atle®. The blobs were printed in full scale to be able to test the attachment solution by assembling the blobs with the current line components. In order to make it possible to attach a line that connects the blobs to the main line holders, the blobs were split in half. The printed parts were glued together after tying the connecting line. Because the prototype parts were assembled before the test, duct tape was used during the test to hold it together while the glue was setting.

4.5.3 Prototype testing

The testing of the prototype was done at Njord Medtech's office. The prototype of the concept was put in Atle[®] and tested during transfers of a person. The transfers were done between a hospital bed and a massage table. Both the authors and two people from Njord tested attaching the solution to the bed sheet. This way, insights about the performance could be discussed and ideas for improvements could be made with input from Njord. Observations were made while operators tested the prototype and the handling of the product was evaluated. The testing was documented through pictures and videos of the transfer and attachment.

4.5.4 RULA

The RULA was conducted to validate the ergonomic aspects of the final design concept. In order to do this, the current solution was also evaluated using the RULA tool. Both solutions were evaluated in the same environment and with the same participant. The RULA was not used in early concept evaluation, and only aimed to validate the performance of the selected concept compared to that of the current solution. The RULA was conducted by one author assuming the role of the Atle[®] operator and attaching the solution to the bed sheet. The body position of the operator was discussed and evaluated according to the RULA chart. When both solutions had been assessed this way, the total scores were calculated.

5. Pre-study

The pre-study created a foundational understanding of Atle[®] 180 and its current attachment solution. The results from the pre-study are presented in this chapter.

5.1 Literature study

The outcome of the literature study is presented in Chapter 2. The insights from this research is about the product Atle[®] 180, the current attachment solution, transfer situations for Atle[®], patient transfers in general and hygiene in healthcare.

5.2 System model

The attachment system that is the main focus in this project exists within a bigger context, illustrated by the system model in Figure 5.1. This shows a box view of the systems that are included in the product's environment. Inside the product, the attachment is only one sub-system of the more complicated functionality. However, the other systems within the product, such as the levelling system and wheel system, are outside the scope of this project. The figure illustrates this with blacked out boxes. Furthermore, the product itself exists in the context of the hospital room. Atle[®] is shown in grey, while the blue boxes are meant to show the attachment system. The bed sheet is also coloured in blue to illustrate that this is the attachment point of the current solution. The main components of the attachment system are the line loops (Left and Right) and the transfer bar.

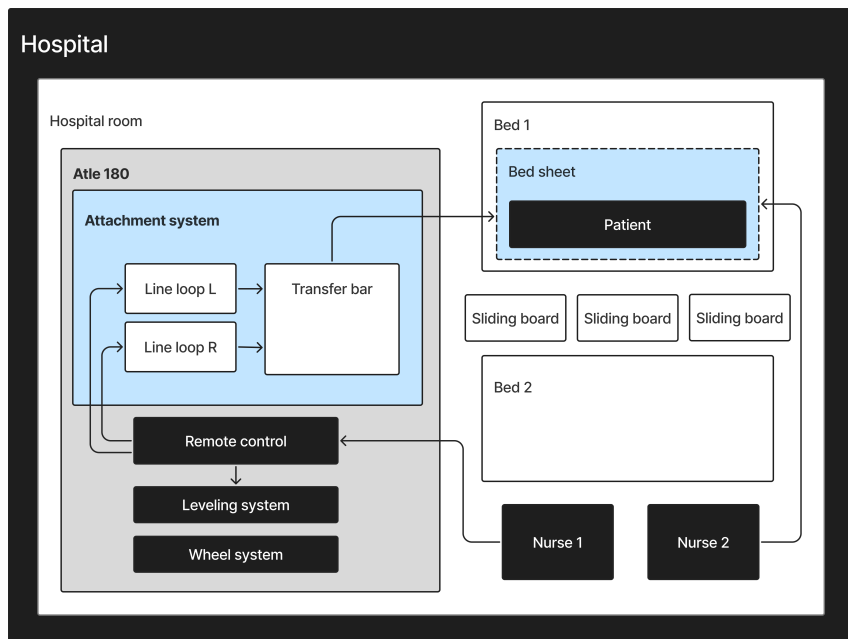


Figure 5.1. *System model of Atle[®] 180 and the environment.*

5.3 User profiles

The main users of Atle[®] are considered the nurses who operates the device and the patients that are transferred with the device. The primary users are the operators, but the patients are still relevant to consider since they also have needs to be met when it comes to the attachment. A presentation of the user profiles for each user group is shown in Table 5.1.

Table 5.1. User profiles for the two user groups identified for Atle[®] 180.

User	Nurse, the operator	Patient
<i>Type of user</i>	Primary user	Secondary / Side user
<i>Education</i>	Nursing programme at university	None
<i>Language understanding</i>	Not required, the device symbol-based. The instruction manual is in Swedish or English or other languages.	Not necessary
<i>Knowledge</i>	Knows how to operate the device safely	None
<i>Mental model</i>	Functional mental models: - Patient transfer with sliding boards is common even without aid, so they are included in the system to be familiar. - Remote control, familiar with the concept of operational control.	None
<i>Experience</i>	General experience of using the device	None, or some experience if the patient is regularly visiting
<i>Frequency of use</i>	Multiple times a day	Rarely
Influence on and responsibility of use	They cannot choose which product to use, but they can choose not to use it.	Usually no influence on the chosen device, however they can ask to move themselves if possible. Most often the patient has no influence on the use situation either. The patient is not responsible.
Emotional relationship towards the device	The user does not take ownership of the device. Communication with the patient being transferred if they are conscious.	The patient does not have ownership of the device. In some cases, they may want to tell the operator when they feel ready to be moved.

5.4 Summary

The pre-study established a foundational understanding of the current Atle[®] 180 system, focusing on its current attachment solution and the broader context in which it operates. Through a literature study, system modelling and user profiling, the pre-study identified key functional elements, limitations of existing solutions and the differences among user groups. This groundwork provided insights for guiding further concept development.

- The attachment system is part of a larger context and is used in hospitals.
- Both operator efficiency and patient comfort and safety are important factors that affect the design of the attachment system.

6. User research

The findings from the user research confirm that there are some problems with the current attachment system that could be improved. Both the observations and the interviews with caregivers at Sahlgrenska University Hospital gave insights in user needs that were valuable in the development of the new attachment solution. This chapter presents the insights gained from the user research.

6.1 Observations

A description of the workflow when transferring a patient with Atle® from a bed to the CT table can be done based on the findings from the observations. The workflow began with the nurses placing the device on the receiving end of the CT table. One of the nurses stood between the bed and CT table with three sliding boards, and placed them under the bed sheet at the feet, torso and head area. Once the sliding boards were in place, the nurse wrapped the transfer bar in the sheet and attached the lines over it. After the attachment was done, the nurse moved away from between the transfer surfaces and the other nurse pushed the bed so it was in contact with the CT table. Figure 6.1 illustrates how the set-up looked.

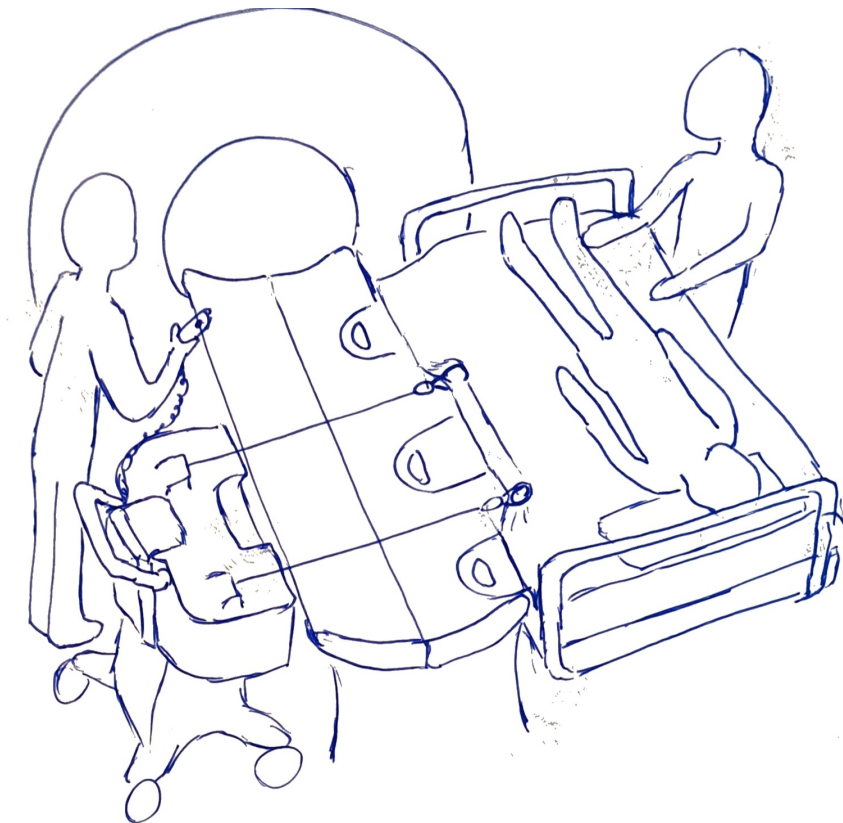


Figure 6.1. *Illustration of the observations in the CT room before transfer.*

The nurse operating Atle® stood at the receiving end, holding the control. The other nurse were at the patient side, ready to guide their legs when the transfer started. After communicating to the patient, the nurse at the receiving end started the transfer. The patient and sheet was transferred over to the CT table and ended up as shown in Figure 6.2. The transfer process was quick, taking only a few seconds. When the patient was at the CT table, the bed was removed by the nurse at the bed side, and then the sliding boards were also removed from under the patient. At the same time, the attachment was undone by the operator nurse and the device was put to the side after the transfer was complete.

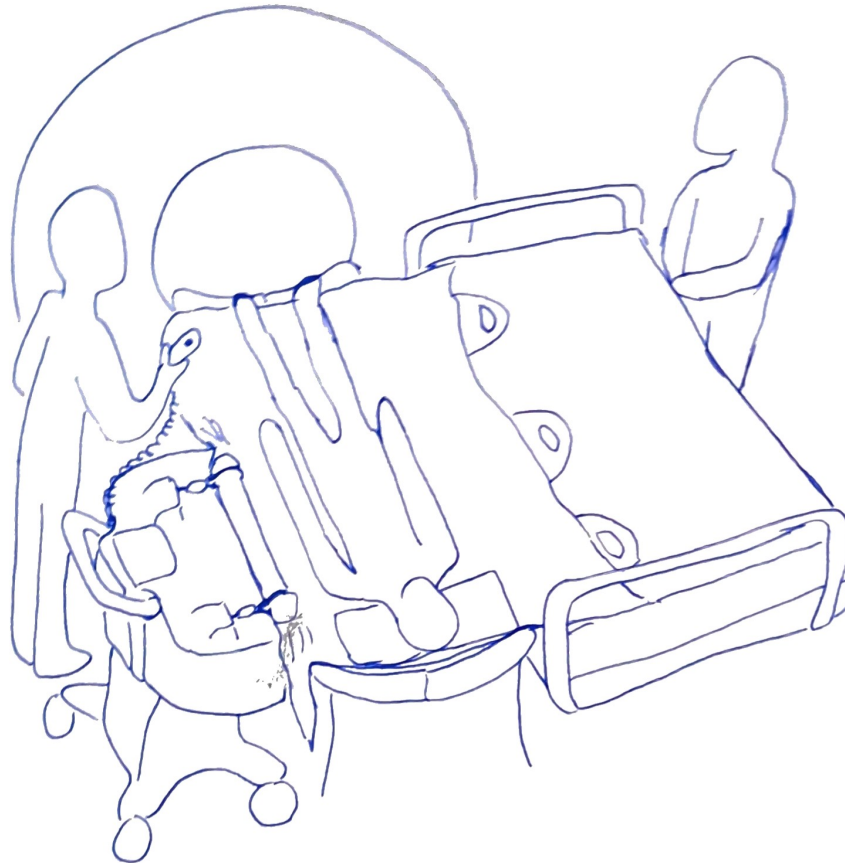


Figure 6.2. *Illustration of the observations in the CT room after transfer.*

The required steps for completing the attachment process of the current solution was observed as:

- Place the transfer bar on bed sheet
- Fold the sheet around the transfer bar
- Attach one loop around the end of the wrapped transfer bar
- Pull the line holder on the line to tighten the loop
- Attach the other loop in a similar way
- Pull the line holder on the line to tighten the loop

6.2 Interviews

The purpose of the interviews was to better understand how Atle[®] is used in practice, identify recurring issues and explore what factors that influence whether the product is used or not. The responses highlighted both practical and contextual challenges, illustrating the complexity of introducing assistive devices into fast-paced clinical settings. The findings from the interviews were summarised and the main take-aways were:

- Timing is crucial in the hospital environment, even small delays can have significant consequences.
- Most of the nurses had experienced Atle[®] detaching of the sheet in some way.
- Using Atle[®] can cause awkward body positioning when operating alone.
- Many users had their own way of attaching the sheets, some roll it, others fold it over.
- Some issues the users had when attaching the line was that either they had too much sheet in between or too little. The issue with too little sheets occurs more often with heavier patients.
- When wrapping the sheets, some had the problem of too much fabric between the lines and the transfer bar, making it detach even though they thought it to be secure.
- When using Atle[®], it can be uncomfortable to hold the control and simultaneously hold the sheet to direct the patient.
- The availability of Atle[®] also affects how much use it gets, and how the experienced usefulness of it is. If Atle[®] requires “more work” before even starting the transfer than what a manual lift would, users said that they sometimes refrain from using it.
- Different scenarios make for different solutions. Some patients in radiology come from the Intensive Care Unit with a team of nurses, so it is quicker to let the team lift the patient instead of using Atle[®]. However, when there is few staff it is more common for the users to use Atle[®].

Overall, the interviews indicate that the effectiveness of Atle[®] is not only dependent on its technical functionality, but also on how well it integrates into the existing workflows. Factors such as time efficiency, ease of setup and usability strongly influence whether the device is used in practice.

6.3 Summary

The user research confirmed that the current attachment system presents usability challenges in real clinical environments. Through observations and interviews with caregivers, important insights were gained into workflows, user behaviour and contextual constraints. The findings highlight that the effectiveness depends not only on its technical performance but also on how well it integrates into time-critical healthcare settings.

7. Problem analysis

In this chapter, an analysis of the current problems are presented. The main areas of problems with the attachment solution were mapped out according to Figure 7.1. Defining the current problem areas was important for understanding the current user experience with the attachment and the product itself. The identified problem areas were *wrapping the sheet*, *detaching*, *time* and *lack of feedback*.

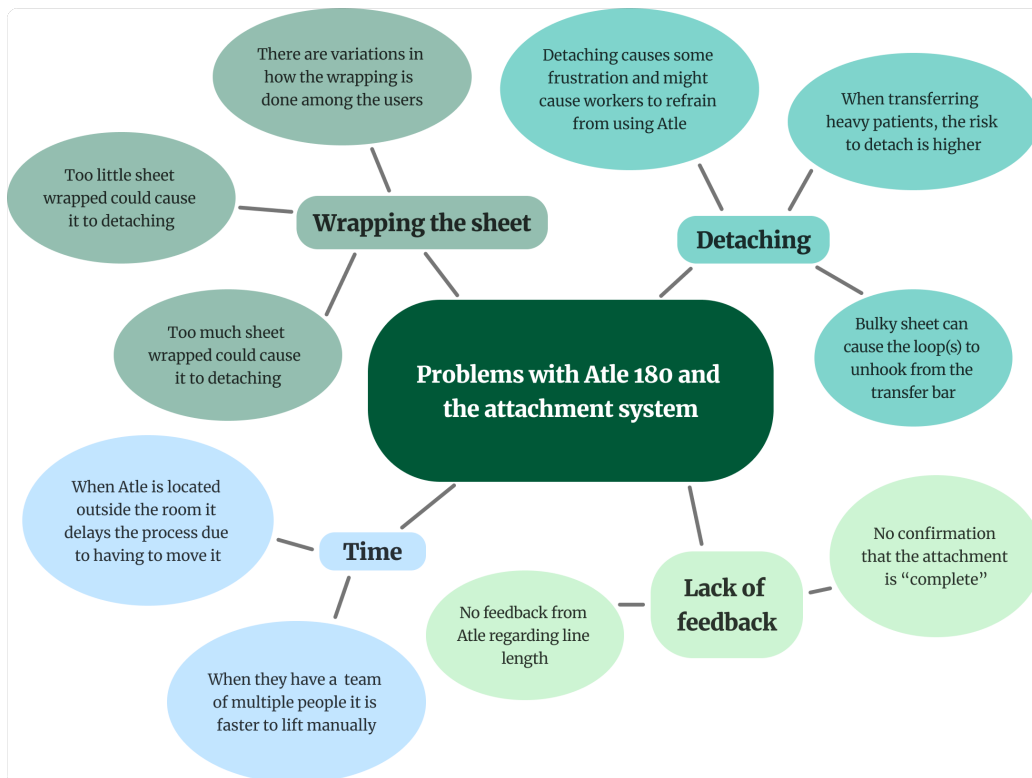


Figure 7.1. Identified problem areas with Atle[®] and the attachment system.

