Autostereoscopic 3D Demo Workstation Industrial Design and Mechanical Construction

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Approved	Examiner	Supervisor
2012-09-19	Carl Michael Johannesson	Martin Wahlstedt
	Commissioner	Contact person
	Setred AB	Thomas Ericsson

Abstract

Setred is a European technology innovation company that has developed a high-end 3D display technology that requires no glasses or head tracking devices. The technology has been incorporated in an autostereoscopic 3D display workstation named Clariti that is specifically designed for the medical environment for use during surgery and surgery planning. The Clariti workstation is in its original state quite large and heavy. This isn't a big problem when the workstation is in place in its intended environment at the hospital or clinic, but poses a huge challenge for the sales and marketing team at Setred whose main task is to travel with the workstation and demonstrate it to potential customers. As a master thesis project at the Royal Institute of Technology (KTH) in Stockholm, Sweden, a demo version of the Clariti workstation was therefore developed. The main goal of the demo-workstation was to make the transportation of easier and at the same time be able to demonstrate the functionality of the Clariti workstation in a satisfactory way.

The task was carried out by two Industrial Design Engineering students from KTH in close collaboration with representatives from Setred, during a period of roughly 20 weeks of work full time, from January until June 2012. Most of the work was carried out at the Setred office located in Stockholm.

The project followed a predefined product development process that started off with a literature study followed by design research in the form of one-on-one interviews, focus groups and customer journeys. Once the main problems with the original design of the Clariti workstation had been identified and summarized, several concepts for a demo-workstation were developed and presented to company representatives in the form of sketches and simple 3D renders. The different concepts were discussed and evaluated and the best ones were chosen for further development. The major design requirements for the demo-workstation were also defined. The most promising concepts were further developed as CAD models where the core structure of Clariti's 3D screen was integrated into the models. The best concept was chosen for further development into a detailed CAD model using guidelines for ergonomic handling and user centered design. Mechanical simulations were made on the design in order to verify the stability of the structure and facilitate material choice.

The project resulted in a detailed CAD model of a demo-workstation adapted for easier transportation and handling. The new workstation has a lowered weight and a modular design more suited for transportation.

KTH Industriell teknik och management

Examensarbete MMK 2012:64 IDE 084

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Godkänt	Examinator	Handledare
2012-09-19	Carl Michael Johannesson	Martin Wahlstedt
	Uppdragsgivare	Kontaktperson
	Setred AB	Thomas Ericsson

Sammanfattning

Setred är ett Europeiskt teknikinnovationsbolag som har utvecklat en 3D-displayteknik som inte kräver glasögon eller headtrackingutrustning. Teknologin har blivit integrerad i en autostereoskopisk 3D-arbetsstation vid namn Clariti som har tagits fram specifikt för medicinsk användning inom kirurgi och kirurgisk planering. I sitt ursprungliga utförande är arbetsstationen ganska stor och tung. Detta är inte ett hinder när den väl är på plats på sjukhuset där produkten är tänkt att användas, men utgör ett stort problem för säljarna på företaget vars främsta uppgift är att åka runt och presentera arbetsstationen för potentiella kunder. Ett examensarbete har därför utförts på Kungliga Tekniska Högskolan (KTH) i Stockholm, för att utveckla en demoversion av arbetsstationen Clariti. Huvudsyftet med demo-arbetsstationen är att förenkla transporten av enheten för säljteamet på Setred och samtidigt kunna demonstrera funktionaliteten hos Clariti på ett tillfredsställande sätt.

Uppgiften utfördes av två studenter på inriktningen industriell design på KTH i tätt samarbete med företagsrepresentanter från Setred. Projektet pågick under 20 veckor med arbete på heltid mellan januari och juni 2012. Huvudsakligen utfördes arbetet på Setreds kontor i Stockholm.

Projektet följde en fördefinierad produktutvecklingsprocess som började med en litteraturstudie och gick vidare med en problemundersökning med hjälp av semistrukturerade intervjuer, fokusgrupper och kundresor. När problemen med den ursprungliga designen hade blivit identifierade togs flera koncept för en demo-arbetsstation fram i form av skisser och enkla 3D renderingar och presenterades för representanter på företaget. Koncepten diskuterades och analyserades och de bästa valdes ut för vidareutveckling. Samtidigt togs en kravspecifikation fram för demo-arbetsstationen som listade de viktigaste kraven på konstruktionen. De mest lovande koncepten utvecklades till enkla CAD modeller där kärnstrukturen av Claritis 3D skärm integrerades i modellerna. Det bästa konceptet valdes senare för vidareutveckling till en detaljerad CAD modell med hjälp av metoder i användarcentrerad design och ergonomiska riktlinjer som stöd. Simuleringar utfördes på den mekaniska konstruktionen för att verifiera stabiliteten i strukturen och underlätta materialval.

Projektet resulterade i en detaljerad CAD modell av en demo-arbetsstation som är anpassad för enkel och smidig transport och hantering. Den nya arbetsstationen har en minskad vikt och en modulär design som ger större transportmöjligheter.

Preface

The work presented in this Master Thesis was performed at Setred AB in Stockholm and at the Department of Machine Design at the Royal Institute of Technology in Stockholm. The project was carried out between January 2012 and June 2012 as the final element in our Master of Science Degree within Industrial Design Engineering.

We would like to thank all people involved for their time and dedication to the project. Great thanks to the Setred staff from all three offices for all their feedback, knowledge and participation in the project. A special thank you goes to Martin Wahlstedt, our supervisor at Setred, for guiding us through the course of the project and providing us with invaluable information and feedback on our designs.

Special thanks to our supervisor Carl Michael Johannesson, our supervisor at KTH, for tutoring and support, and also to our classmates at KTH for the feedback that was received during the seminars and workshops.

Finally we would like to thank our families and friends for all their support during the project.

Alexander Flodin
Johan Olsson
Stockholm, June 2012

Terminology

Autostereoscopy	- A method of displaying stereoscopic images (creating the illusion of depth and 3D) without the use of headgear or glasses.
CAD	- Computer aided design.
CT	- X-Ray computed tomography. A medical imaging procedure that uses computer-processed X-rays to produce cross sectional images ("slices") of specific areas of the body.
DICOM	- Digital Imaging and Communication in Medicine; a medical industry standard of storing, printing and transmitting information in medical imaging.
MRI	- Magnetic resonance imaging. A medical imaging technique used in radiology to visualize internal structures of the body (especially soft tissue).
OR	- Operating room, the modern facility within a hospital where surgical operations are carried out in a sterile environment.
PET	- A nuclear medical imaging technique that produces 3D images or pictures of functional processes in the body.
Qualitative research	- To gather an in-depth understanding of human behavior and its source, through small but focused samples.
Stereoscopy	- A technique for creating the illusion of depth in an image by presenting two offset images separately to the left and right eye of the viewer.

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1. Introduction

Setred is a European technology innovation company founded in 2004 that has developed a high-end 3D display technology that requires no glasses or head tracking devices. The company ambition is to become a world leader in 3D display technology. Setred currently has offices in London, Oslo and Stockholm.

The technology used in Setred's products is a result of research conducted in a PhD study at the University of Cambridge, England. The research has since then evolved into the unique Autostereoscopic 3D display and accompanying software that is produced and sold by Setred. The company also has a number of approved and pending patents that are fully owned.

The 3D display itself is a plug and play device that can be used with a wide range of 3D software applications and runs on any computer using a standard graphics card together with Setred's 3D driver software.

The technology used in the display is based on a time multiplexed method where images are shown at a very rapid rate and at the same time synchronized with a filter to produce the illusion of 3D images for the viewer. Not only does the technology produce high resolution 3D images but it also enables the possibility of looking around objects shown on the screen. The display can be viewed by multiple viewers simultaneously and enables freedom of movement for the viewers.

Although Setred's 3D technology has many potential areas in which it can be used, the primary application today is medicine. The company has developed a medical workstation which is to be used for visualization of medical image data during diagnostic and therapeutic procedures.

1.1 The Workstation – Clariti

The newest version of Setred's medical workstation is named Clariti. The workstation is specifically designed for the medical environment, for use in both operating rooms and in everyday medical practice. Simply put, the workstation consists of a 3D projector that displays images through a 20 inch, 3D display, a normal 2D, 19 inch monitor and an industrial PC that controls all the image data sent to both the 3D and 2D screens. The build consists of an aluminum base on wheels with a fiberglass casing that envelops the steel frame that houses the electrical components. The workstation can be set up at different heights, for use both standing and sitting down, by activating an electric lifting system controlled by two buttons on the front of the 3D screen. The 2D display is held up by a rotatable arm that enables the 2D monitor to be positioned on both sides of the 3D screen. Under the 3D screen there is a removable table for holding a keyboard and mouse used for controlling the software. The wheels of the workstation can be locked simultaneously with a central locking device that is activated by a foot pedal. Fully assembled, the structure has a weight of around 160 kg. An image of the Clariti workstation is shown in *figure 1.*

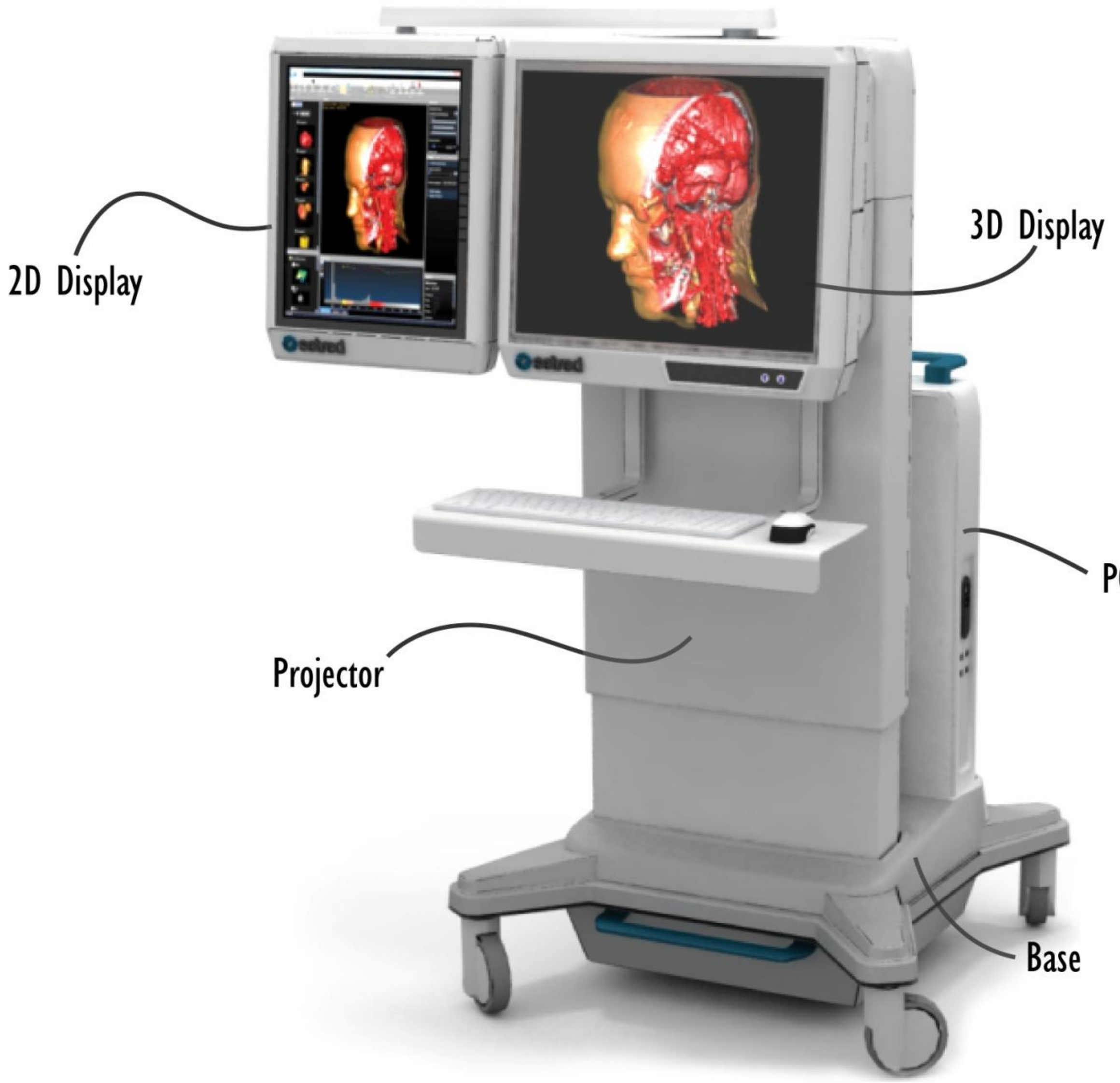


Figure 1. *The Clariti workstation*

Clariti can be used for a wide range of medical applications in fields such as neurosurgery, radiology and cardiology. The workstation together with Setred's Samurai 3D Medical Imaging Software enables surgeons, doctors and other medical professionals to import and view any DICOM-compatible image data from CT-, MRI-, PET-scans, 3D-angiography and ultrasound in high resolution Autostereoscopic 3D. This grants the doctors the ability to view more patient image information at once, both saving time and improving certainty of the medical procedures. Clariti can be used in many different situations like surgery planning, as a help during diagnosis, as navigation aid during surgery and for a wide range of educational purposes in medical studies.

1.2 Problem Definition

The Clariti workstation is in its present state quite large and heavy. This isn't a big problem when the workstation is in place in its intended environment at the hospital or clinic, but it poses a huge challenge for the sales and marketing team at Setred whose main task is to travel with the workstation and demonstrate it to potential customers.

A typical demonstration of Setred's 3D workstation consists of a single salesman that loads the workstation into the trunk of a hatchback car together with all the other needed accessories and equipment, and drives to the location of the product demonstration. Hospitals are the most common setting for the demonstrations; tradeshows and exhibitions are also visited frequently. Upon arriving to the destination the salesman must unload all the equipment from the car and transport it into the building. It is not uncommon for the salesman to encounter obstacles like curbs, dirt roads or rough terrain during the hauling process. Not all places visited have elevators; hence the equipment must sometimes be carried up and down stairs, usually by the lone salesman.

With a weight of 160 kg and the large outer dimensions of base that supports the whole structure, the Clariti workstation is almost impossible for the salesmen to transport, particularly when travelling alone. The weight makes the workstation very hard to lift up even the smallest curbs, and the large dimensions of the base means that the workstation won't fit in most hatchback cars. This has resulted in the sales team still using an earlier smaller model of 3D workstation named the MD-20 when demonstrating the product. The MD-20 is not ideal for transporting either, but it is far more mobile than its successor Clariti.

The main problem with using the MD-20 at product demonstrations is that it looks nothing like the Clariti workstation and lacks certain functionality that has been incorporated in the latter. Potential customers tend to want to see and experience the actual product that is being sold, not an older less capable model; even more so when it comes to such a large and important investment as medical equipment.

1.3 Aim and Objectives

The aim of the project is to investigate not only the mechanical construction of the Clariti workstation but also the whole transportation and handling process of Setred's 3D workstations to identify key areas of improvement. Primarily the goal will be to improve the working conditions for the sales and marketing team at Setred by eliminating or minimizing problems in handling the workstation with the design of a demo-workstation. On a larger scale, possible flaws in the design of Clariti will be highlighted for future alterations.

The research done on the problematic areas in the design and handling of Clariti will be documented along with recommended areas of improvement. From this, a concept for the design of a demo-workstation for use at product demonstrations will be developed using methods of user centered design and ergonomic studies along with methods of industrial design engineering and product development. The concept will primarily be developed as a CAD-model from which a prototype of a demo-workstation easily can be created for further evaluation.

Questions to be answered

- What are the main problems in transporting the Clariti workstation today?
- What functionality is needed in a demo-workstation and what features or functions can be omitted?
- How can a demo-workstation be designed both for easy transport and handling and at the same time be attractive for potential customers?
- What improvements can be made to the design of the Clariti workstation?

Objectives

- From a user centered design approach, set up design requirements for a demo version of the Clariti workstation.
- Develop a complete CAD model of a demo-workstation based on the design requirements.
- Identify key areas of improvement to the design of the Clarity workstation.

At the project's end, the master thesis will be published in a written report. A presentation of the results will also be held at the Department of Machine Design at KTH as well as internally with interested parties at Setred.

The master thesis project followed a predefined product development process that was set up in the inaugural phase of the project according to Paul and Beitz's "Model of the Design Process" (Cross, 2009). The development process was also customized to incorporate the guidelines for master thesis projects at the Department of Machine Design (KTH, 2011), *figure 2*.

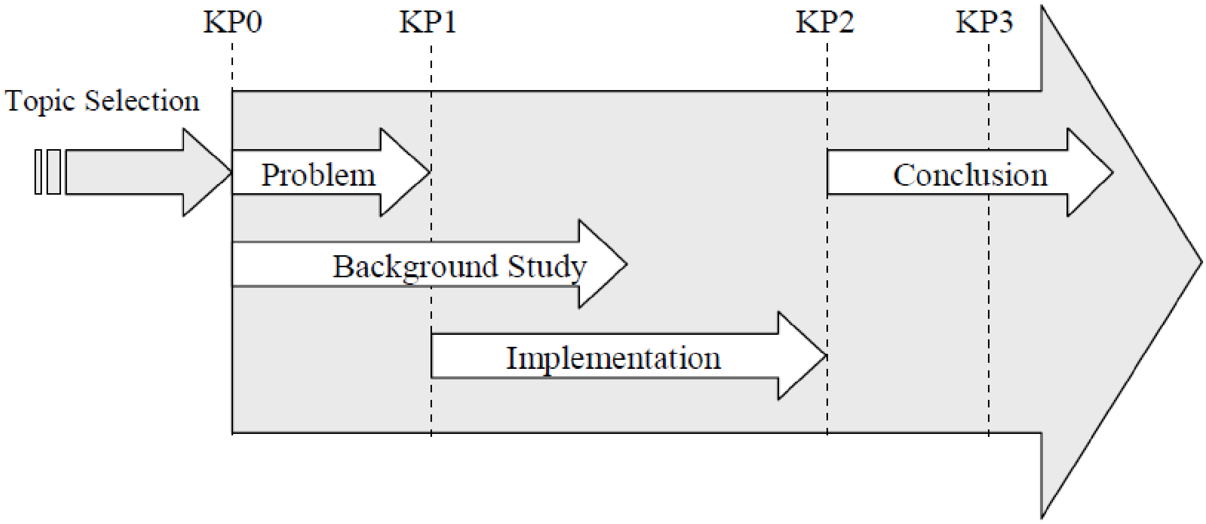


Figure 2. *Diagram showing an overall view of the master thesis project plan developed by the Department of Machine Design at KTH. The KP markings show control points where the current progress of the project will be presented at a seminar together with other master thesis students.*

The time dedicated for the project was roughly 20 weeks of work full time for two engineering students which adds up to about 1600 hours. In the project plan the timeframe was split up into three main phases that each were built up of a number of tasks that needed to be performed. In reality the phases more or less overlapped seamlessly into each other and many tasks reoccurred in different phases but the separation of the project into the different stages was an excellent way of planning the available time to ensure that not too much time was spent on a particular step in the development process.

The first phase in the project was the research and concept development phase and approximately 6 weeks of the project's 20 were allocated for this phase. The main tasks were to clarify the problem, gather information through methods of design research, to identify the key design requirements for the problem solution and the development of a concept that meets these requirements.

The second and largest step of the project was the design and prototyping step. Here the concepts generated in phase 1 of the project were evaluated and the key design requirements were finalized. The most promising concept was to be further developed into a detailed CAD model that later on could be manufactured as a prototype for product evaluation. Material and manufacturing studies were also performed as well as simulations on the mechanical design of the product. Approximately 10 weeks was dedicated to the second phase.

The third and last phase consists of the documentation phase. Here the results of the project were documented in the written report and complete technical drawings of the finalized design were submitted to the company.

An overview of the project plan for the master thesis can be found below in *figure 3.* The project plan in its entirety can be found in *appendix 1.*

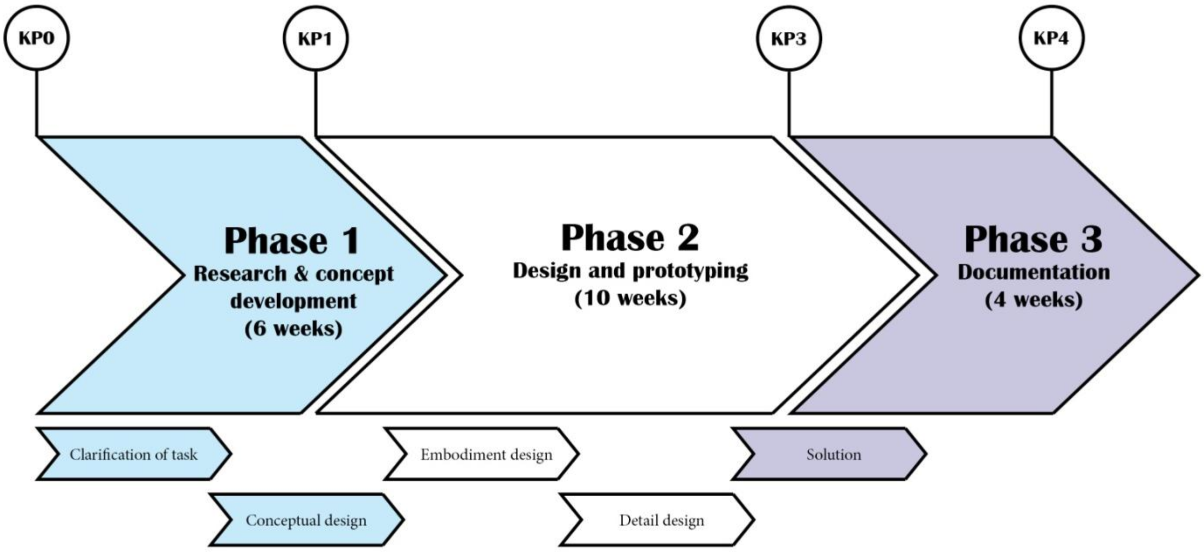


Figure 3. *Overview of the time disposition for the master thesis project. The KP markings show in what stages of the project the planning seminars occurred***.**

After phase 3 of the project the last changes to the written report were made based on feedback received from objectors and during the presentation. After the final changes have been made, the report was submitted for print and turned in to the examiner for grading.

3. Methodology

In this chapter the different methods and tools used in the project are described. They appear to the best possible extent in a chronological order starting with the methods used in the beginning of the project. Only a general description of the methodology and how it was applied is given in this section. The results of the applied methods can be found in the results chapter.

3.1 Literature Study and Information Gathering

A literature study was performed in order to find articles, books and information relevant to the project. The study was done by searching databases of scientific articles, searching the web, and by visits to the library at the Royal Institute of Technology and the Stockholm City Library.

An additional source of information was the employees at Setred who provided the project with necessary files and documents as well as invaluable information through interviews and meetings.

Since a large portion of the problem lies in the transportation of the Clariti workstation, emphasis was put on finding articles and other literature that focuses on the ergonomics for lifting and transporting similar products. Another important goal for the literature study was to find information on the different design research and engineering methods that were to be used in the project and understand how they could be applied to the product development process.

3.2 Design Research Methods

The field of product design has changed greatly during the last century. In early days it was the role of the designer to “educate” the common citizen in what design and good taste was. At the time the world was a “mass market” where people in the same geographical region bought similar things, listened to similar music and wore similar clothes. If the product designer understood just a small group of people he or she could design for millions, (Laurel, 2003).

Today people are very diverse. Globalization has led to the understanding of different cultures and the general acceptance of diversity in product design as well as in everyday life. People nowadays are more open to new ideas and act more on the basis of personal preference rather than on following the masses when choosing what products to spend their money on (even though trends still definitely exist). This poses a large challenge for the designer. He or she may be put to the task of designing for people or cultures that are completely foreign to the designer. This takes a great understanding of people, cultures and beliefs. The different methods that can be used to acquire this kind of knowledge are many. The design research methods used in this project are described below.

User-Centered Design

User-Centered Design (UCD) is essentially a design approach where the end-user of the product being developed plays a major role. The goal of UCD is to involve the end-user in all different phases of the product development process.

The guidelines for User-Centered Design used in the project were acquired from the Usability Professionals' Association (UPA, 2011) and the book "*This is Service Design Thinking*" (Schneider, 2010).

The process can be divided into four main steps. Different teachings call them different names, but the general idea of the steps are the same, as shown below. The steps should not be seen as a straight timeline with four checkpoints along the way, but rather as four different reoccurring stages in the product development process. UCD is very iterative, not only within the four stages of the process, but also within each stage, and each task within the stage. The methodology derives from an ISO standard (originally ISO 13407 now called ISO 9241-210) developed in 1999 named The Human-Centered Design Process. The UPA defines the steps in the UCD process as the following (UPA, 2011):

1. **Specify the context of use**
   Identify the people who will use the product, what they will use it for, and under what conditions they will use it.

2. **Specify requirements**
   Identify any business requirements or user goals that must be met for the product to be successful.

3. **Create design solutions**
   This part of the process may be done in stages, building from a rough concept to a complete design.

4. **Evaluate designs**
   The most important part of this process is evaluation - ideally through usability testing with actual users.

The process ends and the product can be released once the requirements are met. An overall view of the User-Centered Design process defined by the UPA is illustrated in *figure 4*.

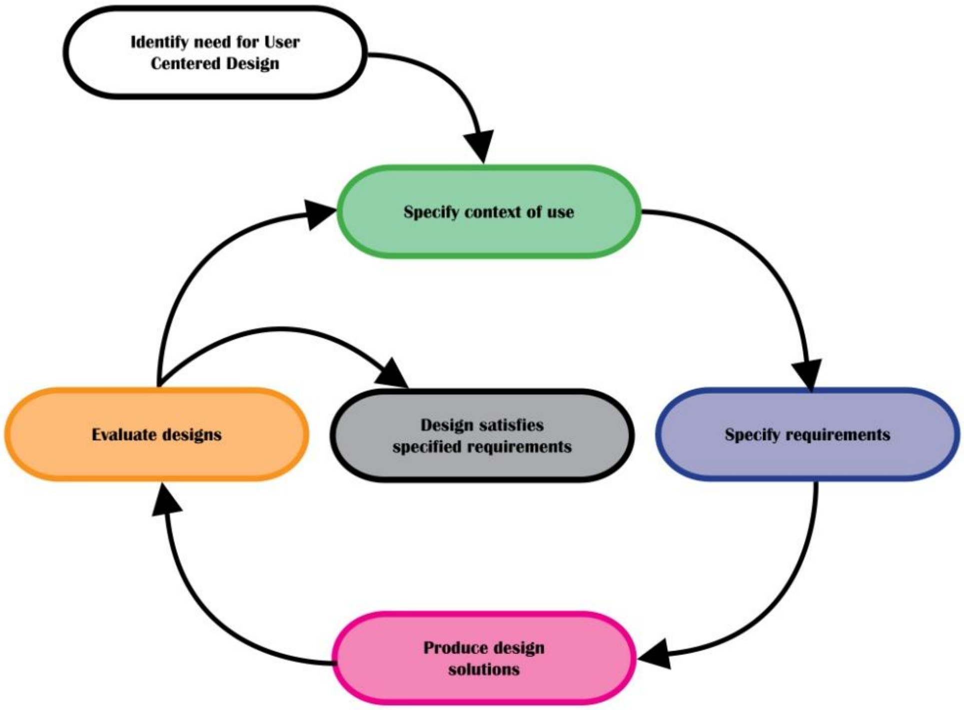


Figure 4. *The iterative User-Centered Design process as defined by the UPA (UPA, 2012).*

The book *"This is Service Design Thinking"* (Schneider, 2010) defines the UCD process in the following stages (also illustrated in *figure 5*):

1. **Exploration**
   Understand the problem from the perspective of the potential user or customer. Investigate the culture and goals of the company providing the product. Visualize the findings as far as possible.

2. **Creation**
   This is the generative stage in the iterative process. The goal is not to avoid mistakes but to explore as many mistakes as possible. In order to achieve holistic and sustainable solutions it is crucial to include all the main stakeholders in the creation process. Achieving co-creation among interdisciplinary teams of customers, employees, management, engineers and designers is a key feature for the creation stage.

3. **Reflection**
   Build on the ideas and concepts from the previous creation stage. Build prototypes and test these on users. Test concepts in reality or circumstances close to reality using staging and roleplay. Learn from the results, whether good or bad.

4. **Implementation**
   Take what you've learned from previous stages and implement this in the final design. Follow up the design of the product once in has been finalized. Can anything be learned from what was done? Make sure to implement this in future versions or upgrades.

