Bachelor Degree Project

HÖGSKOLAN I SKÖVDE

REDESIGN OF TRUCK SEAT BY ANALYSIS OF SEAT BODY INTERACTION USING 3D SCANNING.

Bachelor Degree Project in Product Design Engineering
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HÖGSKOLAN I SKÖVDE

Abstract

The project focuses on evaluating hip width deformation when sitting in a truck seat using 3D scanning technology. The aim includes conducting user tests to study hip width and buttock shape, analyzing data on hip width deformation, and developing guidelines for vehicle seat cushion design. By proceeding with a user test, qualitative and quantitative data were obtained, regarding the seat width of three different variants, where scans were done in the different postures taken.

The user test was designed to keep the participants comfortable during the entire process, several tasks and questions were asked to them, making use of a Volvo truck cabin, truck seat foam variants and a handheld 3D scanner.

After analyzing the data obtained, few trends were found in the data that limited the conclusions of the results. However, the results indicate a difference in the deformation when sitting in a soft seat for male and for women. In addition, the results from the subjective evaluation reveal that most people want a soft seat that is relatively larger than their hip breadth. This study serves as guidance for next possible continuations, as redesign guidelines can be taken for future truck seat design and the user test measurements and files can be used for future evaluations in body shape deformation when sitting on seats with different size, shape and material.

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Assurance of own work

This thesis has been submitted by Lucía Jaime Sánchez to the University of Skövde as a requirement for the degree of Bachelor of Science in Product Design Engineering.

The undersigned certifies that all the material in this thesis that is not my own has been properly acknowledged using accepted referencing practices and, further, that the thesis includes no material for which I have previously received academic credit.

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Table of Contents

List of Nomenclatures

$ADOPTIVE:$ Automated Design and Optimization of Vehicle Ergonomics.

$ANSUR\ II$: Army Anthropometric survey.

BMI: Body Mass Index.

DHM: Digital Human Modeling.

$H - Point$: Hip Point.

$IMMA$: Intelligently Moving Manikin.

IPS: Industrial Path Solutions.

IT: Information Technology.

PDS: Product Design Specification.

$SgRP$: Seating Reference Point.

TLR: Top-Level Requirement.

UCD: User-Centered Design.

1 Introduction

For the present degree project called “Redesign of truck seat by analysis of seat body interaction using 3d scanning”, the following sections provide an explanation of the main ideas and concepts of the thesis, including contextual and introductory aspects.

1.1 Background

This final degree project was carried out together with the University of Skövde, particularly in the project “ADOPTIVE” (Automated Design and Optimization of Vehicle Ergonomics). The ADOPTIVE project focuses on the assessment and optimization of vehicle interior geometries and the user accommodation levels of alternative design solutions. The industrial need is to have more efficient methods and tools to ensure proper ergonomics in future designs of vehicles to benefit product quality aspects such as user diversity considerations, user experience, and active safety (University of Skövde, 2019).

ADOPTIVE is an associated project of SAFER, a hub for traffic safety research in Sweden consisting of close to 50 partners serving as stakeholders within the automotive industry, academia, and government agencies. In the ADOPTIVE project, Volvo Trucks is one of the industrial partners, and the truck cabin that has been placed in ASSAR Industrial Innovation Centre (www.assarinnovation.se) is going to be used for this project, in the purpose of evaluating how the human body interacts with the truck seat.

Automotive seating has a key role to play in improving the comfort and working environment, being in contact with vehicle occupants, and especially for the driver, who tends to experience greater fatigue compared to other passengers. Consequently, increasing attention has been given over the years to the improvement of vehicle seating systems (Mandal, Maity and Prasad, 2015).

In the ADOPTIVE project an evaluation study of body shape interaction has been done focusing on car seats. However, the study used an iPad-attached scanner which had a relatively low resolution. This project will include a similar and, in some aspects, improved study, due to the fact that a 3D scanner will be used for the measuring and evaluation process and the tests will take place in a truck.

Seats from different truck companies will be analyzed regarding shape and dimensions in relation to anthropometric measurements as aspects to consider for future seat redesign. The study focuses on satisfying truck drivers' needs by providing comfort and less risk of injury in their daily work.

1.2 Problem Statement

In the ADOPTIVE research project, an evaluation for statistical prediction of initial static driving posture in cars was performed. When it comes to converting these advances to the precise representation posture of a person sitting in a vehicle, the shape of the seated and deformed body should be accurate. Knowing this need, the thesis project aims to conduct a study on the buttock seat interaction in trucks. The objective is to evaluate the hip width deformation when sitting in a truck seat using a 3D scanning system. This evaluation will be carried out through user tests using different variants of the physical model of the seat cushion from a Volvo truck.

1.3 Objectives

The main objectives of this project are as follows:

- Perform user test: study hip width and the buttock shape when sitting on a seat, using 3D scanning technology.
- Analyze and compare the data obtained in the tests, focusing on the deformation of the hip width between the standing and sitting positions.
- Develop specific guidelines for vehicle seat cushion design, focusing on seat width.

1.4 Methodology

Having clarified 'what' has to be done in the project, there is a need to state 'how' it is going to be done. This section will state the methods and practices that will be used during the entire process of the project, referring to the project process chart (Figure 1). Some of the activities mentioned are drawn from "Design Methods in Engineering and Product Design" by Ian Wright (1998). However, the process will be different to a conventional design process chart due to the fact that this project does not comprise an actual design process, there is a lack of iterative process and creativity methods in the presented project, which means that it stays in the steps previous to the concept development of a conventional design process. When taking a look at the design process stated by Ian Wright (Figure 2) it is visible that this project will stay between the step 1 "Determination of customer requirements" and step 2 "Product design specification", as it will be explained through this section.

The results from the project in the form of redesign guidelines could then be used in the remaining steps of the design process in a future possible design project.