The issues related to *wrapping the sheet* relate to variations in user technique, where both insufficient and excessive wrapping can lead to unintended detachment. For *detaching*, users reported increased frustration during patient transfers, where higher loads and bulky sheets raise the risk of the loops detaching from the transfer bar. In terms of *time*, inefficiencies can occur when the device is not easily accessible, given that Atle[®] is stored in the corridor. Efforts to save time are generally made when having multiple caregivers to assist manually, which was preferred even though it requires lifting the patient. Lastly, the *lack of feedback* creates uncertainty for users, because there is no clear indication when the attachment is correctly secured, nor guidance regarding appropriate line length, which may impact the usability of the product.

7.1 KJ method

Based on findings from the user research and the problem map, the identified needs were written down. These were then sorted into groups using the KJ method. After categorising the identified needs into groups, five main themes were created: *Use*, *Functionality*, *Ergonomics & Safety*, *Material* and *Hygiene*, which are presented in Figure 7.2.

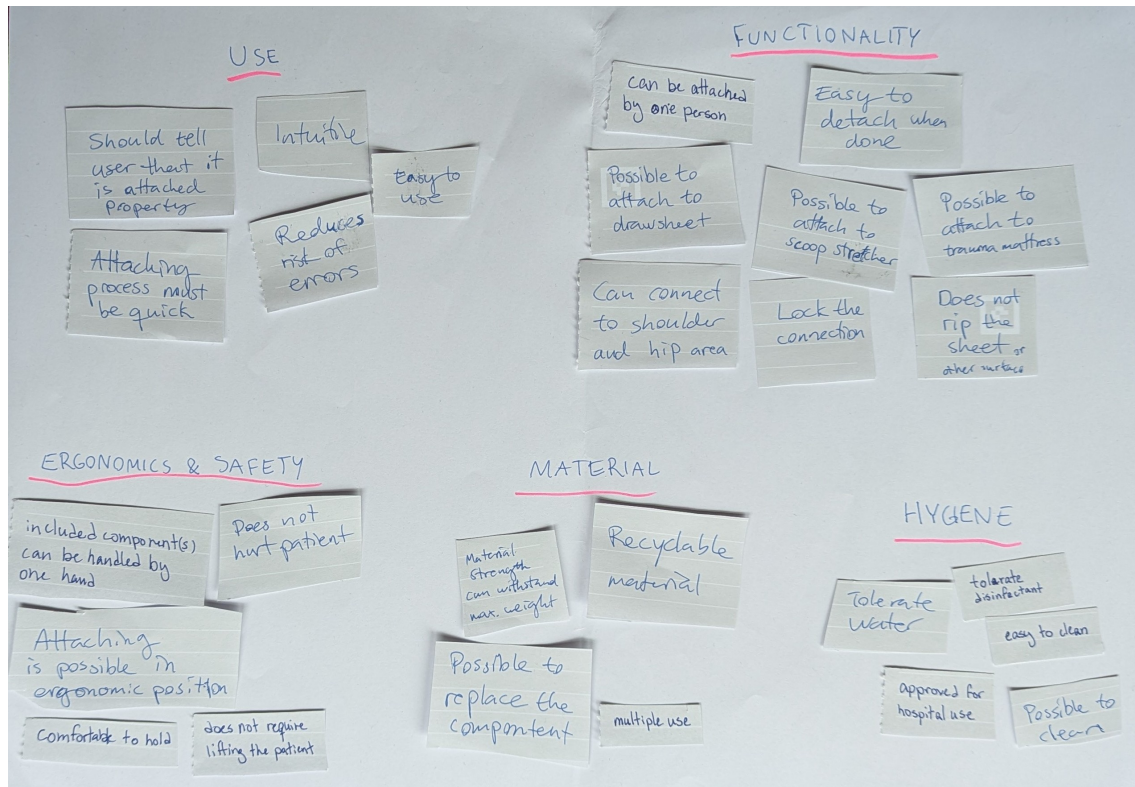


Figure 7.2. Identified needs categories and early requirements and guidelines.

The *Use* category includes needs that relate to the usage of Atle® and the attachment solution. Examples of this is that it should reduce risk of errors and be intuitive. The *Functionality* category includes needs regarding the solutions functions, for example that it should attach to drawsheet, trauma mattress and scoop stretcher. However, the main function is considered to attach to bed sheet as it is the most common use situation for transfers with Atle®. The *Ergonomics & Safety* category includes needs about the users' body positioning and safety. Examples of this kind of needs are related to handling the component in safe and ergonomic positions, and also not hurting the patient. The *Material* category includes the needs for material properties and end-of-life disposal. Lastly, the *Hygiene* category includes needs that relate to the clinical hospital environment and cleaning possibilities.

7.2 Requirements & guidelines

The design guidelines are listed in Table 7.1 and describe criteria that guide the development of the solution. The guidelines address the integration of the attachment system with existing equipment, ease of use for the operator, ergonomic handling, suitable material choices and hygiene considerations relevant to clinical environments. The functional guidelines include compatibility with equipment such as a draw sheet, trauma mattress and scoop stretcher, as well as the ability for the system to be attached by a single user without damaging the attachment surface. Some of the guidelines were considered *wants* rather than *needs*. These criteria were prioritised on a scale of 1-5, where 5 represents highest priority. As an example, it was considered that the locking of the attachment (1.8) was somewhat important, but not crucial to include, so it was rated 3 on the priority scale.

Table 7.1. Design guidelines for the attachment solution.

Guidelines	N/W	Rating	Verification
1 Functionality			
1.1 Attaches to drawsheet	N	-	Testing with prototype
1.2 Attaches to trauma mattress	N	-	Testing with prototype
1.3 Attaches to scoop stretcher	N	-	Testing with prototype
1.4 Connects to shoulder and hip area	N	-	Testing with prototype
1.6 Can be attached by one person	N	-	Testing with prototype
1.7 Does not rip or break the attachment point on the surface	N	-	Testing with prototype
1.8 Locks the attachment	W	3	Testing with prototype
1.9 Compatible with magnets for stop	N	-	Testing with prototype
2 Use			
2.1 Informs user that it is attached properly	W	5	Testing with prototype
2.3 Intuitive	W	5	User testing
2.4 Reduces risk of errors	W	4	Evaluation
2.6 Components remain stationary when set down	N	-	Testing with prototype
2.7 Limits wear and tear on the lines*	N	-	*If the solution requires lines. Evaluation based on current solution
3 Ergonomics & Safety			
3.1 Included component(s) can be handled by one hand	N	-	Testing with prototype
3.2 Does not harm patient	N	-	Evaluation
3.4 Comfortable to hold and adjust	W	4	Evaluation
3.5 Does not require lifting the patient	N	-	Testing / Evaluation
4 Material			
4.2 Recyclable material	W	5	Evaluate material properties
4.3 Possible to replace the component(s)	N	-	Test the disassembling
4.4 Multiple use	N	-	Testing / Evaluation
5 Hygiene			
5.2 Disinfectant compatible	N	-	Material property evaluation
5.3 Easy to clean	W	5	Testing with prototype
5.4 Approved for hospital use	N	-	Check with regulations
5.5 Possible to clean	N	-	Testing with prototype

Table 7.2 shows a specification of the requirements for the new attachment solution. The design requirements translate some of the critical needs into measurable targets. These include performance criteria for the attachment process, such as completing attachment in less than 25 seconds. This criterion was based on the transfer time of 15 seconds (Njord Medtech, 2021) plus 10 seconds extra, since the attachment process include more steps than the transfer itself. Other examples include detaching the system within 15 seconds and limiting the attachment process to fewer than six steps, which was set based on the required steps for the current solution. Ergonomic considerations are addressed by requiring that the attachment can be performed in an ergonomic position, which can be verified using established ergonomic assessment methods.

Table 7.2. Design requirements for the attachment solution.

Requirements	N/W	Rating	Goal value	Unit	Verification
1 Functionality					
1.5 Easy to detach when transfer is done	N	-	< 15	Seconds	Time the detaching process
1.10 Limit the amount of sheet used in attachment	N	-	≤ 15	cm	Measure how much fabric is needed for attachment
2 Use					
2.2 Attaching process is quick	N	-	≤ 25	Seconds	Time the attaching process
2.5 Easy to use	N	-	≤ 6	Steps	Count how many steps are needed for attaching
3 Ergonomics & Safety					
3.3 Attaching is possible in ergonomic position	N	-	Yes	Yes/No	RULA evaluation
4 Material					
4.1 Material strength can withstand max. weight	N	-	> 180	kg	Strength calculation
5 Hygiene					
5.1 Water resistant	N	-	20	IP 20	Compatible with Atle 180

7.3 Summary

This chapter presents the main problem areas of the current attachment solution in Atle® based on user research and observations. Existing issues were identified in how the sheet is wrapped, how detachment occurs, time inefficiencies in accessing the device and a lack of feedback. These insights were further structured using the KJ method, resulting in five main categories of user needs: *Use, Functionality, Ergonomics & Safety, Material* and *Hygiene*. Based on the findings, design guidelines and measurable requirements were listed to support the development.

- Four main problem areas identified: wrapping the sheet, detaching, time and lack of feedback.
- User technique variation can lead to unintended detachment.
- Time inefficiencies can be due to poor accessibility and preference for manual handling.

8. Ideation

The ideation gave a broad variety of ideas to choose from in the selection process. Both brainstorming techniques, SCAMPER and Round Robin, generated a large number of potential concepts. Some ideas were closely related to the current solution, while others explored completely new approaches. This variation was important to avoid narrowing the solution space too early and to allow both minor improvements and more innovative concepts to be considered. The ideas were documented on paper, discussed and later evaluated further as potential options for the final solution.

8.1 SCAMPER

The SCAMPER ideation method was used to generate a wide range of potential design solutions for the attachment. The session produced ideas across all SCAMPER categories, including substitutions of materials, combinations of existing features and simplifications of system components. These ideas were grouped into key concept directions, primarily focusing on *force direction*, *bars with modified ends*, *blobs* and *grip*. The resulting idea themes served as a foundation for following stages, where selected designs were further refined and evaluated.

The theme *force direction* included ideas where the pulling force direction were changed in some way. These ideas were created from several of the SCAMPER guiding words, and because of this it was made into a theme. These ideas were grounded in the problem that the current attachment solution sometimes detaches during use.

Same thing sparked the creation of the theme *bars with modified ends*, where the transfer bar was changed by having other features or attaching mechanisms. The main problem that these ideas were grounded in were that some users expressed that a lock would be good.

In the *blobs* theme, ideas were less like the current transfer bar attachment solution. These were ideas that moved away from the transfer bar and instead used some form of shape to be wrapped around. These ideas often included two separate points of attachment.

The last theme, *grip*, included ideas that did not use the wrapping technique of the current solution. These were ideas that instead gripped the sheet in some way. The most promising ideas among all themes were used in the following ideation stage to be further refined.

Sketches from the SCAMPER sessions can be found in Appendix C.

8.2 Round Robin

By iterating through some of the ideas and finding ways to improve them, some ideas could be developed into more reliable concepts. Figure 8.1 shows a selection of refined ideas using the Round Robin method. This ideation session was valuable for developing the ideas so that the solutions were more likely to meet the requirements and guidelines.

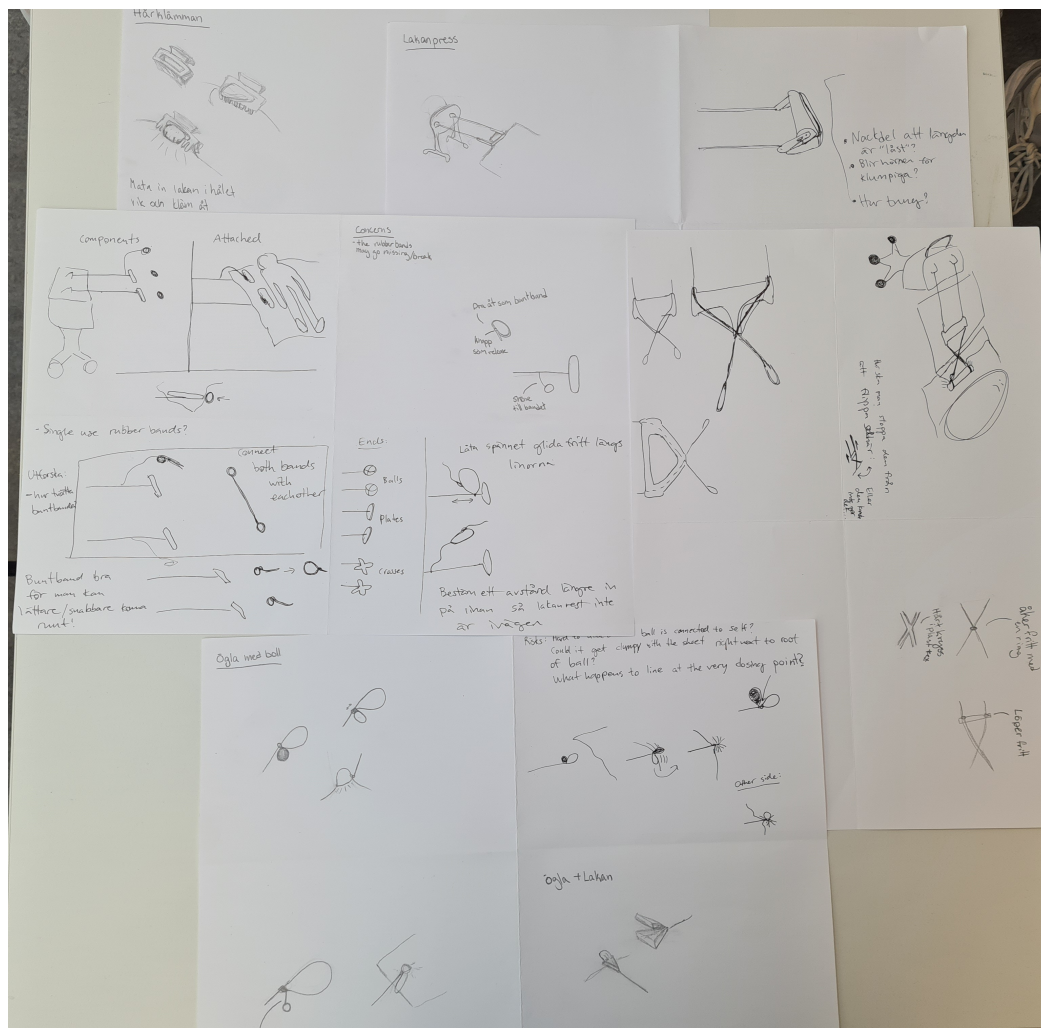


Figure 8.1. Selection of concept ideas that were improved during the Round Robin method.