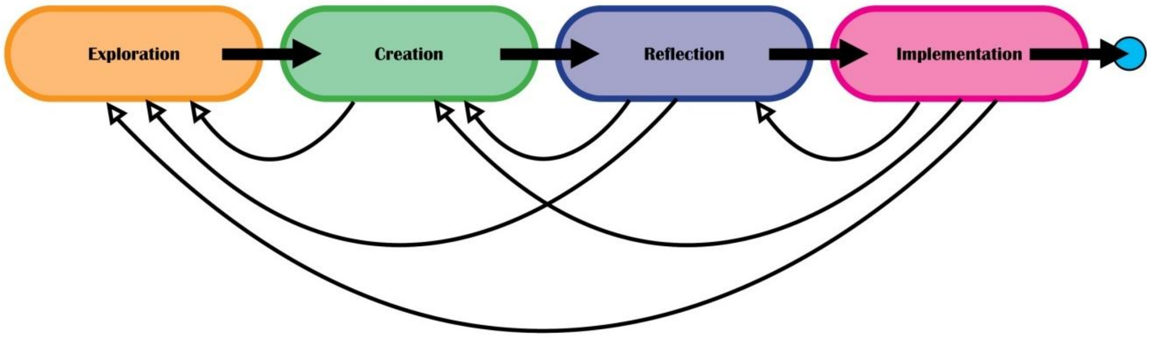


Figure 5. *The User-Centered Design Process defined by the book "This is Service Design Thinking".*

Qualitative Research - One-on-one Interviews

Qualitative research is a great way of collecting valuable information in the starting phase of a project. As opposed to quantitative research where structured data is collected from a large number of people using questionnaires and surveys, qualitative research focuses more on listening in detail to what a small number of potential users or customers of a product have to say.

There are numerous different methods for qualitative research, one-on-one interviews being one of them. Only the methods used in the project are described in this report, but there are numerous other research methods that are being used by designers today. The guidelines for the qualitative research methods used in this project were taken from the book *"Design Research"* (Laurel, 2003).

To start investigating the problems surrounding the current design of the Clariti workstation One-on-one semi-structured interviews were conducted with the employees at Setred. Since the demo-version of the workstation was to be designed mainly to be used by the sales and marketing team at the company, these people were a good starting point for the first interviews.

Prior to the interviews, a list of questions was prepared, in order to keep a general script to follow, and to stay on topic. The questions were designed to engage the interviewee in an open discussion rather than to lead him straight to a specific answer to a question. The goals of the interviews were to identify problems and problematic situations that had been encountered with the current design of the workstation, and also to take note of possible improvements and alterations that can be implemented in a future version of a medical workstation. The full list of questions used in the interviews can be found in *appendix 2*.

During the interviews, the design research team was present along with the interviewee. One person from the design research team was appointed the task of leading the interview while the second person observed the interview while taking down relevant notes on what was said. The audio from the interviews was also recorded to make sure nothing important was overseen.

After the sales and marketing employees had been interviewed, a large portion of the remaining employees at the company were also interviewed using the same interview method. The reason for interviewing almost the whole Setred staff was to engage as many stakeholders as possible in the preliminary stage of the development process. Since some of the employees were stationed at one of the other two Setred offices (Oslo or London), some of the interviews were carried out by using video calls. In the cases where the interviewee did not have a working video camera, the interviews were carried out using normal audio calls.

After each interview the notes taken down were summarized in a short text document and discussed within the design research team. The audio from the interview was in some cases revisited to make sure no information was lost or misinterpreted. The audio recordings were particularly useful in the cases that the interviews were conducted in Swedish while the interviewee replied in Norwegian. Although the two languages are very similar there are many words in the languages that differ which can lead to some misinterpretation.

Once all interviews were completed, the text documents that summarized each interview were revisited and the most important information was extracted from each interview and combined into a new document. This document was later on used in focus groups as a script for leading discussions on the design of the future demo-workstation.

Customer Journey Map

A customer journey map provides a structured visualization of how a user interacts and experiences a product and/or service. So called touch points (interactions with the product and/or service) are identified and connected to create the visual representation of the overall experience. Customer journey maps enable identification of problem areas and where there are opportunities for improvement by analyzing the identified touch points, (Schneider, 2010).

For this project a customer journey map was created for the task of transporting the Clariti workstation. Touch points were identified by interviewing and observing a Setred sales representative performing this task as well as the design team performing the task themselves. The touch points were connected in a chronological order representing the major steps typically involved in transporting the workstation. Furthermore the customer journey map was complemented by photographs giving more detailed information about the necessary steps involved transporting the workstation. The data was analyzed and composed into a graphic representation where identified problem areas were marked.

Focus Groups

Focus groups are probably the design research method that has had the biggest spread worldwide. A major reason for this method’s popularity being that it can be applied to practically any type of design problem. Typical focus groups usually consist of 10-12 people who are led in a tightly scripted discussion by a moderator (Laurel, 2003). A focus group session often lasts for about two hours. The effectiveness of focus groups can be discussed, but if conducted correctly they can provide the design team with valuable input at an early stage in the design process. If one wants to take it one step further, different co-creation methods like service staging and prototyping workshops can easily be integrated in the focus groups giving the stakeholders in a project great influence in the early design process.

The focus groups conducted in this project had certain similarities to the traditional focus groups, but even though the sessions were roughly scripted, participants in the focus groups were free to engage in discussions off topic. Another difference to traditional focus groups was that some of the participants took part in the sessions through video conference.

The first focus group in the project was arranged after the one-on-one interviews and the customer journey had been conducted. The results from these two research methods were presented and discussed. The goal for this particular focus group was to define a few major design requirements for the demo-workstation.

The second focus group was held after the first concept development phase. Here sketches and renderings that had been created were presented along with a revised version of the design requirements for the demo-workstation. A total of 7 concepts were presented and discussed along with some loose ideas surrounding the design of the workstation. The participants all had a chance to voice their opinion on each presented concept and ventilate any ideas that popped into their head at the time. The next task for the focus group was to further define the design requirements for the demo-workstation. This was done by revising the existing demands and wishes and adding new ones along the way.

A third focus group was held after the second concept development stage. Here CAD models of 6 different concepts were presented and once again the participants were asked to share their opinions on each concept. Once this was done, a single concept was chosen for further development and the design requirements were finalized.

3.3 Ergonomic Study

Ergonomics in product design can be summarized as the study of designing equipment and devices that fit the human body, its movements, and its cognitive abilities (The International Ergonomics Association, IEA, 2010). Ergonomic guidelines are implemented in product design to fulfill two goals, namely health and productivity. Proper ergonomic design of products can be essential to avoid repetitive strain injuries that can develop over time and lead to long-term disability. There are also certain ergonomic regulations concerning work environment, and repetitive work tasks that employers must follow to ensure the health and well being of their employees. These will not be covered extensively in this report but should be taken into account when using certain products or performing certain tasks in the work environment.

In the design research phase of the project, the following ergonomic guidelines for lifting, pushing and pulling, along with anthropometric guidelines for screen height, keyboard height and grip size were collected from the Swedish Work Environment Authority (SWEA, 2010) and the book "*Arbete och teknik på människans villkor"* (Bohgard et al. 2008). These guidelines are described below. These guidelines were taken in consideration in the design of the new demo-workstation.

Lifting

To determine if lifting or carrying an object can be detrimental to one's health several simultaneous factors must be taken into account. What is lifted, how the lifting is done, the environment in which the lifting is done, and who is lifting or carrying, must all be analyzed. It is therefore very difficult to set an absolute limit for only one of these factors, like for example how much an object that is being lifted can weigh. There is however enough scientific evidence to provide some practical recommendations for how lifting and carrying should be performed.

Two main factors for analyzing a lifting sequence is the mass of the object being lifted and the horizontal distance from the lower back of the person lifting the object to the object's centre of mass. A model for analyzing a lift by looking at these two factors has been developed by SWEA and is shown in *figure 6* (SWEA, 2010). A conclusion can be drawn from the model that it is generally a bad idea to carry objects heavier than 25 kg, especially if the object's centre of mass is further than under-arm distance (approximately 30 cm) from the lower back.

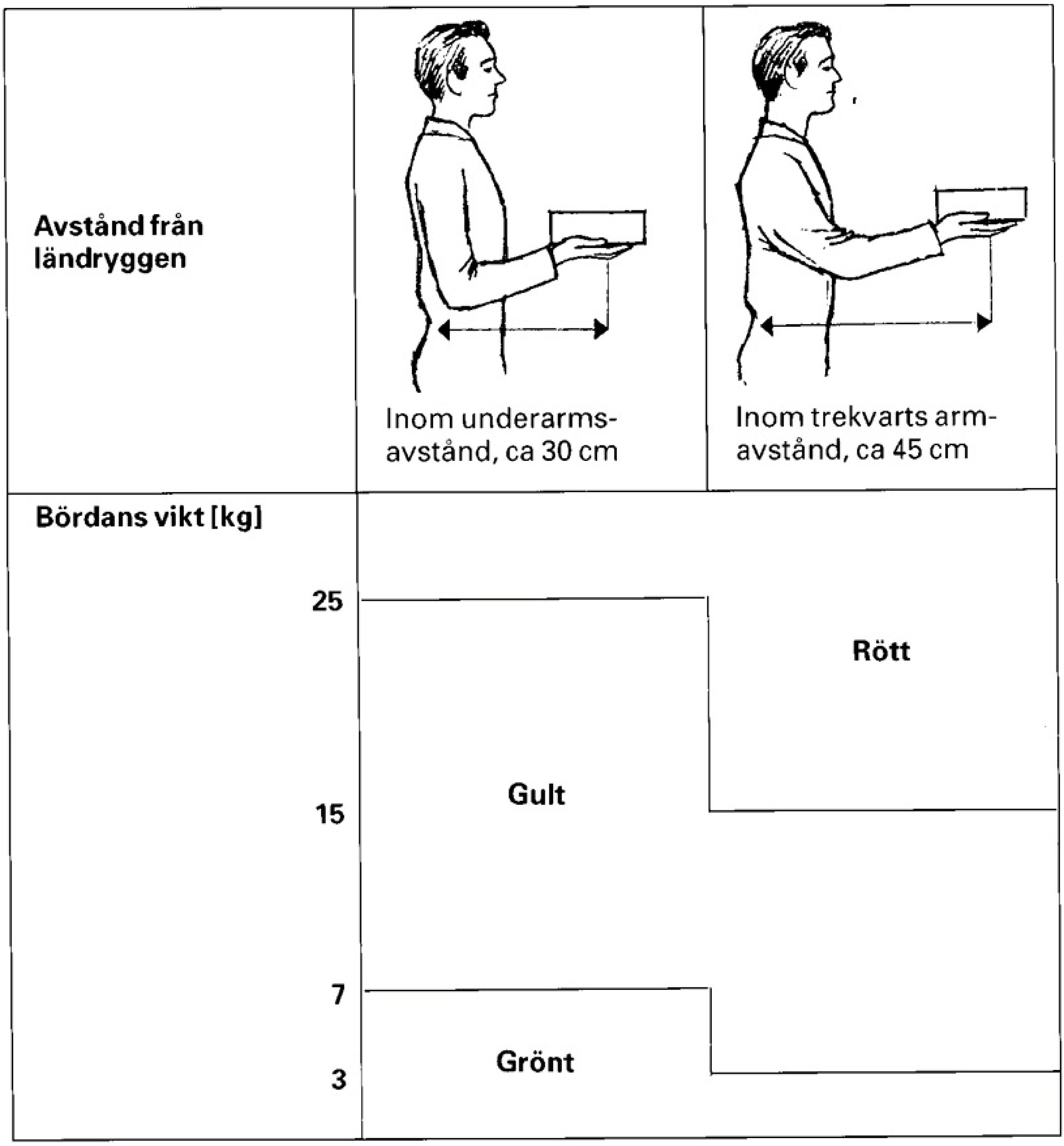


Figure 6. *A model for ergonomic assessment of symmetrical lifting with both hands, standing up under ideal conditions (SWEA, 2010).*

There are however several key factors missing in the model described above. The results of the model should therefore be combined with information on the frequency of the lift, how long time each lift lasts, at what height the lift is performed and how the object is gripped. One must also take into account other limitations like available space or body rotations required when performing the lift. Only once all relevant aspects have been considered, a complete analysis of the lifting sequence can be performed.

There are far more complex models that can be used for analyzing a lifting sequence like the NIOSH Lifting Equation (Bohgard et al. 2008). In this model different variables like lifting frequency, distance factor, asymmetric constant, horizontal factor and vertical factor are multiplied to find a recommended weight limit for the particular lift.

It should be noted that lifting heavy objects should to the best possible extent be avoided. With little effort most objects can be transported by rolling. Carrying heavy or bulky equipment up and down stairs poses considerable risks of muscoskeletal disorders and other accidents (SWEA 2010).

Pushing and Pulling

Pushing and pulling involves moving an object with either the full weight or part of the object's weight resting on the ground or resting on some kind of rail or support. The force needed to set and keep an object in motion depends on the mass of the object, the friction between the object and the ground or support and also on the slope of the ground or rail. To be able to apply force to the object, the friction between ground and shoe of the person pushing or pulling is an important factor. One should strive towards low friction between object and ground and high friction between shoe and ground. It is also important to try avoiding having to lift the object over curbs and other differences in ground level as in *figure 7*, due to the fact that the movements needed to perform these tasks can pose risk of injury (SWEA,2010).

Figure 7. *Transporting rolling objects up curbs should to the best possible extent be avoided. (SWEA, 2010).*

A model for assessment of a pushing or pulling process has been developed by SWEA (SWEA, 2010) and is illustrated in *Table 1* below. For the model to be accurate the pushing or pulling sequence requires good ergonomic circumstances like a symmetrical two hand grip, well-formed handles located at an appropriate height and good environmental conditions.

Table 1. *Model for ergonomic assessment of pushing or pulling tasks.*

Force [N]\ Risk Level	Red (High)	Yellow (Medium)	Green (Low)
Actuation Force	>300 N	300 - 150 N	<150 N
Continuous Force	>200 N	200 - 100 N	<100 N

If the object needs to be moved for a long distance, the task needs to be repeated frequently or for a long duration of time or if the grip height deviates far from the elbow height of the person moving the object, the levels in the model need to be reduced to compensate for this.

Handles

There are many different types of handles and numerous different guidelines for designing them exist. The most important aspect in handle design is to make the type of handle fit the task. The National Aeronautics and Space Agency (NASA) has developed a database called the Main-Systems Integration Standards (NASA, 2008) where human-system integration design considerations, design requirements, and example design solutions for development of manned space systems can be viewed. The guidelines listed in the database can be applied to many areas of product design even those not concerning space systems. Some recommendations for handle design found in the database are listed below (NASA, 2008).

Handle or grasp area designs should consider the following factors:
a. The mass properties of the item to be moved.
b. The operational location of the item relative to other items.
c. The manner in which the item is to be handled.
d. The distance the item needs to be moved.
e. The frequency with which the item may need to be handled.
f. The additional uses which the handle may serve, such as the anchor for a tether or as a handhold.
g. Handles should be located on either side of the center of mass.
h. The number and location of handles shall be determined by the mass, size, and shape of the object.

The complete guidelines used for dimensioning the handles in the project can be examined in *Appendix 4.*

3.4 Concept Development

Sketches

Sketches are valuable tools for the designer to communicate their ideas. Ideas that would otherwise require a long description in words can with the help of a sketch be easily understood by for example the employer. This reduces the risk of miscommunication and sifts out errors early in the design process, (Österling, 2003).

To visualize and communicate a wide range of concepts and ideas in the project, sketches were created using pencils and markers as well as the 3D software Cinema 4D R13 (Maxon, 2011). When using 3D software as a sketching tool the models were kept simple. Shapes were blocked out, mainly using so called primitives such as cubes, spheres and cylinders, while more complex forms were generated using basic polygonal modeling. The purpose of sketching was to provide and communicate details about the different concepts to enable a fair comparison between them and make up a good decision basis in the concept evaluation phase.

Concept Evaluation

Concept evaluation sessions were held along with the Setred staff on several different occasions during the project. During the sessions different design concepts and ideas were presented in words, sketches and 3D models. The concepts were compared to each other as well as to the current workstations. The aim of the sessions was to, in each stage of the product development process, narrow down the amount of concepts that were to be further developed as well as identify their strengths and weaknesses. Discussions were held on which concepts had the biggest potential and how they could be improved further. A total of three major concept evaluation meetings were held during the project.

Design Requirements

”Design problems are always set within certain limits”, (Cross, 2000). Common limits are related to weight and size of the product as well as performance, such as power output, while some limits are set by legal or safety requirements. The perhaps most important limit is that of cost: how much is the client willing to spend on a new design and how much can the customers be expected to pay for the finished product. This set of requirements make up the performance specification of the product and limit the range of acceptable solutions for the design problem. Because of this, it is important to make an accurate performance specification early in the design process. It should not be defined too narrowly for it may eliminate otherwise acceptable solutions and it should not be too broad leaving the designer without a proper direction in which to aim, (Cross, 2000). It is important that the performance specification is defined in measurable attributes, preferably within a range, for example: height between 100 - 120cm, or weight between 0 - 40kg. This gives the designer a proper amount of freedom and makes the specification usable for evaluating different solutions later in the design process.

When setting the design requirements for this project the *performance specification method* was used. This method aims to make an accurate specification of the performance required of a design solution and involves four steps, (Cross, 2000):

1. Consider the different levels of generality of solution which might be applicable.
2. Determine the level of generality at which to operate.
3. Identify the required performance attributes.
4. State succinct and precise performance requirements for each attribute.

Furthermore the attributes were separated into three levels of importance: must have, should have and nice to have. Where applicable, the attributes were quantified and set in ranges between limits.

Concept Development – CAD

"Computer aided design (CAD) can be defined as the use of computer systems to assist in the creation, modification, analysis or optimization of a design." (Narayan, Rao & Sarcar, 2008). There are several reasons for implementing CAD in the design process, (Narayan, Rao & Sarcar, 2008):

1. To increase the productivity of the designer.
2. To improve the quality of design.
3. To improve communications through documentation.
4. To create a database for manufacturing.

The main use for CAD in engineering is in designing detailed 3D models and/or 2D drawings of physical components. Today there is a wide range of CAD software packages available on the market. Most of these software packages allow 2D vector-based drafting as well as 3D solid and surface modeling and offer a lot of additional features such as assemblies, simulation and analysis-tools.

In this project the software Solid Edge ST4 (Siemens, 2012), which is a hybrid 2D/3D CAD system, was used for developing and refining concepts. Sketches and 3D mockups were dimensioned and modeled as solids to be combined with the current CAD parts of the Clariti workstation.

3.5 Detail Design

In the detail design phase, the product that is under development needs to evolve from an idea or a concept to a well defined product that is ready for manufacture. With the design requirements as the main guideline, the detail design of the demo-workstation was developed. The work was performed in the CAD model of the workstation where the biggest challenge was making all the parts in the assembly fit together.

CAD

In the concept development phase simple CAD models were made of different design concepts. In the detail design phase a much more complex CAD model had to be made since every single part in the assembly of the product had to be modeled and dimensioned to fit. This can be a very time consuming activity in the product development process since a change in a single part in the assembly can have an effect on many of the surrounding parts. The detail design of the demo-workstation was performed in Solid Edge ST4 (Siemens, 2012). Many of the parts used in the assembly of the demo-workstation were taken from the CAD model of the Clariti workstation, and some new parts were also added.

Simulations

Modern simulation software is a tool that enables engineers to make key decisions early in the design process. The time a company has at its disposal to bring a product from idea to product launch is constantly being shortened due to an increase in competition. This puts large pressure on engineers to produce designs quicker without a decrease in quality. In many product development projects the need for physical prototypes and mechanical testing can be reduced with the use of simulation models. It is also a very good way to keep costs down in projects with limited budgets.

There are numerous different simulations that can be performed with simulation software (e.g. static stress, fatigue, heat transfer, fluid flow). The main challenge with any simulation is to set up the simulation environment to be as representative of reality as possible. A general opinion among engineers on the accuracy of simulation software is that it is usually accurate within a spread of plus/minus 15% of reality. No scientific source was found that proves this theory, therefore this number shouldn't be accepted as truth.

The simulation software used in this project was Autodesk Simulation Multiphysics 2012 (Autodesk, 2012). Simulations were performed throughout the design process to evaluate different stress and strain occurrences in subsystems of the workstation assembly. The main type of simulation used in the project was stress and strain simulations with linear material models. The results of the simulations were used to make decisions concerning design, material choice, material thickness and weight optimization as well as identifying weak areas in the design of the workstation.

Production Cost Reduction

In order to keep the production costs low, many of the parts used in the Clariti workstation were reused in the demo-workstation. If any new parts were to be manufactured, the goal was to use the same materials, manufacturers and manufacturing methods as some of the parts in the Clariti workstation. This goal played a big role in the design of the workstation due to limitations in the material choice and design of certain parts in the assembly. To the best possible extent the guidelines for design for manufacturability listed by eFunda (eFunda, 2012) were followed during the project.

4. Applied Methods and Results

In this chapter detailed descriptions are given of how the different methods described in the previous chapter are applied, along with the results of these methods.

4.1 Interviews

A total number of 10 one-on-one interviews were conducted with Setred employees. During the interviews, the participants were asked to describe how they would go about when transporting the workstation and what they found difficult doing this. Furthermore questions about aesthetics, functionality and suggestions for improvements where asked as well as the participants view on the future for the workstation. The interviews were recorded and summarized in text. The summaries from the interviews were used to identify problems, sum up wishes and suggestions for improvements and to determine which problems that were most important to solve. This resulted in a problem definition (*appendix 3)* divided into five different categories. The following categories were defined:

- Problems and problematic situations encountered while using and transporting the current Clariti and MD-20 workstations.
- Improvements that can be made to the mechanical design of the workstations.
- Improvements that can be made in the functionality of the workstations.
- How the general appearance of the new demo-workstation should be.
- Other ideas for the demo-workstation.

The most commonly mentioned problems were related to the weight and size of the Clariti workstation. The participants mentioned that because of this, it is very difficult to transport. The hardest part in transporting the workstation is getting it up and down stairs, which requires at least three people to assist. Many of the participants had concerns about damaging the equipment when transporting it. The outer casings are fragile and unprotected and the sensitive optics might be damaged or misaligned by shocks and vibrations. Other important problems that where mentioned was lack of space for placing the 2D monitor and accessories such as mouse, keyboard and navigation equipment as well as having to disassemble a lot of parts to enable transportation.

Suggested improvements on the mechanical design were mainly about reducing weight and size. It was a common wish that the workstation should be small enough to fit in a regular hatchback car and that it should be able to be divided into easily assembled/disassembled modules. It was also suggested that the support structure should be reworked to support the workstation while lying down and that weight could be saved by removing the equipment and plate isolating leaking current (which is only necessary for using the workstation inside an operating room).

On the subject of improving functionality, several suggestions and wishes were made by the participants. Most of these were related to increased mobility, better handling and protection. Adding handles, dampening and making the 2D screen detachable were some of the suggested improvements to functionality.

When it came to appearance, most participants agreed on maintaining a similar aesthetic as Clariti and that a demo-workstation should look like a med-tech product. It was also a common request to add branding to the design by working with colors, shapes and/or logos.

Other ideas and opinions that were mentioned about the demo-workstation were mainly about showcasing the 3D technique and navigation system. The common opinion among the interviewed employees was that the demo-workstation should be a light, modular and less feature rich version of Clariti. Functionality such as height adjustment of the monitors could be sacrificed in order to promote mobility. Transportation of the demo-workstation would benefit from a modular design with quick and easily assembled/disassembled parts that could easily fit in a car's storage compartment or be packed in flight cases for long distance shipping.

4.2 Customer Journey Map

To identify the difficulties and steps involved in transporting a workstation, a customer journey map was created. The map was created in collaboration with a Setred sales representative who demonstrated his usual routine for transporting the MD-20 workstation. The sales representative was continuously asked questions throughout the entire journey to capture details about the different steps involved.

The journey was limited to moving the workstation from the office and packing it into the transportation vehicle. According to the Setred sales representative this covers the most common challenges that he faces each time he is going away to demonstrate the workstation. The vehicle used for transporting the workstation and its accessories was a hatchback car and the Setred office is located on the second floor.

The customer journey is illustrated in 16 different steps in *figure 8*. The journey begins in the Setred office. Firstly, the workstation is unplugged and the PC is removed and carried separately to the car [1]. The second step is pushing the workstation through the office towards the exit to the staircase [2]. Exiting the office the workstation needs to be lifted in order to pass a doorstep. The workstation is lifted by grabbing a hold of the covers beneath the 3D-monitor [3]. In the staircase, the workstation is lifted and carried downstairs by one single person in the same manner as it is lifted over a doorstep. If there are two persons present transporting the workstation, it is carried downstairs with one person holding the wheelbase and one grabbing the covers on the backside of the workstation [4]. Once downstairs the workstation is pushed towards the building exit and is once again carried to pass the doorstep [5]. Outside, the workstation is pushed or dragged over uneven terrain towards the car. The workstation is positioned slightly offset from the cars storage compartment with its back facing the car [6]. The wheels on the workstation are secured and as an additional safety precaution the person loading it into the car also puts his foot behind one of the wheels [7] to prevent the workstation from moving away from the car as it is tilted into the cars storage compartment. While the tilted workstation rests against the car [8], the person loading it places him-/herself in front of it grabbing the base on which the wheels are attached [9]. The workstation is then lifted and pushed [10] on its back cover all the way into the back of the cars storage compartment where it is secured before departure [11]. Upon arrival at destination, the workstation is dragged out of the storage compartment until it is at equilibrium. At that point it is tilted so that it slowly slides out of the car. When the wheels touch the ground the person unloading it puts his/her foot in front of one of the wheels to prevent the workstation to slip away from the car. To level the workstation the person unloading it needs to put a hand on top of the workstation and pull it while keeping pressure on the wheel with his/her foot [12-14]. When leveled the brakes are loosened [15] and the workstation can then be pushed or dragged to the demonstration area [16].

Figure 8. *Steps involved in transporting the MD-20 workstation from the office to the car, loading it into the car and unloading it from the car.*

By reviewing and analyzing the data collected from the customer journey, a customer journey map was composed, see *figure 9*. Clariti is the most current design for the workstation and therefore the customer journey map was created with that workstation in mind. The customer journey itself was performed with the older workstation MD-20. The major differences between the both of them is that Clariti is much heavier and larger which requires several people to transport it safely and comfortably, and that it has fragile casing that needs to be handled with care.

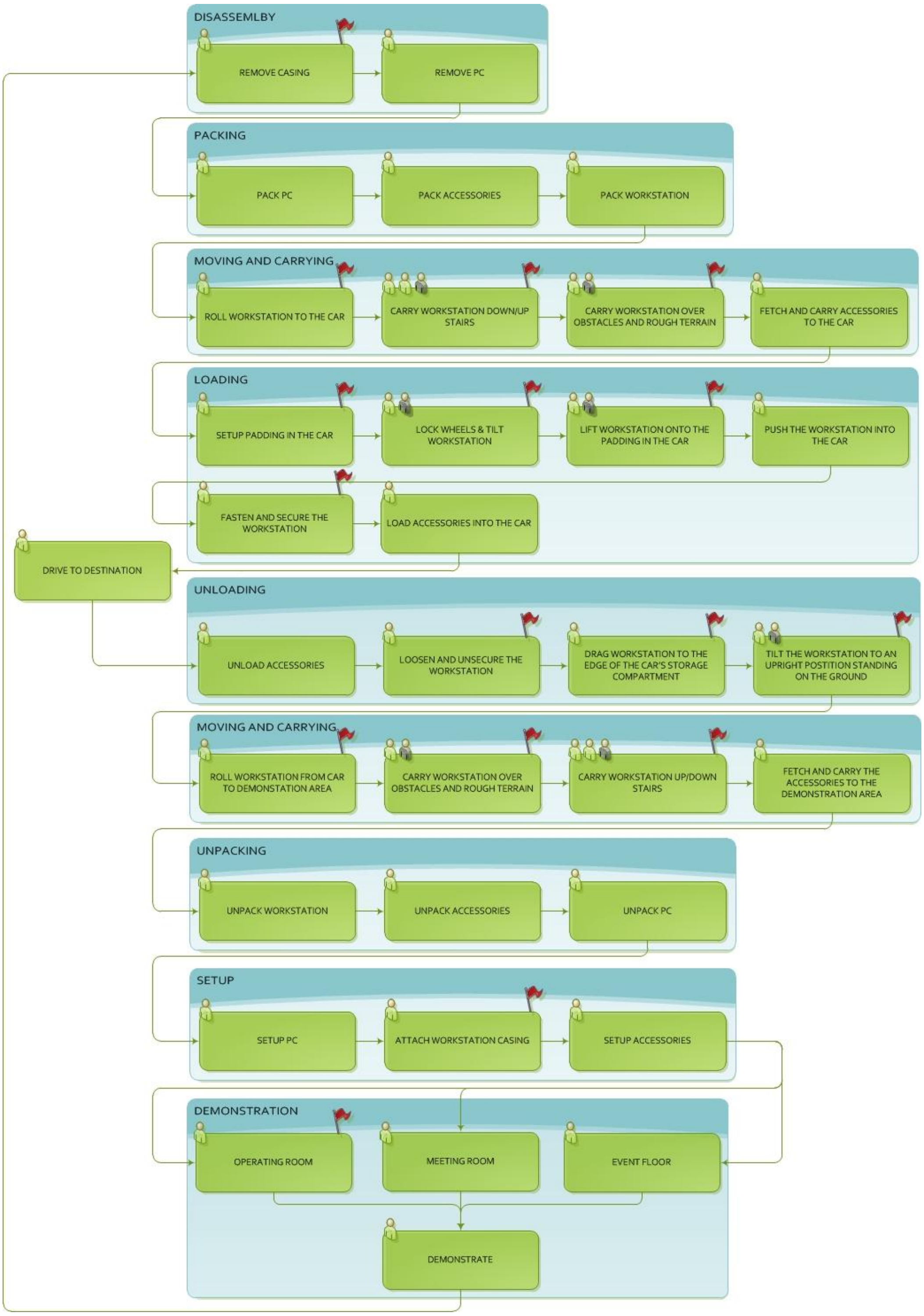


Figure 9. *Customer journey map for transporting the workstation Clariti.*

The map describes all steps involved in transporting the Clariti workstation from the Setred office to a demonstration area. The entire process was ordered chronologically and each step involved is represented by a green box. Furthermore the steps have been ordered into phases which are represented by blue boxes. How many people required to perform each step have been marked in the upper left corner of each step. The green persons indicate the minimum amount of required people and the gray indicate how many additional people would be preferable to perform the task. Steps that have been determined to require extra attention in the design have been marked with red flags.
The following problems were identified in the different phases:

- **Disassembly**: Parts of the casing need to be removed in order to remove the PC and to expose the support structure that can be gripped while handling the workstation. This requires about 15-20 screws to be loosened which takes about 5 minutes.
- **Moving and carrying**: The workstation weighs about 150kg and is too heavy for one person to carry. To carry the workstation safely, at least three people are required. The workstation lacks suitable handles for carrying and the casing is too fragile to grip, therefore the support structure of the workstation is used for gripping. The support structure is thin and sharp which requires the person handling it to use protective gloves to avoid damaging his/her hands.
- **Loading**: Since Clariti shouldn't rest on its casing, it instead rests on the support structure beneath the casing. To avoid damaging the vehicles storage compartment and the workstation itself, padding needs to be set up. After the workstation has been lifted into the vehicle it needs to be fastened and secured, and since there aren't any handles, it becomes difficult securing it with ropes and wires to the cars storage compartment.
- **Demonstration**: The main use for Clariti is as a medical device, and it should be able to function in an operating room. In the operating room there is a limited amount of space, and fitting the workstation for a demonstration is often problematic due to size.