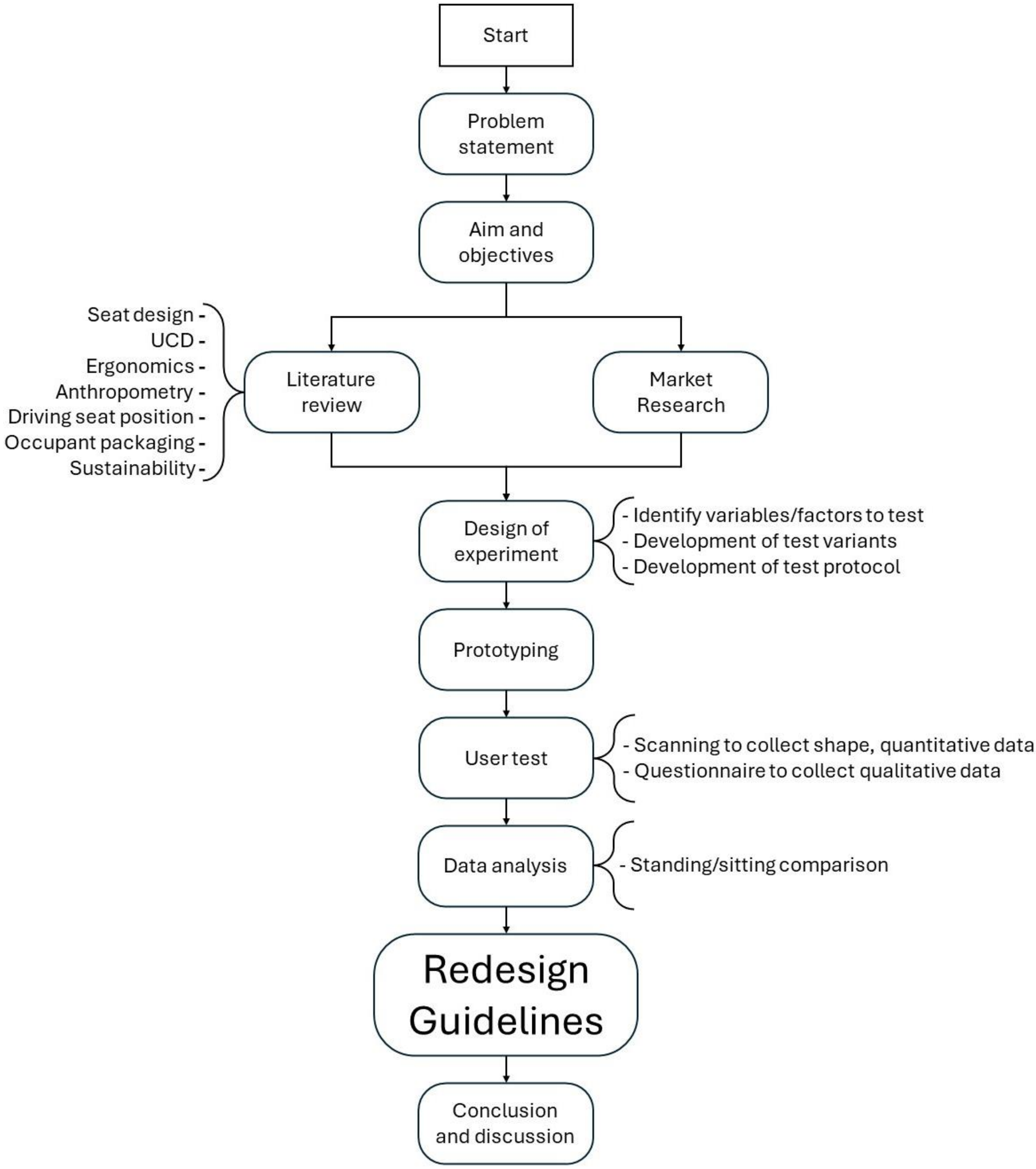

Figure 1. Project process chart.

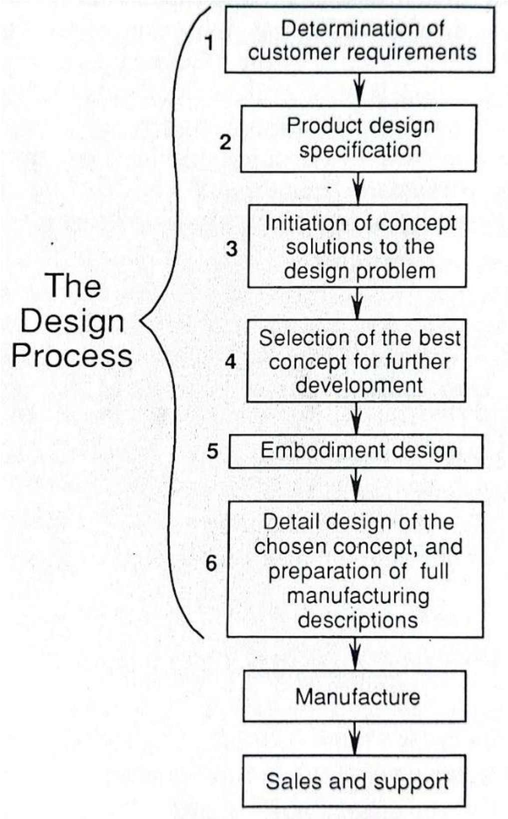

Figure 2. The Design Process (Wright, 1998).

Firstly, the organization of work was set. As it is an individual project, the organizational structure is simple, since following the appropriate methodology and with the right communication with the supervisor, the project will be developed in an orderly manner and taking into consideration every detail to be approached.

The literature review and market research started. Considering Philip Kotler's definition of marketing (Kotler, 1996) it involves an activity that is intended to be reproduced in this research, which is identifying new markets for existing products and selecting target markets (Wright, 1998). This is important to achieve as the variants that will be done to conduct the user test will vary depending on what the models in the market dictate.

Then, the design of the experiment phase comes along. Three different tasks are going to be done, identify variables/factors to test, development of test variants, and development of test protocol. This stage aims to prepare completely the testing part of the project (Figure 1).

A part of the design of experiment is the development of test variants, which can be translated into prototyping. Consisting of modifying some seat cushion foam by removing or adding foam to it, to then proceed with the testing.

The user test is the next step, using the different test variants made in the previous stage. Quantitative data will be collected by scanning the shape of the thighs of the test participants, which will be done with a 3D scanner, and measuring their hip width. Qualitative data is obtained by making a questionnaire to the participants, which was also prepared in the previous phase.

Data has to be analyzed after the user test, a comparison will be done between sitting and standing positions regarding the Army Anthropometric survey (ANSUR II), which has a much larger sample than this study and taking inspiration from it will lead to a better conclusion so as it contains similar measurements to the ones that will be taken (Paquette, 2009). The data processed through this phase will lead to the generation of redesign guidelines, which will suggest seat width based on the person's hip and where seat support (bolsters) should be placed.

These guidelines will enclose the path for future possibilities in the redesign of a truck seat cushion, as guidelines aim to provide the designers with abstract and transferable knowledge through principles (from a set of data or experiences) which works beyond a specific case (Brink *et al.*, 2016). As the project also possesses a narrower perspective because of the existing model of the Volvo truck cabin, a concrete limitation will be given in terms of measurement for the width of the seat cushion. This constraint will be given as a contribution for a possible future PDS (Product Design Specification) document.

At the end of the project, a discussion about every point that has been experienced, such as changes, interesting things or things that maybe needs improvement for future possibility of continuance, will take place. Afterwards a conclusion of the project will also come along, it will expose every aspect of the results that was subtracted by the data analysis, as well as a reflection on the project. The chart in Figure 1 shows the whole project's process.

1.5 Limitations

Firstly, related to the redesign process for the user test evaluation, a fundamental constraint is that the project focuses exclusively on the ergonomic aspect with focus on anthropometry to ensure a comfortable and safe posture for the user while using the vehicle as well as adapting the design to the measurements and proportions of the human body. This is a limitation, since other essential aspects must be considered, such as costs or materials, and that all these aspects must be balanced to develop a product that is completely successful and close to reality.

Secondly, the study has been carried out with students at the University of Skövde. This has been a limitation as the ideal would have been to perform the user tests on real truck drivers and more specifically on those who may have more difficulties in using the product, which in the case of this project, are people with high BMIs (Body Mass Index). Conducting user tests involves finding people available to participate and carry out measurements within a given time frame. Truck drivers, however, due to their busy schedules, often have limited availability for this type of study. For this reason, the tests are conducted with university students, as they have more flexible schedules and greater availability. This limitation should be kept in mind as this approach will result in a sample that does not fully represent the diversity in terms of age and experience within the truck driver population.

Finally, time is also a limitation for all projects. In the end, there is a limited time to carry out all the tasks attached to the project, this kind of work can be developed in more depth having more time but, in this case, the time available is approximately 20 weeks of full-time work which is about 800 for each student in the project group, a total of 1600 hours. This, whether it is a lot of time or not, is a limited amount of time.