8.3 Summary

The ideation phase was revisited once after evaluating the first round of concepts and updating the requirements and guidelines in the second round of the problem analysis phase. This sparked a new set of concepts that were also iterated through the following round of evaluations. To summarise the results of the concept creation, this section describes both rounds of concepts.

8.3.1 Concept descriptions (first round)

The ideation phase generated multiple concepts that were considered as options for the final design solution. However, some of the ideas generated were considered not feasible or impractical, and therefore not included for the evaluation. In the first round of ideation, six concepts were selected to be evaluated further in the following phases, presented in Figure 8.2.

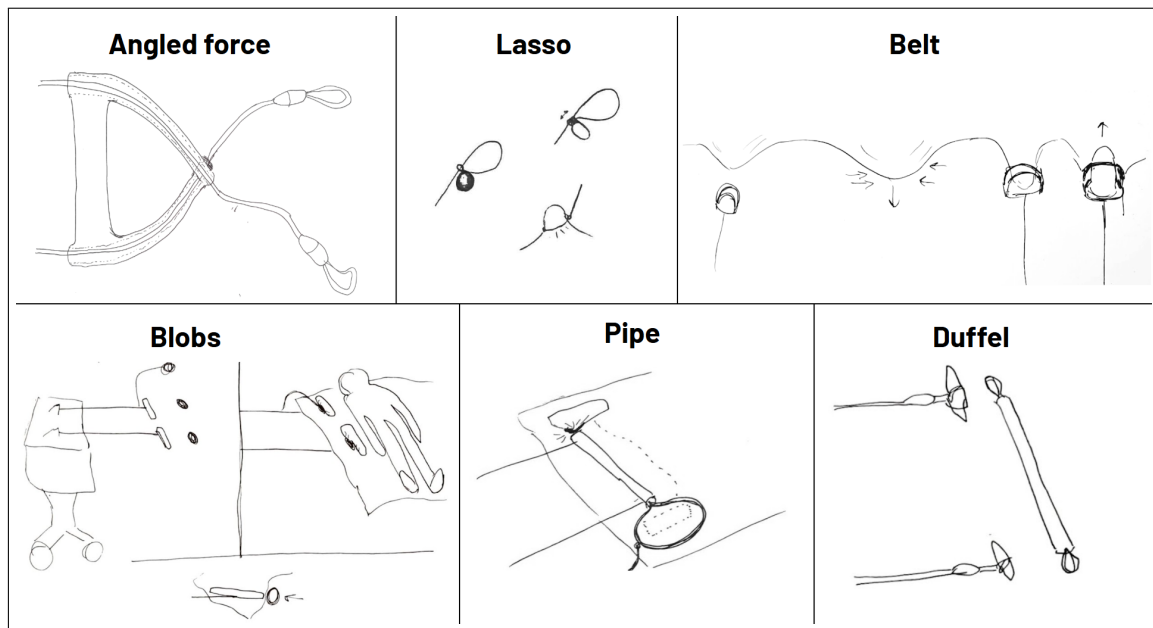


Figure 8.2. Presentation of all the concepts that were selected to be further evaluated.

Angled force: This concept is based on the current attachment solution of a transfer bar that is wrapped in the sheet and the line loops that attaches around the ends. However, the idea behind this concept is to change the pulling direction by crossing the lines and attach to the opposite side of the transfer bar. This is done by guiding the lines inside a construction to make them swap sides.

Blobs: This concept is based on using two points for attachment instead of one continuous bar. The blobs that are wrapped in the sheet is attached using small circles that lock similar to a rubber band.

Lasso: The Lasso concept works similar to the Blobs concept, but instead round balls are attached directly to the line holders of the current solution. The line loops are used to wrap around the balls like a lasso which locks the attachment to the sheet.

Pipe: This concept focuses on the problem with lack of feedback for locking the attachment. It is utilising a pipe with a buckle strap inside. It wraps around two blobs and locks the attachment using the buckle on the strap. The side without the buckle needs to wrap around its blob first and using the pipe to hold it in place. Then the loop of the other side can be pulled to wrap the second blob and lock the attachment with the buckle.

Belt: In this concept, the attachment is done by gripping the sheet and squeezing it while pulling in the transfer direction. This is based on a belt buckle mechanism, one for each attachment point, that is connected directly to the sheet.

Duffel: This concept is another idea that uses blobs for attaching. However, a bar is also included to evenly space out the two attaching points. The bar itself is not wrapped like the current solution, it is the blobs that works as a stop for the loops detaching.

8.3.2 Concept descriptions (second round)

The second round of ideation included a similar group of concepts. Some were concepts from the first round, but with minor modifications. One new concept was added to the selection to be evaluated further. A presentation of the second round of concepts can be seen in Figure 8.3.

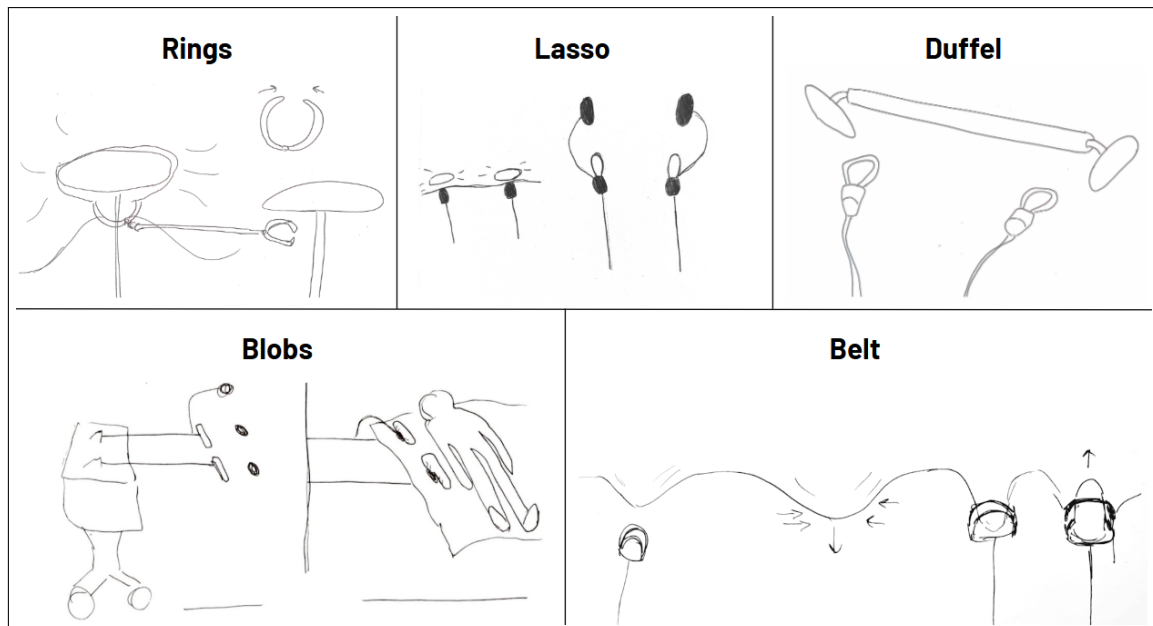


Figure 8.3. *Presentation of all the concepts that were selected to be further evaluated.*

Rings: The newest addition to the selected group of concepts is the Rings concept. This concept is similar to the Blobs concept, but uses hard rings for attaching to the wrapped blobs. The rings can be opened up to ease the process of fitting around the sheet.

Blobs: The second ideation round sparked a new idea for this concept. Instead of the rubber-band-like loops in the first round, it was modified to include the current line loops and line holders. By including an option for opening the loop, it is easier to detach after use. Otherwise, it works like the first version by wrapping the blobs and locking it in place using the loops.

Lasso: The Lasso concept had some improvements done in the second round. Instead of round balls, blobs are used and they are attached to the line holders by a longer line. This makes it possible to wrap further in on the bed sheet in case there is excess sheet hanging at the receiving end of the bed.

Belt: There were no changes made to this concept between the rounds. It was still considered an interesting option to be evaluated and compared to the new and the modified versions of other concepts.

Duffel: This concept changed the placement of the duffels and loops by switching them. In the first version, the loops were placed on the bar, but in the second version the blobs are placed on the bar. This made it possible to use the line loops of the current attachment solution, which were considered more intuitive.

9. Evaluation

In this chapter, the selected concepts are evaluated using physical mockups and they are compared against the guidelines and requirements to ensure that these are fulfilled. The best performing concept was selected for further development.

9.1 Mockups

The two mockups created for the Angled Force concept are presented in Figure 9.1. After testing the first mockup, a second mockup was created more to scale with the product. The concept attaches to a sheet similar to the current solution by using a transfer bar. The idea is to change the direction of the pulling force by letting the lines cross inside the construction. This makes it so that the pulling is not straight, which could reduce the risk of the line loops detaching from the wrapped bar.

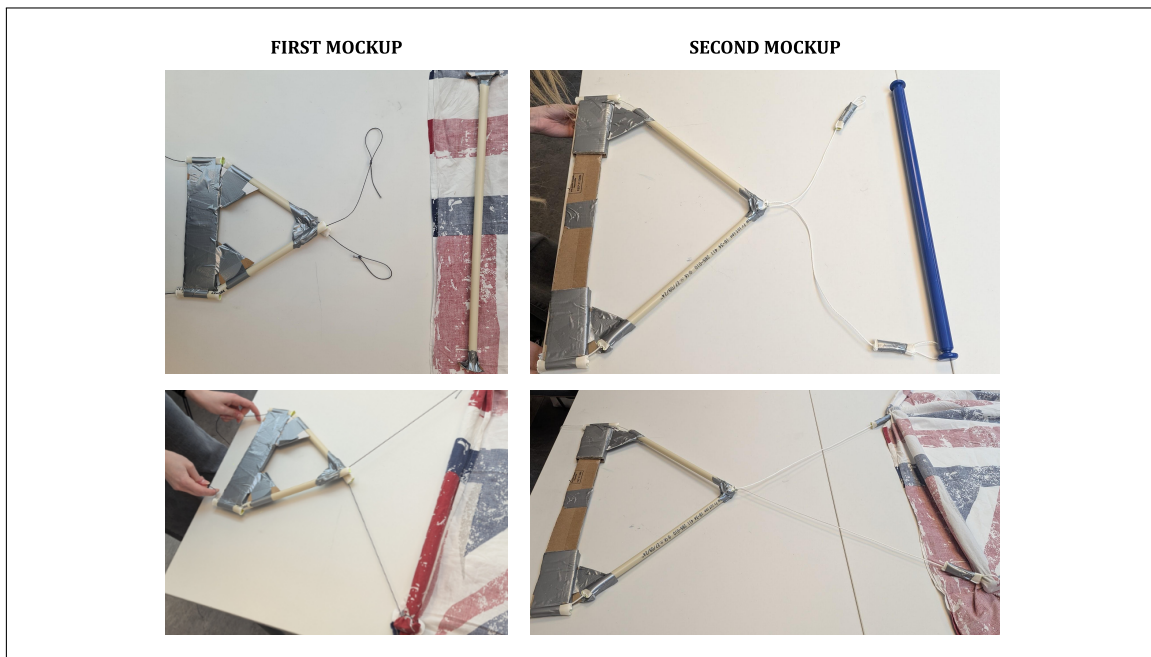


Figure 9.1. *Mockups of the Angled Force concept.*

The first mockup was smaller and used other lines and bar compared to the current solution. When testing this mockup, it was clear that the construction needed to have the same width as the line holes on Atle[®] to reduce the strain on the lines when pulling. Based on this insight, the second mockup was created using the current transfer bar and a wider construction.

The Blobs concept was first created using cardboard and duct tape, seen to the left in Figure 9.2. In the first mockup, the blobs were square shaped and made use of rubber bands for attaching to the sheet. When testing this mockup, it was noticed

that the square shape may cause damage on the sheet when pulling heavy loads. Therefore, the second mockup had more oval shaped blobs to reduce unnecessary strain on the fabric. The second mockup also made use of the current line loops instead of the rubber band solution. The reason for this is that the rubber bands were considered not reliable when testing. The blobs were instead freely connected to each other, not being on the lines, and wrapped by the lines to be more sturdy. This solution was considered more reliable and much easier to detach after use compared to the bands.

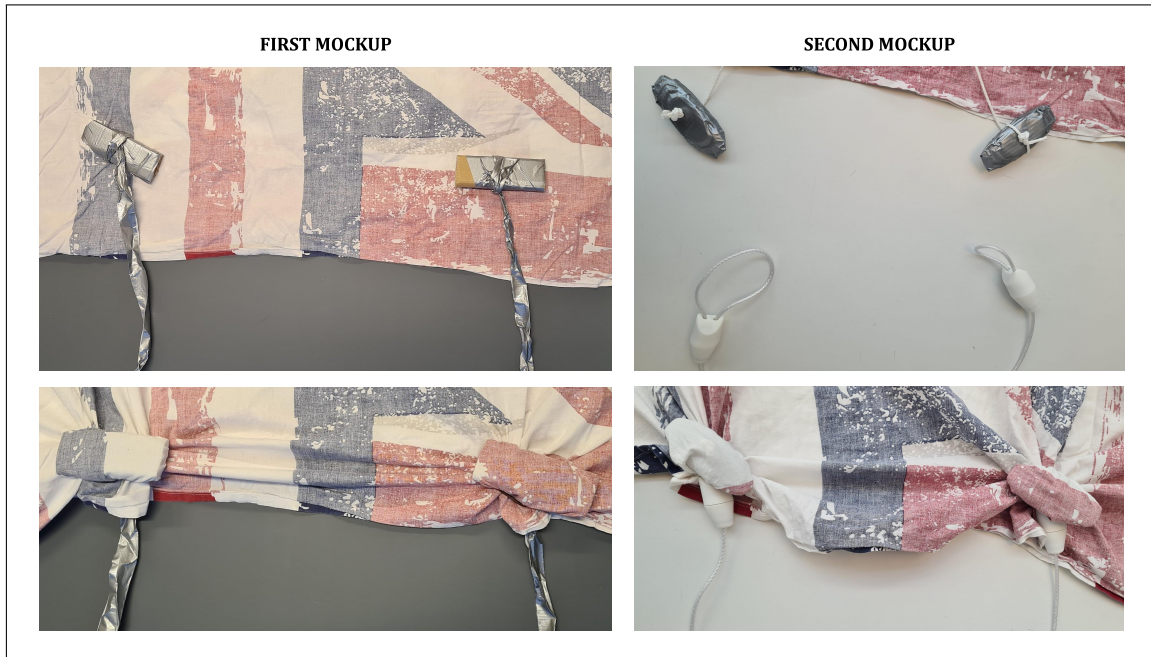


Figure 9.2. *Mockups of the Blobs concept.*

Figure 9.3 shows the two mockups created of the Lasso concept. The first mockup included two round balls, made of paper and duct tape, and used thinner lines than the current attachment solution. It was created to see if the idea of looping around itself would be enough to attach to the sheet. After testing the mockup it was considered that the attachment would work, and the design of the concept was modified and improved in the second mockup. This was done by swapping out the ball shape to the oval blob shape of the Blobs concept. Also, the current Atle® line holders were included in the concept. The length of the connecting part was also increased in case there is a lot of excess sheet that it had to go around. In the second mockup, the thin lines were swapped out by the lines of the current solution. This improved the reliability and made it easier to detach after use.