The customer journey gave an in-depth understanding of the challenges one might face when handling the workstation. It was also concluded that the method used for loading and transporting the MD-20 workstation was relatively easy and efficient as long as no greater obstacles like stairs were encountered. The improvements to the Clariti workstation should in the demo-workstation be made to mimic the handling of the MD-20 workstation. The customer journey map was later used in setting design requirements and to validate that identified problem areas had been resolved.

4.3 Concept Development I

A number of sketches and visualizations were developed in order to present the different concepts that had been developed for the design of the new demo-workstation. The preliminary designs were used to discuss different possible design solutions, a major one being the possibility of setting the height of the workstation for sitting and standing demonstrations. A total of seven concepts were developed along with a number of different ideas.

In order to keep the cost of manufacture low and also to make the demo-workstation resemble the design of the original Clariti workstation, the limitation was set in the concept development phase that the demo-workstation would use the same core for the 3D screen as the Clariti workstation seen in *figure 10.*

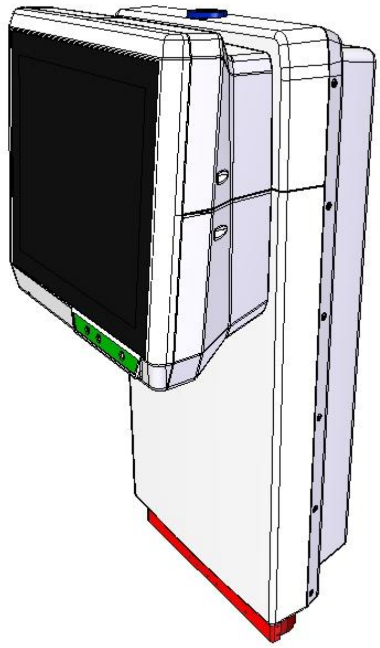


Figure 10. *The limitation was set in the concept development phase that the 3D screen body structure of the Clariti workstation was to be used in the new demo-workstation.*

A number of questions surrounding the design of the new demo-workstation were also composed and discussed together with the presentations of the different concepts. The main questions were the following:

- How should the PC be placed and oriented? (lying down/standing up/facing where?)
- Is the height setting necessary in the demo version? If yes how should it be achieved? Is two positions (standing/sitting) sufficient or are more heights needed? (Is there an intermediate position?)
- How and where should the table for keyboard and mouse be mounted? (Does it need to be movable? If yes, in what positions?)
- How should the 2D monitor be mounted? (Keep the 2D arm from Clariti or new solution?) Should it have the same design (casing) as the Clariti 2D screen, or just a normal monitor? Is the ability to mount it on both sides of the 3D monitor necessary? Should it be able to stand on its own?
- Should the design of the demo-workstation derive from the Clariti workstation or be a MD-20 with a facelift?
- Should the demo-workstation and the planning workstation (that is under development) be the same product or should they be kept separated?
- What are the maximum allowed outer dimensions for the base of the workstation?
- What is the maximum allowed weight of the demo-workstation?

Concept 1

The first concept aimed to achieve the height setting mechanically with the 3D screen body of the workstation being supported by rails instead of using the heavy lifting pillars that the Clariti workstation has. The lifting of the workstation would in some way have to be dampened in order to avoid dropping, either by gas dampers or by springs. The position locking of the height setting could be integrated with the lifting handles so once the handles are released the workstation would lock onto the rail. The PC could be placed either lying flat or standing up in front of the 3D screen body. A sketch and some visualizations for concept 1 are shown in *figure 11.*

Figure 11. *Concept 1, workstation with mechanical height setting by rails.*

Concept 2

In concept 2, *figure 12*, the PC would be placed lying down horizontally. The height setting would be achieved by manually lifting the 3D screen core between two heights (one for standing demo and one for sitting demo) and securing it in place.

Figure 12. *Concept 2, a modular workstation with two height levels on the base.*

Concept 3

The third concept was of more minimalistic character. Here the 3D screen core would be fastened at a fixed position to a base holding the PC. The screen height would be set up for sitting demonstrations, and if standing height is to be achieved, a second lightweight base would be added underneath the workstation, see *figure 13*. The PC would be placed lying down to lower the centre of mass, and to enable the 3D screen to protrude out over a desk with the PC and base neatly fitting under the desk. The concept is in theory both cost and weight efficient since the lifting pillars, cable management and the inner metal sweeps that Clariti has would no longer be needed. A question that needed to be answered was how the workstation would be lifted onto the second base.

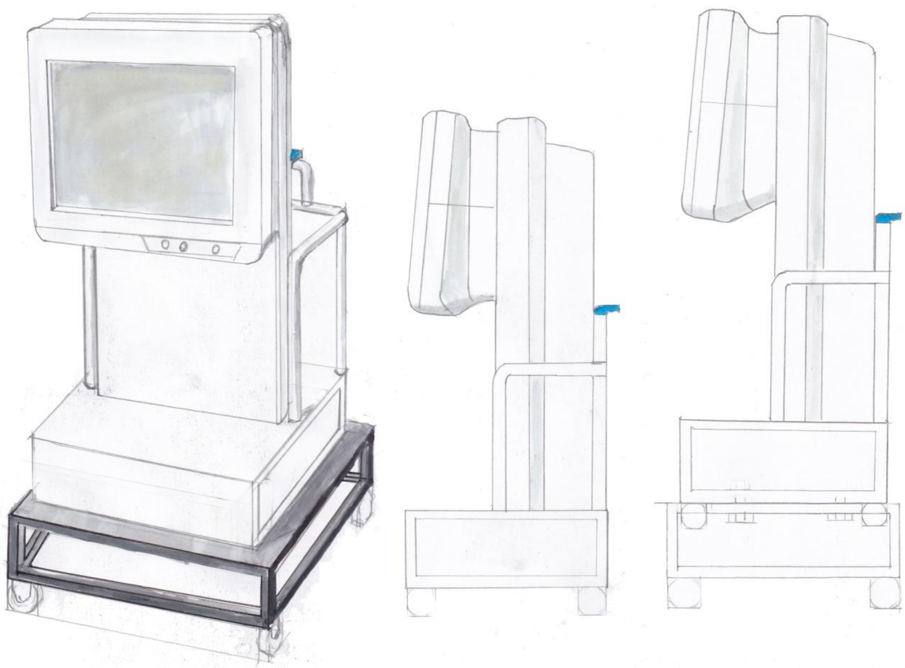


Figure 13. *Concept 3 fixed workstation with second base for height adjustment.*

Concept 4

Like concept 3, the fourth concept would have the workstation fixed to a base holding the PC. To achieve the height setting, the base would have foldable legs that could be unfolded when standing height was to be achieved, *figure 14.* A big question with this concept was how the legs would be unfolded.

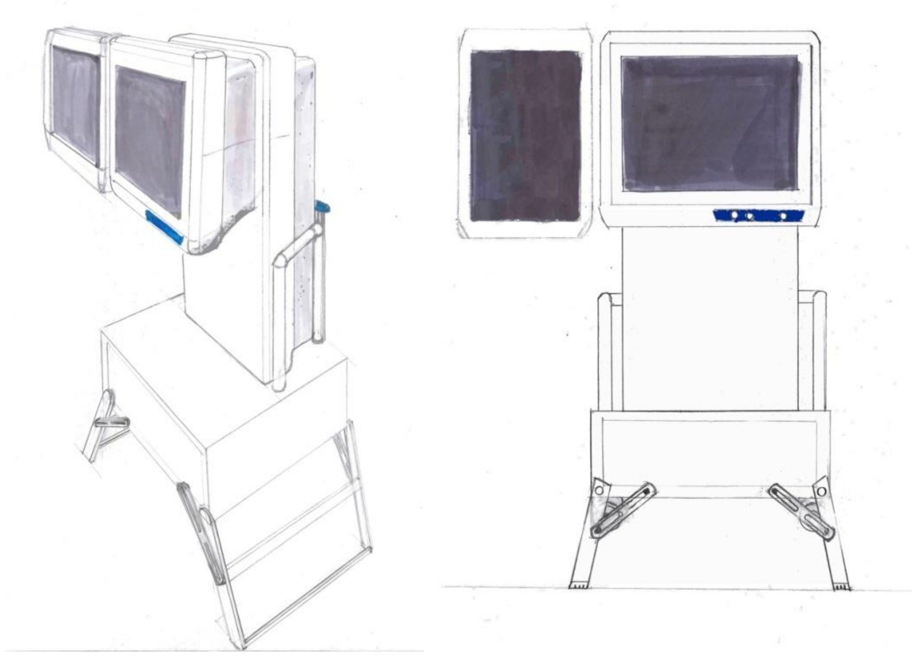


Figure 14. *Concept 4 Fixed workstation with foldable legs for height adjustment.*

Concept 5

A question arose during the concept development phase if the height setting really was necessary in a demo-workstation. Concept five represents a workstation where the 3D screen body was fixed at an intermediate height to a base holding the PC, *figure 15*. The idea was that since the workstation would only be used for demonstrating the 3D technology that the Clariti workstation uses, the exact height of the 3D screen while demonstrating the technology was not so important. The idea was that an intermediate height could be found that would work for both standing and sitting demonstrations of the technology.

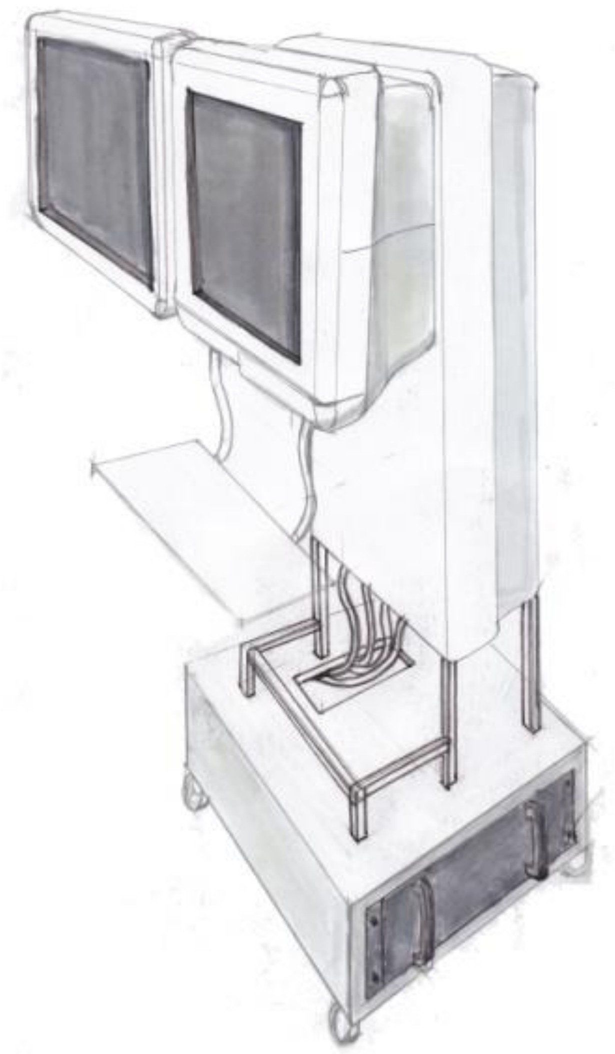


Figure 15. *Concept 5, a workstation with a fixed intermediate height for both standing & sitting demonstrations.*

Concept 6

This concept was a collection of different ideas where the height setting was achieved in the base rather than inside the 3D screen core. One of the ideas implemented a scissor lift table to lift and lower the 3D screen core and another idea used a rotation of the base to enable two height settings, see *figure 16*.

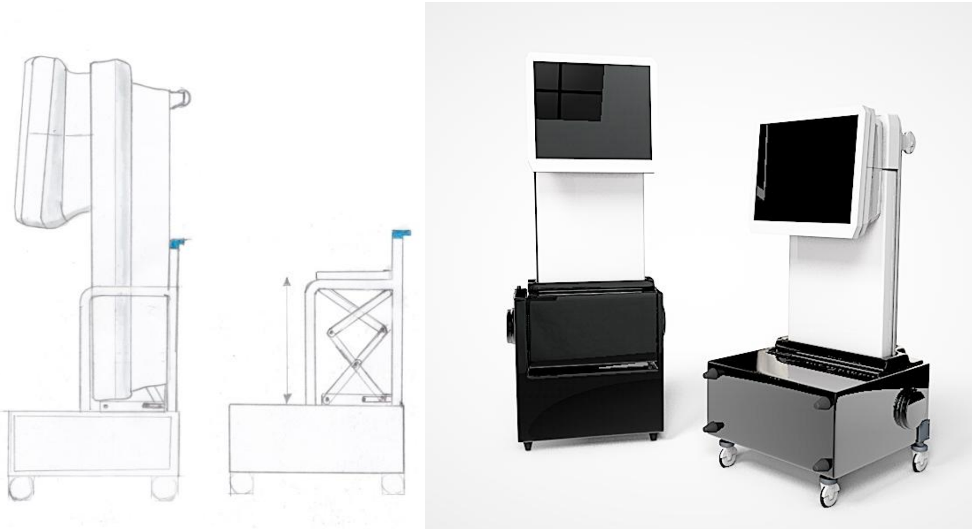


Figure 16. *Concept 6, a workstation with an adjustable base for height adjustment.*

Concept 7

At the same time as the demo-workstation was being developed, a decision was made at the company that a smaller workstation for use only during surgery planning was to be developed. This product was only to be used sitting down and required no height setting. There was an idea that this planning station could work as a core for the demo-workstation and that only a transportation unit for this planning station was necessary. A concept for a transportation unit was therefore developed. The transportation unit would enable ergonomic lifting and loading of the planning station by adding wheels and handles in necessary positions. A visualization of the transportation unit together with a mockup planning station is shown in *figure 17*.

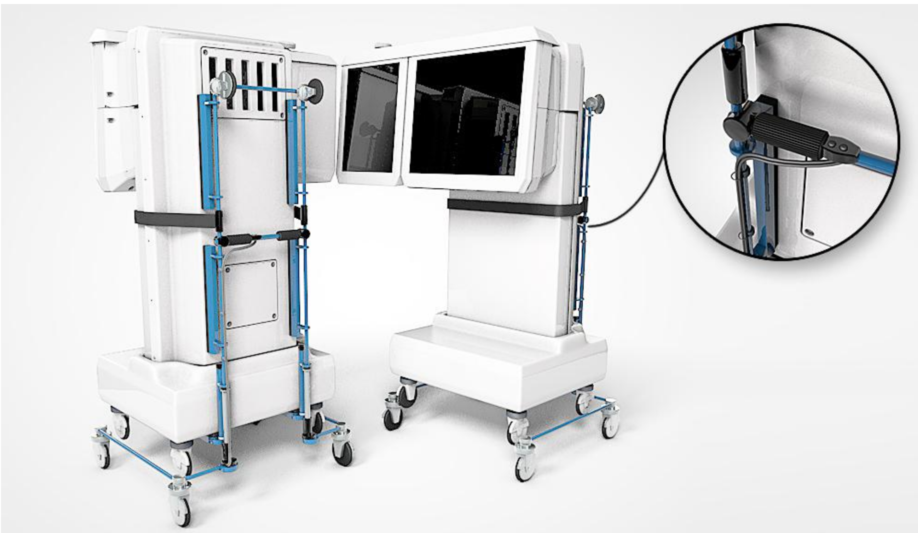
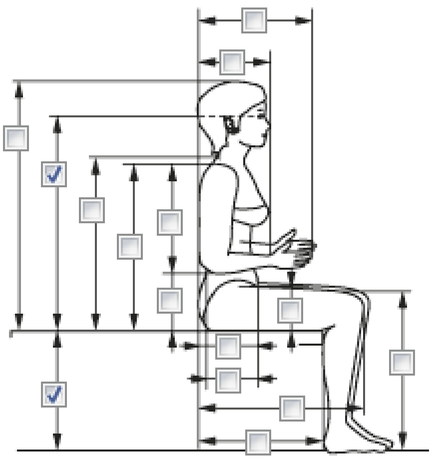


Figure 17. *Concept 7, a transportation unit for the planning station.*

4.4 Design Requirements

The results of the customer journey and the interviews were along with the initial concepts presented and discussed with the Setred staff. During this meeting a first set of design requirements were set for the demo-workstation using the performance specification method. It was decided that demo-workstation were to remain as similar as possible to the Clariti workstation in order to reduce tooling and manufacturing costs. A core set of parts (the support structure and casing for the 3D monitor and projector) were specified as a base on which to add new parts and features. The performance attributes where identified by reviewing the customer journey and interview data and sorted into three levels of importance; must have, should have and nice to have. By discussion, performance requirements for each attribute were set. On the "must have" section of the requirements it was specified that the workstation should be modular and be able to be separated into pieces no heavier than 60kg each and that one single person should be able to lift and pack these parts into a car by him-/herself. The weight was set based on the older workstation, the MD-20, which weighs roughly 60kg (without PC) and has repeatedly been transported successfully by a single Setred sales representative. Although it should be able to be separated into modules, another requirement was set stating that there should also be an option for transporting the whole workstation as a single unit. It was also specified that the outer dimensions of the workstation should be no larger than 65cm x 75cm so that it could fit in the storage compartment of a regular hatchback car. The dimensions were set based on measurements performed on a Volkswagen Passat which has a storage compartment 100cm wide, 77cm high and 160cm deep at approximately 60cm above ground. Furthermore the workstation must have wheels that enable rolling on uneven surfaces and be able to be transported lying on its back. As for functionality, it was decided that the 2D screen should be attachable to at least one side of the 3D screen and be able to rotate at least 90°. The workstation should have a height of 118cm measured from the ground to the centre of the 3D screen. This is slightly below the eye height (from ground) of an average person sitting based upon anthropometric data of the average Swedish population (Hanson et al. 2009), see *figure 18*.



	Kvinnor, 2009 (Hanson et al.)		Män, 2009 (Hanson et al.)	
Valda mått	Medel	S.D.	Medel	S.D.
Eye height, sitting	765.80	32.93	814.47	38.84
Lower leg length (popliteal height)	447.49	28.17	485.55	31.77

Figure 18. *Anthropometric calculation tool (antropometri.se) using data from (Hanson et al. 2009) displaying the average ("Medel") eye height and lower leg length of average Swedish women ("Kvinnor") and men ("Män") which combined makes up the average eye height from ground of a sitting person.*

It was also an important requirement that the 3D screen was to be placed so that it didn't extend outside the projected area of the outer boundaries of the base, this to prevent the most sensitive parts in the structure from being damaged in case of a collision when rolling the workstation.

The second most important requirements have been called “should have”. It was decided that the entire workstation, without 2D monitor and PC, should weigh less than 70kg and that it should be able to be transported without removing the covers or risk damaging them. The 2D monitor should be able to be transported separately from the workstation and be able to be mounted on both sides of the 3D monitor. It was also stated that the 2D monitor should be able to hold an attachable/detachable table for a mouse and keyboard. Furthermore it was decided that the workstation should have handles that enable ergonomic lifting, pushing, dragging and tilting with two hands (according to AFS 1998:1) and geometry such as loops that enables it to be secured during transport.

The “nice to have” requirements defines the lowest priority requirements for the demo-workstation. It is here stated that the workstation should be able to be transported without removing the PC and cables and that the workstation should be able to be set up in different heights. There were also requirements added that would further improve its use as a medical device, such as having no exposed fasteners and covered wheels that would prevent dirt from entering and make it easier to clean.

For a full definition of the design requirements see *appendix 5.*

4.5 Concept Development II

After the preliminary design requirements had been set, six new concepts were developed using the concepts from the first concept development and the design requirements as a starting point. The concepts were created in the CAD program Solid Edge ST4 (Siemens, 2012) and therefore had a higher level of detail than the earlier concepts. The aim of the second concept development was to investigate in detail how the different ideas for setting the height of the workstation could be realized, and to find a preliminary design for the demo-workstation that could be developed into a final design. In the CAD models, the model of the 3D screen core from Clariti was imported into the concept assemblies and needed parts were modeled to fit together with the core. To avoid having to fully develop every concept, the modeled parts were kept at a relatively low level of detail and many parts were reused in several concepts. The six different concepts that were developed are described below.

Concept 1

The first concept derived from the sketches shown in the first concept development phase where the 3D screen core which was being supported by aluminum rails. The handles on each side of the 3D screen body release a lock once pulled, enabling the change of height setting. The height setting is dampened by two gas dampers placed beside each aluminum rail, which aid the user with both lifting and lowering the 3D screen height. The PC is placed lying down in a base made of welded aluminum profiles in order to lower the centre of gravity for the workstation.

The large arm that the Clariti workstation has to support the 2D screen has been replaced with a smaller standard screen mount that is fastened to the inner steel structure of the 3D screen body. A design of a possible plastic casing covering the aluminum base was also given in this concept and can be viewed in *figure 19* below.

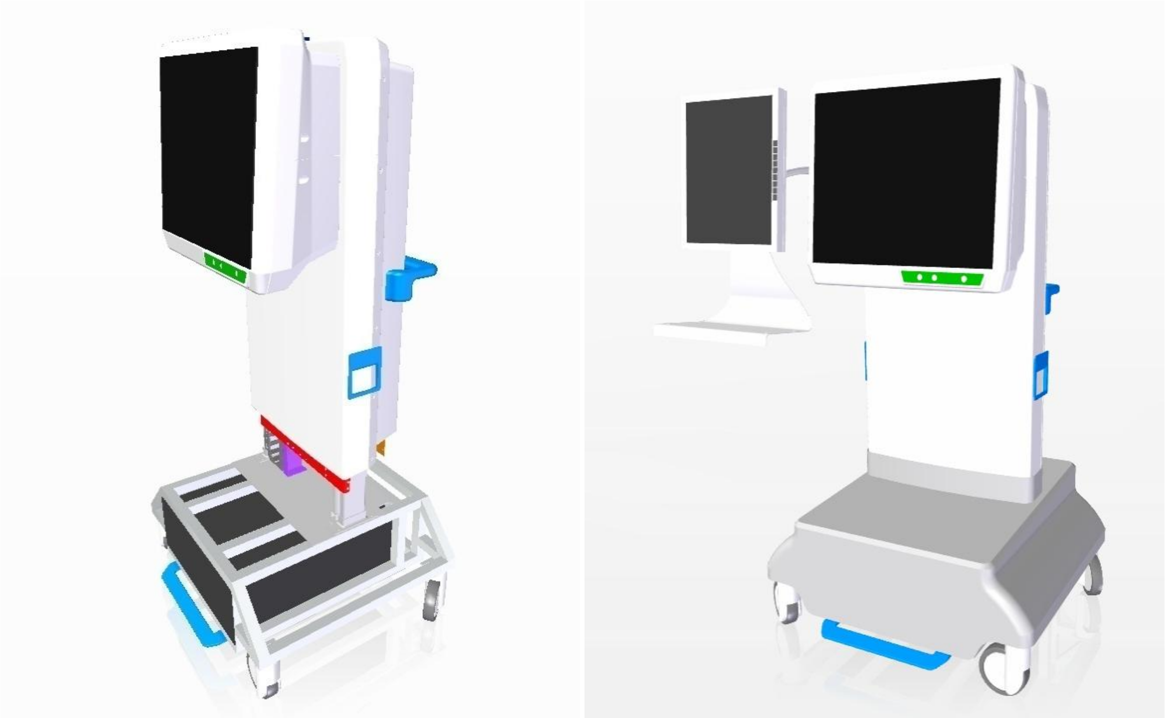


Figure 19. *Left: concept 1 with the 3D screen core being supported by aluminum profiles. Right: the conceptual design of the workstation with 2D screen and base covers.*

Concept 2

In the second concept the 3D screen core was fastened to a base-plate that could be raised and lowered relative to the aluminum base holding the PC. The profiles that protrude downwards from the base plate fit inside the profiles of the aluminum base and the whole motion is controlled by activating the two gas dampers on either side of the base, see *figure 20*.

Figure 20. *Concept 2 with a height adjustable base plate controlled by gas dampers.*

Concept 3 & Concept 5

In order to avoid the need for cable handling and inner metal sweeps in the assembly, two concepts were developed where the PC and 3D screen body could be raised and lowered as a single modular unit. Since the PC together with the 3D core weigh a lot together, the height setting is achieved by electrical lifting columns placed above each wheel in concept 3 and on the right and left side of the base in concept 5, see *figure 21*. In concept 5 the lower part of the 3D screen body has been cut off in order to enable the wheels to sit underneath the base without the workstation becoming too tall. The advantage of having lifting columns is that they enable a variable height setting. The downside of lifting columns is that they add a lot of weight to the structure and need electrical cables and control boxes.

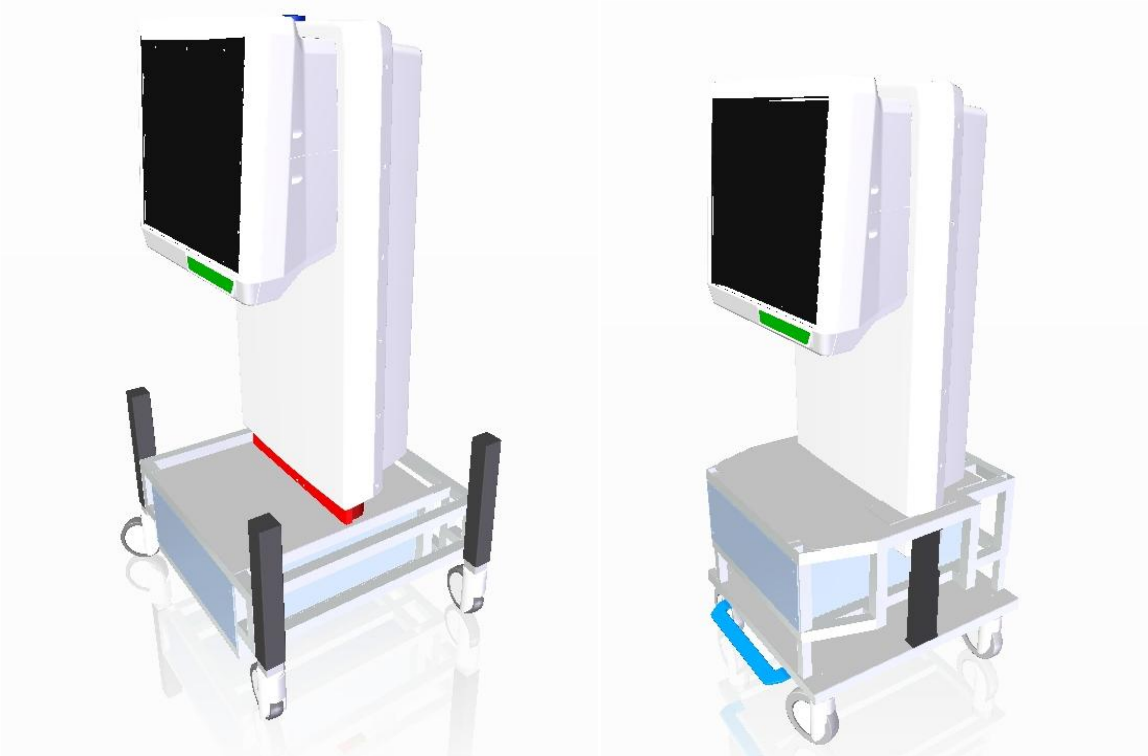


Figure 21. *Left: concept 3 with a lifting column placed above each wheel. Right: concept 5 with two lifting columns integrated in the base for variable height setting.*

Concept 4

To achieve a lightweight, simple and cost effective construction, a fixed height concept was developed, see *figure 22*. With a fixed height there is no need for advanced cable management or expensive and heavy lifting mechanisms. In order to keep the total weight as low as possible, the base construction is made up of aluminum profiles. The profiles form a cage-like structure that will house the PC and support the core parts from the Clariti workstation. The fixed height is set for a sitting user, with the center of the 3D screen just beneath average eye height.