1.6 Overview of the thesis

This section summarizes the structure of the project and what the reader will find in each of the sections of this thesis. Firstly, in Chapter 1 the project is described extensively, explaining its background, the objectives to be achieved, the methodology to be used for the realization of the project and the limitations to be considered. In Chapter 2, the pre-study includes the literature review, which provides a base of knowledge and theories that allow establishing the theoretical and conceptual context in which the object of study is developed. In this chapter market research is also conducted and some topics related to the field of study, such as previous research and the current design, will be explained. In Chapter 3, design of experiment, explains how the whole user test has been prepared and developed. This is followed by Chapter 4, where all the results obtained from the user test are presented. The results are analyzed in Chapter 5, in which general design guidelines are also established. Moving into the final part of the project, Chapter 6 presents the discussion, in which a reflection is made on the work done, the objectives achieved, and possible future lines are presented. Finally, Chapter 7 summarizes the conclusions of the project, which gives a clear overview of the results and synthesizes the most important aspects of the project.

2 Pre-study

In this chapter, all the knowledge acquired to carry out the process is presented. First of all, a relevant literature review has been carried out, followed by a field study that will help to better understand and clarify some aspects to facilitate the start of the user testing.

2.1 Literature review

In this section, relevant information from various scientific articles, books, and projects related to the field of study is introduced, analyzed, and compiled to facilitate the advancement of the project.

2.1.1 Overview about automotive seat design

The seat is a structure intended for a person to sit on. Regarding automotive seats, they have the function of supporting, protecting, and providing a comfortable posture for their occupants. Seats are where people who are professional drivers spend most of their time (around 50 hours per week), making them one of the most important elements of a vehicle (Mandal, Maity and Prasad, 2015). For this reason, consumers demand comfort as an indispensable attribute of their vehicles and one of the parts most involved in providing this need is the seat.

In this project, the study focuses on a truck seat, and going into detail, with the part of the seat known as the cushion. This is the part of the seat where the driver sits. Drivers of vehicles such as trucks experience a particularly long and heavy load of driving hours. So, as mentioned above, the most important part of a truck driver's working environment is the seat.

During the process of designing an automotive seat, the effects of the different causes of discomfort have to be taken into account. In addition, it is necessary to evaluate whether user satisfaction related to comfort can be achieved without reducing stimuli that are normally related to discomfort (Mehta and Tewari, 2000). Within truck seat design, one of the most worked-on improvements related to user comfort is the design of the seat bolsters, to achieve a good posture of the driver (Seigler, 2002).

Some factors mainly related to the user's comfort when using the vehicle are to be considered when designing an automotive seat (Mandal, Maity, and Prasad, 2015). One of these is body position, which depends on vision and reach. The vehicle occupant should have a clear view and a comfortable posture. The automotive seat should minimize postural strain and optimize muscular effort; thus, body posture is another factor to be taken into account in the seat design. Providing comfortable support for the seat is essential, otherwise, postural stress can be caused after a long period in the same posture. Other factors that are important to most individuals when evaluating seat comfort are vibration, shock, and impact. Therefore, the vehicle suspension and the vibration transmitted to the driver are interesting aspects to include in the seat design.

2.1.2 User-Centered Design

User-Centered Design (UCD) is a design approach that arose in the Information Technology (IT) field in the 1970s-80s and was subsequently adopted and applied in the field of Design (Tosi, 2020). The goal of this approach has always been to focus the development process of the product/service in such a way as to ensure a high degree of usability. In the 90s, UCD underwent an evolution due to many studies in the field of Design, defining investigative methodologies for defining users' needs.

From the user experience perspective (Tosi, 2020), the procedures for using professional products or systems, that is, those that are specifically intended for use by specialized workers, are, or should be, planned and regulated, supervised, and appropriately explained to those who must perform them and carried out in the correct manner. So, the user experience perspective is a philosophy that would be interesting to suit in this project as much as possible.

Some articles comment on how the user-centered perspective in vehicle design is mostly based on interviews with professionals in the driving and automotive fields (Bryant and Wrigley, 2014). Reflecting on the dialogue with interview participants presents opportunities, which can be oriented to help automobile manufacturers transition towards a user-centered perspective in vehicle design. This also affects the truck seat design, whose user should get involved in the process of creating the product as they tend to suffer its design's problems, which affect directly their health.

Two particular techniques deserve special attention: *task analysis* and *user trial* (Pheasant and Haslegrave, 2018). A task analysis is really a formal or semi-formal attempt to define and state what the user/operator is actually going to do with the product/system/environment in question. This is stated in terms of the desired ends of the task, the physical operations the user will perform, the information processing requirements it entails, the constraints, and so on. A user trial is just what its name suggests: an experimental investigation in which a sample of people test a prototype version of the product under controlled conditions, also called a user test.

2.1.2.1 Ergonomics

Ergonomics is a science closely linked to user-centered design as it is the study of the interaction between people and machines along with the factors that affect this interaction (Bridger, 2008). Its main focus is the study of human characteristics, capabilities, and limitations to apply this knowledge to the design and evaluation of equipment and systems used by people in their daily lives (Bhise, 2012).

User-centered design also aims to improve the usability of systems, achieving good ergonomics. In this way, the capabilities of humans are adapted to the requirements of a machine or task (Brolin, 2016). Taking ergonomics into account when designing work systems increases productivity, improves quality, and reduces worker injuries and fatigue. Ergonomics is a fundamental component in creating sustainable and efficient work systems that benefit both workers and organizations (Berlin and Adams, 2017).

An ergonomically designed product should fit the user comfortably and, in most cases, require minimal physical and mental effort to use. In addition, it should be intuitive and easy to learn. These applications of ergonomic principles in product design improve the user experience as well as lead to numerous benefits, including the creation of functionally superior products and the reduction of costs and time by avoiding the need for lengthy redesigns. By making knowledge-based decisions about users early in the design process, potential problems can be avoided and outstanding results can be achieved more efficiently (Bhise, 2012).

Within the automotive industry, the most common diseases are work-related injuries. That is why ergonomic quality and comfort are very important to ensure good quality throughout the entire product lifecycle, from vehicles to all types of equipment and systems (Rasmussen *et al.*, 2005).

In the system approach to vehicle design, in addition to designing the physical components to fit together and function correctly, the users must be recognized as an essential part and considered as a human component (Bhise, 2012). This implies that detailed consideration must be given to the characteristics of the main components of the system, which are: the driver or user, the vehicle, the environment, and their relationship to driver performance, preference, and perception (Figure 3).