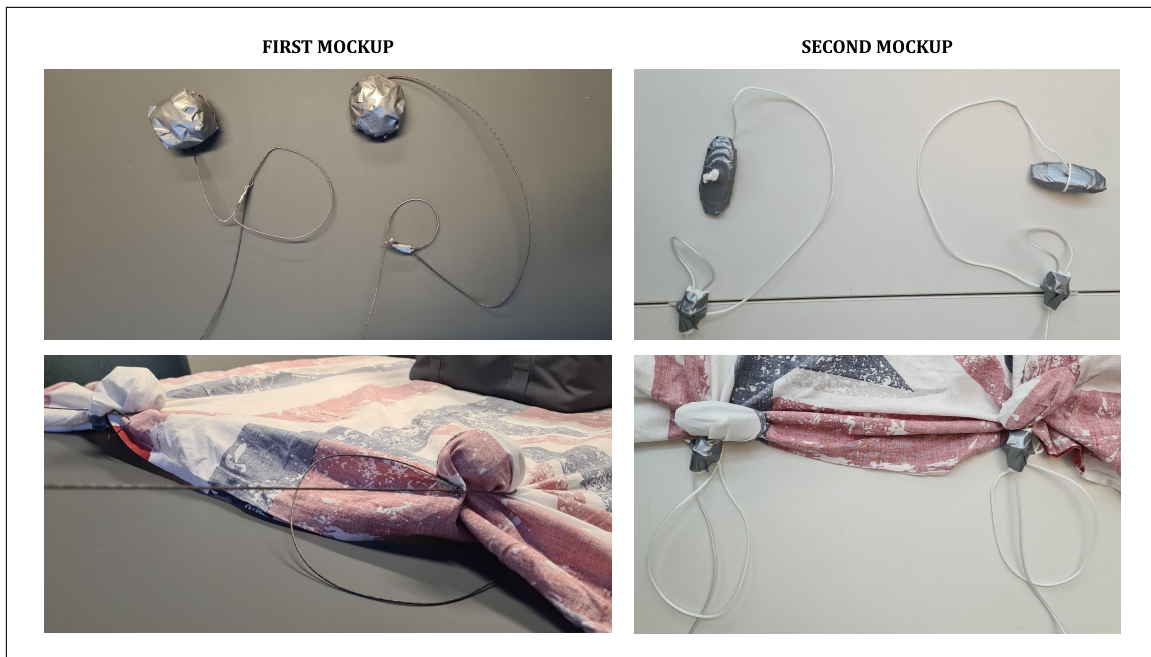


Figure 9.3. *Mockups of the Lasso concept.*

The Pipe concept was also evaluated by testing the function using mockups. Two versions of the Pipe concept were made, seen in Figure 9.4. The first mockup, to the left, was made using a paper roll for the pipe and a belt that was put inside the roll. It was attached by looping first one end of the belt around a square shape, and then pulling the pipe to make room for looping around the second square on the other end. The buckle of the belt was then used to secure the attachment. When testing this, it was noted that the attachment process was a bit tricky.

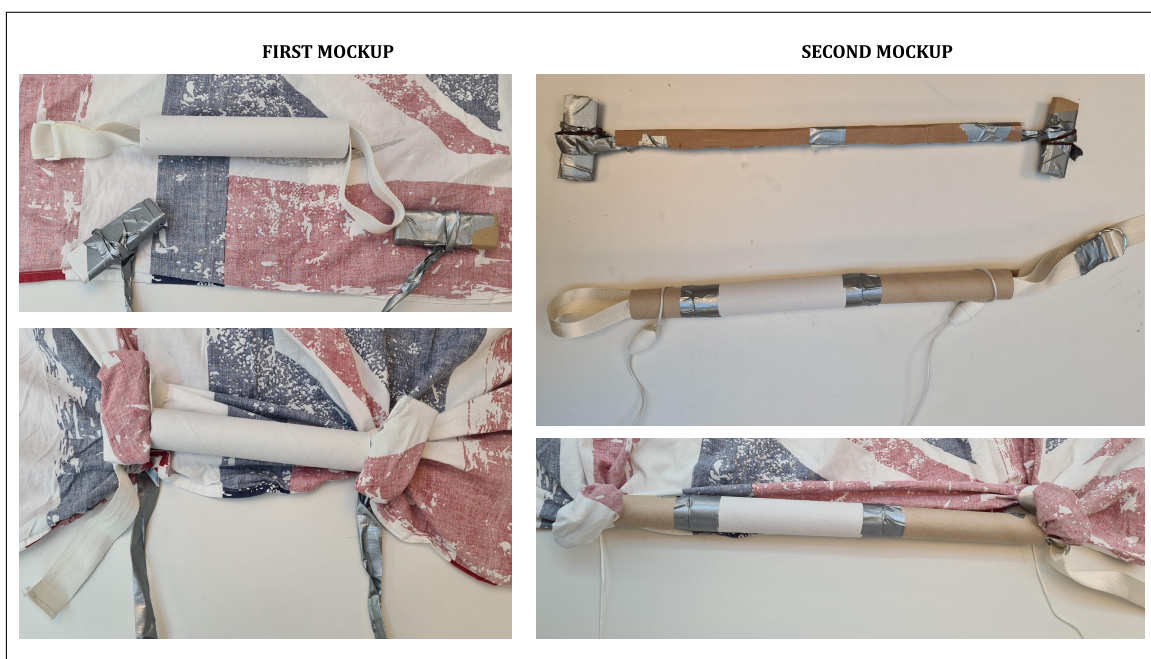


Figure 9.4. *Mockups of the Pipe concept.*

After evaluating the first mockup of the Pipe concept, some improvements of the design were made. The second mockup was created more to scale with the actual width between the lines, and it included a stiff connection between the blobs. It also included the line loops of the current solution that were wrapped around the pipe, instead of pulling on the shapes themselves.

Figure 9.5 shows the mockups created for the Belt concept. The first mockup had only one belt, so it was only used to test if the attachment would even work for a bed sheet. After trying to connect the belt to the sheet, it seemed like the idea would work. Therefore, a second belt buckle was made using two D-rings and a strap. Having two belt buckles made it possible to test the concept with two attaching points on the sheet. This made the pulling more even, and when pulling on the belt it would squeeze the sheet harder the more you pulled on it.

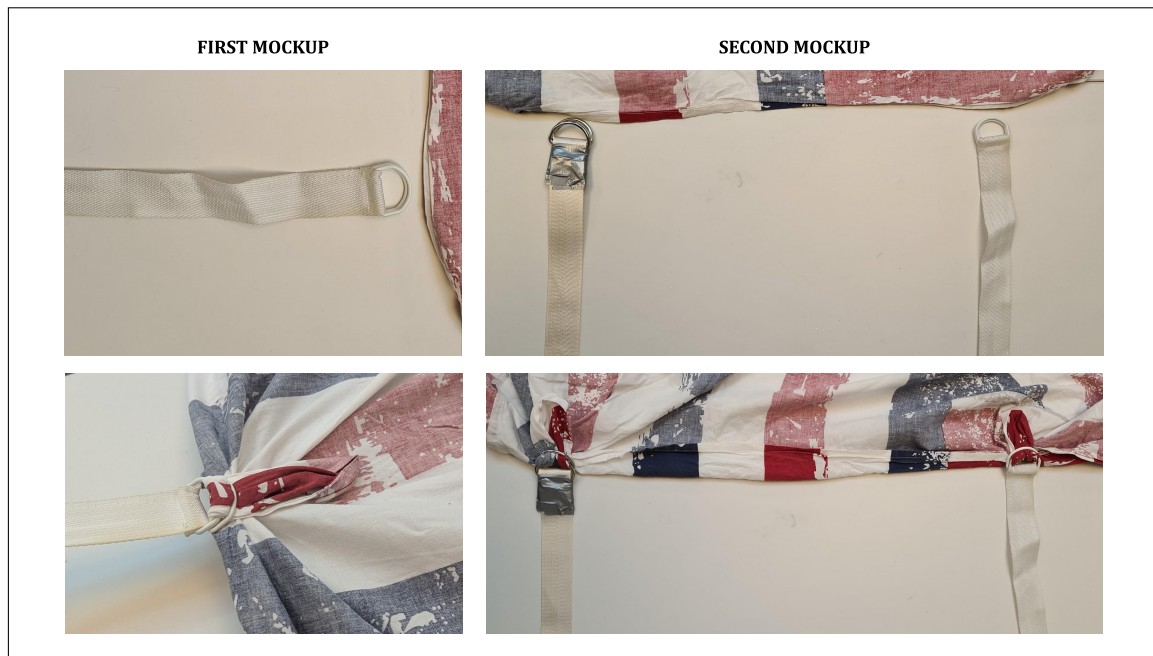


Figure 9.5. *Mockups of the Belt concept.*

The two mockups of the Duffel concept are presented in Figure 9.6. The first mockup was made of cardboard and duct tape, and it had square shaped blobs. The idea with the Duffel concept was inspired by coat buttons, but instead of putting a button through a hole in the coat it would be put through the line loops. When testing the first mockup, it was discovered that the cardboard was not sturdy enough, so the second mockup used the transfer bar of the current solution as a base. In this testing process, the same conclusion was made about the square shaped ends, so these were swapped to the oval shaped blobs.

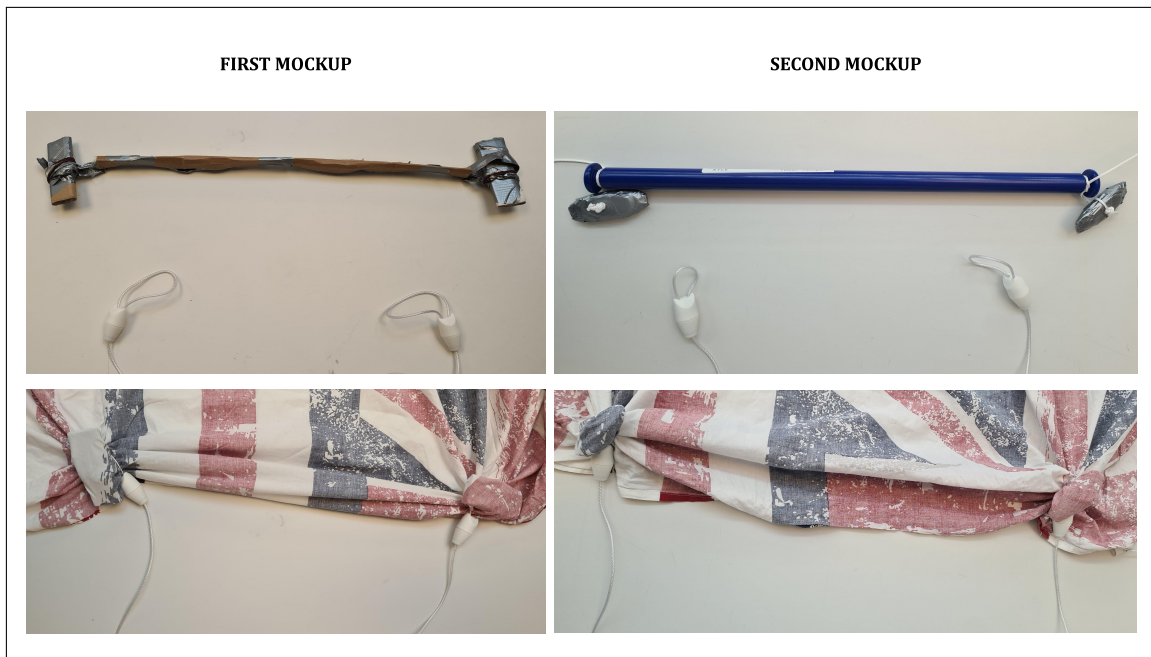


Figure 9.6. *Mockups of the Duffel concept.*

Figure 9.7 shows the two mockups created of the Rings concept. It works similar to some of the other concepts, by wrapping the fabric around each blob and locking the wrapping. In this concept, the locking is done using metal rings that open wide to ensure it is easy to get around all the fabric. The metal rings close by an S-shaped connection that can be opened by lightly pushing the ring halves in opposite direction and pulling them apart. Testing of the Rings concept confirmed that the metal rings could break the sheet when it was stretched out.

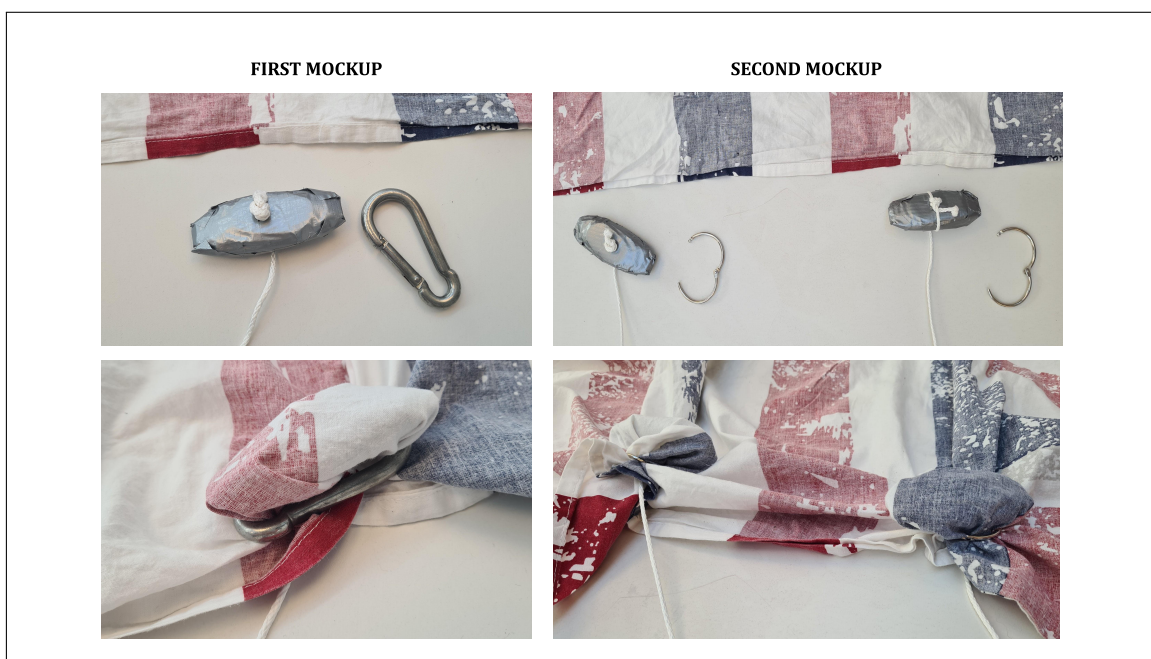


Figure 9.7. *Mockups of the Rings concept.*

Overall, the mockup testing showed that most of the concepts required iteration to improve functionality. Changes in shape and dimensions had a clear impact on performance. Solutions that were quicker and easier to attach and detach generally worked better. These insights were used to refine the concepts further and guide the selection of the most promising concept. The mockup evaluation confirmed that several of the concepts could work as a feasible attachment solution for Atle®.

9.2 Pugh matrix

Table 9.1 shows the results from the Pugh matrix evaluation of all concepts. It includes the criteria from both the requirements and guidelines, marked with either R or G in the left column. The concepts were compared to the current solution of Atle® 180 that is listed as the first concept column in the table. This was the reference for evaluating the other concepts, so it was given a score of 0 for all criteria. The other concepts got scored either same (0), better (1) or worse (-1) on each criterion, depending on their performance compared to the current solution.

Table 9.1. Result from Pugh matrix evaluation of all concepts.