The core parts from Clariti spans from the center of the aluminum base to the back of it, so that the base of the workstation can fit underneath a table making the screen itself hover over the table while the body of the workstation rests against the table's edge. To enable comfortable moving of the workstation as well as addressing the matter of having a support that enables the workstation to be packed lying on its back, a robust handle was added, mounted just behind Clariti's core parts. When packing the workstation the handle and aluminum base will support the workstation making it possible to leave the covers mounted without risking having them damaged during transport.

In order to make the construction modular, the core and handle are mounted on a plate that is fixed with screws to the aluminum base. The base and PC could then be detached simply by loosening a couple of screws which enables it to be transported separately if necessary. The plate also distributes the gravitational force on the aluminum base onto a larger area, making the base less likely to deform.

Figure 22. *Concept 4, a cost effective workstation with a fixed height.*

Concept 6

During the concept development phase a lot of research was done in the field of how different things are lifted. An interesting product that was found was the scissor lift. Scissor lifts are used in many different products like height adjustable tables and work platforms due to their combination of weight capacity and good maximum to minimum height ratio. A scissor lift base for the demo-workstation was modeled in concept 6 seen in *figure 23*. The PC was to be placed lying down horizontally in the u-shaped part of the base and the 3D screen body was to be attached to the base on both sides of the PC. The height setting of the scissor base was to be achieved either with the help of an electric motor or by a manual crank shaft.

Figure 23. *Concept 6, a scissor lift base for the demo-workstation.*

4.6 Concept Evaluation

In order to evaluate the six different concepts that had been developed, a meeting was held with the Setred staff at the Stockholm office. Staff members from the Oslo and London offices participated in the meeting by video-link. Each concept was presented and discussed in detail prior to having a general discussion surrounding the design of the demo-workstation under development.

Prior to the meeting, a decision had been made by the company that a new 3D workstation product was to be developed. This new workstation would be used mainly as a planning tool for surgery and would essentially be a smaller version of the Clariti workstation with fewer features and functionality, and a lower price. The "planning station" would for example not need the height setting feature since the idea is that it is to be used sitting down behind a desk.

Since the main purpose of the demo-workstation is to showcase the 3D technology and at the same time be both easy to transport and attractive to the potential customers, the demo-workstation would essentially have similar design requirements to the planning station. The decision was therefore made at the meeting that the design of the demo-workstation should be applicable to a possible design of the planning station, see *figure 24*. The demo-workstation should in essence have the same technical features as the Clariti workstation in terms of advanced software capabilities and accessories such as the 3D navigation camera and the 2D monitor, and at the same time have generally the same mechanical design as the planning station.

The decision of integrating the mechanical design of the demo-workstation and the planning station led to the requirement of height setting capabilities in the demo-workstation being discarded. This due to the fact that a goal with the planning station was to cut costs and complexity in the design as much as possible. Weighing these factors against the different designs, the staff along with the design team made the decision that concept 4 was the best solution for further development due to its estimated simplicity and cost effective design.

The choice of integrating the design of the two workstations also led to an alteration in the design requirements that were set up earlier. The height setting requirements for the demo-workstation were removed, and due to the decision of keeping the 3D screen body structure from Clariti intact, the weight requirement for the individual modules had to be adjusted.

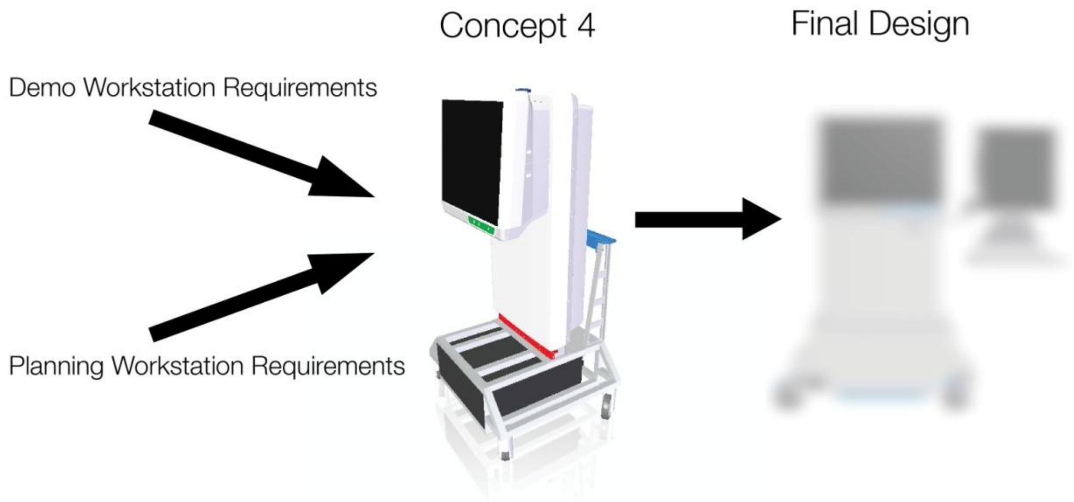


Figure 24. *Diagram showing that the design of the two workstations would be integrated as one. The final design of the two workstations derived from concept 4.*

In short, the demo-workstation should be designed with a fixed height for a sitting audience. It should be easy to transport and have a mechanical construction that could be reused for an eventual planning station. The aim was to keep manufacturing costs as low as possible by using many of the same parts as the Clariti workstation. Concept 4 was therefore chosen to act as a base for further development.

4.7 Detail Design

The detailed design work derived from concept 4, but many ideas from the other concepts were incorporated in the design of the demo-workstation. The design requirements were used as guidelines as the different parts in the assembly were modeled. The detail modeling was divided into several different sub systems which were developed simultaneously by the members of the design team. The major sub systems include:

- The aluminum frame base with wheels that houses the PC.
- A steel base plate that supports the 3D screen body and attaches to the aluminum frame.
- The attachment of the 3D core body to the base plate
- Handles for support and maneuvering.
- A mount for the 2D monitor, keyboard and mouse.
- Covers for the assembled base.

The design of each sub system is described further in the following sections.

Aluminum Frame Base

A decision to place the PC lying horizontally beneath the 3D screen body had been taken earlier in the project, this in order to lower the centre of mass of the workstation and at the same time enable the 3D screen to protrude out over a desk as shown in *figure 25*. In order to house the PC and support the 3D screen body, while at the same time remain lightweight, an aluminum frame structure was chosen to be the supporting base structure of the workstation. The design requirements affecting the dimensions of this base were primarily the maximum allowed outer dimensions of the base (65 cm x 75 cm), the desired height of the centre of the 3D screen from the ground (118 cm), and the dimensions of the PC.

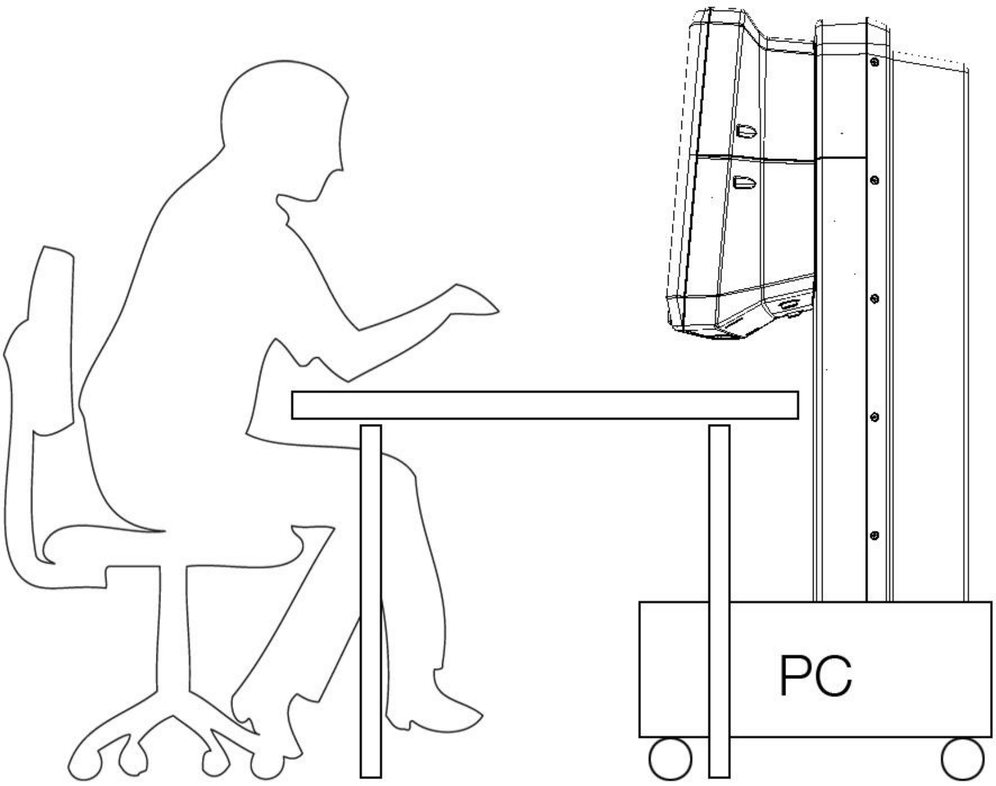


Figure 25. *The PC was placed lying down below the 3D screen body in order to lower the centre of mass and enable the 3D screen to protrude out over a desk with the base fitting underneath the desk.*

The aluminum frame base was modeled using 20 mm by 20 mm aluminum (6063-T6) profiles with a wall thickness of 2 mm which were to be welded together. The dimensions of the profiles were chosen after stress and strain simulations had been performed on profiles with different dimensions. To achieve the desired screen height for the workstation, the wheels that were to be attached to the aluminum frame had to be placed on the outside of the PC-cage and pocketed so the height of the workstation would be lowered. This led to a slightly wider base and less ground clearance, but also a lower centre of mass and a wider distance between the wheels which is good for stability. An image of the aluminum frame base is shown in *figure 26.*

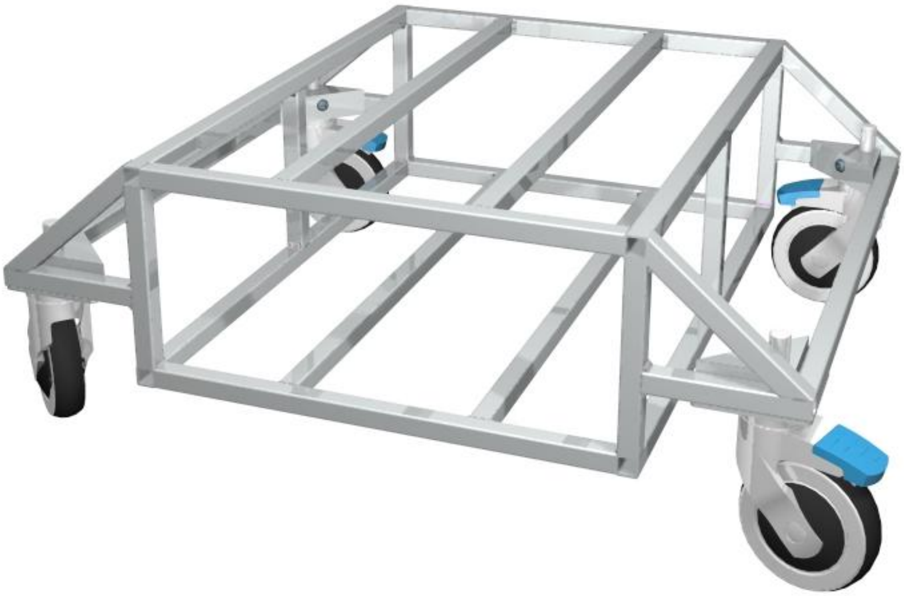


Figure 26. *The aluminum frame base for the demo-workstation was constructed from aluminum profiles that were welded together. The wheels were pocketed on the outside of the PC-cage to lower the 3D screen height.*

Once the shape of the aluminum base had been determined welds were added to the assembly to define in which locations the structure should be welded. The wheels for the workstation were selected from the same supplier as the wheels for the Clariti workstation, but for the demo-workstation a wheel diameter of 125mm was chosen, instead of the 150 mm wheels that Clariti has. To keep the complexity in the demo-workstation at a low, the central wheel locking system from Clariti was not implemented. Instead wheels with individual wheel locking were chosen. The CAD files for the wheels used in the assembly were provided by the wheel supplier (Tente, 2012).

When the final design of the aluminum base had been completed, several simulations were performed to investigate how well the structure could withstand elastic and plastic deformation when loaded with forces in different situations.

Base Plate

The base plate that sits on top of the aluminum frame connects the 3D screen body with the aluminum frame base. To keep costs low, the base plate was designed to be made from 3 mm stainless steel (EN 1.4301) sheet metal, which is the same material that the side and front plates of the 3D screen body are made of. When manufacturing the base plate, a 2D profile is first cut out from a piece of sheet metal using laser cutting, stamping or milling tools. The 2D profile is then bent in the desired places to achieve the appearance visible to the left in *figure 27*. The base plate is shaped to fit over the four horizontal aluminum profiles that make up the top of the aluminum base frame. The bends in the base plate do not only help position the plate onto the aluminum frame, they also help the base plate withstand bending that may occur.

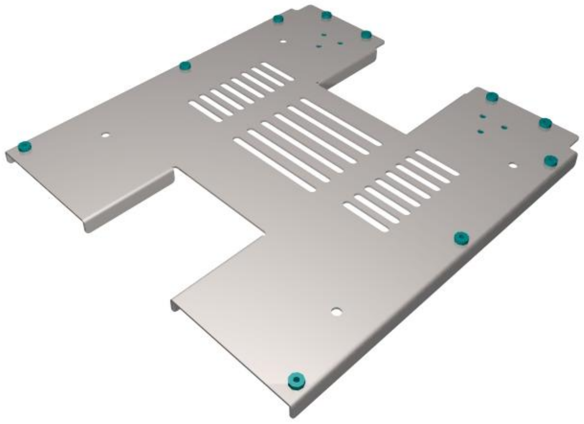



Figure 27. *Left: The base plate after bends have been made. Right: The base plate fits over the top four horizontal aluminum profiles in the aluminum frame base.*

When the bends in the base plate have been made, clinch nuts are fastened to holes in the base plate using specialized machines. These clinch nuts are used to fasten the base plate to the aluminum base with the help of ten M8 screws, see *figure 28.*

Figure 28. *The base plate is fastened to the aluminum frame using ten M8 screws that fit the clinch nuts that are fixed to the base plate.*

Attachment of 3D Screen Body to Base Plate

In the Clariti workstation, the 3D screen body is supported by the lifting columns that are attached to the base plate. Since these columns have been removed in the design of the demo-workstation (due to the height adjustment no longer being necessary), a new way to attach the 3D screen body to the base plate had to be designed. The supporting structure of the 3D screen body consists of a 3mm thick stainless steel front plate and two 2mm thick stainless steel side plates on either side of the 3D screen, see *figure 29*.

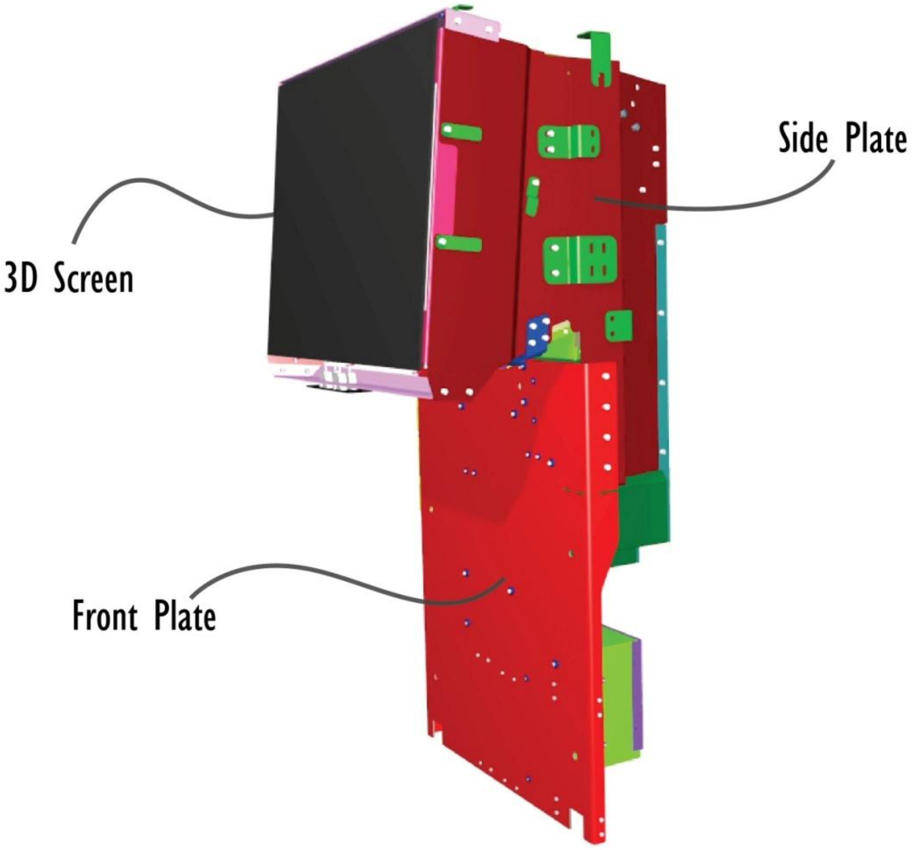


Figure 29. *The supporting structure of the 3D screen body, without the fiberglass covers.*

To support the weight of the 3D screen body without adding to much weight to the structure, two aluminum fixtures were designed. Since the most rigid part in the structure was the 3mm thick front plate, the fixtures were constructed to attach to this. The fixtures were designed to be made from welded aluminum (6063-T6) profiles that are attached to the front plate and base plate by M10 screws. The aluminum fixtures and their position in the assembly can be viewed in *figure 30*.

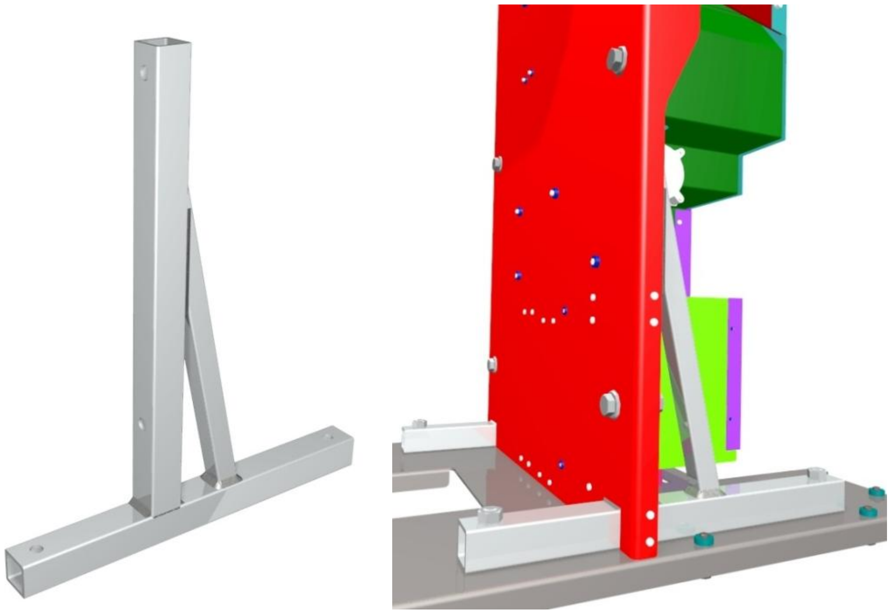


Figure 30. *The left figure shows one of the welded aluminum fixtures. In the right figure, the four M10 fasteners used for fixating each aluminum fixture the front plate and base plate can be seen.*

A big challenge in the design of the fixtures was to maintain the stability in the structure without adding too much weight to the total weight of the workstation. To avoid torque development in the front plate of the 3D screen body, the top of the vertical aluminum profile in the fixture was dimensioned to be fastened as close as possible to the centre of mass of the 3D core body, see *figure 31*.

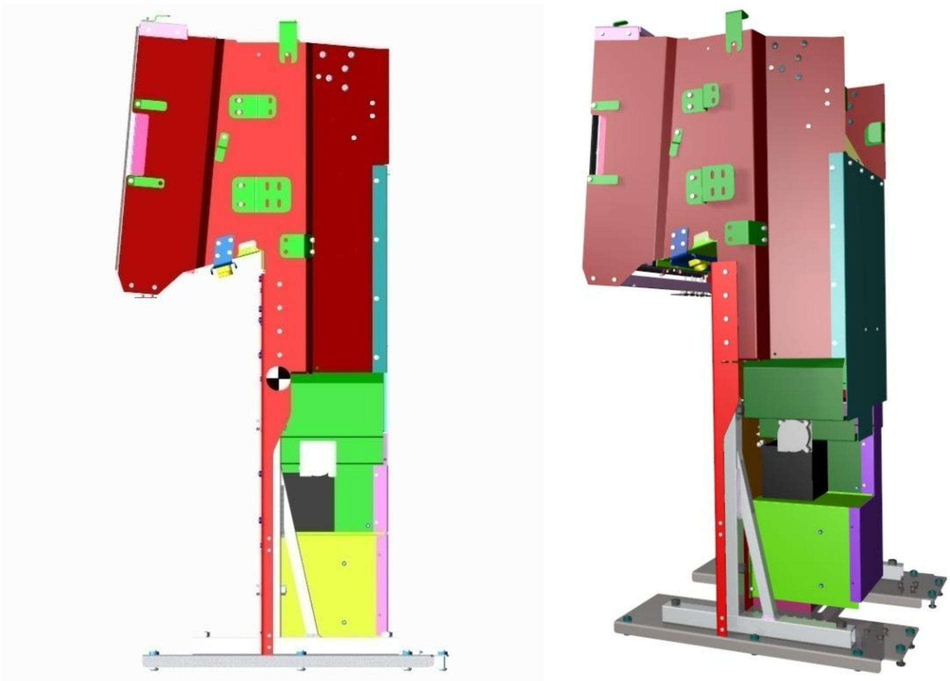


Figure 31. *The figure to the left shows the centre of mass marked out in the assembly of the 3D screen body. To the right, the placements of the aluminum fixtures in the assembly are illustrated.*

Handles For Loading and Stability

In the design requirements for the demo-workstation, there was a demand to be able to transport the workstation lying on its back without having to remove the fiberglass covers of the workstation. When transporting the Clariti workstation the back covers and the PC have to be removed and transported separately which can be quite time consuming if a lot of traveling with the workstation is to be done. To enable the transportation of the demo-workstation without having to remove the covers, two curved handles that run along the back of the workstation were designed. The handles are fixated at one end to the side plates of the 3D screen body and at the other end to the steel base plate with M6 screws and are made from bent circular hollow aluminum (or steel) profiles. The handles don't only enable the workstation to be loaded into a car without removing the fiberglass covers; they also increase the stability in the whole structure of the workstation. They were designed according to the ergonomic guidelines for grip diameter, grip height and pushing and pulling motions mentioned in the methods chapter. An image of the workstation with the handles can be viewed below in *figure 32*.

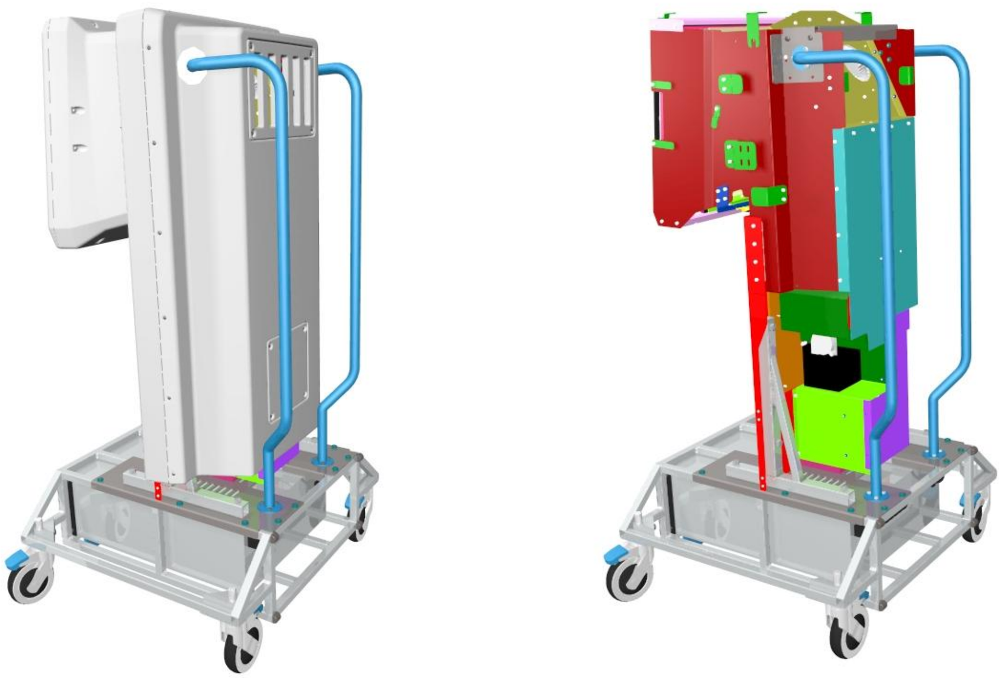


Figure 32. *To the left the demo-workstation is shown with the blue handles and the fiberglass covers mounted. The right figure shows where the handles are fastened.*

Simulations investigating the forces that are transferred to the side plates when loading the workstation into a car with the new handles led to some reinforcements and changes in the original parts in the assembly. In order for the handles to be fastened to the side plates of the 3D screen body without leading to plastic deformation in the side plates when transporting the workstation, 3 mm steel reinforcement plates were added to each side plate. The reinforcement plates are made to be welded onto the side of each side plate at the location where the handles are fastened. A stabilizing cross beam was also added along the top of the workstation to strengthen the construction around the top edges of the side plates where the handles are fastened. The reinforcement plates and stabilizing beam are shown in *figure 33*.

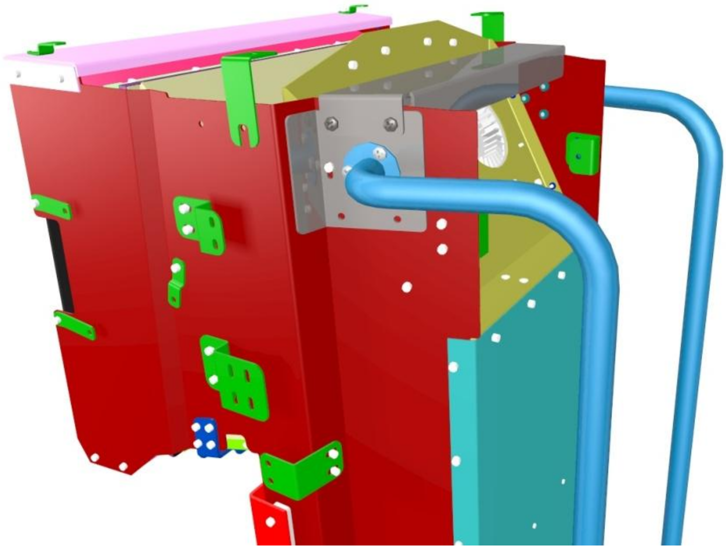


Figure 33. *The handles are fastened to the 3mm thick reinforcement plates by M6 screws. The structure is strengthened by the cross beam that runs over the top of the workstation and is fastened to each reinforcement plate.*

Another alteration that was done to the 3D screen body assembly was that one hole was cut on either side of the rear fiberglass cover, left image in *figure 34*. The holes are necessary since it otherwise would be impossible to fasten the handles to the side plates (the covers would be in the way). Once the handles have been fastened to the side plates, the two holes in the covers can be covered with a small rubber gasket that fits around the handle and is held in place in the hole opening by its shape as seen the right image in *figure 34*.

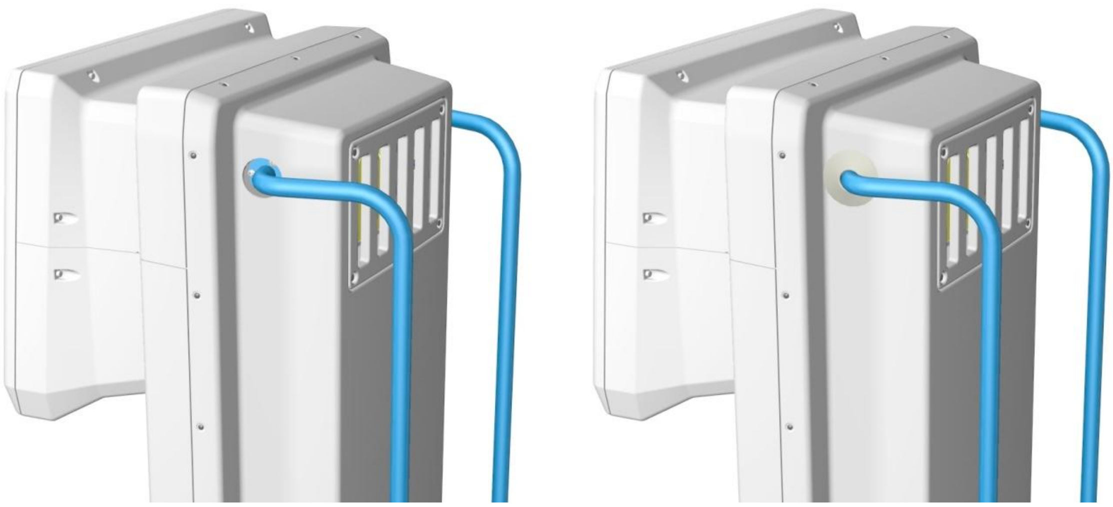


Figure 34. *The left image shows the hole that is cut in the rear cover in order to fit the handle. The image to the right shows the same image but now with the rubber gasket that covers the hole in place.*

A mount for the 2D Monitor and Input Devices

To mount the 2D monitor to the workstation, a desk mount LCD arm from the supplier Ergotron (Ergotron, 2012) was used. The model used was the "LX Desk Mount LCD Arm" (see *figure 35*) which has the capacity to support a monitor with a weight up to 9.1kg and uses standard mounting hole patterns: 100 x 100 mm and 75 x 75 mm. The monitor attached to the arm can be tilted, panned and rotated enough so that it can be viewed in both a horizontal and vertical orientation.