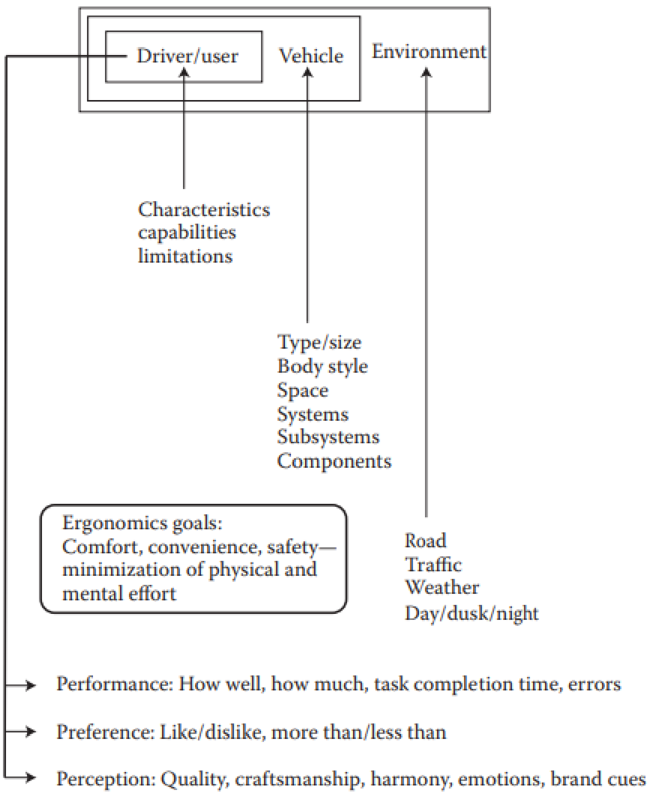

Figure 3. Ergonomics considerations between the characteristics of the driver, the vehicle, and the environment with the driver performance, preference, and perception. (Bhise, 2012)

A vehicle has to present certain criteria such as the following to establish ergonomic superiority (Bhise, 2012):

- The vehicle has to be perceived by consumers as the best in its sector.
- Fulfill the relevant ergonomic requirements and all applicable regulations.
- Satisfy the user accommodation objectives established in the initial phase of the program.
- Meet minimum acceptable levels in attributes such as ease of learning, usability, and safety.

Producing ergonomically superior vehicles is one of the main objectives of ergonomics engineers while collaborating with the design team (Bhise, 2012). In addition, they have the responsibility to consider the characteristics of all components and evaluate how the user performs different tasks using the product.

2.1.3 Anthropometry

Anthropometry is the science within physical ergonomics that focuses on measurements of the human body, more specifically on size, shape, work capacity, mobility, and flexibility (Pheasant and Haslegrave, 2018). Humans are anthropometrically variable, whether in dimensions, shape, or proportions. When talking about designing a product through a user-centered approach, it is necessary to understand anthropometric variability for an ergonomic process or product.

Anthropometric engineering aims to design and evaluate products that fit people through the application of anthropometric measurement data (Bhise, 2012). Using anthropometric data from a diverse group of people with a variety of body measurements ensures that the design of products and workplace environments can be adapted to most users without regard to specific anthropometry (Brolin, 2016).

In order to obtain an appropriate source of anthropometric data, a target population of users must be defined. To do so, several factors are worth considering, such as gender, age, nationality (or ethnicity), and occupation (or social class), preferably in that order of importance (Pheasant and Haslegrave, 2018). Where insufficient anthropometric data are available from the target population, it is possible to use data from a sample of the user population (Brolin, 2016).

In terms of vehicle design, one of the first phases of the process is to determine the user population and their anthropometric characteristics. This anthropometric data is essential to help determine the basic dimensions of the vehicle. In some cases, to avoid estimating or calculating postural measurements or angles of different body segments, measurements of the relevant dimensions are taken directly under the real postures while using the vehicle and not with the static anthropometric data, measured in erect postures either standing or sitting (Bhise, 2012).

Another anthropometric variable of truck drivers, that would be interesting to take into account is BMI (Body Mass Index). The BMI is generally high among truck drivers, according to a medical survey with almost one hundred thousand drivers more than half of them were obese or morbidly obese, 26,6% obese and 26,6% morbidly obese, with a combined total of 53,2%, which means they are between 30 and 35 in BMI or over 35 when it is about morbid obesity (Thiese, 2016).

When it comes to seat design, it is essential to consider the anthropometric measurements and seating postures of vehicle occupants to ensure their comfort and health (Shen and Vértiz, 1997). To ensure that vehicle seats are adequately accommodated for a wide range of users, it is beneficial to use percentiles as the basis for their design. By taking into account the 95th percentile male and 5th percentile female anthropometric data, the majority of body dimensions within the population are covered (Reed,2000).

The male 95th percentile represents larger individuals in terms of body size, while the female 5th percentile represents smaller ones. The selection of these percentiles is based on a statistical distribution of the population. Designing seats for these percentiles at the tails of the distribution ensures that most users will find the seat wide enough to cover their hip. However, it is worth mentioning that in this study, the 5th and 95th percentiles of hip width for both males and females will be considered. In this case, this anthropometric dimension is larger in females than in males, so the measurements of females will be taken into account in order to cover the maximum population.

2.1.4 Driving posture

Driving is a task that involves prolonged sitting in static and forced postures as well as muscular strain such as using the steering wheel and pedals. The length of time a person spends driving is a predetermining risk factor linked to back pain. This factor stems from what is known as postural fixity, a phenomenon that occurs when an individual sits without experiencing any postural movement for a long period of time (Grieco, 1986). This causes the driver to experience overload in the spinal column area which may lead to musculoskeletal symptoms (Gkikas, 2012).

When sitting, the curve of the lumbar spine changes shape from a standing to a sitting position due to the rotation of the pelvis (see Figure 4). This makes the intervertebral discs vulnerable to damage. When it comes to a seat with a backrest, the pelvis is rotated until the user's back rests against the backrest (Gkikas, 2012).

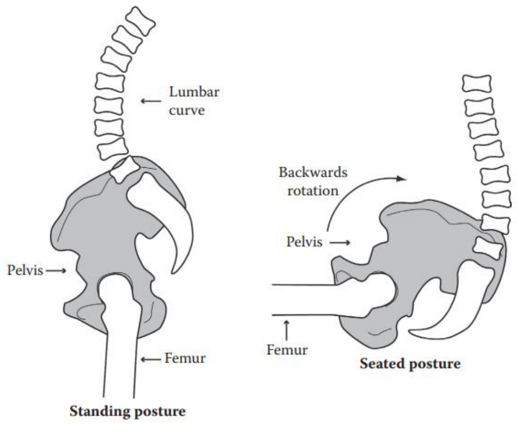

Figure 4. Rotation of the pelvis (Gkikas, 2012).

A seat is well designed when the backrest supports the weight of the shoulders, as this allows the muscles to relax and supports the curve of the lumbar spine (Gkikas, 2012). However, when the lumbar curve flattens, increasing pressure on the internal discs and strain on the ligaments of the spine causing a slouching posture, the seat is poorly designed.

Static muscle work also takes place in the driving environment, as postures are determined and fixed by pedals, safety belts, or visual demands (Kolich, 2008). When muscle tissue contracts, blood vessels are compressed, which reduces blood supply, nutrient supply, and metabolite elimination. If these metabolites accumulate, symptoms of muscle fatigue and acute discomfort occur (Gkikas, 2012). To prevent these effects, it is advisable to vary posture, which is somewhat difficult while driving. Alternatively, McGill suggests that people who spend prolonged periods sitting, such as truck drivers, should take breaks, spending some of their time standing, preferably walking (McGill, 2015).

The postures adopted while driving depend on the factors mentioned above, such as the arrangement of the pedals, the steering wheel, and the seat itself, as well as the visual requirements of the configuration. Environmental influences, such as lack of foot support, low seat friction, or the height of the steering wheel, can also cause additional muscular stress (Gkikas, 2012).

Poor design makes driving postures uncomfortable and inefficient can lead to discomfort, pain, or, in some cases, if the effects persist, chronic disability (Gkikas, 2012). For this reason, in order to achieve the best seated posture, it should be considered that the more adjustable elements there are in the seat, the more likely it is that the driver will be able to adopt a more comfortable posture and achieve a good fit (Figure 5).