		ATLE 180	ANGLED FORCE	LASSO	PIPE	BELT	DUFFEL	BLOBS	RINGS
G/R	1 Functionality								
G	1.1 Attaches to drawsheet	0	0	0	0	0	0	0	0
G	1.2 Attaches to trauma mattress	0	0	1	-1	0	0	0	0
G	1.3 Attaches to scoop stretcher	0	0	1	-1	0	0	0	0
G	1.4 Connects to shoulder and hip area	0	0	-1	0	-1	0	-1	-1
R	1.5 Easy to detach when transfer is done	0	0	0	0	-1	0	-1	0
G	1.6 Can be attached by one person	0	0	1	0	1	1	1	1
G	1.7 Does not rip or break the attachment point on the surface	0	0	0	0	0	0	0	-1
G	1.8 Locks the attachment	0	0	0	1	1	0	1	1
G	1.9 Compatible with magnets for stop	0	0	0	0	0	0	0	0
R	1.10 Limit the amount of sheet used in attachment	0	0	0	0	1	0	0	0
	2 Use								
G	2.1 Informs user that it is attached properly	0	0	1	1	1	1	1	1
R	2.2 Attaching process is quick	0	0	0	-1	0	0	0	0
G	2.3 Intuitive	0	-1	0	-1	-1	0	-1	0
G	2.4 Reduces risk of errors	0	-1	0	-1	-1	0	0	0
R	2.5 Easy to use	0	-1	0	0	1	0	1	0
G	2.6 Components remain stationary when set down	0	1	1	1	1	1	1	1
G	2.7 Limits wear and tear on the lines*	0	-1	0	1	1	0	0	1
	3 Ergonomics & Safety								
G	3.1 Included component(s) can be handled by one hand	0	0	1	0	1	0	0	1
G	3.2 Does not harm patient	0	0	0	0	0	0	0	0
R	3.3 Attaching is possible in ergonomic position	0	0	0	0	0	0	0	0
G	3.4 Comfortable to hold and adjust	0	0	1	-1	0	0	-1	0
G	3.5 Does not require lifting the patient	0	0	0	0	0	0	0	0
	4 Material								
R	4.1 Material strength can withstand max. weight	0	0	0	0	0	0	0	0
G	4.2 Recyclable material	0	0	0	0	0	0	0	0
G	4.3 Possible to replace the component(s)	0	0	0	0	0	0	0	0
G	4.4 Multiple use	0	0	0	0	0	0	0	0
	5 Hygiene								
R	5.1 Water resistant	0	0	0	0	0	0	0	0
G	5.2 Disinfectant compatible	0	0	0	0	0	0	0	0
G	5.3 Easy to clean	0	0	1	-1	1	0	1	1
G	5.4 Approved for hospital use	0	0	0	0	0	0	0	0
G	5.5 Possible to clean	0	0	0	0	0	0	0	0
	Total Score	0	-3	7	-3	5	3	2	5

The *Functionality* criteria included compatibility with different attachment points and other functionality features. The functional comparison highlights some differences between the concepts, and Lasso achieved the strongest functional performance with 2 points relative to the current attachment solution. Belt and Duffel also scored better with 1 point, indicating that they bring some improvements. Additionally, multiple concepts were considered to perform somewhat better than the baseline in easing attachment by a single user and being able to lock the attachment.

In terms of the *Use* criteria, Rings was given the highest score with 3 points, followed by Belt, Lasso and Duffel, which were given 2 points. A strength across the higher-ranking concepts is the ability to provide clear feedback to the user when the system is correctly attached. All concepts perform well in keeping components still when set down, which stem from an existing problem with the current system. However, several concepts scored negatively in intuitiveness and error reduction, suggesting that changes and complexity in design can be an issue. Pipe and Angled Force perform weakest in these criteria, indicating that they are less user-friendly than the current solution.

The evaluation of *Ergonomics & Safety* were mostly based on assumptions. Results therefore shows more limited differentiation between concepts. Some improvements were observed for Lasso, Belt and Rings in enabling one-handed handling of components, which can be beneficial in time-critical situations. Although most criteria, such as avoiding patient harm and ensuring ergonomic working positions, remained neutral across all concepts including the current solution. The reason for this is that these criteria are considered crucial and must be fulfilled. Overall, this category did not strongly influence the ranking of concepts.

The *Material*-related criteria were not included in this stage of the evaluation and therefore did not contribute to the comparison between concepts. Similarly, most of the *Hygiene* criteria were not actively assessed, with the exception of ease of cleaning. Lasso, Belt, Blobs and Rings showed some improvement over the baseline, while Pipe perform worse. This pattern indicate that less complicated components are easier to clean. Since the majority of material and hygiene factors were excluded, these criteria had minimal impact on the overall results and would be addressed in later stages of the project.

The overall scoring identifies Lasso as the strongest concept with 7 points, with Belt and Rings sharing second place (5 points). These concepts demonstrated a more balanced performance across both functionality and usability, which were the most influential categories in this evaluation. The results suggested that Lasso provided the most promising foundation for further development. In contrast, Pipe and Angled Force received the lowest scores (-3 points), suggesting limitations in effectiveness and overall usability. Despite the strong performance of Lasso, no concept fully satisfied all functional criteria, indicating that further refinement is needed to achieve a fully optimised final solution. It also indicates that the current attachment solution is a reliable solution in many aspects.

9.3 Summary

The evaluation phase was completed twice, where the first round narrowed down the options. The second round was when the final concept was selected for further development. This section summarise the selection process for each of the rounds.

9.3.1 Selection process (first round)

After considering the mockup testing and Pugh matrix evaluation of the first concept group, two concepts were eliminated. The concepts that were eliminated were Angled Force and Pipe. Both of the concepts received low overall scores and showed limitations during practical testing.

The Angled Force concept introduced concerns regarding reliability and safety during transfer. The crossed-line construction created an increased risk for an incomplete transfer due to the length of it being in the way when its end reaches Atle®. The concept was also considered more complex without providing enough improvement compared to the other concepts.

The Pipe concept was eliminated mainly due to hygiene concerns. Testing showed that the attachment process was relatively complicated and required several handling steps. In addition, the enclosed structure was considered more difficult to clean and sanitise between patients. Pipe was therefore considered less practical for the intended use environment.

9.3.2 Selection process (second round)

In the second round of evaluation, the final selection of concept was done. This time, the second group of concept was considered, and only one of them was to be selected. The Blobs concept showed improved reliability after modifications to the mockup, but the attachment process was still considered less practical because of multiple loose components which created some uncertainty during handling.

The Duffel concept demonstrated secure attachment functionality, but was considered as somewhat more impractical than some of the alternatives. The Rings concept performed well in usability-related criteria, but testing revealed concerns regarding the risk of damaging the sheet due to concentrated forces from the metal rings. The locking mechanism also introduced additional complexity and loose parts.

The Belt concept provided stable attachment that locked itself when applying force, but the buckle solution was considered less flexible in handling varying amounts of excess fabric. Overall, the Lasso concept was selected for further development because it provided the best balance between functionality, usability, reliability and simplicity. The concept demonstrated secure attachment while remaining intuitive, easy to handle and detach after use.

10. Development

This chapter presents the outcomes of the final phase of the project. The further development of the selected concept is described, including prototyping and selection of material.

10.1 Selected concept

The concept selected for further development was Lasso. It consists of the current lines with line holders and the new addition of blobs that the line loops wraps around like a lasso, illustrated by Figure 10.1. The figure shows an overview of the selected concept and what it looks like when it is attached to a bed sheet. As seen in the figure, the blob is connected by a line to the line holder, making it easy to handle and attach by wrapping the sheet around it. The already existing line holder and its bobbin were modified to use the suggested attachment mechanism instead of relying on the current transfer bar.

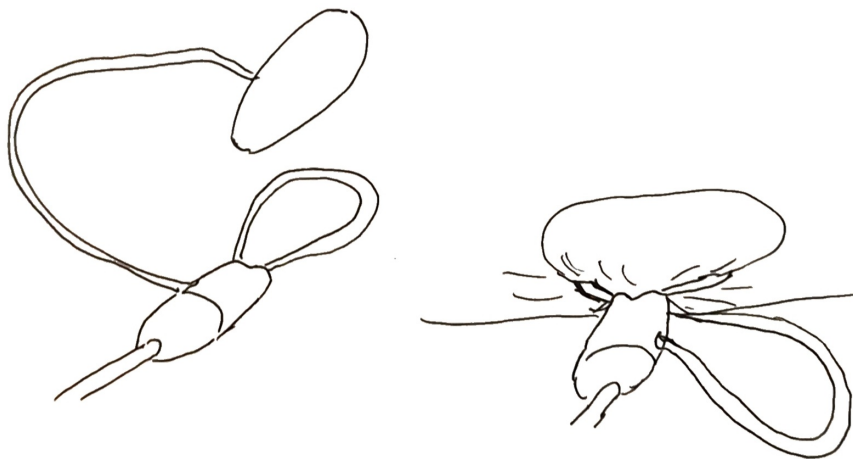


Figure 10.1. *Sketch of the concept Lasso showing the attachment solution.*

10.2 CAD modelling

The concept was modelled in CATIA and the main components are presented in Figure 10.2. This shows the two parts that make up the blob for the Lasso concept. One of the parts have a hole that allows for a line to go through, and the other part has a pocket for the knot which allows the surfaces to be aligned. Compared to the mockup, the choice to decrease the width was made. This decision was based on the mockup testing, and aimed to minimise the fabric usage. The round edges of the design were kept, and the hole diameter was selected by measuring the holes for the lines in the current line holders.

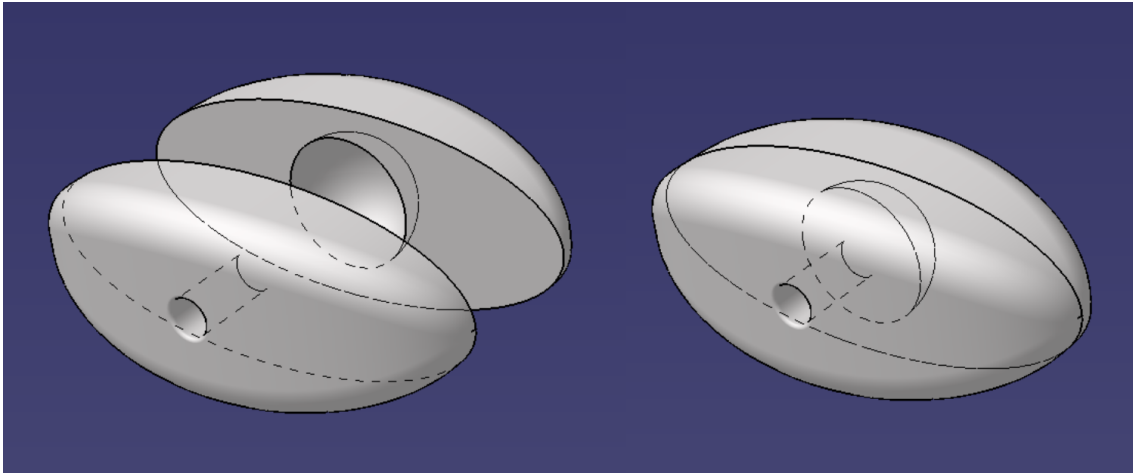


Figure 10.2. *The 3D model of the blobs showing the two parts separated and connected.*

10.3 Prototype creation

The digital 3D model was used to create a physical prototype of the concept. This was done by printing the parts and assembling it with lines and the current line holders using glue, as shown in Figure 10.3. While the glue was setting, duct tape was put around the blobs to ensure that they would not separate during the test.



Figure 10.3. *How the halves were connected to the line.*

For connecting the blobs to the current line holder, the holder was split at the dividing line. A hole was made in the top of the line holder for the connecting line to go through. The existing rivet inside the line holder was used to hold the new line in place, presented in Figure 10.4. When the new line had been attached, the holder was closed shut.



Figure 10.4. *Attachment of the blob line to the current line holder.*

Only one complete prototype was done before the prototype test. This was to enable any final changes based on feedback from Njord. However, to test the concept fully, two line loops were needed, and the other line loop was modified by attaching the blob using cable ties as shown in Figure 10.5.

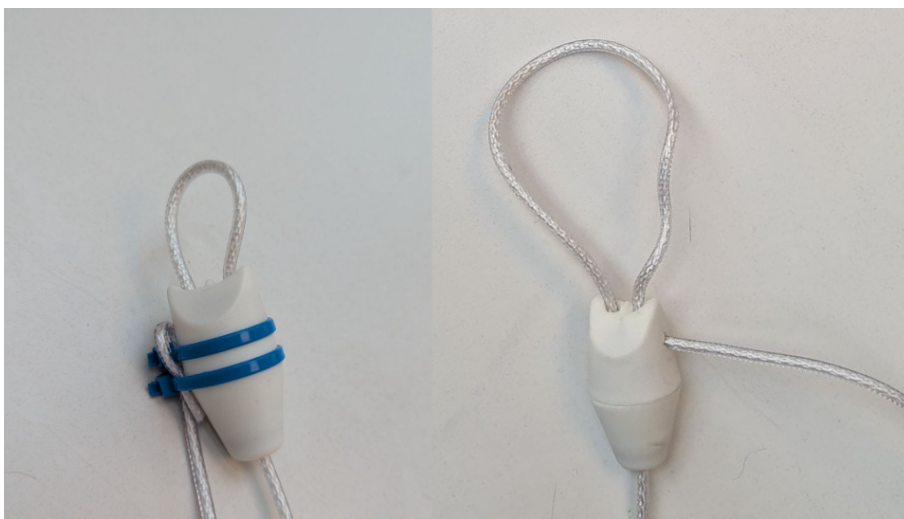


Figure 10.5. *The two variants of the connection to the line holder.*

10.4 Prototype testing

The concept was put inside Atle[®] for testing the overall compatibility and attachment functionality. The lines, which were the main part of the prototype were connected to Atle[®] by the bobbins. Figure 10.6 shows Atle[®] with the Lasso prototype included. In the figure, Atle[®] is placed next to the two beds used during the testing. One of the beds (with bed sheet) is a hospital bed and the other is a massage table that represents an examination table. The hospital bed was the starting point where the acting patient was transferred from, and the table was where the patient were moved to using the help of Atle[®].



Figure 10.6. *The transfer setup for the prototype test.*

The test was completed twice by transferring two people between the beds. To evaluate the attachment procedure, the authors first conducted the test themselves. The procedure was later repeated by the personnel at Njord during a second transfer. This way, the concept could be judged fairly and from different perspectives. Figure 10.7 shows the process of attaching the prototype to the bed sheet.



Figure 10.7. *The attachment of the Lasso prototype before transfer.*

Both rounds of testing confirmed that the concept does achieve the goal of attaching to the bed sheet and safely transferring the patient. The process of attaching to and detaching from the sheet was considered quick and easy. There was some discussion regarding the spacing between the two attachment points and how the user would know where to attach each blob. The current attachment solution that includes a bar gives the user the correct measurement right away, while the new concept does not indicate where it should be attached. During the prototype testing, the idea of making the connection line to the blobs the guiding element sparked.

By making the length of the connecting lines half the length of the transfer bar of the current system, the user can measure the right distance before attaching the second blob. This can be done by first attaching one side to the bed sheet, and then using the length of the connection line to space out two lengths to get an even pulling force. The insights from the testing was used in the final refinement of the concept.

10.5 RULA

The final design concept was evaluated using RULA, and the complete assessment is presented in Appendix D. There were no difference in the ergonomics for using the Lasso concept compared to the current attachment solution of Atle®. Both of the attachment solutions received a score of 3 points, which corresponds to the low risk of MSD. This means that change may be needed, but since the risk of MSD is considered low it is acceptable in daily work.

10.6 Material selection

Because the final design solution is closely related to the current line loops and line holders, the materials for the concept were decided to be the same as that of the current plastic and line materials. The line that connects the blob to the line holder is made from the same material as the original line and the blob is made from the same material as the line holder. There have been no investigation of alternative materials to use for the concept, and because of the strict hygiene requirements and regulations the current materials was considered appropriate for the clinical context.

10.7 Summary

The selected concept, Lasso, was developed and refined in the final phase of the project. The concept uses the current line holders and loops, but replaced the transfer bar with two blobs connected directly to the holders. The development consisted of modelling the concept in CAD, followed by printing a physical model and creating a prototype. The prototype was tested with Atle® and completed two transfers in a constructed hospital environment at Njord's office.

- The main prototype components were made using additive manufacturing and the complete prototype included modifications of current line holders.
- Changes to the design were made based on insights gained in the prototype testing and validation.
- The RULA of the concept was compared to the assessment of the current solution.
- The material of the concept was selected to be the same as the current solution due to the strict hygiene requirements.

11. Final design solution

This chapter presents the final design solution for the new concept for attachment in Atle® 180. It includes description of the concept, how it is compatible with the current line holders, and the material.

11.1 Attachment solution

The attachment solution that has been developed in this project is based on the current line loops of Atle® 180. However, the transfer bar is not included in the new solution and it is replaced by two blobs connected to each line holder. This reduces the amount of components in the system and the amount of material needed. The blobs of the Lasso concept are connected to the line holders by a similar line as the pulling lines of the product. An overview of the main components of the Lasso concept is presented in Figure 11.1.