Figure 35. *LX Desk Mount LCD Arm (Ergotron, 2012).*

This particular model was chosen as a suitable mounting arm for the 2D monitor because it could be attached underneath the 3D monitor, utilizing the mounts previously used for attaching the mouse- and keyboard tray in Clariti, see *figure 36*.

Figure 36. *Mounting brackets attached to the support structure on the inside of the 3D screen's casing. The brackets go through two holes in the casing, making it accessible from the outside.*

To ensure desired positioning of the 2D monitor using the LX Desk Mount LCD Arm with the mounting brackets for Claritis mouse- and keyboard tray, a simplified model of the desk mount arm was made in Solid Edge with appropriate dimensions and joints. By attaching a monitor to the arm and attaching these to the brackets underneath the 3D monitor in the CAD assembly, the design team could verify that desired positioning of the monitor was possible.

In order to enable mounting of the arm, two parts were added to the current bracket for the mouse- and keyboard tray. The first part was a machined aluminum insert whose purpose was to adapt a flat face into a cylindrical one, to fit the second part. The second part is a bent circular aluminum profile on which the LX Desk Mount LCD Arm can be mounted in the same way it is mounted to its regular table bracket.

Figure 37. *2D monitor mounting bracket components: 1. Sheet metal support structure, 2-4. Current mounting brackets for the mouse- and keyboard tray, 5-7. Adaptor parts enabling attachment of the LX Desk Mount LCD Arm.*

As seen in *figure 37*, a square shaped aluminum part with a cylindrical top [3] is fitted within a threaded bracket [2] attached to the sheet metal support structure [1] and fixed to it with a nut [4]. A machined aluminum part with one cylindrical face and one square cut surface [5] is placed inside a bent cylindrical aluminum profile [6] on which the LX Desk Mount LCD Arm can be attached. Part number [5] fills the space between the cylindrical inside of [6] and the square faces of [3] making all three parts fit together without any gaps. When in place, parts [5] and [6] are fixed to [3] with two bolts [7]. Since there were two threaded brackets attached to the sheet metal support structure in the 3D screen, the arm and 2D monitor could be placed on either side of the 3D screen as well as being detached before transport.

To enable the 2D monitor to stand by itself on a table, while at the same time providing a tray for input devices such as a mouse and keyboard, a custom monitor stand was made using swept sheet metal, see *figure 38.*

Figure 38. *Swept sheet metal monitor stand that enables the monitor to stand by itself and acts as a tray for input devices when the monitor is attached to the workstation.*

The swept sheet metal stand uses the same mounting hole pattern as the monitor arm and most standard monitors (100 x 100 mm and 75 x 75 mm). The bottom plane of the monitor stand was given a width of 400 mm and a depth of 150 mm, which were considered suitable dimensions to fit a keyboard and a mouse. To ensure stability when the monitor is detached from the workstation, four rubber feet were added to the bottom plane of the monitor stand. These feet were placed so that the centre of gravity from the monitor attached to the stand would be within the boundaries of the feet, ensuring that the monitor wouldn't tilt, see *figure 39.*

Figure 39. *Center of gravity for the monitor attached to the stand. The center of gravity is within the boundaries of the four rubber feet ensuring that the monitor won't tilt while detached from the workstation.*

Plastic or Sheet Metal Casing

In order to enclose the aluminum frame base and the PC, and to improve the overall appearance of the assembled base for the workstation, casings were needed. To achieve easy assembly and disassembly, two casings were made, one to cover the front of the base and one to cover the rear, se *figure 40*.

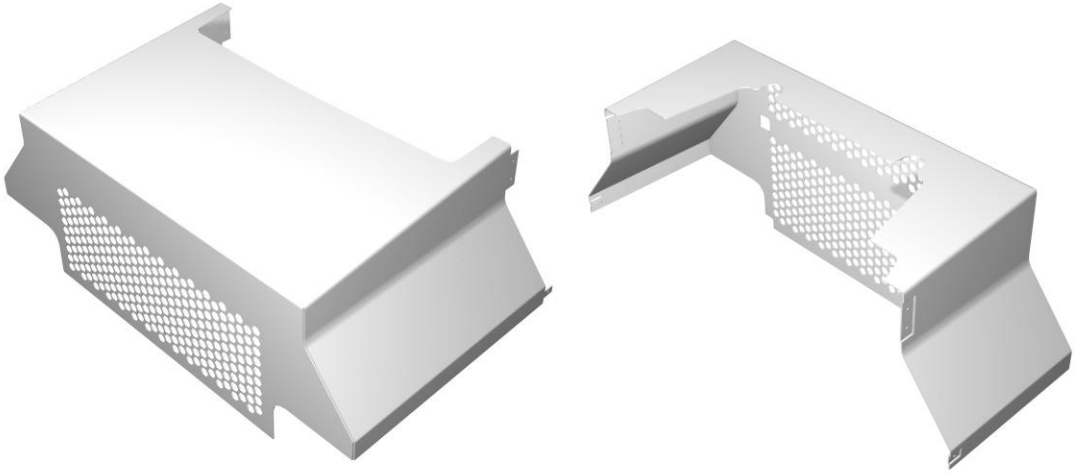


Figure 40. *Isometric views of the base casing. To the left is the front and to the right the rear.*

The casings were designed so that they can be cut from a plastic or metal sheet and then be bent into its final shape. In order to attach the casing to other parts of the base, each casing has three “L-shaped” brackets attached to it on the inside, one to fit along the width of the base and two (one on each side of the casing) to go along the length of the base, see *figure 41*.

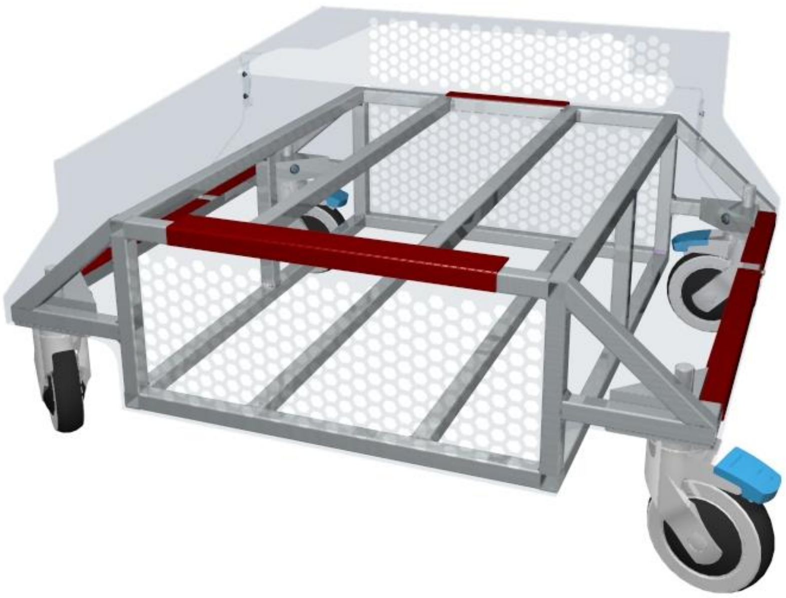


Figure 41. *The ”L-shaped” brackets are marked in red and are used for attaching the casing to the aluminum frame.*

When attaching the casings to the base they are placed so that the “L-shaped” brackets rest on top of the aluminum profiles. Since both casings have an almost identical cross section where they meet, the front casing was given four extended tabs (two on each side) through which threaded holes were added. These four tabs have matching dimples that were added to the rear casing so that the two parts could be screwed together, see *figure 42*. When both casings have been placed, they are screwed together with six M4 bolts (three on each side of the casing) as seen in *figure 42*. All six bolts secure the casings to each other and the two lower bolts also screw into the aluminum frame, fixing the casing so that they won’t nudge during transportation.

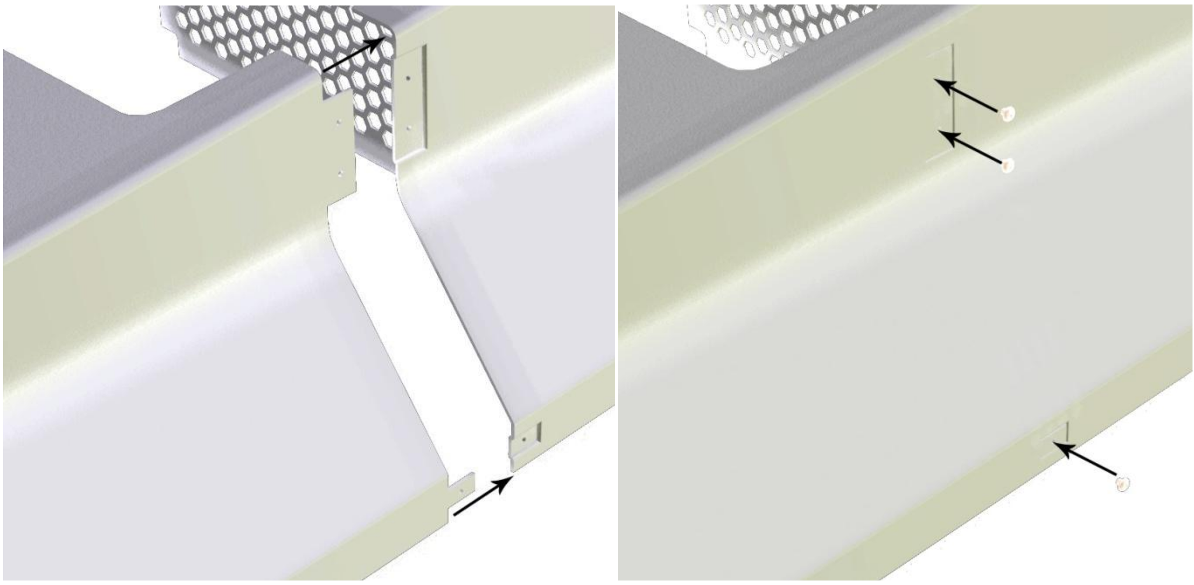


Figure 42. *This image illustrates how the two parts of the casing are attached to each other. The front casing have four extended tabs with threaded holes that have matching dimples on the rear cover. When aligned the two parts can be screwed together using six M4 bolts.*

To provide ventilation for the PC that the casings enclose, a “honeycomb” pattern was cut out in both the front and rear casing, see *figure 43*.

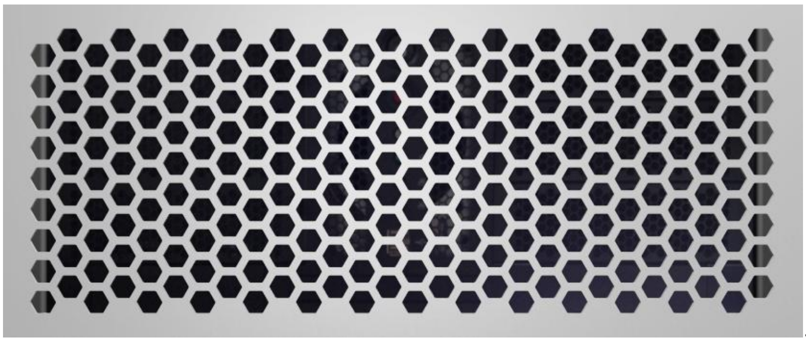


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Figure 43. *Cut-out pattern used to increase airflow through the casing.*

This pattern was chosen by the design team since it was considered to be visually appealing while at the same time providing the PC with a satisfactory airflow. In the front casing the mesh created works as an inlet for the air to the PC, while the mesh on the rear case works as an outlet for the warm air from both the PC and the projector electronics of the 3D base body. As for the remaining appearance of the casings, they were given a similar idiom as the casings of the Clariti workstation, which was achieved by working with simple shapes, angles and by adding a small roundness to the edges. If the casings were to be made from plastic, a colorable plastic such as ABS could be used to achieve a similar finish as the casings of the 3D core body. If sheet metal were to be used it would have to be painted and/or treated to accomplish the same effect. Furthermore the casings were split so that the seam between the front and rear casing was in line with the seam between the front and rear casings of the 3D core body, which was considered to create a nicer looking flow between the parts and establish a greater sense of unity for the workstation’s appearance.

4.8 Simulations

In order to test different design solutions during the detailed design process, several simulations were performed using Autodesk Simulation Multiphysics (Autodesk, 2012). The simulation models were imported into the program straight from the CAD assembly, and forces, constraints and materials were added in the simulation. Several models were set up with different load-cases in order to investigate how the parts being analyzed would perform in different situations. In order to perform the simulations parts in the assemblies were simplified prior to running the simulations. A summary of the most important simulations are given in this chapter. The complete simulation data and results can be found in *appendix 6*.

Base Frame Static Analysis

The first simulation that was performed aimed to investigate whether the aluminum frame base of the workstation was strong enough to support the weight of the workstation. In order to test this, stress and strain simulations with linear material models were performed. The assembly of the base was imported into the simulation workspace along with a few other large parts that stabilize the base structure. At the location of the workstation’s four wheels, fixed constraints were placed in the model to simulate the workstation standing on the ground. A force of 1000 N was then applied to the top edge of the front plate of the structure to simulate the weight of the workstation, see *figure 44*. Before running the simulation, each part in the model was assigned a material. For the base profiles aluminum 6063-T6 (dimensions 20 mm x 20 mm, thickness 2 mm) was chosen. The front plate and base plate were assigned stainless steel 1.4301 with a thickness of 3mm. The contacts between the profiles in the base structure were also defined as welded together. Once the material had been assigned and the forces had been applied, the model was meshed and the simulation was executed.

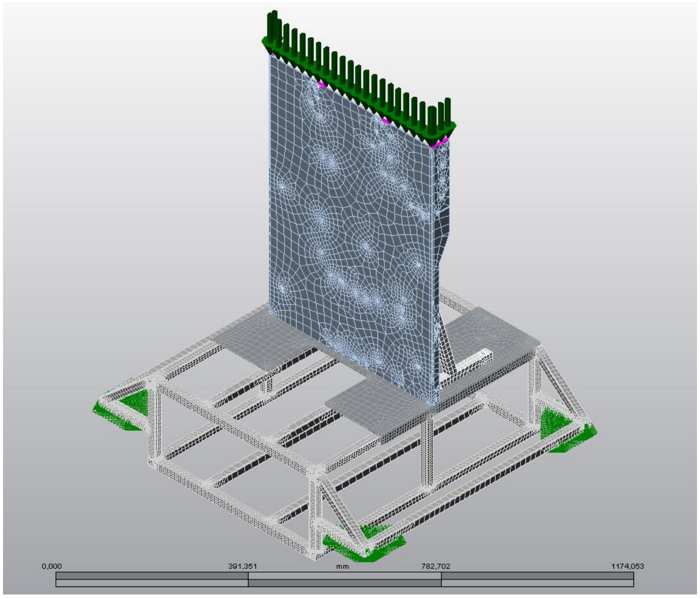

Figure 44. *Load-case 1, a force of 1000N is applied to the top edge of part 1002430. The wheels on the base have been replaced with fixed constraints at each wheel placement to simulate the workstation standing on the ground.*

The results of the simulation showed that with the current dimensions of the aluminum profiles and the simulation configuration, the maximum effective stress in the base frame structure amounts to around 25 MPa With the largest stress concentrations occurring in the corner welds between the aluminum profiles, *see figure 45*. The stress value is far below the yield stress value of the aluminum profiles which is around 170 MPa resulting in a safety factor of around 6. A similar simulation with a force of 250 N at each wheel position and the top of the structure in a fixed constraint was also executed to ensure that the simulation gave accurate results. This second simulation gave a maximum effective stress of 39 MPa in the aluminum base.

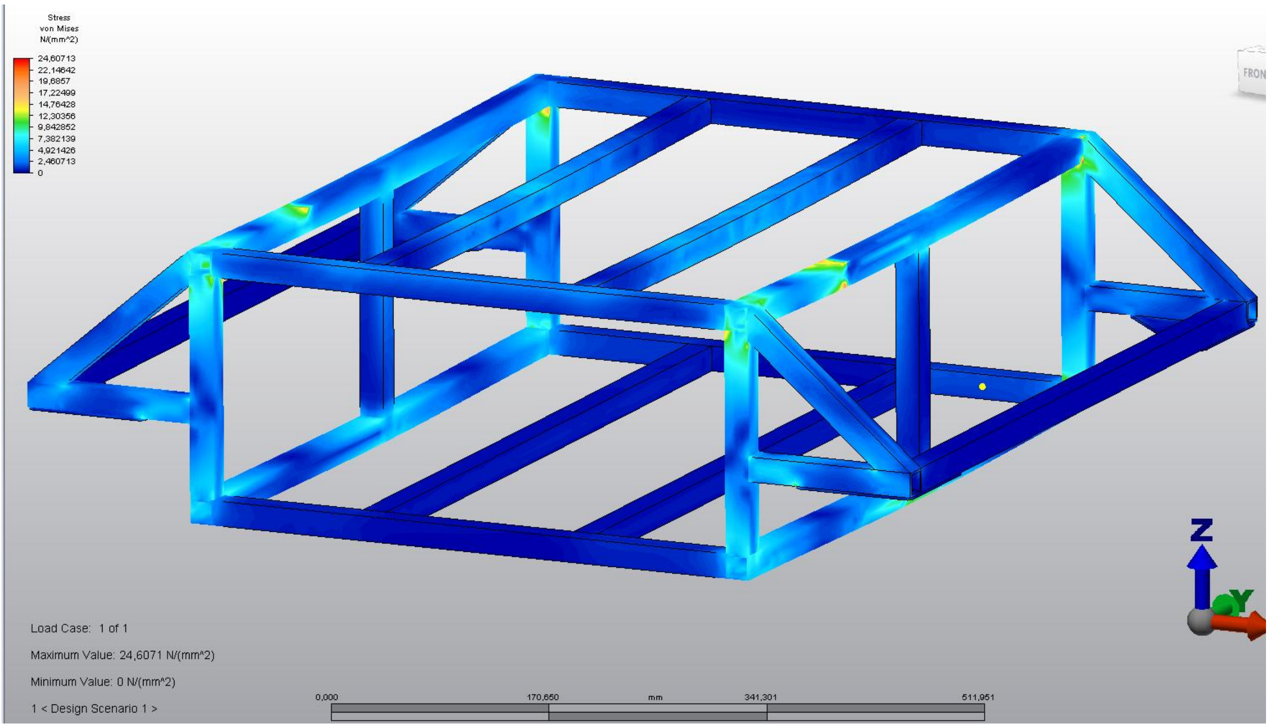

Figure 45. *The stress analysis in the base shows a maximum stress of around 25-39 MPa in the aluminum profiles with the current load case. The maximum stress values are located in the corner welds where the aluminum profiles meet (yellow and red color in the figure).*

Side Plate Resistance to Plastic Deformation

Another simulation that was performed aimed to investigate the forces that may occur if handles were to be attached to the inner steel plate structure of the workstation and act as the bearing structure when the workstation is being transported lying down on its back, see *figure 46*. In order to analyze this, a 100 mm straight beam was attached to each one of the side plates in the simulation model at the desired mounting points for the handles. Fixed constraints were added to the surfaces of the side plates that were far away from the handles and also to the holes where the side plates are fixated in order to mimic the structure of the original assembly. A force of 500 N was then applied to each one of the beams to simulate the workstation lying down. The stress and strain that occurs in the structure was then analyzed.

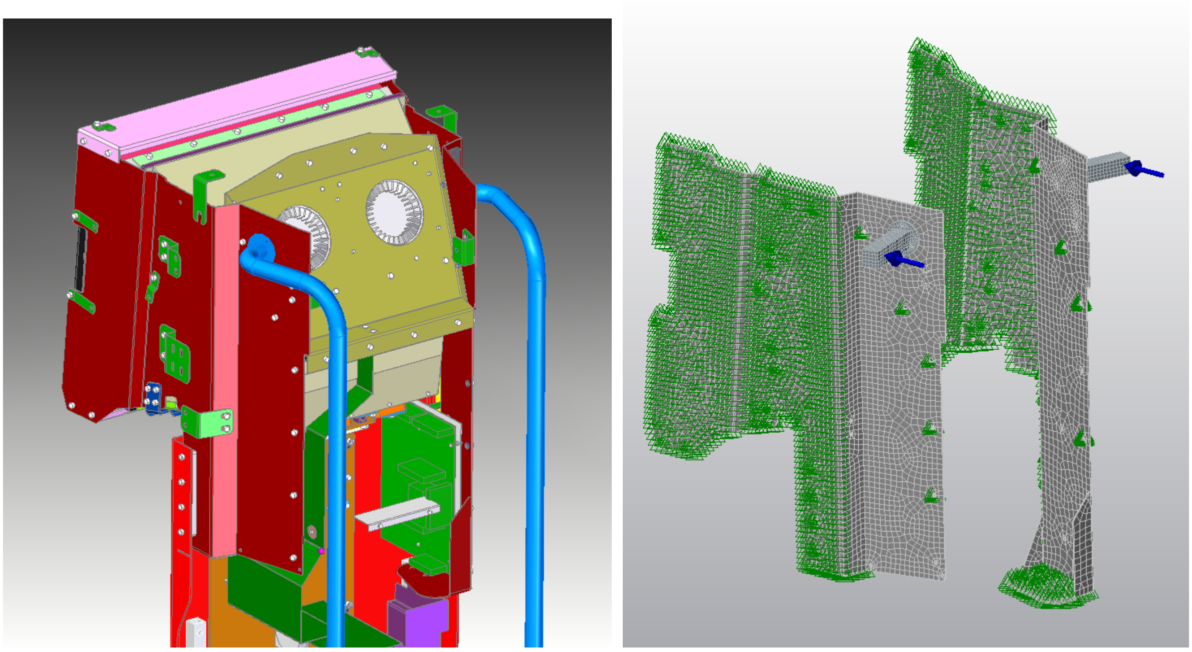

Figure 46. *Left: the workstation assembly with handles (blue) in the desired mounting position. Right: the simulation model with the right and left side plate and the 100mm beams. The blue arrows represent loads of 500 N each.*

According to the analysis, a stress of 309 MPa occurs in the side plate with the current simulation scenario, see *figure 47*. This would lead to permanent plastic deformation in the side plates. If handles are to be attached to the structure, the side plates therefore needed to be reinforced in some way.

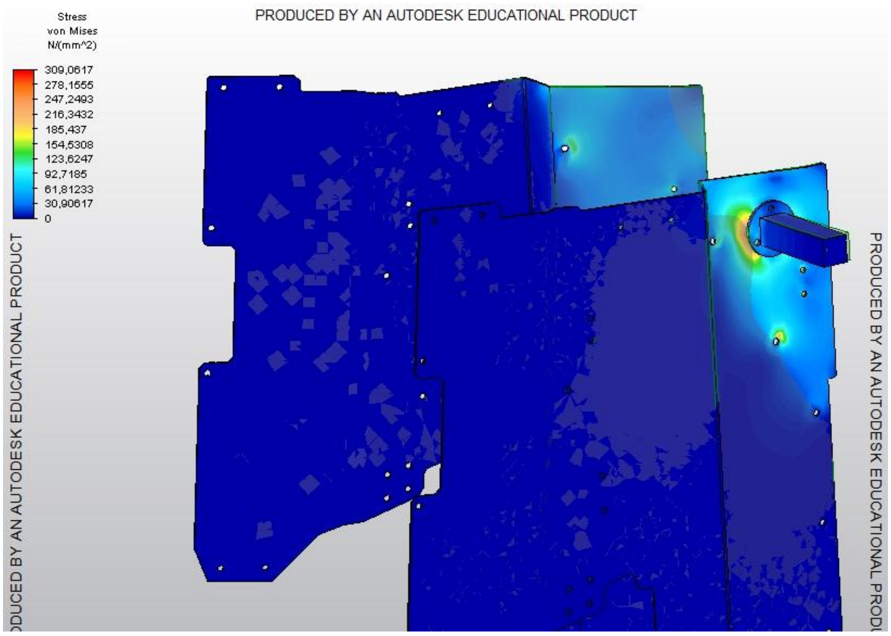

Figure 47. *The figure shows stress concentrations in the side plates that arise due to the 500 N of force that is applied to the handles. The stress is larger than the elastic limit of the material and would therefore lead to plastic deformation in the side plates.*

To avoid plastic deformation in the side plates, 3 mm reinforcement plates were added to the area where the handles are to be fastened. Also, since the old arm carrying the 2D screen in the Clariti workstation isn't used in the demo-workstation the stabilizing beam that runs over the top of the workstation is no longer needed. Instead a stabilizing beam can be added further back along the top edges of the side plates to stabilize the area around the mounting position of the handles. To investigate the effects that this would have on the stability of the structure around the handles a new simulation similar to the earlier ones was executed. The same forces (500 N) were used and the stabilizing cross beam and reinforcement plates were added to the simulation model, see *figure 48*.

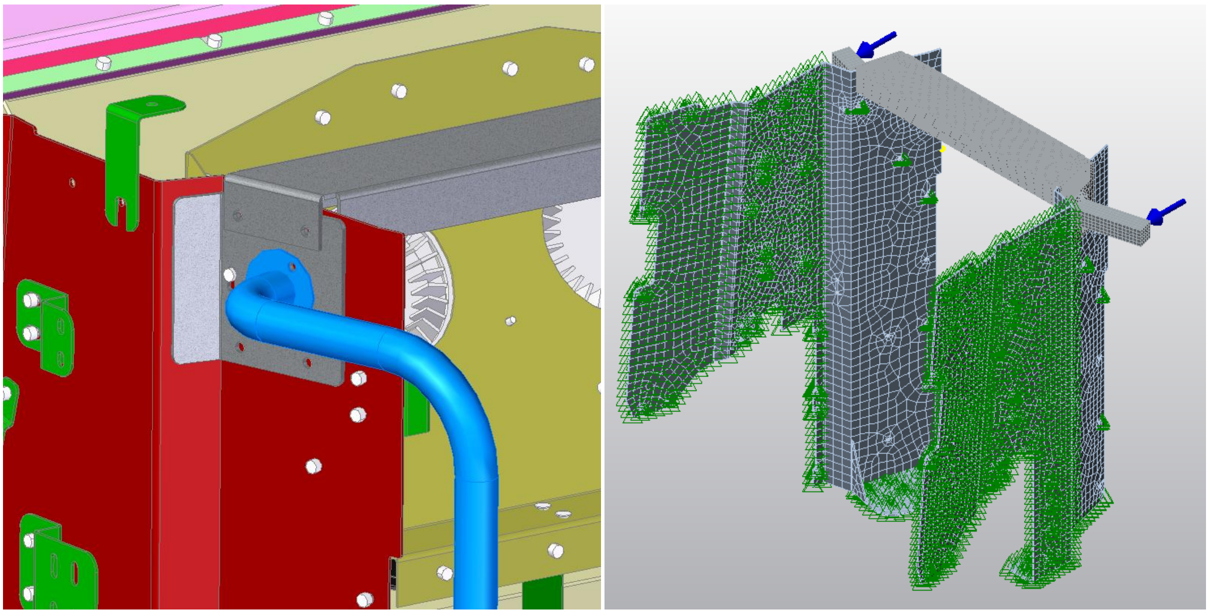

Figure 48. *Left: a stabilizing cross beam and two reinforcement plates were added to the assembly structure. Right: the simulation model with the new parts added. The forces in the simulation are still 500 N each and the constraints are located at the same places as the previous simulations.*

With the new parts the maximum stress value in the assembly structure now occurs in the bend of the cross beam, see *figure 49*. The stress value (86MPa) is low enough to not have to worry about plastic deformation (with the cross beam yield strength being 170MPa). By adding the cross beam, a lot of the stress is removed from the side plates and reinforcement plates and instead absorbed by the cross beam. This leads to a maximum stress value of about 42 MPa in the side and reinforcement plates (illustrated in *figure 50)* which can be considered to be a satisfactory value for preventing plastic deformation in the structure.