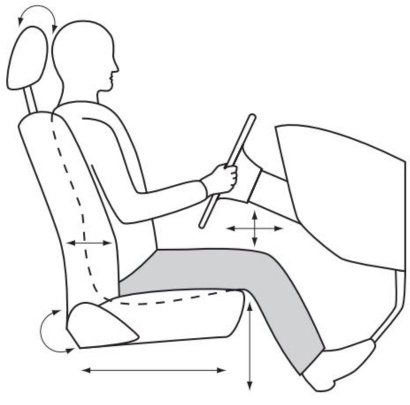

Figure 5. Seated posture and adjustments of seat and steering wheel (Gkikas,2012).

According to Callaghan and McGill (2001), although an individual may sit in a posture that is initially comfortable, it is likely to become fatiguing over time. Therefore, there is no single ideal seated posture but the best strategy to reduce muscle overload is a seat that allows for safe adjustments and variable posture (Callaghan and McGill, 2001).

2.1.5 Occupant packaging

The term "occupant packaging" is used in the automotive design industry to describe the safe placement of various systems and components in the vehicle space and their design around various drivers and passengers. This placement involves fitting all the parts together so that they interact harmoniously (Gkikas, 2012). The main components are, of course, the driver and passengers. In addition, the main vehicle systems, and components (powertrain, chassis, electrical system as well as bodywork) are taken into account, as well as numerous smaller components (switches, fuses, etc.).

Occupant packaging aims to achieve the following objectives:

- Achieve a comfortable driving position for as many drivers as possible.
- Being able to comfortably reach the primary and secondary controls.
- Have a good view of the exterior panoramic view as well as the vehicle's interior displays.

For the driver to feel comfortable and safe inside the vehicle, an envelope must be created around the driver using key reference data within their geometries to configure the rest of the vehicle package (Macey and Wardle, 2009). Thus, vehicles should be designed from the inside out, prioritizing the occupant packaging over the internal systems.

The first step in the design process is to determine the position of the driver and, from there, to develop the initial vehicle architecture around the driver (Gkikas, 2012). For this purpose, the driver’s Hip Point (H-point) should be considered as the most important reference point in the environment, since all elements are influenced by its location and provides key data for configuring the vehicle's interior systems (Macey and Wardle, 2009).

The H-point is the point at the driver's hip that describes an intersection at the pivot center of the back pan and cushion pan assemblies, located on the lateral centerline of the H-point device (ISO, 2020). It is also the intersection of the lines of the occupant's cushion and torso (Figure 6).

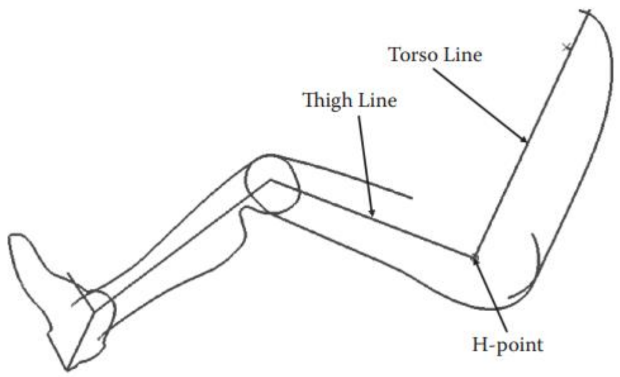

Figure 6. H-point position (Gkikas, 2012).

When a seat is not adjustable, there is only one position of the H-point. On the contrary, in an adjustable seat, such as the driver's seat, the H point can be located in several positions (Gkikas, 2012). The most extreme points of these positions are described as the envelope of the seat movement.

In order to have a reference point for this occupant envelope, the SgRP (Seating Reference Point) (Figure 7) point has been created, a uniquely designed H-point that serves as the seat reference point. It is also used to establish the occupant and vehicle accommodation tools and dimensions (ISO, 2020).

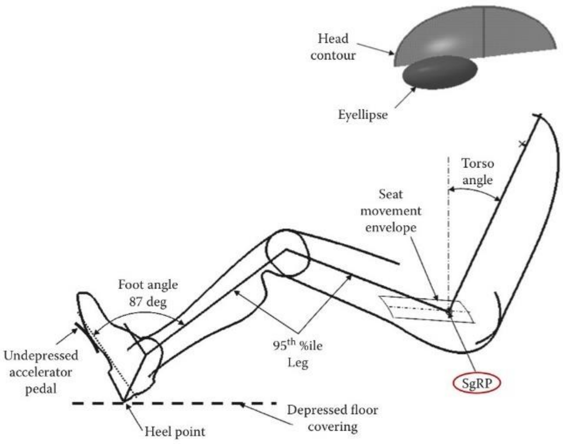

Figure 7. SgRP point position (Gkikas, 2012).

Once the driver's package is established, it is possible to start defining the position and location of the other passengers in relation to the driver and the space (Gkikas, 2012).

2.1.6 Ergonomics evaluation methods and user testing

When assessing the ergonomic suitability of a product and its alignment with user needs, various methodologies utilize specific parameters to evaluate the ergonomic aspects of the product. These influencing parameters encompass the nature of the activity, body posture and time spent. The evolution of user-centered design has spurred a demand for the development of evaluation methods and the exploration of novel approaches, resulting in an increasing variety over the years (Stanton, Young and Harvey, 2014) . Various evaluation methods exist for assessing human-machine or human-workstation performance, including heuristics, checklists, observation, and interviews, among others.

According to Stanton and Baber (1996), the selection of an appropriate evaluation method depends on four key factors:

- The stage of the design process.
- The form that the product takes.
- Access to end users.
- Time constraints.

These factors align with the critical constraints or limitations for ergonomic methods outlined by Shorrock and Williams (2016), encompassing accessibility, usability, and contextual constraints.

In this project, seat ergonomics will be assessed by studying the interaction between participants and the truck seat through user testing, analyzing how the hip deforms when seated. Body dimensions can be measured in different ways, they can be obtained manually using traditional tools such as the metric tape measure or automatically, with 3D scanners where the data obtained are used to extract the dimensions (Bartol *et al.*, 2021). To ensure that measurements are comparable and repeatable, standards are established through the definition of measurement postures and body reference points. Although manual measurement can be very accurate, it has been demonstrated that the results obtained with 3D scanners are more accurate and repeatable. Another advantage is the ability to capture measurements simultaneously and without the need to have contact with the subject.

Therefore, 3D scanning method will be used in this study since time is limited and due to the scanning method accurate measurements can be taken simultaneously and quickly. Furthermore, hip width is a difficult part of the body to measure accurately using only a tape measure and even more difficult to measure its deformation when sitting on a seat, something which can be measured with the scanner.

2.1.6.1 3D Scanning method

In this thesis, the method for conducting the ergonomic evaluation will be 3D scanning technology, which allows for direct measurement and capturing details quickly and easily with high quality data output. The use of this technology can provide useful information for product design, as not only simple dimensions can be measured but also complex dimensions such as surface shape, surface area or volume can be obtained (D’Apuzzo, 2017).

Data processing in 3D scanners is a complex process consisting of different phases in which the captured information is transformed into an accurate three-dimensional representation of the scanned subject using appropriate software.