Figure 11.1. *The final prototype of the Lasso concept.*

Figure 11.2 shows what the attachment concept looks like when it is used with Atle® and both sides are attached to a bed sheet. Similar to how the line loops were wrapped around the ends of the transfer bar in the current solution, the line loops are wrapped around each blob in the new concept. The concept uses the same pulling mechanism as the current attachment system, where the lines are rolled up to make the patient transfer onto the receiving surface.



Figure 11.2. *The Lasso concept attached to a bed sheet.*

For transfer situations that do not include a bed sheet, but instead includes a trauma mattress or a scoop stretcher, the Lasso concept is also compatible. These alternatives differ from a bed sheet because they have handles on the side where the attachment takes place. The suggested attachment solution can be connected to both of these alternatives in the same manner as it is currently practised, using a carabiner, since the concept is based on the original line loops and holders. The carabiner gets connected to the line loop that has gone through the handle, as seen in Figure 11.3 to the left. It is also possible to attach to a handle without including the carabiner, seen to the right in the figure. Although, it was considered better to use the current practice instead, because the length of the connecting line to the blob created too much distance between the line holder and the patient. The distance can cause an incomplete patient transfer, since the line holder stops the transfer as soon as it reaches the machine. This method of attachment did not work for the scoop stretcher handles because the blobs were about the same size as the handle holes and would need to be somewhat slimmer in order to go through. However, this is not a change that is required because the carabiner method is considered the correct practice.



Figure 11.3. *Two ways of attaching the Lasso concept to a surface with handles.*

11.2 User guide

A user guide was developed to help users understand how the suggested concept for the attachment system works. This was done by breaking down the steps for attaching the Lasso concept to a bed sheet before doing a patient transfer. Before attaching the device to the bed sheet, the transfer surfaces should be prepared. The beds should be placed next to each other, where the bed sheet is under the patient on the bed furthest from the device. Sliding boards can be placed under the sheet at the patients head, torso and feet area to ease the transfer process. When the setup is complete, the attachment process can begin.

Figure 11.4 shows the complete user guide for the suggested attachment solution. The first step is to pull out the lines from the device and placing them at the transfer area. Take one of the line ends to attach that side to the sheet. This is done by placing the blob under the sheet and taking the loop around the wrapped blob. The attachment can be tightened by pulling the line so that the loop gets smaller. The third step is to measure the second attachment point on the bed sheet using two connection line lengths. This is done by taking the line holder of the detached end and stretching the connecting line, placing the blob near the first one. Then, the blob end is moved passed the line holder to map out where it should be attached, as shown in the guide. Where it ends up is where the second line end is attached in the same way as the first end. Once both ends are attached, the attachment process is complete and the transfer can begin.

Step 1. Pull out the lines

After setting up the beds next to each other and sliding boards under the bed sheet, pull out the lines in front of the transfer surface.



**Step 2. Attach one side**

Begin by attaching one side. Wrap the blob underneath the sheet and loop the line around it over the sheet. Pull on the line to tighten the loop.

Step 3. Measure distance

When the first side is attached, use the other end to measure two lengths away from the first attachment point. This is where the next attachment should be.



Step 4. Attach next side

Attach the other side similar to step 2.



Step 5. Start transfer

When both sides are attached properly to the sheet, the transfer can begin.



Figure 11.4. *User guide for attaching the Lasso concept to a bed sheet.*

11.3 Construction details

After testing the prototype, the construction of the main component in the concept was modified to ease the assembling process. This was done by including a second cavity in the bottom half similar to the one in the top half to increase the space for the knot. The changes made to the construction are presented in Figure 11.5.

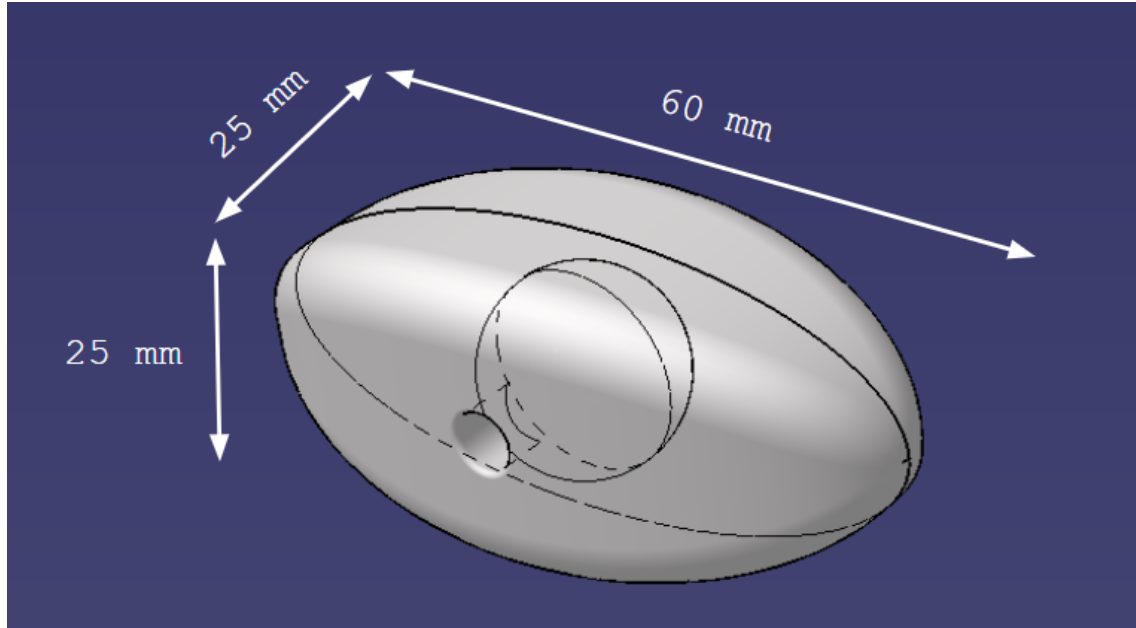


Figure 11.5. *Updated construction of the blob component.*

As for the construction dimensions, the blob of the final design solution is smaller than the physical mockup in cardboard was. The total length was set to 60 mm, and the height and width both 25 mm. The hole in the bottom half has a diameter of 5 mm to fit the line through. It is the same as the holes for the lines on the line holders. The cavity sphere inside the blob has a diameter of 8 mm.

11.4 Material & design

The suggested concept of the attachment solution is based on the current solution, which is why the material is kept from the previous design. This ensures that the new concept fulfils the hygiene and clinical requirements. However, based on the prototype testing, the suggestion to change the colour of the blob and connecting line was made, as shown in Figure 11.6. The testing showed that the lines of the loops and the connecting lines could easily be mixed up, so by changing to two different colour, this confusion could be avoided. It also improves communication when explaining the use of the concept, as it becomes possible for users to refer to components more clearly, for example by saying “the blue line” rather than “the other line”.



Figure 11.6. *The concept with blue blobs and connecting lines.*

11.5 Summary

This chapter presents the final design concept for the new attachment solution for Atle[®] 180, named Lasso. The solution is based on the current solution but replaces the transfer bar with two blobs connected to the line holders, reducing both the number of components and the material required. The chapter describes how the concept functions when attached to a bed sheet and explained the attachment process through a user guide. It also explains how attachment to a trauma mattress and scoop stretcher can be done. Construction modifications made after the prototype testing are also presented, including updates to the blob geometry to simplify the assembly. Finally, the material and design of the concept is described, where the original materials were retained to meet hygiene and clinical requirements. Colour differentiation of the blobs and connecting lines was introduced to reduce user confusion and improve communication during use.

12. Discussion

The aim of this project was to explore, develop and evaluate concepts for the attachment solution in Atle® 180, a patient transfer device. The focus of the work was on developing a solution that is easier to attach, more secure and time-efficient during use. Overall, the project has fulfilled its aim by including both the developing and evaluating of several concept solutions for the attachment system. The project resulted in a final design suggestion, Lasso, that does address many of the identified needs for improved ease of attachment, security and time efficiency.

This chapter presents the discussions of this work and the outcomes of the project including the work process and recommendations for future development. Furthermore, a discussion of the societal, ethical and ecological aspects of implementing the suggested design solution is presented.

12.1 Work process

This project was conducted in six main phases, of which three were revisited in an iterative manner. This approach allowed for continuous refinement and improvement where new insights helped driving the work. This section presents a discussion of the overall work process. It includes the *Limitations & scope*, *Project structure*, *Concept selection* and *Use of AI*.

12.1.1 Limitations & scope

Any conclusions drawn to drive the decision making in this project are affected by the limitations and scope. One important limitation is that the prototype validation was not performed with real end-users in a clinical environment. Although the user research was conducted with caregivers at Sahlgrenska University Hospital, the prototype testing only involved the authors and personnel from Njord. Since the concept was not validated by hospital workers in realistic working conditions, the reliability of the results can be questioned. The user research showed that workflow, timing and ease of setup strongly influence whether Atle® is used or not, which makes it important to consider when introducing a new attachment mechanism.

The scope of the project also affects the results. Because the main focus has been the attachment system, the surrounding sub-systems have only been partially taken into account for. The maintenance and long-term usage have not been addressed or investigated in the project. However, the user research showed that accessibility and preparation time affect whether Atle® is used in practice. Therefore, the surrounding factors may influence the success of the suggested attachment solution despite being outside the scope of this project.

The material selection also represents a limitation. The materials of the current attachment solution were assumed sufficient for the purpose, and no broader exploration of alternative materials was performed. This reduced the possibility of investigating improvements related to durability, environmental impact, recyclability or manufacturing methods. The prototype itself consisted mostly of the current materials of the line components. However, the plastic that was used to print the blobs is not the same material. There was no testing done under representative loading conditions.

12.1.2 Project structure

This project consisted of six phases: *Pre-study*, *User research*, *Problem analysis*, *Ideation*, *Evaluation* and *Development*. Three of these phases were approached iteratively rather than linearly, which had significant impact on the development process and final concept selection. The revisited phases were the *Problem analysis*, *Ideation* and *Evaluation*. The first round of evaluation gave valuable insights for refining the design requirements and guidelines in the second round of the problem analysis, which affected the next ideation round by including aspects previously missed. This iterative approach enabled new insights to guide the work in the following phase.

The first rounds of problem analysis, ideation and evaluation set the direction for the second rounds of these phases. By eliminating two concepts (Angled Force and Pipe) early in the first evaluation round, the variety in ideas were narrowed down to increase concept quality. In the second round of ideation, these more complicated designs were not investigated further and the focus could be on more feasible options. The iterative structure also contributed to improving the final concept selection. Instead of evaluating concepts only once, repeated mockup testing and refinement enabled gradual elimination of weaknesses before the final comparison. Since the attachment system is meant to be used in a time-critical context, small changes in usability can have a large impact on practical implementation. Allowing concepts to evolve between evaluation rounds therefore increased the possibility of identifying solutions better adapted to the healthcare environment.

Another strength with the project structure was the combination of user research and hands-on evaluation using mockups. The pre-study established an understanding of the current attachment solution and its technical limitations, while the user research provided information regarding user behaviour and contextual aspects. These findings formed the basis for the first round of problem analysis, where identified needs were translated into design requirements and guidelines. This approach allowed decisions made during later phases to be connected back to user needs and observed problems. Consequently, the early project phases established a strong foundation for the development. Overall, the project structure enabled flexibility in the development process while maintaining a clear direction. The iterations allowed insights from previous phases to influence concept development and reduced the risk of progressing with solutions that did not sufficiently address the identified user needs.

12.1.3 Concept selection

The concept selection process had a significant impact on the final design outcome since it determined which concepts progressed into the later project stages. This selection process, which included physical evaluation using mockups and Pugh matrix evaluation for assessing criteria fulfilment, had its own limitations. The mockups gave valuable insights of what the concepts could feel like to use, which was a strong motivator in this product.

The mockups of the concepts were low fidelity, meaning that they did not fully represent the heavy loads that the attachment solution is meant to operate with. This was done intentionally with the focus instead being on the attachment mechanism and interaction. This was considered suitable for early concept evaluation, but not sufficient for evaluating any structural performance. A strength with the mockup evaluation was that it was done twice for each concept. Between the first and second mockup, improvements could be made to the design to test minor refinements. This allowed for weaknesses to be eliminated or reduced.

The second part of the evaluation was done with the Pugh matrix, which introduced uncertainty. Not all requirements and guidelines were assessed equally in this stage of the project. For example, material-related criteria were excluded and hygiene considerations only had limited influence. Since hygiene and material properties both were identified as important categories during the problem analysis, their reduced impact could mean that some concepts may have been favoured despite incomplete evaluation. The results from the Pugh matrix evaluation were partly estimated from observations and mockup interaction rather than validated in objective measurements. This means that the matrix scores reflects expected performance rather than verified performance.

The relatively small score differences between concepts should also be considered. As an example, Lasso received 7 points while Belt and Rings received 5 points. Since the differences were small, subjective judgement likely influenced the final selection. Feedback from Njord and internal discussions were both important decision factors. This is relevant because the final concept was selected not only based on the scoring, but also on perceived simplicity, reliability and compatibility based on testing with the mockups. The potential bias could be avoided by including external input in the selection and discussions, preferably including users in this stage as well.

12.1.4 Use of AI

The use of AI in this project has been limited to spell checking the report and to help with translating some of the references to L^AT_EXformat. AI has not been used to generate, ideate or create any pictures, text or design concepts. All concepts created in this project are the authors' own ideas.

12.2 Societal, ethical & ecological

The suggested design of a new attachment solution has influence on the societal, ethical and ecological impact of the product. From an ecological perspective, the concept reduces material consumption compared to the current attachment solution since the transfer bar is replaced by two smaller attachment components. Reducing the amount of material included in the product can decrease resource usage during manufacturing and potentially lower waste generation. However, the total environmental impact also depends on production methods and material selection, which were outside the scope of this project.

The manufacturing of the new attachment solution is important to consider, since it is part of the complete life cycle of the attachment. Factors such as local production, reduced transportation distances and the use of recyclable materials could contribute to lowering the environmental footprint of the attachment system. Before implementing the new design concept in the product, the manufacturing considerations should be assessed further.

Similarly, the end-of-life for the attachment solution should be investigated more. In this project, there have been no study on the complete components life cycle. Although, this is important to consider before introducing changes to the system. However, since the new the design suggestion utilises the same lines as the current solution, it should have a similar life time expectancy.

The inclusion of the current line holders strengthens the suggested design. Maintaining similarities with the current system may simplify the potential implementation since users do not need to learn a completely unfamiliar attachment procedure. The conducted user research in this project showed that ease of use and time efficiency affect whether Atle[®] is used in practice, making familiarity an important aspect. Although, this claim would need to be confirmed with real operators of Atle[®].

From an ethical perspective, the suggested attachment solution should not be implemented without further validation from real Atle[®] users. The project identified detachment as a problem with the current solution and aimed to reduce this issue through an alternative attachment mechanism. However, the concept has not been tested with end-users or under representative loading conditions. Therefore, conclusions regarding performance improvements require further testing with end-users before clinical implementation.

From a societal perspective, the suggested design may contribute to more efficient use of healthcare resources if it reduces the risk of detachment and eases the attachment process. The suggested attachment system could therefore reduce the need for reattachment and extra time spent, which could potentially improve workflow efficiency in clinical settings. However, these potential societal benefits remain theoretical and should be validated further in real healthcare settings.

12.3 Recommendations for future development

The suggested solution for the attachment system is overall considered fulfilling of the set design guidelines and requirements. However, there are some improvements to be made before the concept could be produced. As an example, the connection between the blob halves could be further refined, and possibly have a similar solution as the split of the current line holders. This would make it so it clicks together, which could make assembling easier and limit unnecessary use of glue. By including the option to disassemble the component it would also be possible to replace the component easily if anything breaks or get damaged from frequent use.