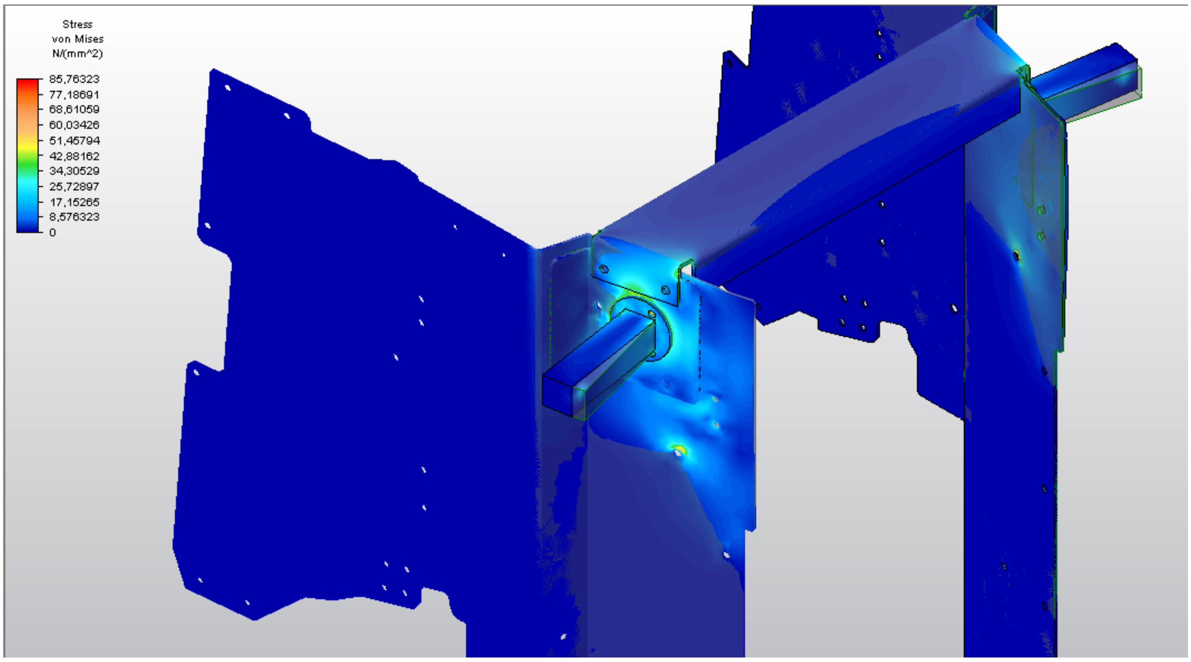

Figure 49. *Stress concentrations in the simulation model due to static loading. The maximum value is around 86 MPa and occurs in the bend of the cross beam.*

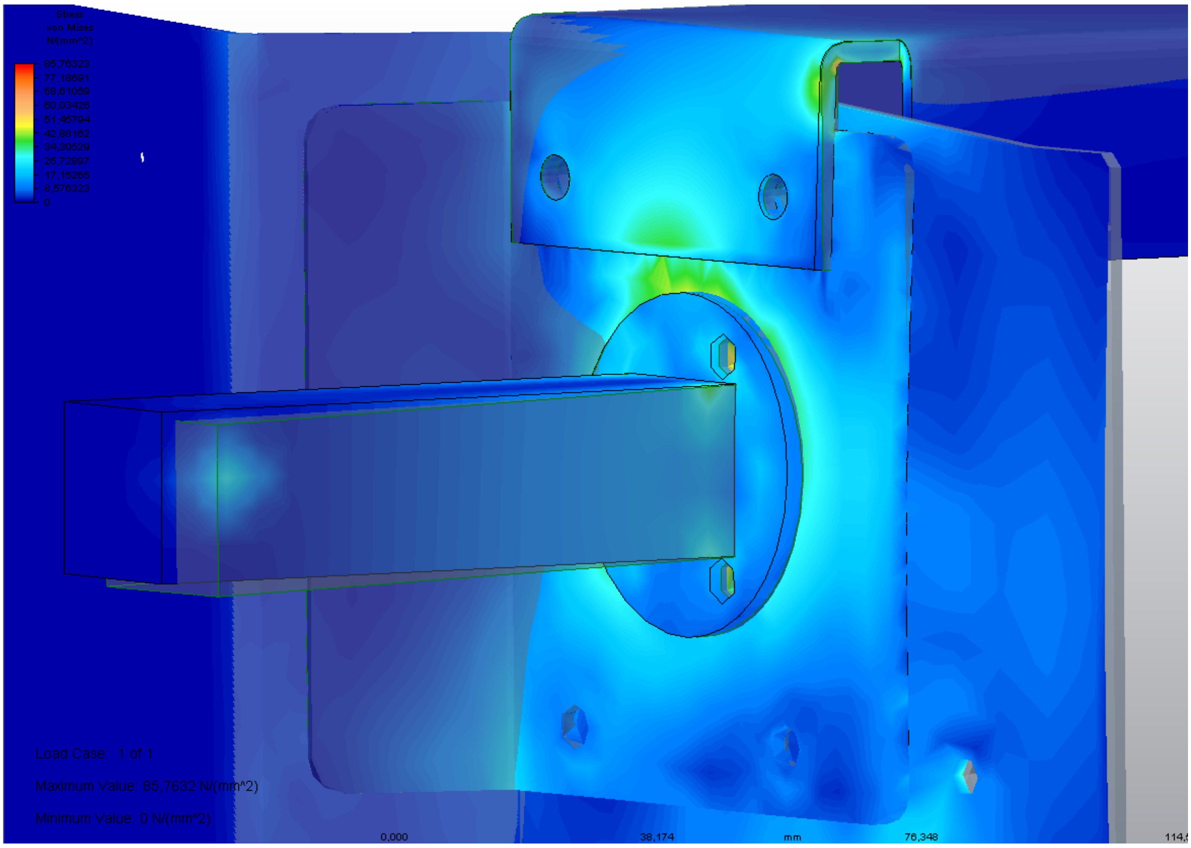

Figure 50. *The area around the handle's mounting position is affected with around 42 MPa of stress.*

5.1 The Demo Workstation

The final design of the demo-workstation is presented in this chapter. The workstation’s intended use is for demonstrating the 3D technology and medical imaging software that has been developed by Setred for use during surgery and surgery planning. Compared to the Clariti workstation, the new demo-workstation is far more mobile and easier to handle due to a large weight reduction and smaller outer dimensions. The design of the demo-workstation is adapted for quick disassembly of larger parts and the workstation can also be transported as a single unit with the weight of the workstation being supported by the aluminum base and the two large handles on the back of the structure. The demo-workstation is also a good base from which to create the planning workstation that is under development. A rendered image of the demo-workstation can be viewed in *figure 51*.

Figure 51. *The final design of the demo-workstation.*

The workstation consists of four larger modules: the aluminum frame base holding the PC, the 3D screen body and base plate, the mount for the 2D monitor and input devices and lastly the covers for the base. These four modules are built up of many smaller sub-systems and are assembled as shown in *figure 52.*

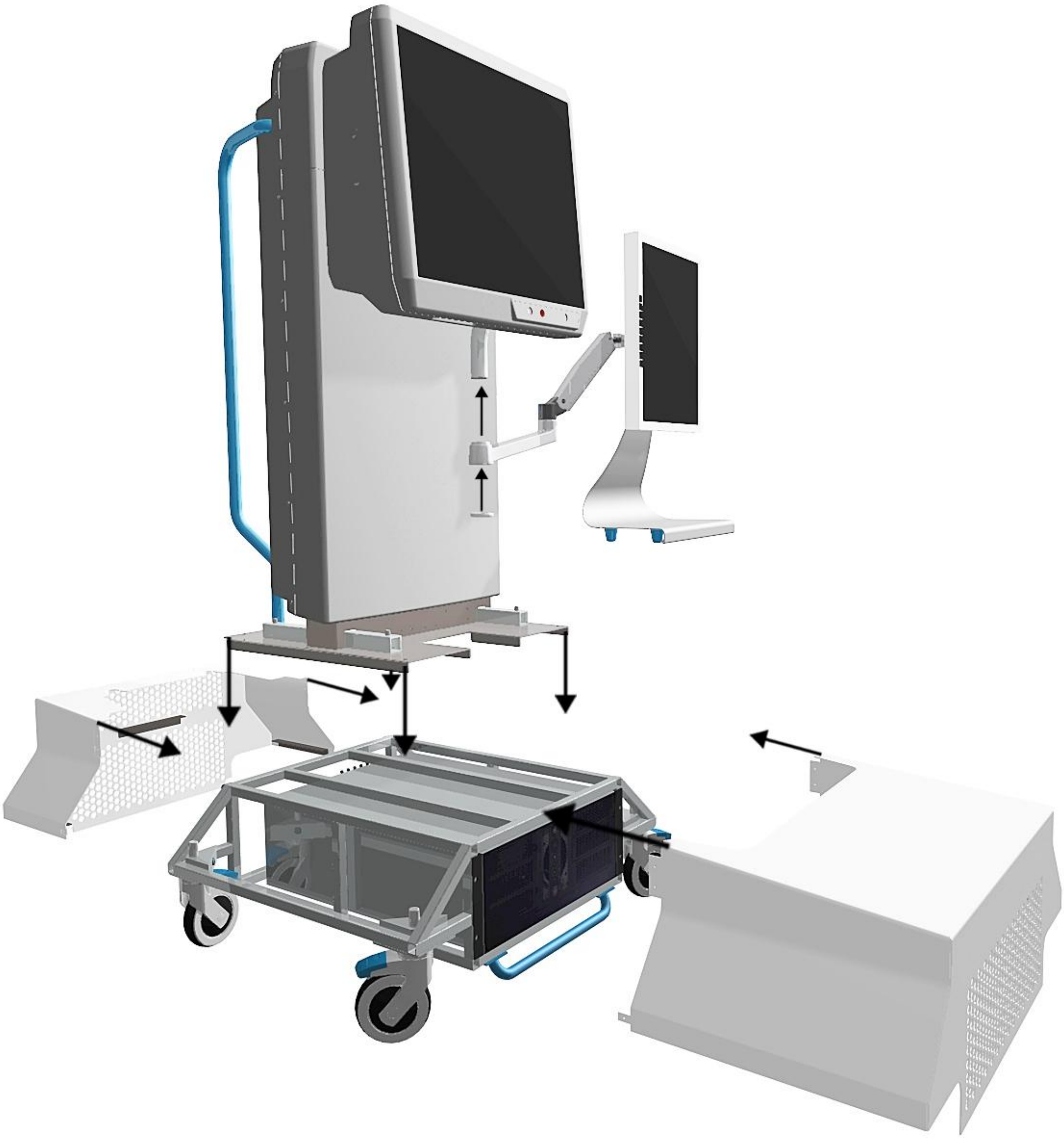

Figure 52. *The four main modules of the demo-workstation are the 3D screen body, the 2D screen and arm, the aluminum frame base and PC and lastly the base covers. The modules are assembled as shown in the figure.*

The demo-workstation uses essentially the same 3D core body and covers as the Clariti workstation with some minor alterations. Some major features from Clariti have been omitted in the design of the demo-workstation in order to achieve a more cost effective and mobile product. A major difference between the two products apart from the design of the base is that the screen height adjustment feature from the Clariti workstation is not present in the demo-workstation. The decision was made midway into the project that since the demo-workstation and planning station should be designed from the same platform; the height adjustment feature (which is not needed in the planning station) would only add unnecessary cost and complexity to the project.

The base structure has four lockable wheels with swivel castors that make it possible to push or drag the workstation in order to move it around. The base structure also houses a rack-mountable PC which is placed lying down inside the aluminum profile base underneath the 3D core body.

To increase the visual appeal of the base and protect the embedded components, covers were made. The covers feature ventilation holes for the PC's cooling fans, as well as the embedded electrical components of the 3D core body and have a similar visual appearance as the other casings covering the workstation.

The large handles on the back of the workstation are for use both when moving the workstation around by pushing it, and also for supporting the weight of the workstation when it is being transported lying down on its back.

The mount for the 2D monitor consists of a standard Ergotron LX Desk Mount LCD Arm (Ergotron, 2012). The LCD arm slides onto a small bent metal pipe where it can be secured in place. The metal pipe can be fastened both to the right and to the left of the 3D screen by securing it to the table mounts located underneath the 3D screen. This design gives the option to place the 2D monitor on either side of the workstation, rotate it 90 degrees backwards, rotate the screen 90 degrees vertically both ways and also adjust the height of the 2D monitor.

A list of the new components designed specifically for the demo-workstation can be viewed in *table 2*. In this list the components from the subassemblies of the 3D screen body and covers used from the Clariti workstation that haven't been modified have been excluded. The list is divided into three levels, with the main assembly as the first level, the different subassemblies as the second level and the single components as the third level. To the right the suggested material for each component is listed along with how the component can be manufactured and from which supplier.

Table 2. *Demo-workstation Parts List*

DEMO WORKSTATION PART INDEX

Assembly	Part No.	Part	Sub-part No.	Sub-part	Material	Manufacturing	Supplier
200000							
	200100	Aluminum Frame Base			Al 6063-T6	Welding	TBD
			200101	Aluminum Profile 650 mm 20 x 20 mm	Al 6063-T6	From Supplier	BE Group Sverige AB
			200102	Aluminum Profile 180 mm 20 x 20 mm	Al 6063-T6	From Supplier	BE Group Sverige AB
			200103	Aluminum Profile 140 mm 20 x 20 mm	Al 6063-T6	From Supplier	BE Group Sverige AB
			200104	Aluminum Profile Angled 184,39 mm 20 x 20 mm	Al 6063-T6	From Supplier	BE Group Sverige AB
			200105	Aluminum Profile 610 mm 20 x 20 mm	Al 6063-T6	From Supplier	BE Group Sverige AB
			200106	Aluminum Profile 448 mm 20 x 20 mm	Al 6063-T6	From Supplier	BE Group Sverige AB
			200107	Mounting Bracket for Castor Wheels	Aluminum	Milling	TBD
			200108	Plastic Profile End Cap	Polymer	From Supplier	TBD
	200201	Sheet Metal Base Plate			Stainless Steel EN 1.4301	Bending, Cutting	TBD
	200300	Plastic/Sheet Metal Base Casing					
			200301	Front Casing	Polymer or Sheet Metal	Bending, Cutting	TBD
			200302	Rear Casing	Polymer or Sheet Metal	Bending, Cutting	TBD
			200304	Front Casing Support Bracket 350 mm	Polymer or Sheet Metal	Bending, Cutting	TBD
			200305	Rear Casing Support Bracket 180 mm	Polymer or Sheet Metal	Bending, Cutting	TBD
			200306	Front Casing Side Support Bracket 350 mm	Polymer or Sheet Metal	Bending, Cutting	TBD
			200307	Rear Casing Side Support Bracket 200 mm	Polymer or Sheet Metal	Bending, Cutting	TBD
	200400	Aluminum Mounting Frame					
			200401	Aluminum Profile 380 mm 30 x 30 mm	Al 6063-T6	From Supplier	BE Group Sverige AB
			200402	Aluminum Profile 350 mm 30 x 30 mm	Al 6063-T6	From Supplier	BE Group Sverige AB
			200403	Aluminum Profile Angled 300 mm 30 x 30 mm	Al 6063-T6	From Supplier	BE Group Sverige AB
	200500	Sheet Metal Handle Mounting Structure					
			200501	Sheet Metal Base Plate Cross Beam	Stainless Steel EN 1.4301	Bending, Cutting	TBD
			200502	Sheet Metal Hanlde Mounting Plate	Stainless Steel EN 1.4301	Bending, Cutting	TBD
	200601	Pipe Handle Left			Aluminum or Steel	Bending, Cutting	TBD
	200602	Pipe Handle Right			Aluminum or Steel	Bending, Cutting	TBD
	200603	Rubber Gasket			Rubber	From Supplier	TBD
	200700	2D Monitor Arm and Mount					
			200701	Ergotron LX Desk Mount Arm	Misc.	From Supplier	Ergotron
			200701_1	First Arm			
			200701_2	Joint Between First and Second Arm			
			200701_3	Second Arm			
			200701_4	Joint Between Second and Third Arm			
			200701_5	Third Arm			
			200701_6	Joint Between Third Arm and LCD Bracket			
			200701_7	LCD Bracket			
			200701_8	Mounting Ring			
			200702	Pipe for Mounting Ergotron LX Desk Mount Arm	Aluminum or Steel	Bending, Cutting	TBD
			200703	Aluminum Pipe Insert	Aluminum	Milling	TBD
			200704	Pipe End Cap	Polymer	From Supplier	TBD
	200800	Sheet Metal Monitor Stand					
			200801	Sheet Metal Sweep and Mounting Bracket	Sheet Metal	Bending, Cutting	TBD
			200802	Rubber Feet	Rubber	From Supplier	TBD
			200803	Hexagon M6 Bolt	Standard Part	From Supplier	TBD
	200900	Chenbro RM41300G			Misc.	From Supplier	Chenbro
			200901	Chenbro RM41300G PC			
			200902	Chenbro RM41300G Left Mounting Bracket			
			200903	Chenbro RM41300G Right Mounting Bracket			
	201001	Pipe Front Handle			Aluminum or Steel	Bending, Cutting	TBD
	201101	Mesh for Cable Protection			Aluminum or Steel	Cutting	TBD
	201200	Tente Castor Wheels 5377PJP125R05			Misc.	From Supplier	Tente International
			201201	Hub			
			201202	Wheel			
			201203	Brake			
	201300	Fasteners			Standard Part	From Supplier	TBD
			201301	Clinch Nut M8			
			201302	Bolt M8 35 mm			
			201303	Clinch Nut M6			
			201304	Bolt M6 12 mm			
			201305	Bolt M8 40,6 mm			
			201306	Bolt M6 16 mm			
			201307	Bolt M4			
			201308	Washer_ISO_7090_2000_12			
			201309	Bolt_ISO_4014_1999_M10x45			
			201310	Nut_ISO_4032_1999_WF_M10			

Reused Assemblies and Parts From the Clariti Workstation

Part No.	Part
1001385	3D Screen Core Assembly
1002392	Cover Assembly
1001399	2D Display

Modified Parts

Part No.	Part	Modification
1002350	Cover Pillar Back	Added cutouts for pipe handles, 200601 and 200602
1002348	Cover Neck Bottom	Added cutouts for 2D monitor cables
1002430	Front structure	Added cutouts and holes for aluminum mounting frame, 200400
1003204	Structure plate right	Added holes for pipe handle, 200601
1003208	Structure plate left	Added holes for pipe handle, 200602

5.2 Transporting the Demo-workstation

For transportation, the demo-workstation offers several options which are more or less suitable depending on the situation. For long distance transportation the most preferable alternative would be separating the workstation into the smaller modules and securing them to a covered pallet. When transporting the workstation from the office to a demonstration or the other way around there are several approaches. If a lone person were to transport the workstation one alternative would be separating it into the smaller modules as seen in *figure 53*. These modules could then be carried and packed separately into the car.

Figure 53. *The assembly of the demo-workstation can be divided into total of five smaller modules to facilitate transportation.*

The quickest and easiest way to transport the demo-workstation would be keeping it fully assembled (only detaching the 2D monitor and arm) and rolling it to and from the vehicle. This method may require two persons to carry the workstation over larger obstacles like for example up and down stairs. One person would then grab the handles on the back of the workstation and one the handle or aluminum frame on the base as illustrated in *figure 54*.

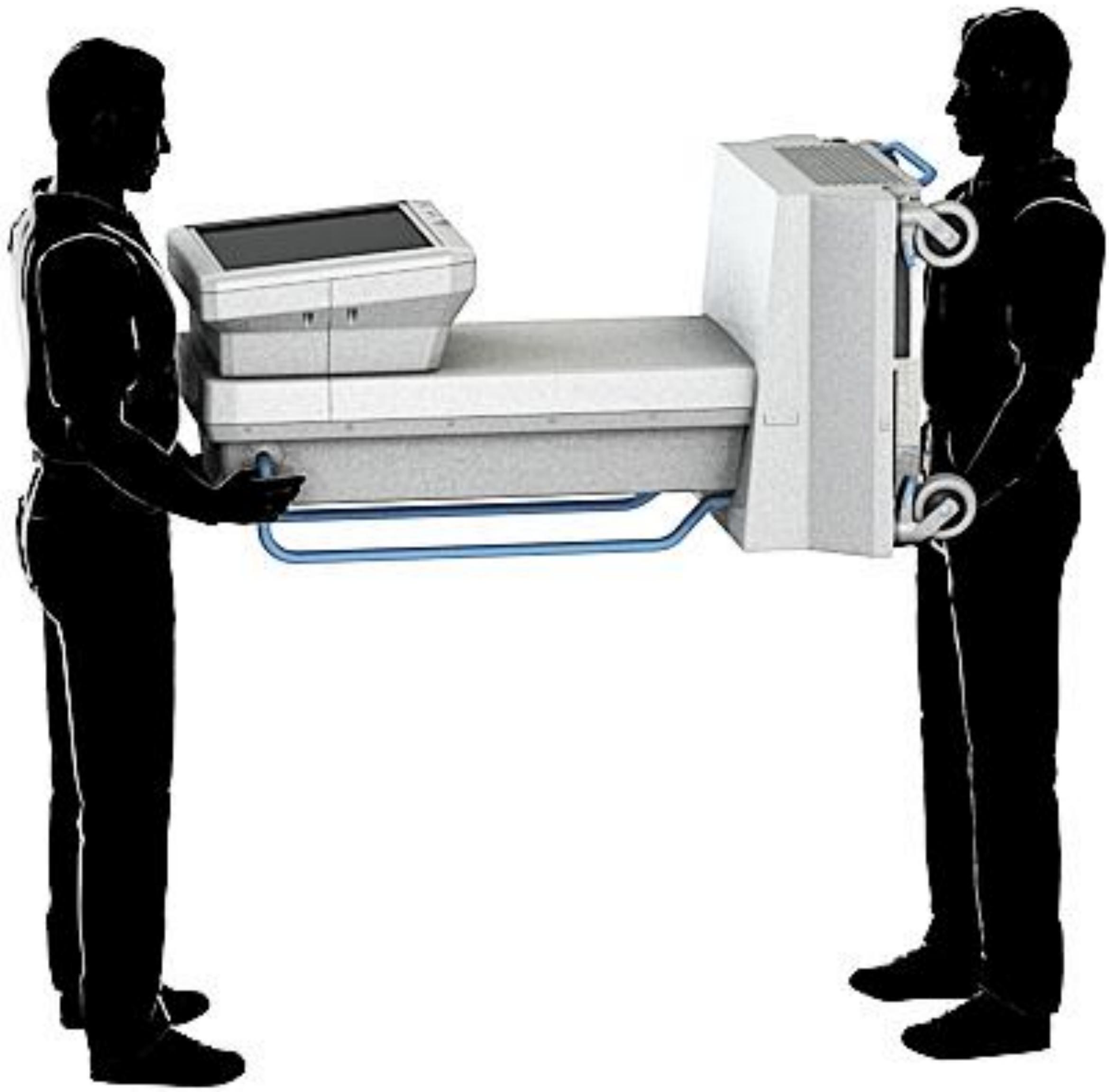

Figure 54. *If the workstation needs to be carried over obstacles like curbs or stairs it can be lifted by two persons, with one person grabbing the handles behind the 3D screen and the other person holding on to the handle on the front of the aluminum frame base, or underneath the base itself.*

In order to load the workstation into the car, one would position the workstation roughly 50 cm offset the cars storage compartment. The brakes on the wheels would then be secured and the workstation tilted into the car, resting on its two vertical handles. The person loading the workstation would then grab the handle at the front of the aluminum frame, lifting the workstation and pushing it into the back of the storage compartment where it could be secured for example by tying ropes around the handles and castor wheels, see *figure 55*.

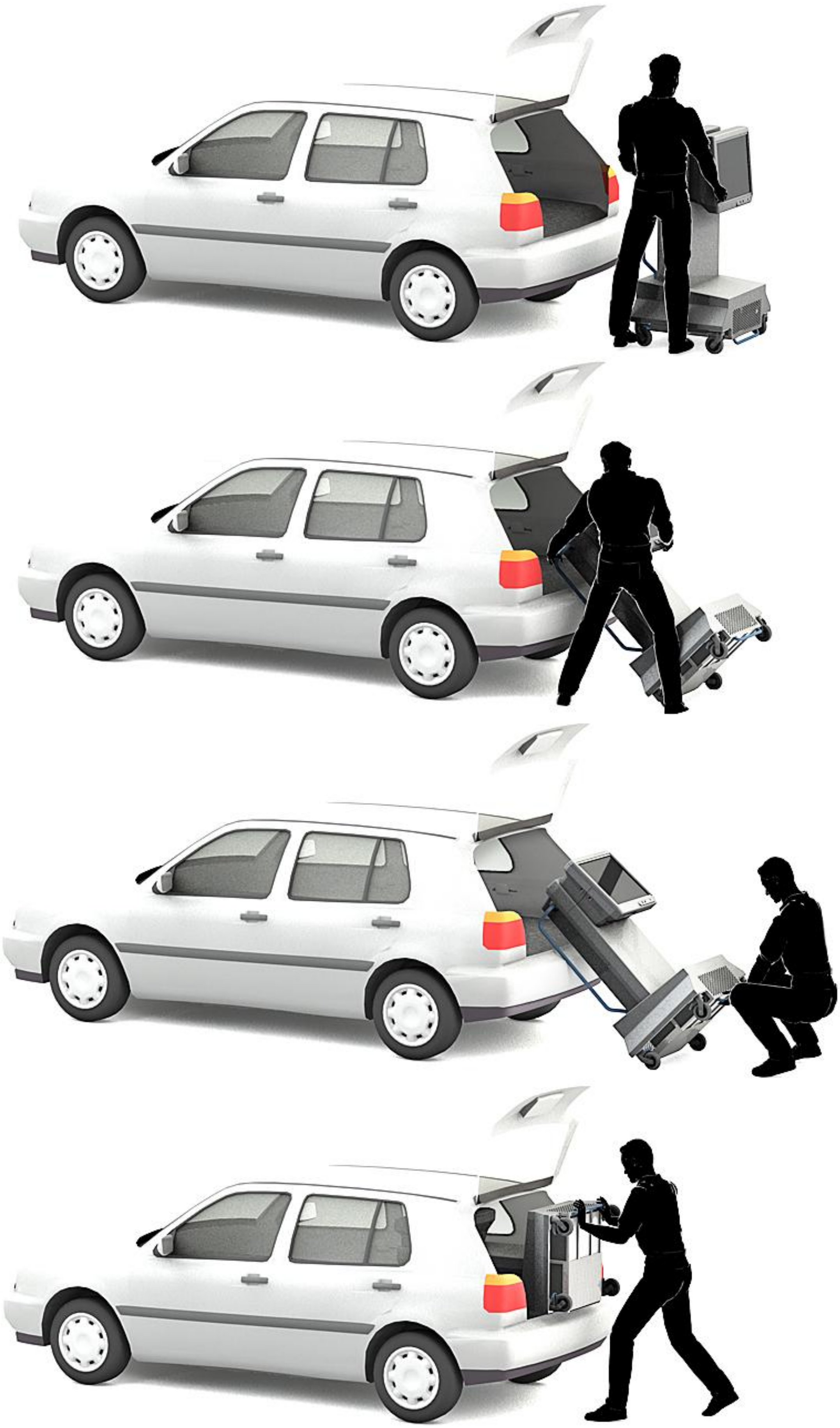

Figure 55. *The loading process for transporting the demo-workstation as an assembled unit (with only the 2D arm removed).*

The design of the demo-workstation enables it to be transported in a few different ways. Compared to Clariti, it is much easier to handle with an estimated weight reduction of around 40 kg (from ~160 kg down to 117 kg for the full assembly including the PC and 2D monitor), and a form factor that allows the workstation to be transported without the need for extensive disassembly. The workstation fits in the storage compartment of a normal hatchback car (VW Passat was used as reference) by tipping it backwards into the car and letting the vertical handles on the back of the workstation and the exposed end caps on the aluminum frame base support the weight. This can save a lot of time when traveling to different potential customers for demonstration of the workstation, and also prevent wear on many components like the cable connectors from frequent assembly and disassembly.

In order to keep production costs low, some components in the demo-workstation had to be redesigned to fit the desired manufacturing method. An example of this is the covers for the aluminum frame base. The original idea was to produce covers that could be molded in order to mimic the aesthetics of the 3D screen covers so the workstation as a whole would have a uniform appearance. Since producing a mold for a small series of products can be quite costly, the covers had to be redesigned to be produced by 2D cutting and shaping. This led to sharper edges and visible seams in the corners of the covers and a contrast between the smooth rounded edges of the 3D screen covers and the sharp edges of the base covers (see *figure 56).* If the planning station that is under development is to be produced in larger series, and is intended to have the same base covers as the demo-workstation, an investment in molding tools for the base covers should be strongly considered. This would greatly improve the design of the workstation.

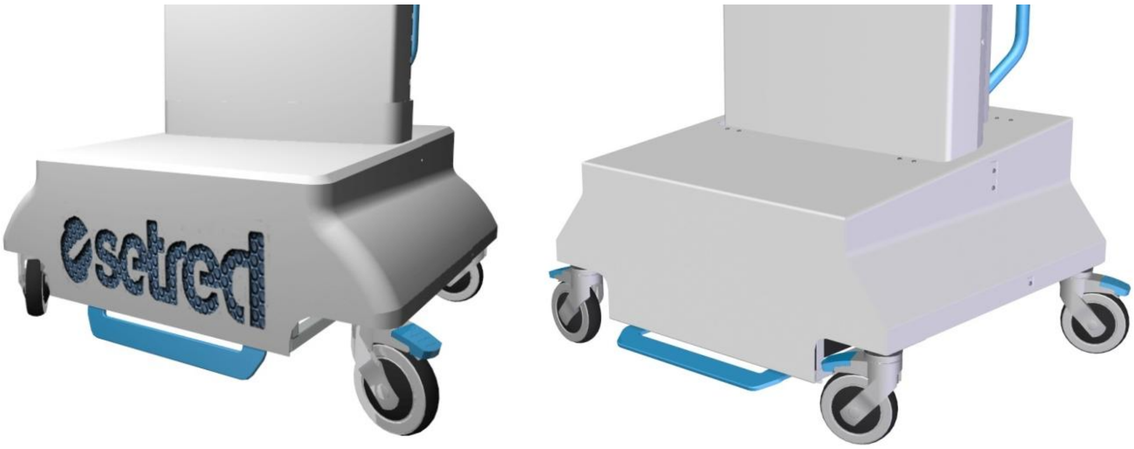

Figure 56. *The left image shows a design concept for molded base covers. The image to the right shows the covers designed for 2D cutting and bending manufacture.*

After a comparison between the final design of the demo-workstation and the design requirements that were determined in the concept development phase of the project, the conclusion can be made that the new workstation theoretically meets all the “must have demands”. Some of these requirements are however hard to evaluate based on the virtual prototype and would require a physical prototype to be built and tested. An example of this type of requirement is whether a single person could without extensive effort be able to lift and pack the various parts of the workstation. Furthermore, the workstation has been estimated to meet most of the “should have” and “nice to have” requirements. Naturally some of these lower level requirements had to be discarded due to restrictions or unreasonable costs for the project. Some lower level demands were also discarded during the design process (like the height setting feature) due to decisions made between the design team and the Setred staff.