The first step in the process is data capture, where the scanner collects information about the scanned surface (Besl and McKay, 1992). This data is represented in the form of a three-dimensional point cloud and thus describes the geometry and position of the points on the surface of the person. Once the data is collected, the different views or scans have to be aligned to create a coherent representation in three-dimensional space. The next step is to reconstruct the scanned surface in the form of a three-dimensional mesh, generating through interpolation of points in the point cloud a continuous surface of the subject's shape. Finally, the processed data can be analyzed and visualized in different ways depending on the purpose of the scan, such as measuring specific dimensions or comparison with virtual models.

The use of 3D scanning technology as a method of ergonomic assessment focusing on body shape and dimensions is a very convenient option for both the user and the individual carrying out the assessment and, due to the large amount of data it processes, it allows for a comprehensive analysis to achieve an improvement of the design adapted to the human being. The scanner used in the project, its characteristics, functions, and parameters will be explained in detail in a later part of this report.

2.1.7 Sustainability

Integrating concerns for environmental health, economic viability, and human well-being remains central to any attempt to identify what is implied in the concept of sustainability (Walker and Giard, 2013). A culture of sustainability is a thing to support and improve as much as possible with this project, for the present and future engineers and designers. Providing some of the goals with more information and support. Thereupon an explanation about the points where the project is helping the most among the Sustainable Development Goals (Figure 8) will be provided (*THE 17 GOALS | Sustainable Development*, 2024):

Figure 8. Sustainable Development Goals.

- Goal 3, Ensure healthy lives and promote well-being for all at all ages. This project is helping to this aim in the way of prioritizing the comfort and good health of truck drivers who work for long-time sessions, which in many cases lead to several injuries or diseases.

- Goal 5, Achieve gender equality and empower all women and girls. In this project, the participation and implication of women is present in all aspects, as it is done by one and supervised by another. Also, tests will be carried out with both genders, as truck driving is a feasible profession for all kinds of people.

- Goal 9, Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. As the work will be done using 3D scanning techniques and for a big industry group such as SAFER, this goal is supported.

Assessing the ethical implications of things which may not yet exist, or things which may have impacts that cannot be predicted, is very difficult (Cahill, 2020). However, this should not be barrier to posing important questions and ensuring that these questions are addressed as part of the design process. Thinking about both potential positive, negative consequences and unintended consequences enables designers to build in protections into the design concept.

The implementation of a Human Factors and Ethics Canvas in this project is difficult as it does not follow the normal stages that a design project would. Because of that, ethics concerns in this project will be integrated in a theoretical and non-visual frame (Cahill, 2020).

Ethics concerns the moral principles that govern a person's behavior or how an activity is conducted (Cahill, 2020). When trying to innovate and participate in a research process with this work, we should consider research and technical innovation ethics frameworks, having to gain consciousness of their impact in different levels.

Applying this theoretical framework, a debate came up to mind regarding what is better to improve the design of truck seats, having no decided answer for it. The goal is that the seats should better fit a wider population. There is a continuously increase in BMI in the general public but especially within the truck driver population. What is most ethical correct, to design products so they better fit more obese users, or should other actions be made? Related to health and exercise? Perhaps it is better to design a truck seat in order to maintain a forced correct posture for health issues instead of focusing on comfort. Maybe even measuring BMI is not the best way to be aware of the obesity in the truck sector, since BMI only considers mass, not the amount of muscle or body fat that a human body contains.

2.2 Field study

This section aims to gather information on truck seats and their most relevant characteristics for the realization of this project. To this end, the previous study carried out by Volvo Cars on the investigation of the shape of the bodywork will be explained first. Then, a market study was carried out to observe the existing products on the market and to find out the measurements and design features of real products. In addition, in this section, the current Volvo truck seat design will also be analyzed and explained, as it is the design basis for the execution of the project.

2.2.1 Previous study within the ADOPTIVE project

As exposed before, this project is preceded by another one done by the ergonomic department of Volvo Cars (University of Skövde, 2019). That study contains scanning in standing and sitting position but with a low-resolution iPad camera. The previous study also included a comparison between real measured values and the Digital Human Modelling (DHM) software, IPS (Industrial Path Solutions) IMMA (Intelligently Moving Manikin). The part first mentioned has been analyzed in order to take reference of it and compare. However, the second part comparing real measured values and body shapes in DHM software is not included in this thesis project.

- **Research questions**

The previous study covered two research questions. Where the first question is the one that is relevant to this thesis focused on the hip width deformation in real life.

- How does real life person's body shape change between standard anthropometric postures and sitting in car seat?

- How does the shape differ between a real life person and an IMMA manikin?

- **Test persons**

In the previous study, the test sample consisted of eight people with higher BMI, plus two reference people with normal BMI (Figure 9). The test sample was set with this distribution:

- Males: 3 test people with BMI between 33,0 to 34,7 kg/m^2
- Female: 5 test people with BMI between 28,1 to 41,8 kg/m^2

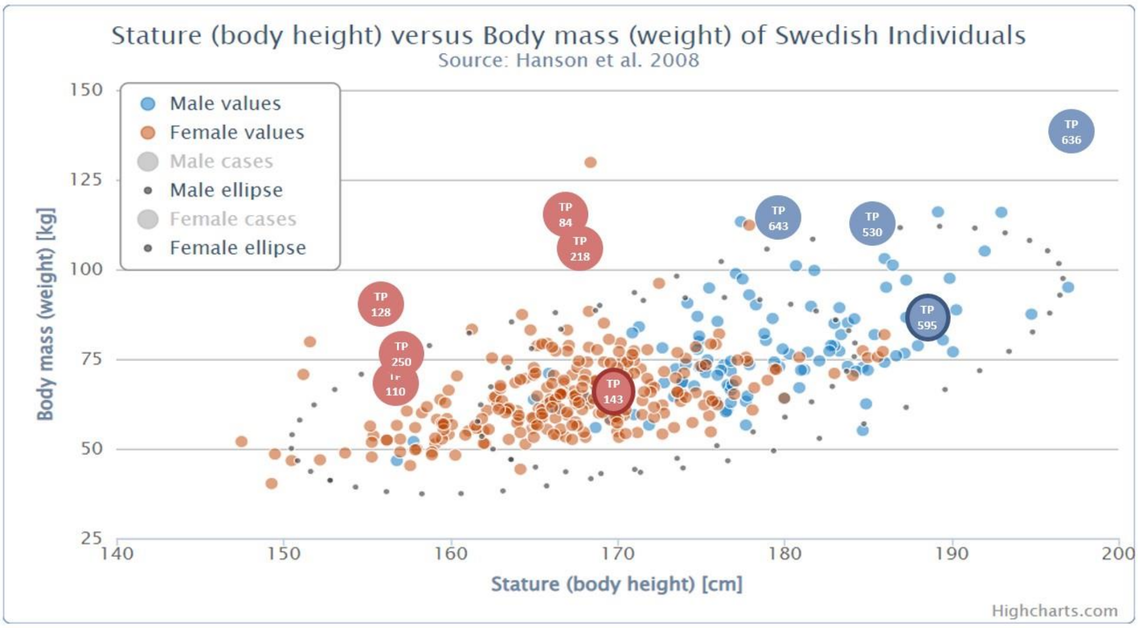

Figure 9. Ellipse of confidence for the study sample.

- **Measured and scanned postures**

Three different postures were measured and scanned in the previous study, they were standing, sitting and sitting in car seat. Here it can be seen that the resolution of the scanning procedure is low, although enough to do some measurements (Figure 10). To achieve a better performance, in the previous study three different scanning postures and body landmarks were added, hands had to be on the steering wheel when seated in car and duct tape was set for more fitted clothes.