Another important consideration for future development is the storage between uses. As of now, the transfer bar has its own resting place on Atle® for storage. One of the reported problems with the current solution is the fact that the bar can roll on flat surfaces, which causes frustration when it happens unintentionally. By replacing the bar with the blobs, this problem has been solved. There have been no investigation of where the blobs can be stored, but they could hang straight down from Atle® since they are connected. However, there is a risk for them to become squished between the bed and Atle® causing them to break. If this becomes a problem or is deemed unsafe in any way it would be appropriate to develop a protective storing solution.

Before implementing this new design suggestion in the product, more testing would need to be done. Especially with real end-users to gain feedback and approval before making any changes to the current system. It is also important that the testing is done in the clinical setting to ensure that any contextual constraints are identified. The operators, which are the primary users, should give their input on the final design to validate the usability of the concept. It would also be recommended to conduct the testing with healthcare workers and patients together, since this could show all interactions around the attachment process.

Similarly, the RULA should be performed with a more representative participant group to better validate the ergonomical aspects of the solution. The results of the RULA depends on the height of the participant and should therefore be done with a wider variety of users, since the results are affected by the body posture. The participants should represent the workers in healthcare that use Atle® in their daily work. Another important factor to consider while evaluating ergonomics using RULA is that it focuses on a position at a specific time and does not take into account how the body moves throughout a task.

Future work should investigate alternative materials to potentially identify further improvements of recyclability, durability, hygiene performance or environmental impact of the product. This includes mechanical testing with representative patient loads. The long-term durability of the attachment solution should be validated through testing, which would also help exploring the afterlife of the components and how frequently they would need to be replaced.

13. Conclusion

The aim of the project was to improve the attachment solution for the patient transfer device Atle® 180 with the focus on improving usability, attachment security and time efficiency during patient transfers. Through a combination of background research, observations, interviews and iterative concept development, issues with the current attachment system were identified. The user research confirmed that the effectiveness of Atle® is influenced not only by its technical functionality but also by how well the attachment process fits into the time-critical healthcare environments. User insights became an important part of the development process and helped guide the translation of needs into design requirements and evaluation criteria.

By approaching ideation and evaluation methods iteratively, multiple concepts were created and tested before selecting one concept for development. The final design concept, Lasso, was developed into a detailed prototype and tested with regard to functionality, ergonomics and feasibility. The concept demonstrates potential to simplify handling and improve the interaction between user and device while maintaining compatibility with existing transfer situations.

Although the project was limited to one prototype and did not include extensive clinical validation or cost analysis, the work provides a foundation for potential future development. Future work should focus on long-term testing in healthcare environments with caregivers and patients, in order to further validate with end-users and explore alternative materials.

Overall, the project shows that improvements to a relatively small part of a product can have meaningful effects on usability, workflow efficiency and user experience in healthcare applications, contributing to safe and ergonomic patient transfers.

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A. Interview & observation guide

This is a list of the interview and observation questions used during the visit at Sahlgrenska University Hospital. All of the questions are written in Swedish:

- Hur rengörs Atle efter användning?
- Är det stressigt att använda Atle ibland?
- Hur det är att styra själv utan kollega närvarande?
- Hur går förutsättningarna för att fästa lakanet till, att dra ut linorna osv.?
- Hur är miljön i rummet?
- Hur känns lakanet / underlaget?
- Måste jag rulla på ett visst sätt för att set-up ska bli korrekt?
- Hur känns Atle när man är patient?
- Är det läskigt?
- Är det skönt?
- Känns det tryggt?
- Hur är det när man själv ligger på lakanet och styr samtidigt?
- Hur lätt är det att sätta fast dragstaven?
- Hur är det att styra Atle?
- Är det svårt att veta när man är klar?
- Är det lätt att klicka på knappen?
- Jobba tillsammans: hur lätt är det att kommunicera / göra lika utan erfarenhet?

B. Pugh matrix criteria assessment & evaluation description

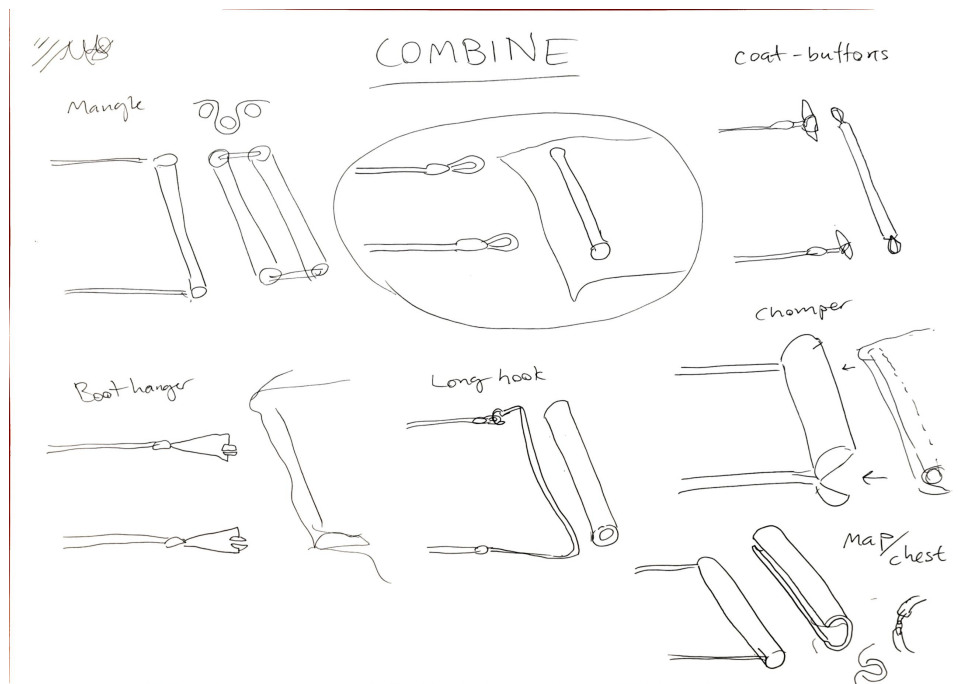
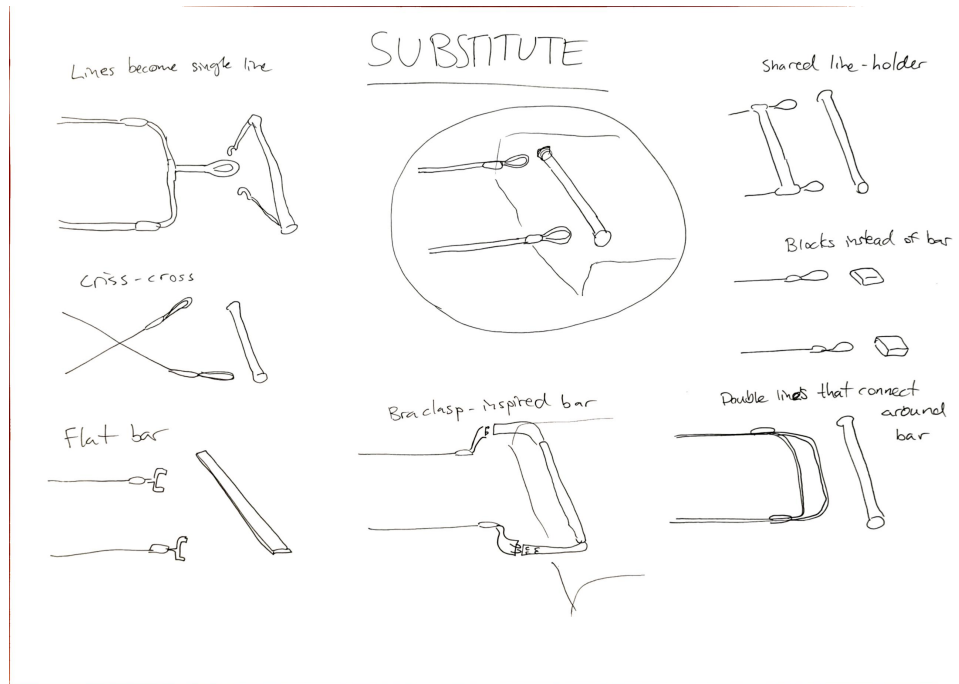
Table B.1 shows which criterion was assessed with what evaluation. Some of the criteria were not assessed in the evaluation phase and instead based on assumptions or expected performance, mostly the *Material* and *Hygiene* related criteria were in this category of assessment. Most of the other criteria was tested for all concepts based on mockups. For a few criteria, the evaluation was done only for the final design solution and based on the prototype created in the development phase.

Table B.1. Criteria assessment & testing description for Pugh matrix.

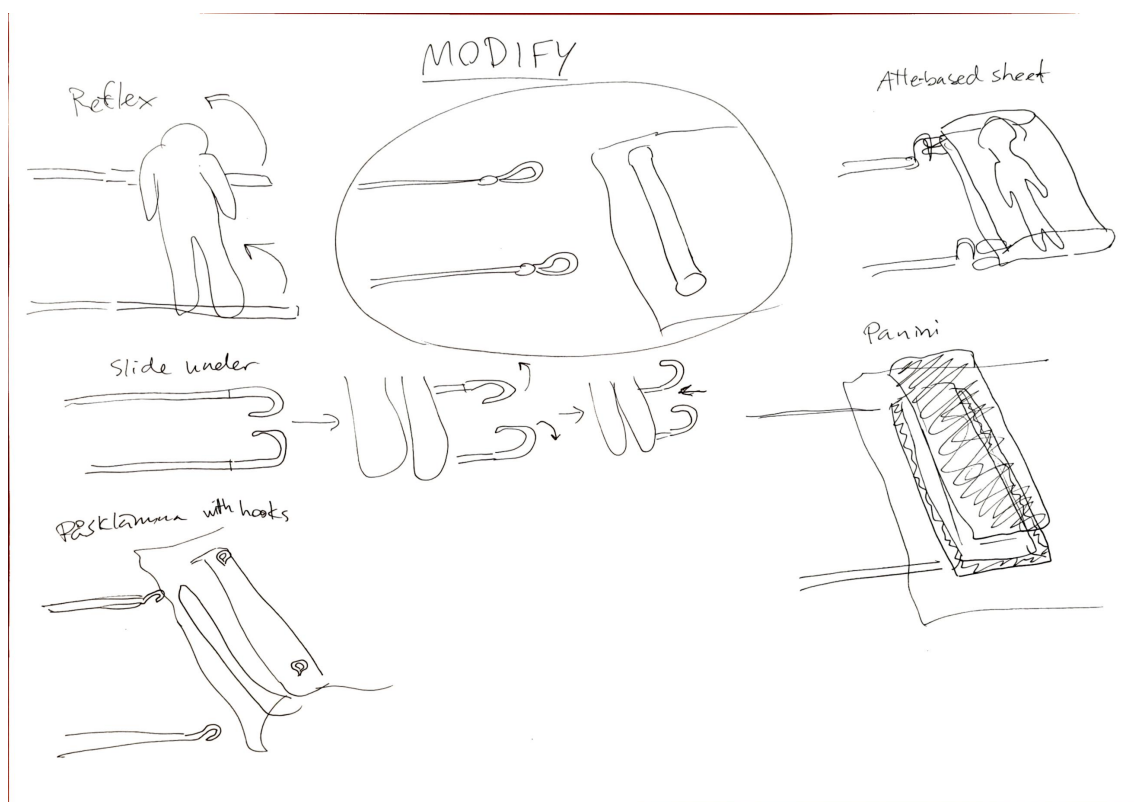
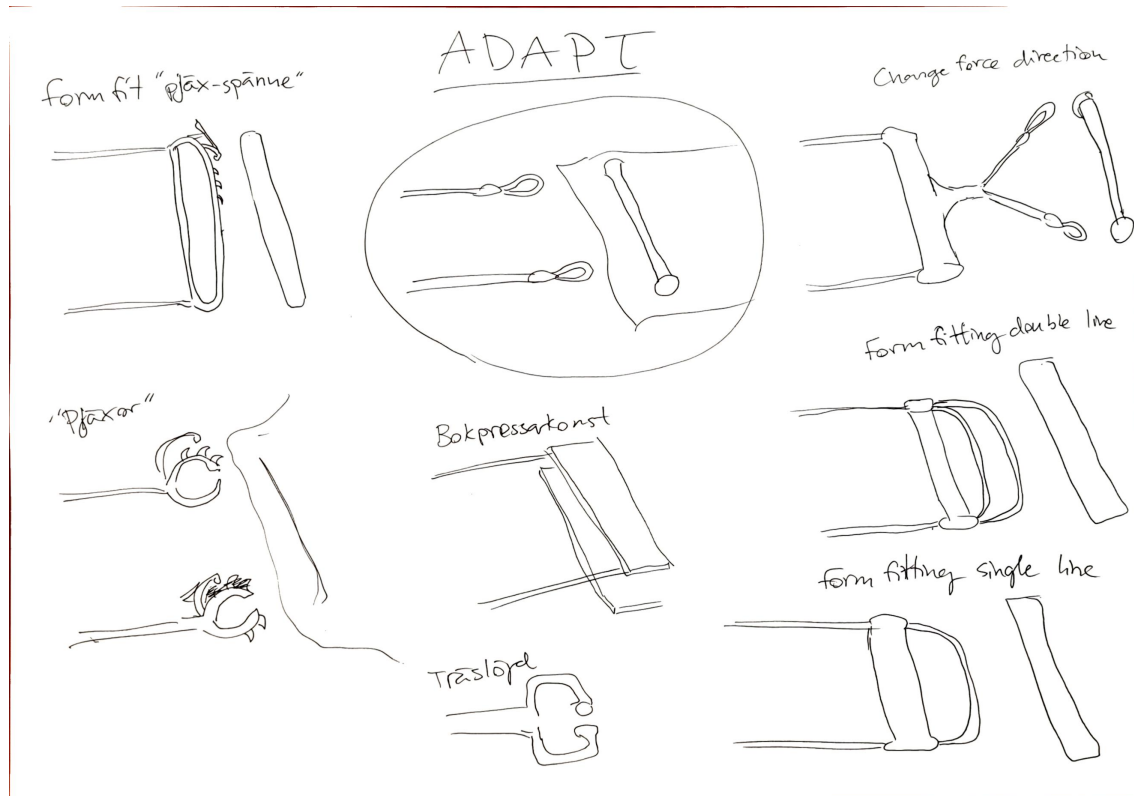
		EVALUATION
G/R	1 Functionality	
G	1.1 Attaches to drawsheet	Testing with mockups
G	1.2 Attaches to trauma mattress	Testing with prototype of final concept
G	1.3 Attaches to scoop stretcher	Testing with prototype of final concept
G	1.4 Connects to shoulder and hip area	Testing with mockups
R	1.5 Easy to detach when transfer is done	Testing with mockups
G	1.6 Can be attached by one person	Testing with mockups
G	1.7 Does not rip or break the attachment point on the surface	Testing with mockups
G	1.8 Locks the attachment	Testing with mockups
G	1.9 Compatible with magnets for stop	Evaluation based on design and testing
R	1.10 Limit the amount of sheet used in attachment	Testing with mockups
	2 Use	
G	2.1 Informs user that it is attached properly	Testing with mockups
R	2.2 Attaching process is quick	Testing with mockups
G	2.3 Intuitive	Evaluation based on design and testing
G	2.4 Reduces risk of errors	Evaluation based on design and testing
R	2.5 Easy to use	Evaluation based on design and testing
G	2.6 Components remain stationary when set down	Testing with mockups
G	2.7 Limits wear and tear on the lines*	Evaluation based on design and testing
	3 Ergonomics & Safety	
G	3.1 Included component(s) can be handled by one hand	Testing with mockups
G	3.2 Does not harm patient	Evaluation based on design and testing
R	3.3 Attaching is possible in ergonomic position	Evaluation based on design and testing
G	3.4 Comfortable to hold and adjust	Testing with mockups
G	3.5 Does not require lifting the patient	Evaluation based on design and testing
	4 Material	
R	4.1 Material strength can withstand max. weight	Evaluation based on design and material selection
G	4.2 Recyclable material	Evaluation based on design and material selection
G	4.3 Possible to replace the component(s)	Evaluation based on design and material selection
G	4.4 Multiple use	Evaluation based on design and material selection
	5 Hygiene	
R	5.1 Water resistant	Evaluation based on design and material selection
G	5.2 Disinfectant compatible	Evaluation based on design and material selection
G	5.3 Easy to clean	Evaluation based on design and testing
G	5.4 Approved for hospital use	Evaluation based on design and material selection
G	5.5 Possible to clean	Testing with prototype of final concept