To ensure a good fit between the designed components of the demo-workstation, a few minor design changes may be necessary before parts are manufactured. The manufacturers of the different parts may have professional opinions on the design of certain components that might be helpful in determining the final dimensions and tolerances for the different parts. The manufacturers of the different components should therefore be consulted before manufacturing orders for the parts are placed.

Further weight reduction of both Clariti and the demo-workstation is possible both by a change in material and by component redesign. This would however require new simulations to investigate changes in stability and strength in the structures. The cost of such a design change must also be considered to determine whether such a design change can be motivated. A large weight saving change that can be made in the assemblies without part redesign is to change material in the large sheet metal components of the workstations. A change from stainless steel to aluminum could reduce the total weight of these parts down to 1/3 of the current weight. The costs and consequences of this material change must however be considered first. A larger possible weight reducing design change could be to investigate the possibility of constructing the 3D screen body in a similar way as the aluminum frame base of the demo-workstation, as a welded frame structure of aluminum (or steel) profiles. This would however be quite time consuming and would require a lot of design work to be performed.

Looking at the 3D screen core assembly, there are few improvements to the core structure that should be considered. For example, the stress concentrations in the fixture for the optical assembly should be investigated and design changes should be made in order to reduce the stress concentrations in the front plate. Due to a limited time frame to complete the project, these improvements were not looked at further.

For evaluation purposes, virtual prototypes have been used throughout the project. They have generated data considering part fit, dimensions and appearance and these attributes shouldn't differ much in a physical prototype. However, when it comes to stability and stress simulations on the virtual prototype, certain generalizations and simplifications had to be made, which adds a risk of the resulted data being unreliable or inaccurate. Mechanical simulations in general have an accuracy span of about plus/minus 15%. Therefore, a high level of safety was added in order to compensate for eventual differences between simulations and physical prototype testing.

When it comes to evaluating the user experience of the demo-workstation (for example: "how much effort is required to lift and pack the workstation" or "how much time is saved by the added features"), the performance of the virtual prototypes can only be roughly estimated by discussion and comparison between previous models, such as Clariti and the MD-20 workstations. If a prototype of the demo-workstation is manufactured, usability tests investigating lifting ergonomics and overall product performance should be conducted.

Due to the uncertainties in the mechanical simulations and virtual prototype it is recommended that a physical prototype of the demo-workstation is made and evaluated further before defining the final design.

Another thing that remains to be determined is what the common features and differences between the demo-workstation and planning workstation should be. Since the demo-workstation is to be used for promoting both the Clariti and the lower priced planning workstation, the demo-workstation must possess features that can demonstrate the functionality of both these units. A comparison between the possible features of the three workstations is made in *table 3* below.

Table 3. *Comparison of features for the 3 workstations.*

Feature\Workstation	**Clariti**	**Demo-workstation**	**Planning Station**
Certified for OR	Yes	No	No
Navigation tools	Yes	Yes	No
2D arm	Yes	Yes (smaller arm)	No (optional)
Table for keyboard	Yes	Yes	No (optional)
Height adjustable	Yes	No	No
Advanced software	Yes	Yes	No
Adapted for transport	No	Yes	No

In conclusion, some minor design changes and usability testing on a prototype may be required before the demo-workstation can be fully evaluated. However, with the specified design of the demo-workstation, the design team estimates that the transportation and handling of the device is greatly improved in comparison with the Clariti workstation.

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Software

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Solid Edge ST4 is a registered trademark of Siemens, Wittelsbacherplatz 2, 80333 Munich, Germany.

Appendix 1. Project Plan

Project description

The project goal is to design a demo version of the autostereoscopic 3D display *Clariti* that the sales and marketing team at Setred can use for sales meetings, conferences, fairs and trade shows. The current version of the workstation is large and heavy and not very suited for easy transportation. The demo version should have a design that fits well together with the current appearance of the *Clariti* workstation, and should be designed for easy assembly/disassembly and ergonomic transportation.

The project will be divided into a number of phases such as information gathering, understanding the product, usability studies, human factors engineering, industrial design and mechanical design. A lot of weight in the project will be put on usability studies and ergonomic design in order to develop a product that is easy to use and understand.

A key to the success of the project is end user involvement in many of the steps in the design process. The project group will therefore involve the Setred staff throughout the project, especially the sales and marketing team who will have a major role in determining the final design of the demo-workstation.

The results of the project will be presented in a written report at the end of the project together with prototypes of the finalized design of the new demo-workstation.

Participants: Alexander Flodin, alexanderflodin@gmail.com
Johan Olsson, johaol@kth.se
University: Royal Institute of Technology, Stockholm
Timeframe: 2012-01-16 to 2012-06-01
Number of weeks: 20
Supervisor at KTH: Carl Michael Johannesson, cmj@kth.se
Supervisor at Setred: Martin Wahlstedt, martin.wahlstedt@setred.com

Project Plan

Phase 1. Research and information gathering (6 weeks)

The first phase of the project will consist of research and information gathering to begin with. Interviews with the Setred staff will be conducted and necessary information on Clariti and how it works will be obtained. Usability studies will also be conducted at this stage in the project. With the results of the interviews and usability studies as a foundation, a few different concepts for a demo version will be developed. The concepts will be presented as sketches, renderings and simple prototypes at the end of the first phase of the project and will be evaluated together with the Setred staff. Listed below are the different steps of the project's first phase.

Research and information gathering

- Investigate similar projects
- Interviews with employees
- Understanding Clariti
- User studies
- Ergonomic studies
- Human factors engineering

Concept development
- Sketches
- Renderings
- Simple prototypes
- Rough data on specifications
- Cost and manufacture estimates
- Evaluation and selection of concepts
- Identify steps for transportation

Phase 2. Design and manufacture (10 weeks)

During the second phase, the concepts and ideas generated and selected in phase one, will be implemented into the final design of the demo-workstation. A document containing the design requirements will be produced and the workstation will be designed as a 3D CAD model in which part fittings, movement and loads can be evaluated. The 3D CAD model will also be used for creating photo-realistic renderings of the design to evaluate its appearance before a prototype is produced.

A prototype of the demo-workstation will be created for trials and testing. This prototype might also be used as a basis for further development and/or serve as a next-generation version of the current product. The steps for the second phase of the project are listed below.

Design
- Identify design requirements
- Detailed design in CAD model
- Search for suitable standard components
- Weight optimization

Manufacturing and material studies
- Determine suitable material
- Determine suitable manufacturing methods
- Search for suitable suppliers and manufacturers
- Cost estimates on material and manufacture

Testing
- Stress and strain simulations from CAD model
- Transportation tests of prototype
- User evaluation of design and function

Prototyping
- Determine suitable prototyping method
- Manufacture prototype

Evaluation
- Evaluation of design
- Evaluation of prototype
- Identifying areas of further development

Phase 3. Documentation (4 weeks)

The final phase of the project will consist of summarizing all documentation and further document all aspects of the work that has been done. This will result in a technical master thesis report which will be printed and made available to interested parties.

- Write and edit technical report
- Submit for print

Additional aspects & tasks (if there is time):

If there is time for further work within the project time-frame some additional tasks that can be executed within the project are listed below.

- Investigate whether Clariti can be wall/ceiling mounted
- Can the demo version be the next generation of Clariti
- Design of flight/transport cases for Clariti and/or the new demo version.

Risk analysis

The main risk in the project is the time limitation. To fully design and manufacture a product within the time limit of 20 weeks will be a large challenge. The manufacture of the final prototype will not start until the final design of the demo-workstation is complete. In the event that the time dedicated for the project is not sufficient to manufacture a prototype, the project will focus on finalizing the CAD design and producing 2D-drawings so that the prototype can be manufactured outside of the project time-frame.

A second risk of the project will be to successfully fulfill all the desired functionality of the demo version. It is often a large challenge to design a product that meets all the desired functions of a design concept. Usually some compromises will have to be made during the design process in order to find a suitable and cost efficient solution for the problem at hand.

Since the demo version of the workstation will be used as a marketing tool and may be the first contact between the product and the end user, one can’t ignore the importance of the products aesthetic appearance. Some sacrifices in the functionality of the demo version may therefore be necessary to ensure that the product will attract and appeal to the customer.

Appendix 2. Semi-structured Interview Script

1 . Describe, step by step, how you go about transporting the current workstation from point A (the office) to point B (the potential customer).
packing/unpacking
loading/unloading
vehicle
tools required
restrictions

2. How much time does packing/unpacking and loading/unloading of the workstation take?
how much time does each individual step take?
what is most time consuming?

3. What do you consider to be the biggest problems in transporting the current workstation?
Weight
Size
Assembly/Disassembly
Handles

4. What improvements or alterations would you like to implement in the demo-workstation?
appearance
functions
mobility
adjustment
setup

5. Do you think the current workstation lacks any functionality, and if so, what?
adjustments
mobility

6. What features do you like about the current design of the Clariti workstation?
appearance
functionality

7. Describe how a typical demonstration of the workstation is performed
surroundings
position
amount of people involved

8. Describe the people that the workstation is usually demonstrated to
Profession
Male/female
Age

9. What features of the demo-workstation do you think are most important?
mobility
appearance
adjustable
storage

10. Describe what you think the end-users expectations on the workstation are.
what features do they think are most important?
what functionality do they require?

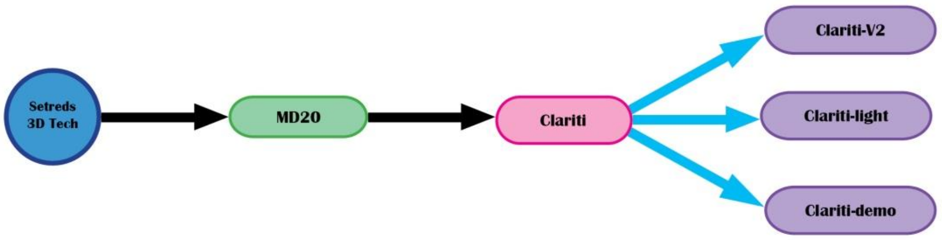
11. How do you think the aesthetic look of the demo-workstation should be?
shapes
colors
similarity/differences compared to Clariti

12. What markets do you think Clariti will target in the near future?
Medical
Gaming
Engineering
Architecture
Home users

13. What effects do you think the future markets will have on the design of the workstation?

Summary of information gathered from interviews with staff members

Main question for the research phase:
What is the goal of the demo-version/prototype?



Problems and problematic situations encountered while demoing MD-20 or Clariti

- Transporting workstation up and down curbs due to the weight
- Transporting workstation up and down stairs due to the weight
- Rolling workstation on gravel, dirt and uneven roads
- Wheels sometimes get stuck/damaged (like shopping cart wheels)
- Fitting the workstation in the car. Especially Clariti
- Securing the workstation during transport
- No place to put the keyboard and mouse (and 2Dscreen) while demoing in the OR
- Vibrations when rolling the workstation on uneven ground
- Vibrations when transporting the workstation in car
- Workstation moves around when being transported
- Risk of damaging the workstation when tipping it into the car
- Risk of dropping the workstation while lifting it
- DVI cables sometimes get damaged
- The arm for the 2D-screen (Clariti) moves around and is in the way during loading and transportation.
- Sharp edges on Clariti workstation support structure when transporting without casing. Edges get stuck while loading workstation into car.
- Limited space when demoing in OR and hospital corridors
- You often need at least 2 people to lift the Clariti workstation up and down stairs, into the car …etc.
- The Clariti outer casing must be removed before it is transported

Improvements mechanical construction

- Lower weight, weight optimization
- Take less space, smaller loading size
- Size of base must be made smaller to fit in hatchback car
- Lower transportation height (either by tipping or by mechanical construction or separation into modules)
- Modular based construction that enables separation for easier transport. Preferably pieces of no more than 40 kg / piece, possible transportation in flightcases.More rigid casing
- Bottom plate used to isolate from leaking current can be removed or made smaller.

- Larger space margins for electrical and mechanical components inside the chassis.
- Supporting structure that is made to be transported lying down

Improvements in functionality

- Easier transport over curbs and up stairs
- Easier loading and unloading into car
- Easier transportation over rough terrain
- Less risk of damaging workstation when loading it into the car (when tipping it over)
- One person should alone be able to load and unload the demo-workstation from the car and transport it to the location of the sales meeting, preferably in one trip.
- Service of the workstation should be easy and accessible
- Handles or shapes on structure that facilitate lifting
- Flexibility (should be possible to set up easily both in a viewing room and in the OR)
- Mobility (should be able to move all equipment easily, preferably in one trip)
- Better wheels (bigger with more suspension), air-filled wheels
- Attachable/Detachable Table for keyboard and mouse (and navigation),option to put table in front or beside 3D-screen depending on the situation.
- Mounts to hang the 2D screen beside the 3D screen (if the arm is removed).
- Loops or handles for securing the workstation in place while being transported so it doesn't move around.
- Compartment for keyboard and mouse in PC case or bag for 2D-screen
- Mechanical height setting instead of electrical automatic, maybe two height settings one for standing/one for sitting or many different height settings
- locking mechanism for the 2D screen arm while being transported
- Easy to clean
- Casing that is easily attached and detached, snapfits or some kind of fast locking
- When transporting the equipment in the car it needs to be packed to withstand vibrations.
- One brake that controls all wheels instead of one brake on every wheel
- 2D monitor fixed instead of being mounted on an arm

Appearance

- Similar appearance as Clariti/ as close as possible
- Same aesthetic design but more mobile
- Designed focused on med-tech
- A more branded design with colors, shapes and/or logos
- Should look like a finished product

Improvements of Clariti

- Protection of DVI cables so they don't get worn out
- Close the gap around the edges of the 2D screen.
- More rigid casing
- Small fixes like screws that fall out
- A nicer looking solution for the keyboard and mouse tray
- The arm for the 2D screen can be made more mobile/adjustable/removable
- Mounts or storage for accessories like keyboard and mouse, (kinect camera, gyro-mouse)

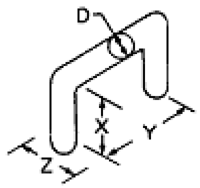
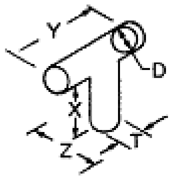
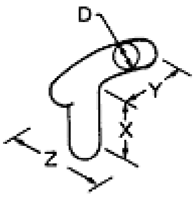
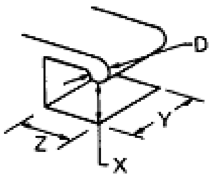
Ideas

- The focus of the demo version should be on showing the 3D technique and the navigation system. Settings and adjustments can be shown in brochures and videos. A small box with wheels can perhaps be used for support under the top of the workstation during transport, and may also facilitate the loading process.
- Casing can be fastened with snapfits or wing-nuts instead of screws

- A modular design consisting of an aluminum base, on which the PC and 3D screen easily can be mounted and dismounted on.
- Some functionality can be sacrificed in order to promote a mobile demo-version. If clients are interested in seeing the real product a new meeting can be booked where Clarity is demonstrated
- It is important that the nurses find the workstation easy to clean otherwise it will not be used in an operating room.

Things that must be transported when demoing

- Navigation equipment, with cables and customizable tripod plus 2m electrical cable for the navigation system. The navigation equipment must be able to be raised 2-2,5m above the ground for a clear sight of view.
- 2D Screen
- Workstation
- PC
- DVI Cables
- Power Cables and extension cords
- Extension cords
- Keyboard and mouse (+ gyro mouse?)
- Skull and tool accessories
- Brochures

Illustration	Type of Handle	Dimensions in mm (in inches) (Bare Hand) X	Y	Z
	Two-finger bar	32 (1-1/4)	65 (2-1/2)	75 (3)
	One-hand bar	48 (1-7/8)	111 (4-3/8)	75 (3)
	Two-hand bar	48 (1-7/8)	215 (8-1/2)	75 (3)
	T-bar	38 (1-1/2)	100 (4)	75 (3)
	J-bar	50 (2)	100 (4)	75 (3)
	Two-finger recess	32 (1-1/4)	65 (2-1/2)	75 (3)
	One-hand recess	50 (2)	110 (4-1/4)	90 (3-1/2)
	Finger-tip recess	19 (3/4)	-	13 (1/2)
	One-finger recess	32 (1-1/4)	-	50 (2)

Curvature of handle or edge (DOES NOT PRECLUDE USE OF OVAL HANDLES)	**Weight of item:**	**Minimum diameter**	
	Up to 6.8 kg (up to 15 lbs)	D = 6 mm (1/4 in)	Gripping efficiency is best if finger can curl around handle or edge to any angle of 2/3 π rad (120°) or more
	6.8 to 9.0 kg (15 to 20 lbs)	D = 13 mm (1/2 in)	
	9.0 to 18 kg (20 to 40 lbs)	D = 19 mm (3/4 in)	
	Over 18 kg (Over 40 lbs)	D = 25 mm (1 in)	
	T-bar post	T = 13 mm (1/2 in)	

Design Requirements Demo Clariti
Last change 120323

Must Have:

- The workstation should have a modular based construction that enables separation into pieces of no more than 70 kg / piece (MD-20 weight without pc)
- The outer dimensions of the workstation base should be no larger than 65 cm x 75 cm (same as MD-20?)
- The workstation should have a height of 118 cm measured from the ground to the centre of the 3D screen.
- One person should without extensive effort be able to lift and pack the various parts of the workstation into a car
- The workstation must have (large) wheels to enable rolling on uneven surfaces (fixed or detachable)
- The wheels of the workstation must be lockable (individual wheel locking)
- The workstation must be able to be transported lying down on its back
- The workstation must be easy to slide into the car
- The 3D-screen must not be placed so that it extends outside the projected area of the base of the workstation seen from a top perspective. This to avoid direct impact on the 3D screen when rolling the workstation.
- The workstation, PC, keyboard, mouse and 2D screen must be able to be transported as a single unit retaining the outer dimensions of the base (when being transported)
- One single power cord for the whole workstation
- The 3D screen should have a size the same as the current platform (Clariti)
- The 2D screen should be attachable to one side of the 3D screen and rotate at least 90 degrees
- The 2D screen should be detachable and able to stand on its own

Should Have

- The 2D screen should be attachable to both sides of the 3D screen and rotate at least 90 degrees
- The workstation should be able to be transported lying down on its back without having to remove the casing.
- The 2D monitor must be able to be transported separately from the workstation
- The workstation should have an attachable/detachable table for holding the keyboard under the 2D screen at a height of 118 cm while standing and 83cm while sitting
- The workstation should have handles that enable ergonomic (according to AFS 1998:1) lifting, pushing, dragging and tilting with 2 hands.
- One person should without extensive effort be able to lift the workstation up and down a normal sized flight of stairs (approximately 20 steps).
- The workstation should have geometry such as loops and/or handles that enables it to be secured during transport.
- The workstation should have wheels that offer some suspension during rolling on rough surfaces
- All outer edges and corners exposed to the user should have a radius of at least 2 mm
- The demo-workstation should have a total weight of less than 70 kg without the 2D screen

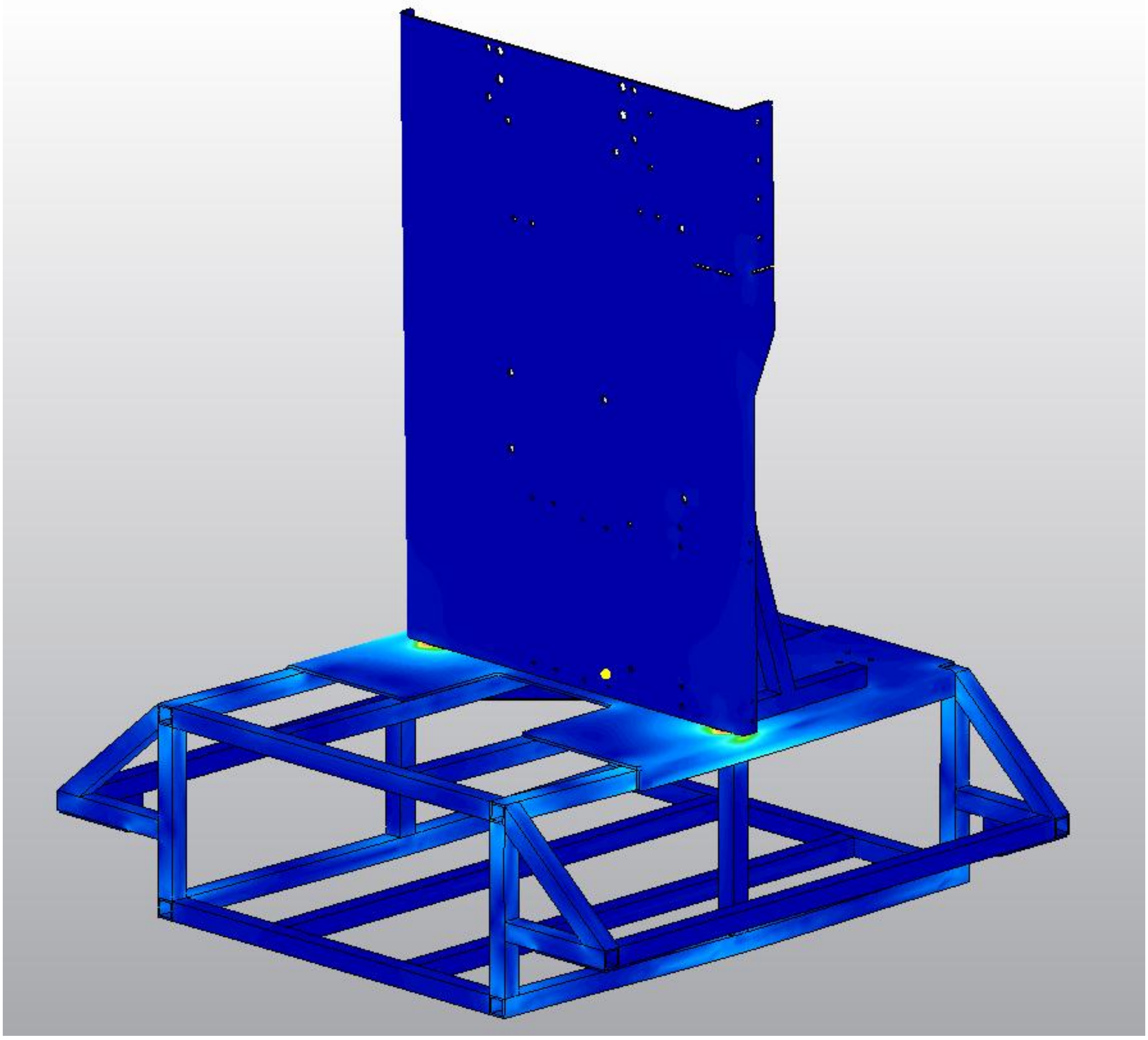
- The casing of the workstation should be protected from scratches during loading and transportation
- The workstation should have a flight-case for long distance transportation (by cargo), where all components can fit.

Nice To Have

- The workstation should be able to be transported without removing the PC and cables
- The workstation should have no exposed fasteners for an easier to clean product
- The spacing between components should be equal to or greater than 2 mm
- The workstation should be able to be set up in step-less height setting (between 70cm to 190cm)
- The wheels on the workstation should be covered to prevent dirt from entering and to give a more medical appearance
- Storage compartment for cables when not connected to PC
- The casing should be fastened with snap fits, wing nuts or quick release fasteners
- The workstation should be able to be set up in two different heights (standing position 158 cm from ground and sitting position 118 cm from ground measured from the centre of the 3D screen)

2012-04-04
Stress and Strain Simulations

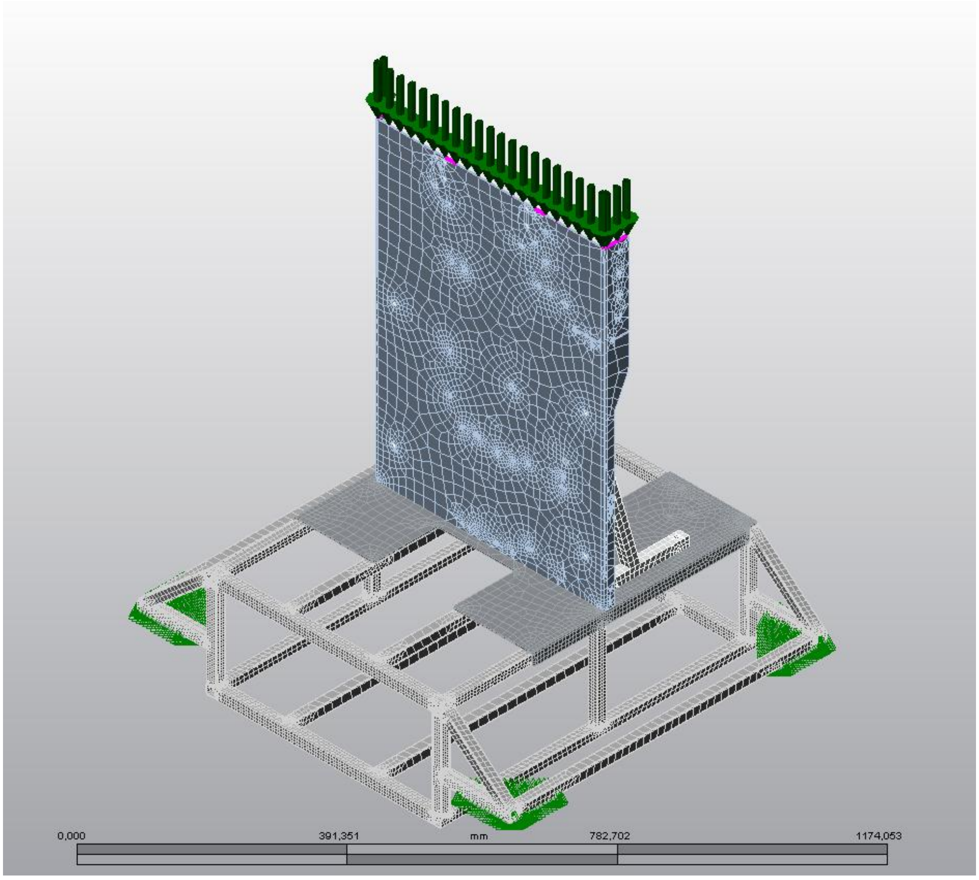
This document summarizes the stress and strain simulations performed on the base structure of the demo/planning station. All simulations were done using Autodesk Simulation 2012. The simulations are done in different load-cases and each load-case is presented along with their results. In order to perform the simulations some parts in the assemblies have been simplified prior to running the simulations.



Load-case 1 – Base frame static analysis

Description: The aim of the simulation is to investigate how the framework base will react when the mass of the workstation module is loaded on top of it.

The wheels of the framework base have in this simulation been replaced with fixed constraints at each wheel's location. A force of 1000 N (representing the mass of the workstation module) is loaded on the top edge of the steel part 1002430 and transferred to the base structure though the points of contact.



Load-case 1, a force of 1000N is applied to the top edge of part 1002430. The wheels on the base have been replaced with fixed constraints at each wheel placement to simulate the workstation standing on the ground.