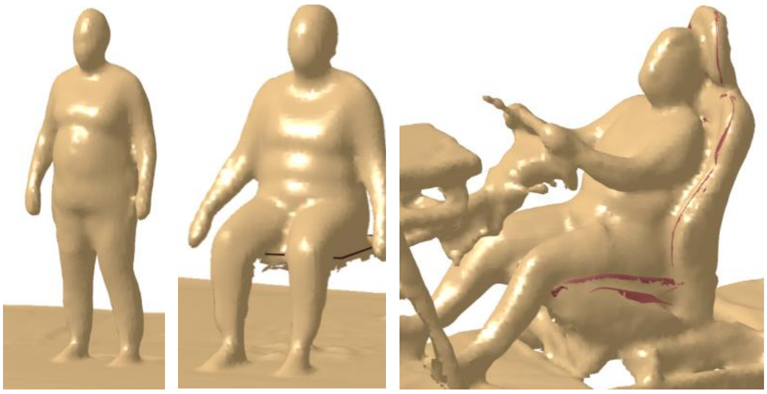

Figure 10. Standing, sitting and sitting in a car seat 3D scans.

- **Key body measurements**

The different body measurements taken to compare the different postures were: waist and belly circumference in different sections, belly width and depth, hip width, thigh circumference in different sections and thigh width and depth.

- **Results and conclusions**

The result related to how body shape changes between sitting in anthropometric posture and sitting in car seat showed:

- The waist circumference is similar between sitting in car seat and sitting anthropometric posture.
- However, the belly width is wider when sitting in car seat compared to sitting anthropometric posture.
- The thigh width is wider when sitting in a car seat compared to sitting anthropometric posture, especially for males.

The research questions, procedure and measuring setup including different positions, from the previous study at Volvo Cars, will serve as a reference for conducting the upcoming user test for this thesis project, using a better scanner and having higher resolution in the scanned images.

2.2.2 Market research

In order to understand the different aspects that contribute to the comfort and well-being of the driver while using the product, this section has collected some of the fundamental characteristics that distinguish the different types of truck seats available on the market, such as dimensions, foam design and additional functionalities and safety features. In this way, by knowing certain aspects of truck seats, it is possible to start establishing measurements and features that will help to prepare the user tests.

The following table (Table 1) shows this analysis of different truck seats, of different origins and brands that provide service to large road transport companies. Finally, this market research will be used to present, in another more summarized table, the main characteristics and ergonomic measurements of the truck seats on the market.

Table 1. Comparative Table of Current Truck Seats.

Truck Seat	Features
	**Ergo 8500/217** Air suspension, quick release, weight adjustment, suspension stroke, height and tilt adjustment slide travel, backrest adjustment, lumbar adjustment, seat cushion depth adjustment, heater. Automatic air suspension that drivers raised using a tilt adjustment.
	**Ergo 8600/237** Air suspension, lumbar support, side support, adjustable damper, height adjustment, length adjustment, back tilt adjustment, fully foldable backrest, seat cushion depth adjustment of 60mm, electric heating.
	**ISRI 6860/870 NTS** Pneumatic suspension with automatic weight adjustment, height adjustment with memory, backrest adjustment, tilt adjustment, horizontal adjustment, adjustable vertical shock-absorber, seat cushion adjustment, Integrated Pneumatic System (IPS) to ensure that the backrest fits the body’s contour, quick release, integrated 3 points belt.
	**ISRI 6860/875 NTS** Six different temperature levels to meet with the built-in seat climate control. Height adjustable seat belts, height adjustment 100 mm with memory, angulation of the back, integrate headrest, depth setting the seat cushion, angulation of the seat cushion, IPS for an individual seat-back adjustment, horizontal suspension.

<table>
<tr><td></td><td>ISRI 6860/880 NTS

Pneumatic suspension with automatic weight adjustment, height adjustment with memory, backrest adjustment, tilt adjustment, horizontal adjustment, adjustable vertical shock-absorber, seat cushion adjustment, IPS to ensure that the backrest fits the body’s contour, quick release.</td></tr>
<tr><td></td><td>Renault Trucks Seats

Pneumatically controlled seats, operational controls when there is sufficient air pressure, depending on the seat configuration, the controls are located on one side or other of the seat, head restraint, contains a button to lock it, the angle is adjustable, backrest tilt adjustment, driver’s backrest comfort settings, upper and lower lumbar support adjustment, driver’s seat heating and ventilation.

Seat adjustments: seat side support, seat tilt, vertical suspension settings, adjust the flexibility of the suspension, seat vertical suspension adjustment, height adjuster, quick air release, armrest adjustment.</td></tr>
<tr><td colspan="2">Seat specialists.

Source who dedicates to exposing and selling seats from different big firms and their manufacturers also can facilitate individuals for personalized seats. Referring to truck seats, they have catalogue seats for such brands as Mack, Volvo, Mercedes Benz, Ford, GMC, Chevy, Dodge, and much more. Also, they deliver information and options of cushions and bolsters.

The manufacturers they show, and whose information has been analyzed are: Bostrom Parts, Bostrom Seating, GRAMAG, Iowa Customs, Knoedler Parts, National Seating, National Seating, National Seating Parts, Prime Seating, and Sears Seating.</td></tr>
</table>

- **Main market features**

The table contains the main ergonomic features and measurements of all firms and manufacturers analyzed for this project. These characteristics remain to the currently common truck seat from high standards companies. For this project, the focus is on the aspect of seat width, which will be used later when creating the cushion variants. (See Table 2).

Table 2. Main market features.

Attribute	Value
General assets	Air suspension, pneumatic suspension with wight adjustment, seat climate control, and quick air release.
Adjustable features	Head restraint (angle included), backrest tilt, upper and lower back support, height, seat cushion depth, vertical shock absorber, and angulation of the back
Height adjustment	Between 60 mm and 120 mm.
Length adjustment	190 mm.
Weight adjustment	Up to 150 kg.
Cushion width	From 50,8 cm to 58,42 cm.

2.2.3 Current design

The current Volvo truck seat will be the starting point for the seat redesign and will also be used in the user tests. This design brings together ergonomics and comfort features that define the user experience when sitting in it after long hours (Figure 11). It is located in the Volvo truck cabin which is in the ASSAR building (Figure 12).

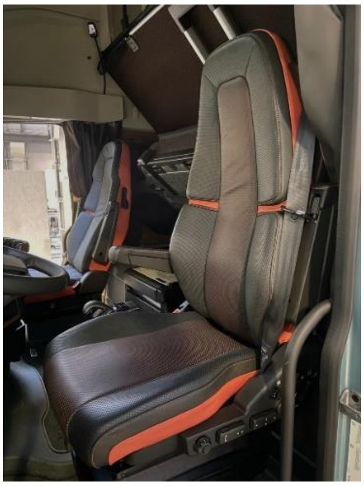

Figure 11. Current seat.

Figure 12. Volvo truck cabin.

As mentioned previously, in this project the focus is on the seat bolster part (Figure 13), the part where the buttocks are supported when sitting on it. To get a better view of the shape of this part the structure of the seat in the foam material has been used (Figure 14). With the two structures of the current design, two variants will be made in the user test step by modifying its width in order to test how the users interact with the different seat variations.