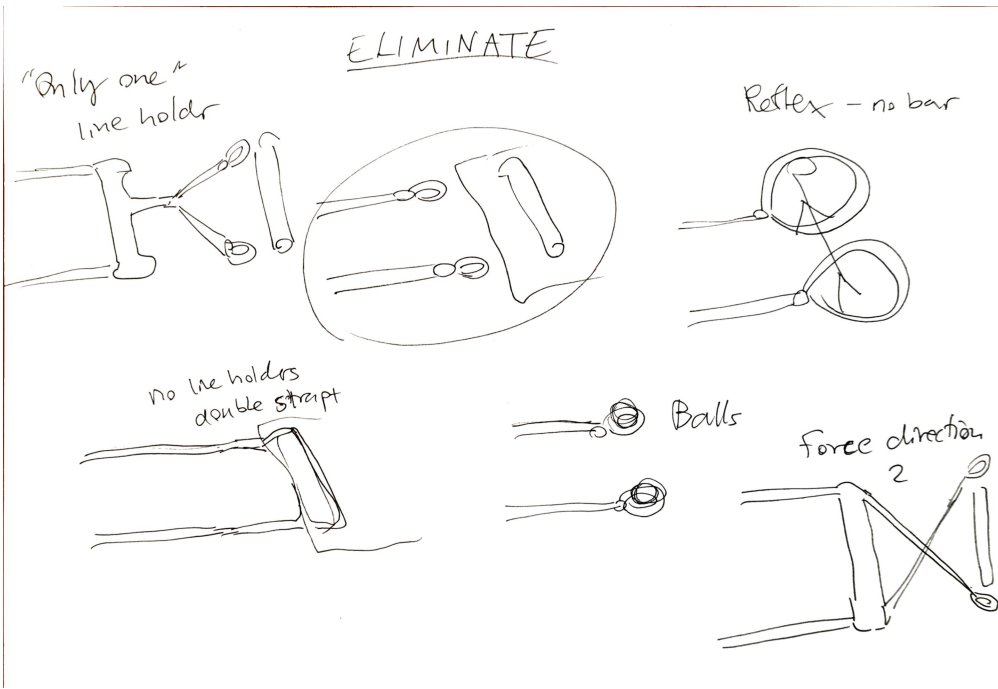
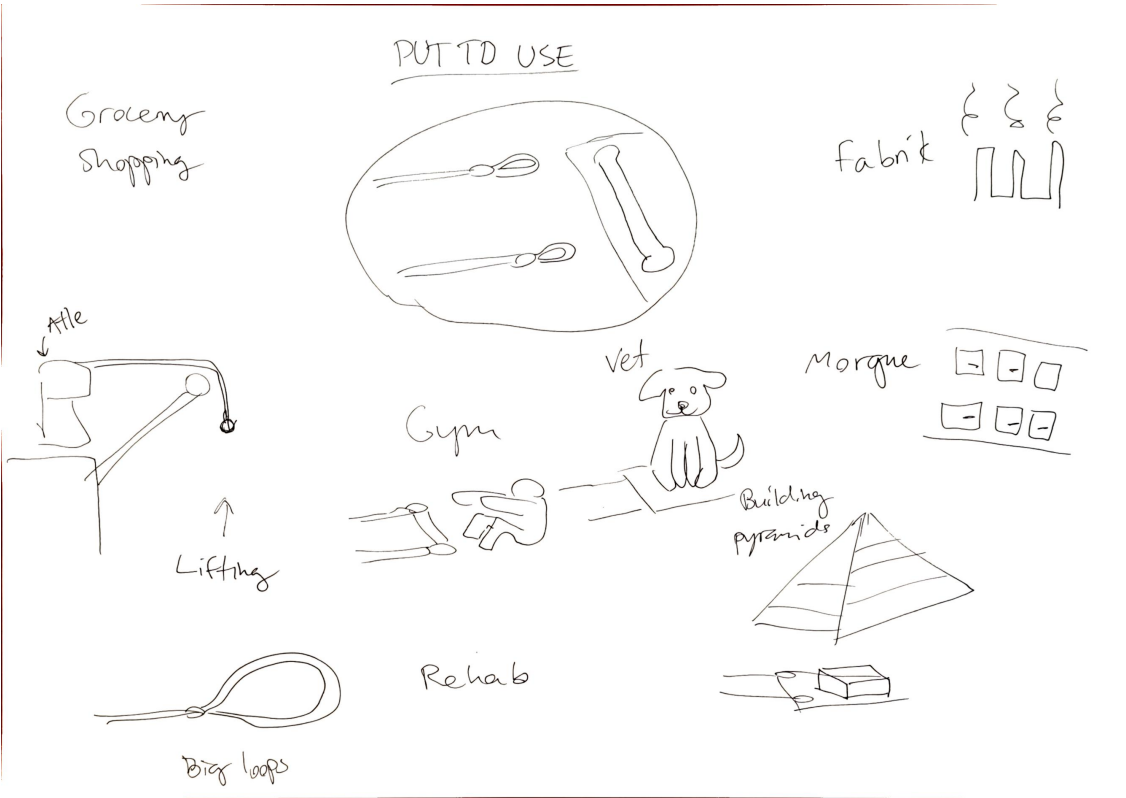
C. Early sketches & ideas

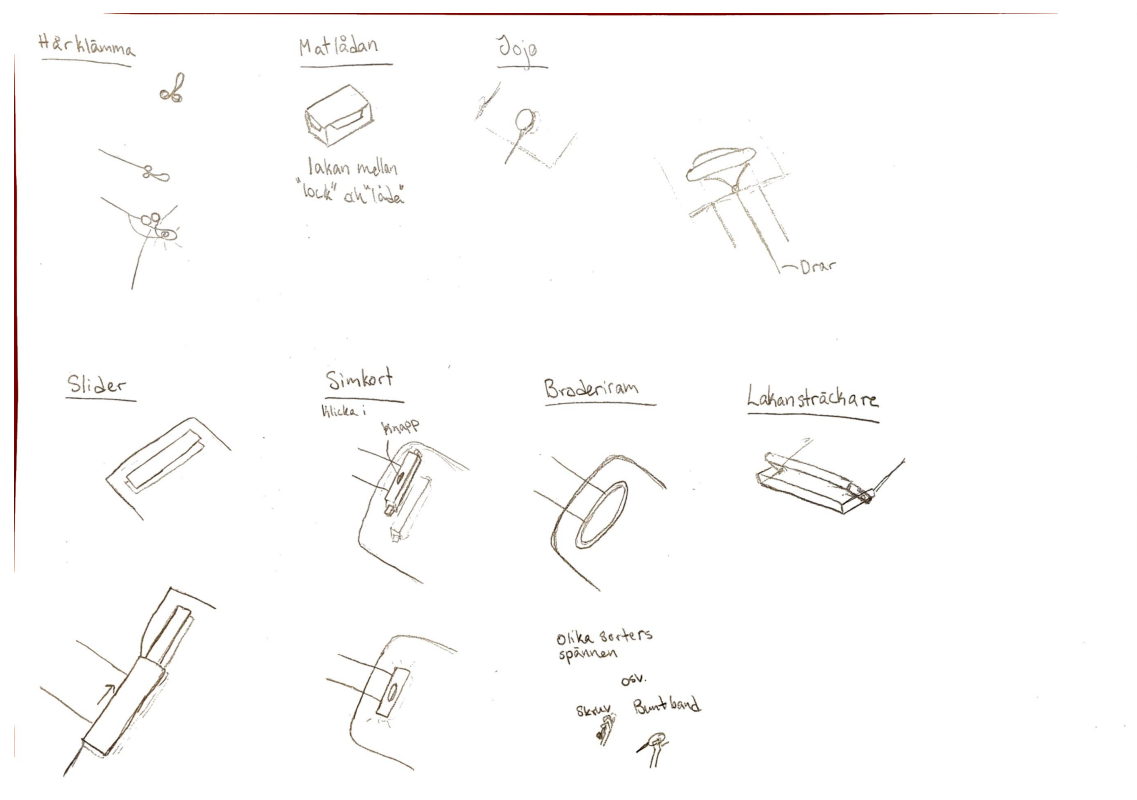
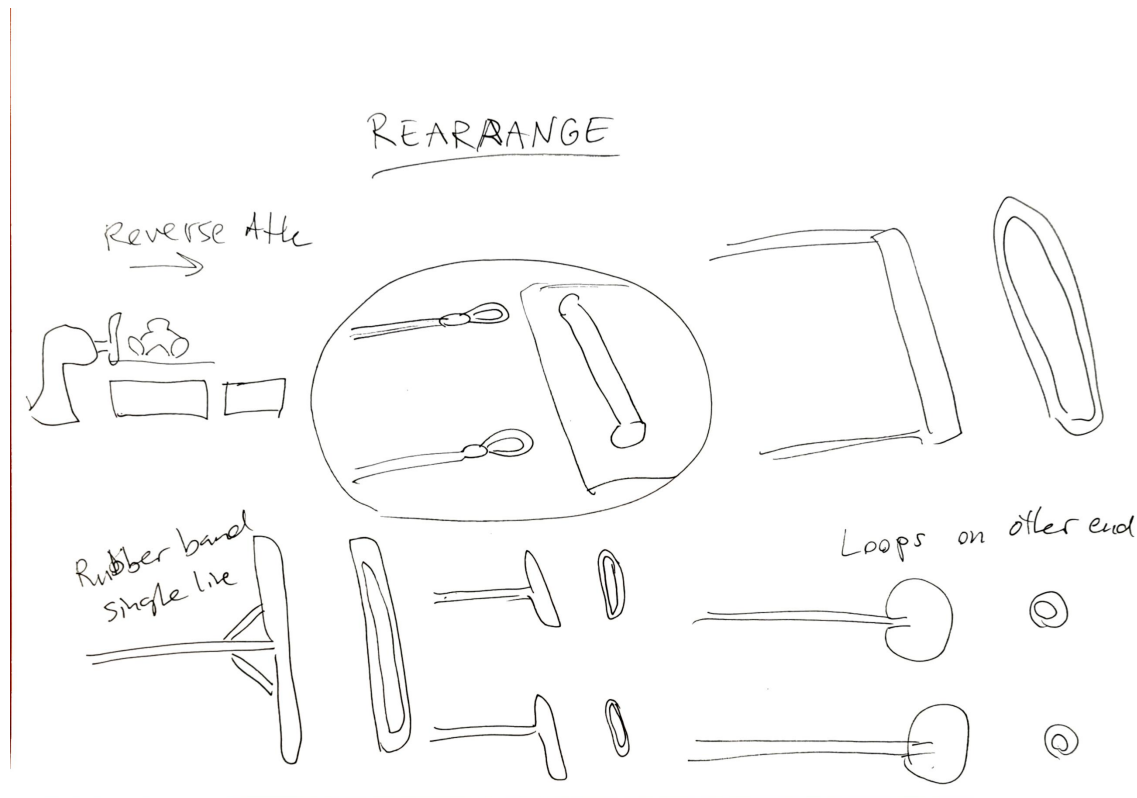
Early sketches and ideas generated in the initial ideation of the project are presented in this chapter. The SCAMPER method was used to brainstorm the ideas.

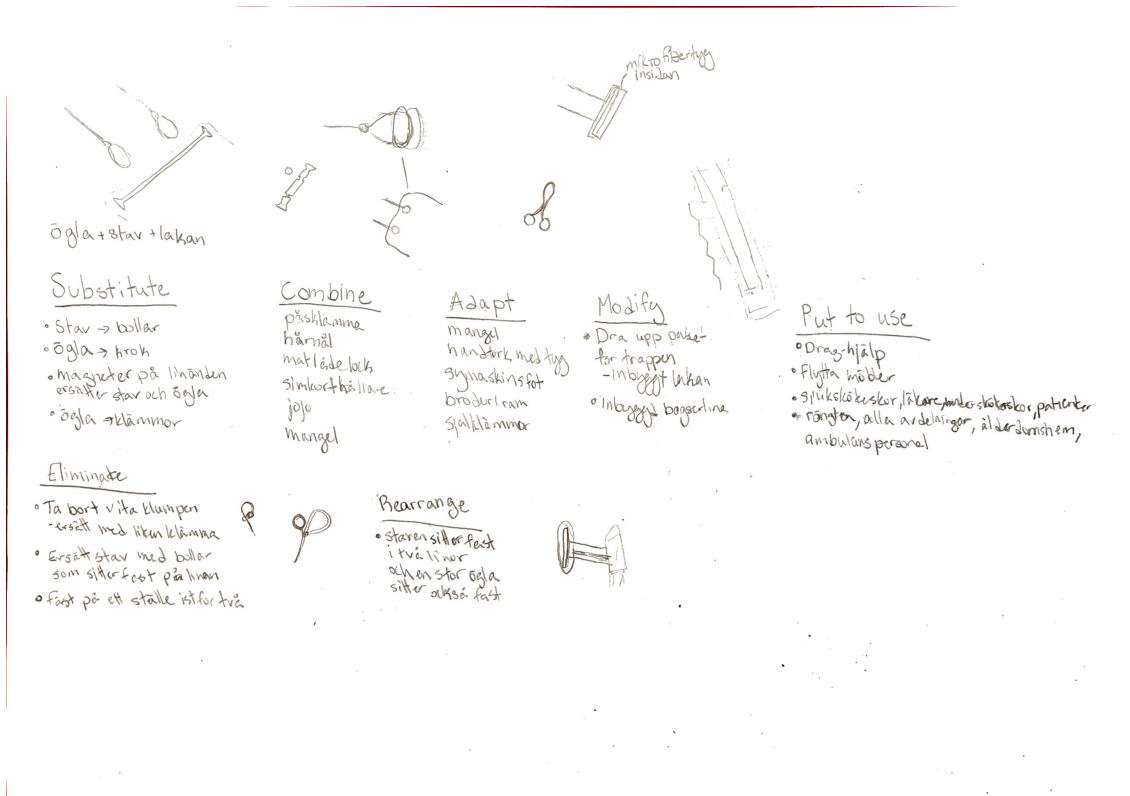


C. Early sketches & ideas









D. RULA

The position used for the RULA of the current solution is presented in Figure D.1 and the scores of the assessment can be seen in Table D.1. Likewise, the position used for the RULA of the suggested solution, Lasso, is presented in Figure D.2 and the scores are shown in Table D.2.



Figure D.1. *The position in which the current attachment solution was evaluated with RULA.*

Table D.1. RULA results for the current attachment system.

Assessment Item	Score
Upper Arm Score	2
Lower Arm Score	2
Wrist Score	2
Wrist Twist Score	0
Table A Score	3
Muscle Use Adjustment (A)	0
Force/Load Adjustment (A)	0
Score A	3
Neck Score	3
Trunk Score	2
Leg Score	1
Table B Score	3
Muscle Use Adjustment (B)	0
Force/Load Adjustment (B)	0
Score B	3
Final RULA Score (Table C)	3
Action Level	Low risk



Figure D.2. *The position in which the Lasso concept was evaluated with RULA.*

Table D.2. RULA results for the Lasso concept.

Assessment Item	Score
Upper Arm Score	2
Lower Arm Score	2
Wrist Score	2
Wrist Twist Score	0
Table A Score	3
Muscle Use Adjustment (A)	0
Force/Load Adjustment (A)	0
Score A	3
Neck Score	3
Trunk Score	2
Leg Score	1
Table B Score	3
Muscle Use Adjustment (B)	0
Force/Load Adjustment (B)	0
Score B	3
Final RULA Score (Table C)	3
Action Level	Low risk

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