Parts included in the analysis: Base, base plate, triangle mount, 1002430

Type of simulation: Static stress with linear material models

Material data:

Aluminum profiles: Al 6063 T6, 20mm x 20 mm x 2mm

Yield strength: Rm 0,2 = 170 MPa,

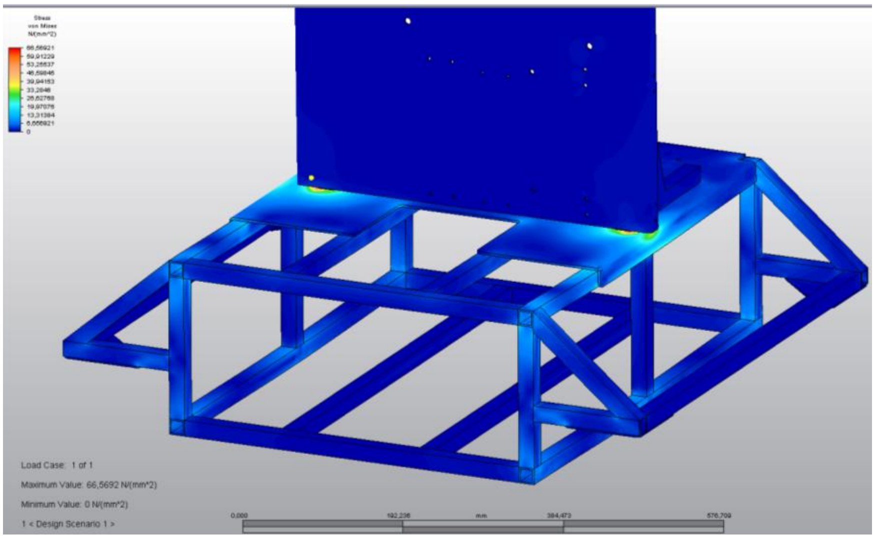
Modulus of elasticity: E= 70 GPa

1002430, Baseplate: Steel 1.4301, t= 3mm,

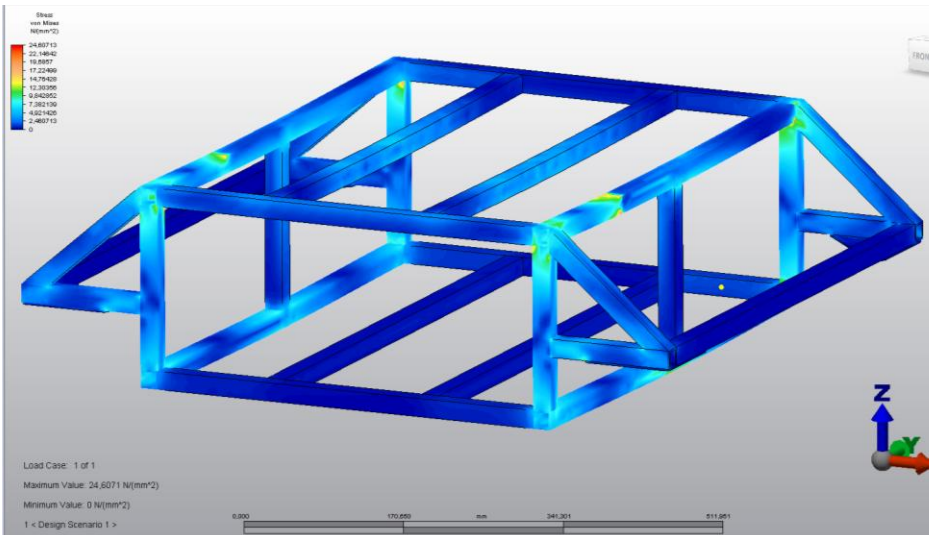
Yield strength: Rm 0,2 = 195 MPa

Modulus of elasticity: E= 200 GPa

Results:
Von Mises Yield Criterion: 66 MPa in base plate, 25 MPa in aluminum frame
Maximum Dispalcement: 0,38 mm



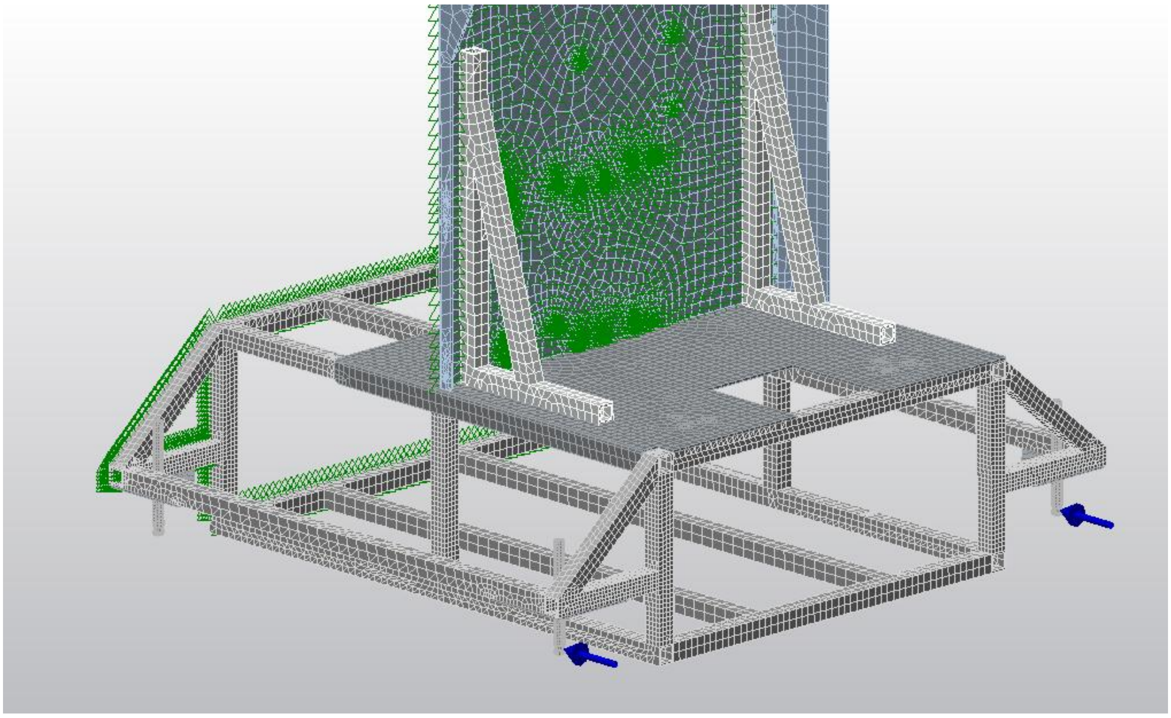
The results of the stress analysis show that the largest stress locations occur in the base plate with a max value of 66 MPa.



The stress analysis in the base shows a max stress of around 25 MPa in the aluminum profiles with the current load case. The maximum values located in the corner welds.

Comments: With the current aluminum profiles (20 mm x 20 mm, t2 mm) and the simulation configuration, the maximum effective stress in the base frame structure amounts to around 25 MPa which is far below the yield stress value of the aluminum profiles which is around 170 MPa.
A similar simulation with a force of 250 N at each wheel position and the top of the structure in a fixed constraint gave a maximum effective stress of 39 MPa.
Load case 2 – Rear Wheel Tilt Analysis
Description: The aim of the simulation is to investigate how the base structure reacts when the workstation is tilted on its rear wheels in order to load it into a car. Since a dynamic analysis of the tilting sequence is a bit too complex to simulate with accurate results (and also very time

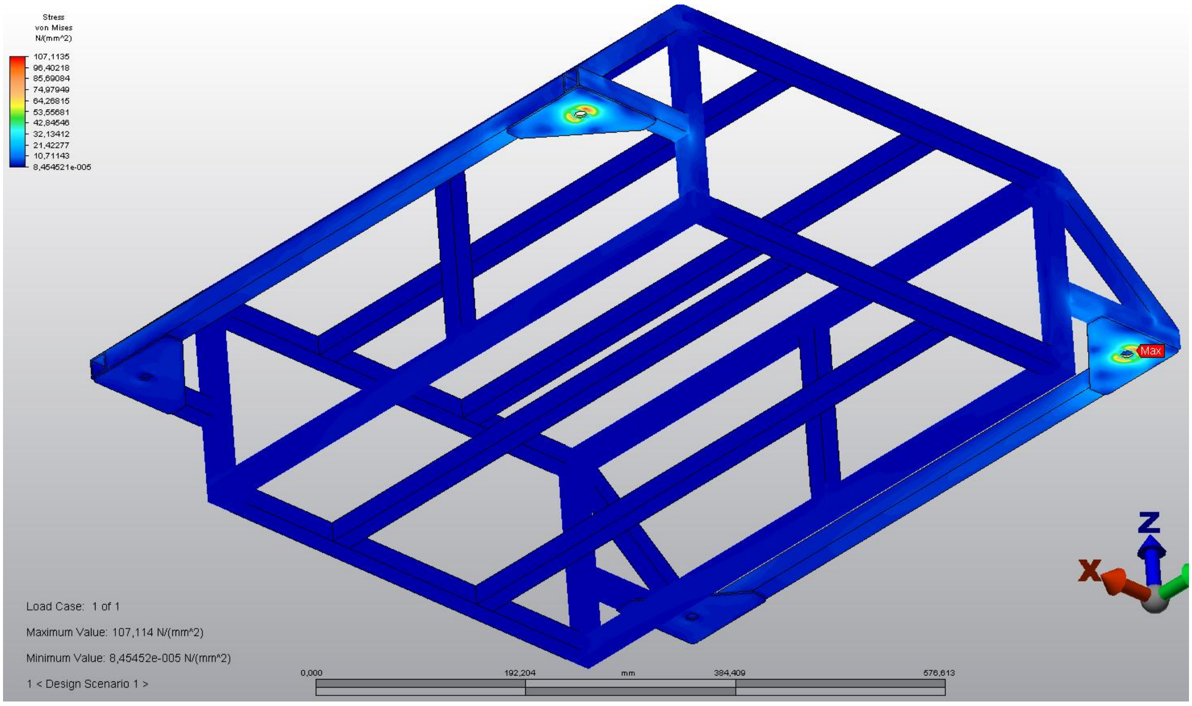
consuming to set up), a static analysis is preformed. A force of 500 N is loaded on each wheel screw at the bottom of the screw to achieve a "worst case scenario". In reality the force transferred from the wheel castor to the screw would affect an area of the screw closer to the middle of the screw giving a smaller lever thus resulting in less torque and less stress. Fixed constraints are added to the front structure of the framework base structure and the steel plate (part 1002430) in order to "lock" the assembly in place and focus the analysis on the area where the rear wheels are mounted.



The screws holding the wheels are loaded with 500 N each (blue arrows) to simulate the workstation being tilted into a car. The green triangles in the figure represent the areas where fixed constraints are added.

Parts included in the analysis: Base, base plate, triangle mount, 1002430
Type of simulation: Static stress with linear material models
Material data:
Aluminum profiles: Al 6063 T6, 20mm x 20 mm x 2mm
Yield strength: Rm 0,2 = 170 MPa,
Modulus of elasticity: E= 70 GPa
1002430, Baseplate, wheelplates: Steel 1.4301, t= 3mm,
Yield strength: Rm 0,2 = 195 MPa
Modulus of elasticity: E= 200 GPa
Wheel screws: Steel, yield strength Rm= 640 MPa,

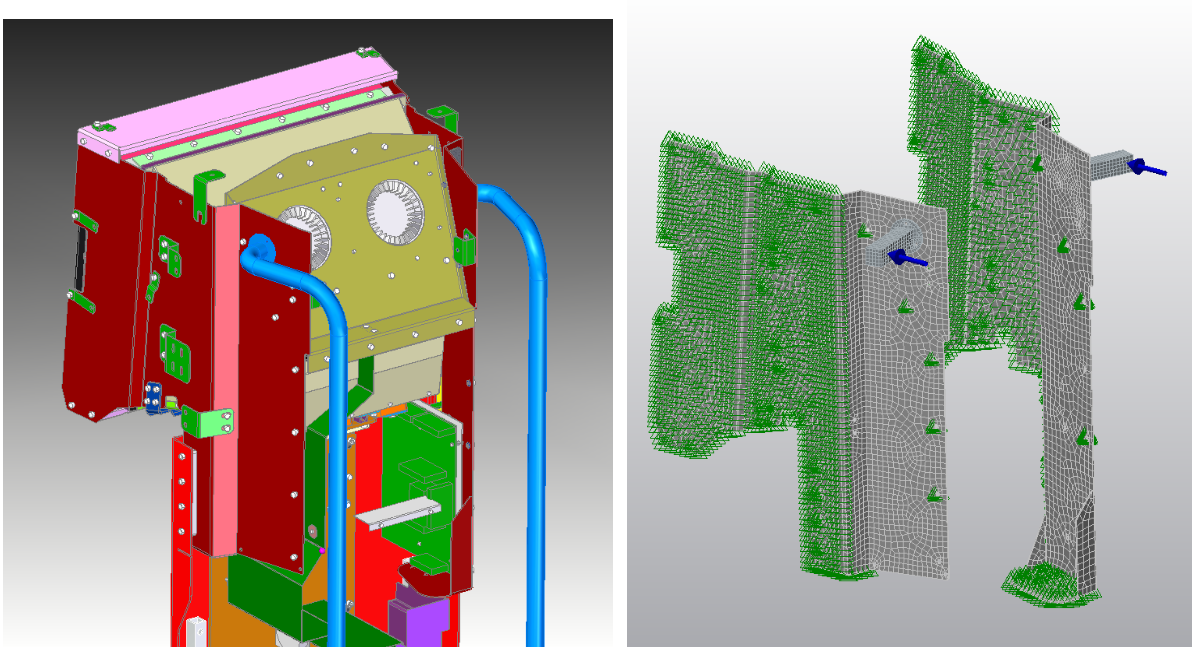
Results:
Von Mises max (in wheelplate) = 107 MPa
Tresca max (in wheelplate) = 122 MPa
Von Mises max (in base frame) = 29 MPa



Comments: Even with a "worst case scenario", the stress in the base structure does not exceed the yield strength of the materials in the base structure. The largest stress occurs in the wheel plates in the base structure and amounts to 107 MPa with the current simulation scenario. This value can be lowered even more by adding a washer between the screw and the wheel plate. The aluminum frame reacted well to the applied forces with a maximum stress level of 29 MPa.

Load-case 3 - Side plate 1003204 resistance to plastic deformation

Description: The aim of load-case 3 is to investigate the forces that may occur if handles are to be attached to the steel structure of the workstation and act as the bearing structure when the workstation is being transported lying down on its back. In the simulation a 100mm straight beam is attached to each one of the side plates (1003204 & 1003208) at the desired mounting points for the handles. Fixed constraints are added to the surfaces of the side plates that are far away from the mounting points and also to the holes where screws are present in order to mimic the structure of the original assembly. A force of 500 N is then applied to each one of the beams to simulate the workstation lying down and the stress and strain in the structure is analyzed.



Left: the workstation assembly with handles (blue) in the desired mounting position. Right: the simulation model with parts 1003204, 1003208 and the 100mm beams. The blue arrows represent loads of 500 N each.

Parts included in the analysis: 1003204, 1003208

Type of simulation: Static stress with linear material models

Material data:

1003204:

Material : Steel EN 1.4301

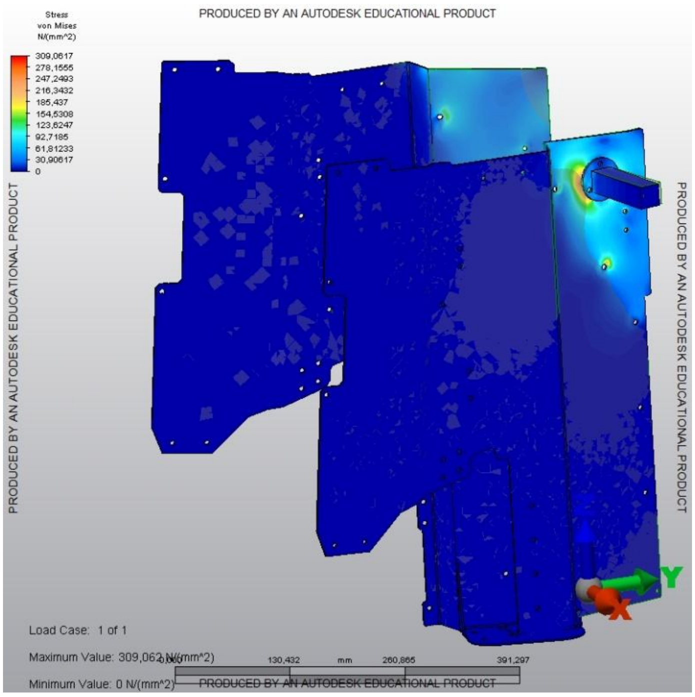
Yield strength: Rm 0,2 = 195 MPa

Tesile strength: 500 – 700 MPa

Modulus of elasticity: E= 200 GPa

Results:

Von Mises Yield Criterion: 309 MPa
Maximum Displacement: 6,2 mm in the top right edge of the side plate.

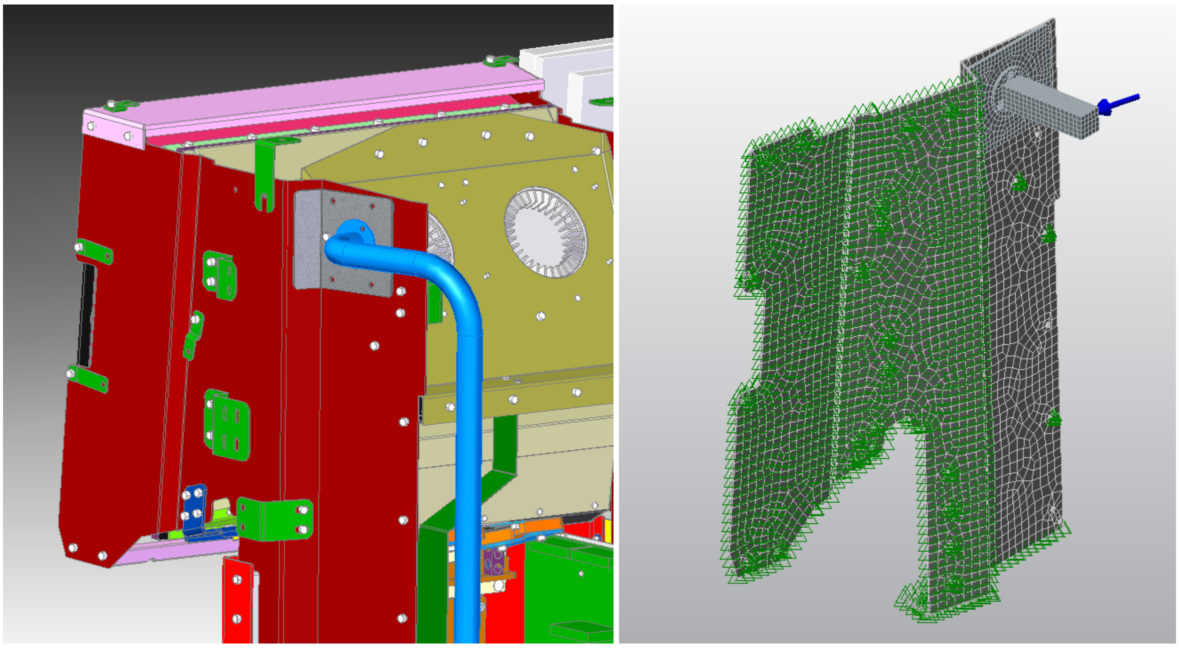


The figure shows stress concentrations in the side plates that arise due to the 500 N of force that is applied to the handles in a negative Y direction. The stress is larger than the elastic limit of the material and would therefore lead to plastic deformation in the side plate.

Comments: According to the analysis a stress of 309 MPa occurs in the side plate with the current simulation scenario. This would lead to plastic deformation in the side plates. If handles are to be attached to the side plates they need to be reinforced in some way.

Load-case 4 - Side plate 1003204 resistance to plastic deformation with 3mm reinforcement plate

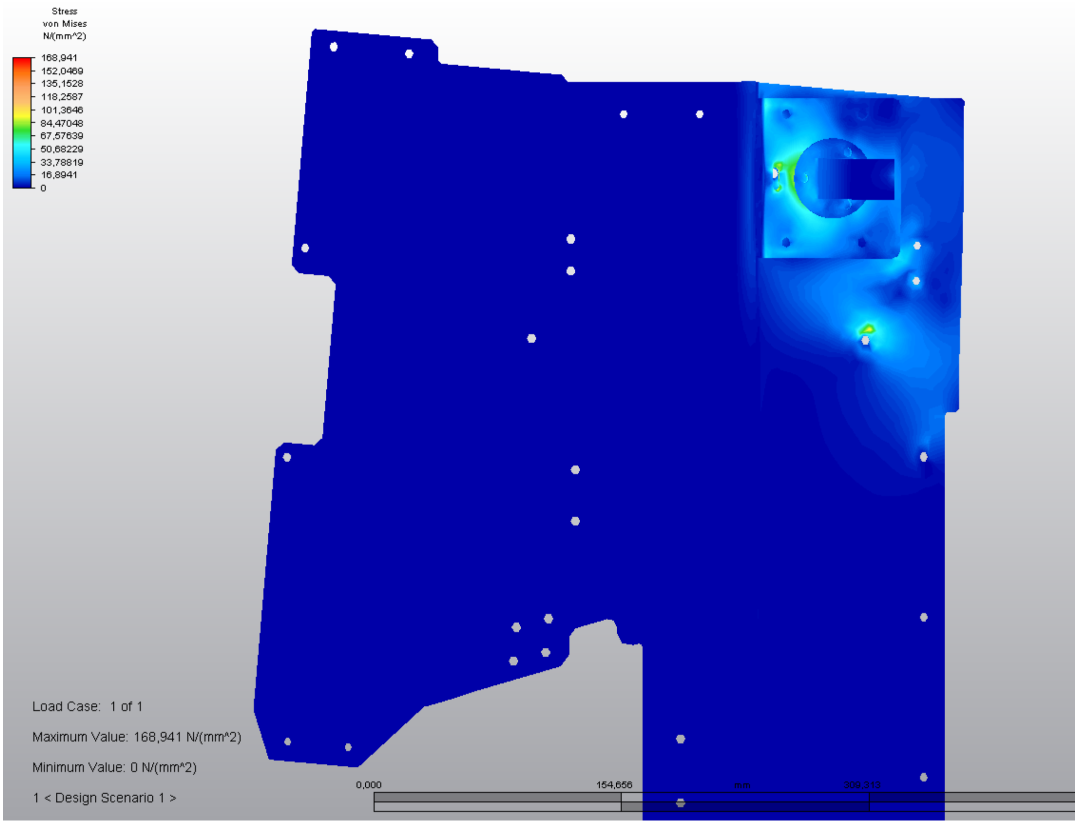
Description: The aim of this simulation is to investigate whether of the side plate 1003204 would be more resistant to plastic deformation with a 3 mm reinforcement plate added to the area where the handle is to be fastened. The same force (500 N) and orientation is used as in load-case 3, the only difference is the 3mm reinforcement plate that is added to the simulation model.



Left: the handle and the reinforcement plate in the CAD assembly. Right: the simulation model; the green triangles represent fixed constraints and the blue arrow shows where the 500 N of force is applied.

Parts included in the analysis: 1003204 (1003208), plate-handle-left
Type of simulation: Static stress with linear material models
Material data:
1003204, plate-handle-left:
Material : Steel EN 1.4301, ,
Yield strength: Rm 0,2 = 195 MPa
Tensile strength: 500 – 700 MPa
Modulus of elasticity: E= 200 GPa

Results:
Von Mises Yield Criterion: Maximum value 168 MPa
Maximum Displcement: Top edge of side plate 0,35 mm

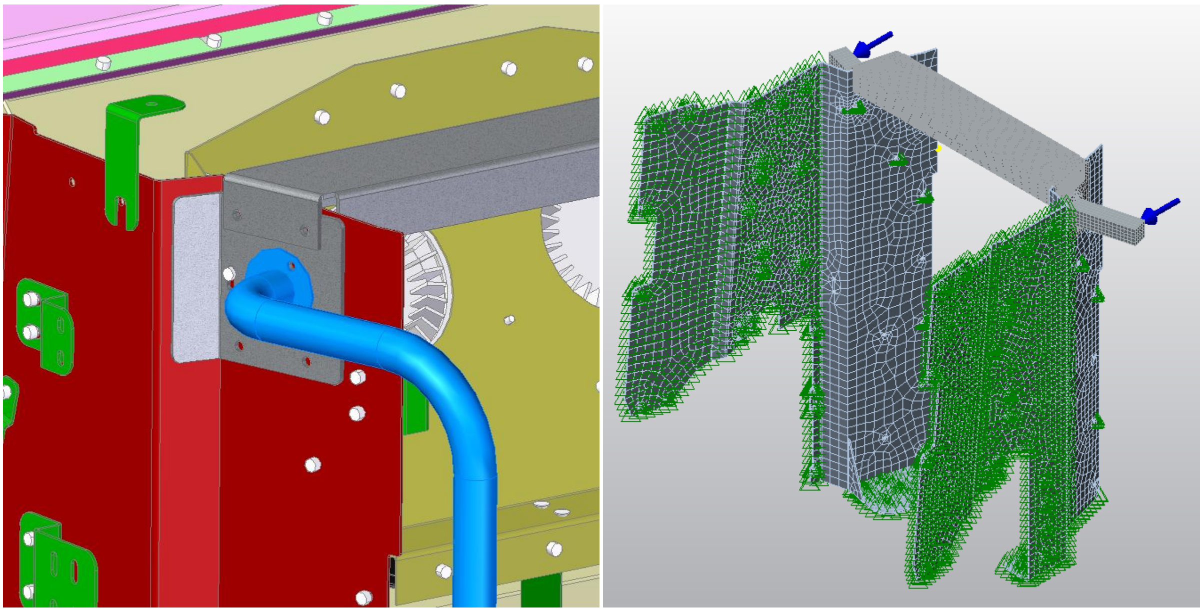


Stress concentrations in the model due to static loading. The maximum value is 168 MPa and occurs in the reinforcement plate.

Comments: The highest stress value occurs in the reinforcement plate with a value of 168 MPa. The highest stress in the side plates is around 84 MPa which should be considered to be an acceptable value.

Load-case 5 - Side plate 1003204 resistance to plastic deformation with 3mm reinforcement plate and crossbar beam

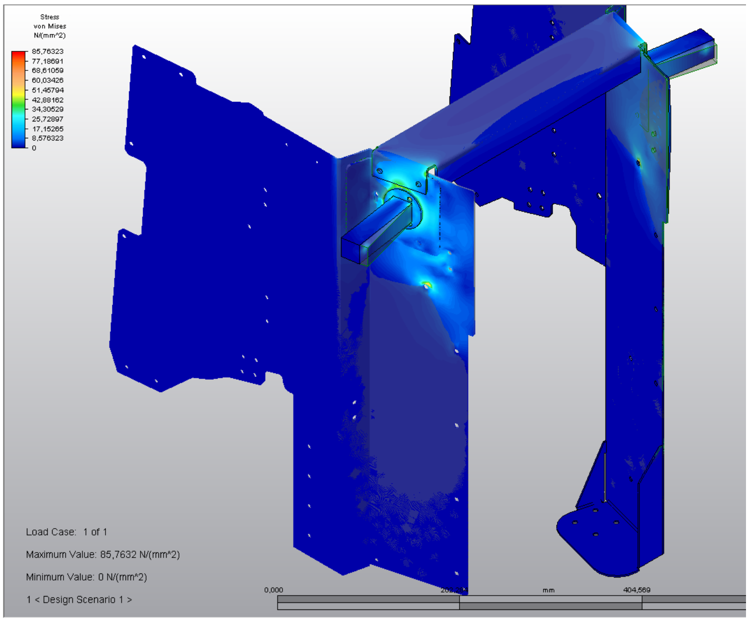
Description: Since the arm for the 2D screen has been removed the stabilizing beam with part number 1002432 is no longer needed. Instead a stabilizing beam can be added further back along the top edges of the side plates to stabilize the area around the mounting position of the handles. To investigate the effects that this would have on the stability of the structure around the handles a new simulation similar to the earlier ones was executed. The same forces (500 N) and reinforcement plates as in load case 4 are used and the stabilizing cross bar is added to the simulation model.



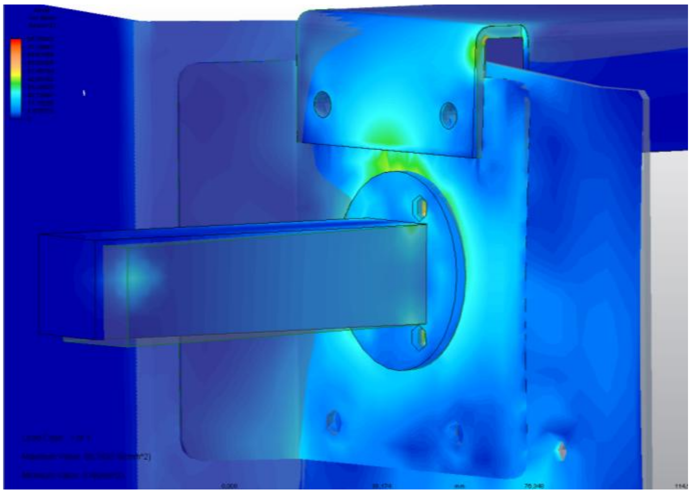
Left: a stabilizing cross beam is added to the assembly structure. Right: the simulation model with the cross beam added. The forces in the simulation are still 500 N each and the constraints are located at the same places as the previous simulations.

Parts included in the analysis: 1003204, 1003208, crossbar, plate-handle-left
Type of simulation: Static stress with linear material models
Material data:
1003204, 1004308, , plate-handle-left, crossbar:
Material : Steel EN 1.4301,
Yield strength: Rm 0,2 = 195 MPa
Tesile strength: 500 – 700 MPa
Modulus of elasticity: E= 200 GPa

Results:
Von Mises Yield Criterion: Maximum value 85 MPa
Tresca: Maximum value 92 MPa
Maximum Displcement: 0,1 mm in top right edge of side plates



Stress concentrations in the simulation model due to static loading. The maximum value is around 86 MPa and occurs in the bend of the cross beam.



The area around the handle's mounting position is affected with around 42 MPa of stress.

Comment: The maximum stress value (86MPa) occurs in the bend of the cross beam and is low enough to not have to worry about plastic deformation. By adding the cross beam a lot of the stress is removed from the side plates and reinforcement plates and instead absorbed by the cross beam. This leads to a maximum stress value of about 42 MPa in the side plates and reinforcement plates which can be considered to be a satisfactory value for preventing plastic deformation in the structure.