Figure 13. Current seat bolster.

Figure 14. Foam bolster structure.

The main dimensions of the seat have been measured in order to have more information about it and to start establishing and defining reference measurements for developing the two seat variants (see Figure 15).

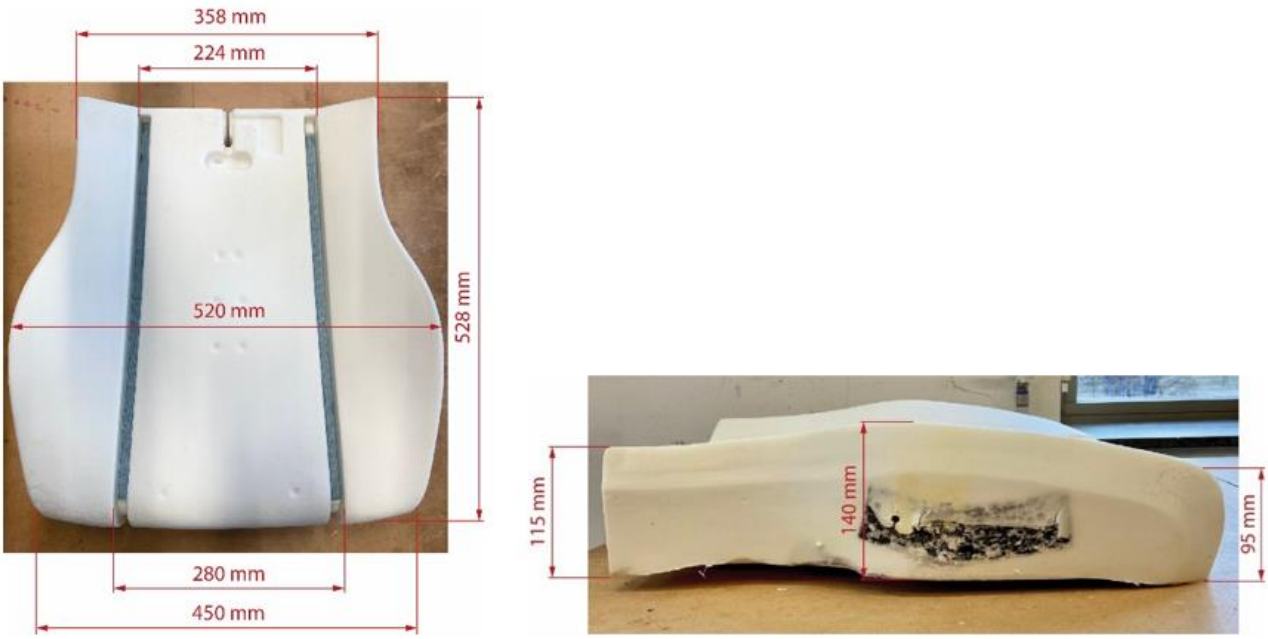

Figure 15. Measurements of the current bolster.

3 Design of experiment

3.1 Overview

The experiment was designed to study the hip width deformation in different variations of the Volvo truck seat width by using 3D technology and to analyze the hip width compared to the sitting and standing positions. This was done through a user test where participants were scanned in different postures and had to answer a subjective test conducting a questionnaire. This experiment collected 3D scans in the form of a 3D polygonal mesh model of each subject in every of the positions they were asked to perform. In addition, quantitative values were also obtained in terms of the hip measurements taken from each participant as well as qualitative values from the questionnaire. The results obtained from this test will be studied and compared using graphs to find out if there is any connection that helps to establish some general guidelines on truck seat design.

3.2 User test

3.2.1 Environment

The user test took place in a specific area of the ASSAR Innovation Centre (Figure 16). The scenario has been set up close to the cabin of the truck, as it cannot be moved, and it is essential to use it to perform the user test. All elements of the test environment have been configured in such a way they are close together to make it more suitable for me and the participants to carry out the user test because, as mentioned above, the truck cabin is not mobile, and the scanner has to be connected to a power source and the range of the cable is limited. The scenario is made up of three distinct zones in which different tasks will be performed. Each of these zones are explained in more detail below.

Figure 16. User test scenario in ASSAR.

The first place (Figure 17) is the table where one will be processing the scans on the computer, configuring the software to ensure that everything is saved correctly while the other is in charge of guiding the user test, explaining the steps to follow to the participants and interacting with them. The scanner needs to be placed on a surface where it cannot be damaged while not being used, so the table is essential. In addition, the participants will have to sign the consent document with the iPad and fill in some data on the computer, so it is necessary to have two chairs and table at the appropriate height for them to sit down and feel comfortable.

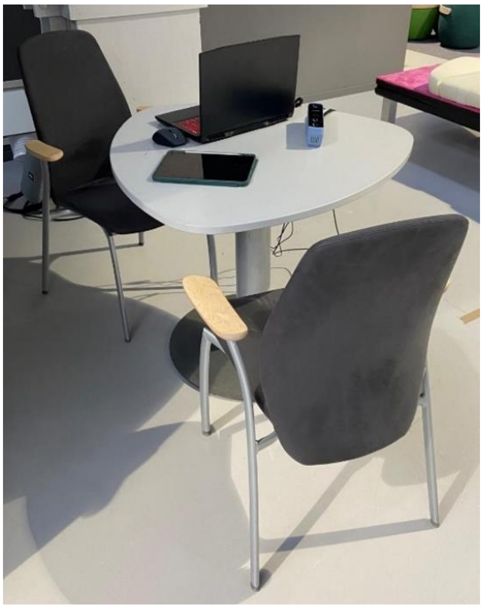

Figure 17. User test first place.

Right next to the table, with enough space for the participants to feel free to move, a tape has been placed on the floor (Figure 18). This tape will help to guide the participants to get into the same position, as shown in the picture, when it comes to getting into a specific posture.

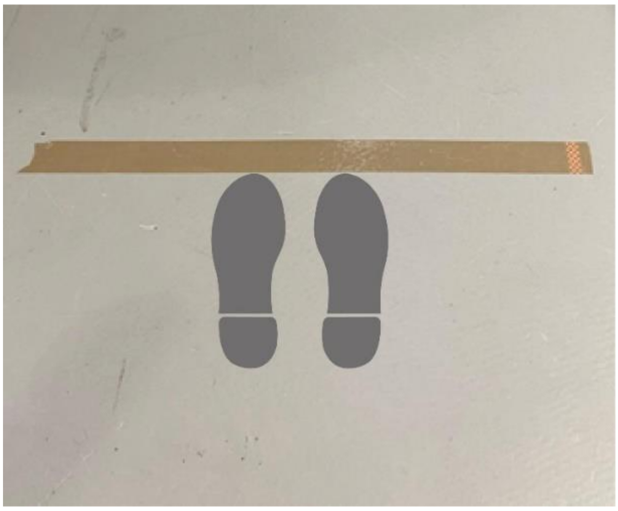

Figure 18. User test location for first posture.

One of the postures must be performed on a hard surface. For this purpose, the following structure has been used (Figure 19), which is a hard metal surface, but is covered with velvet so that it does not cause any damage to the participants.

Figure 19.User test hard surface.

The last spaces of the test are as follows (Figure 20). When testing each of the variants, one of them is the current truck seat, so users will have to test it inside the cabin of the Volvo truck. The other two variants will be tested on the hard surface, which is at a suitable distance from the floor so that the users can test the variants in a comfortable environment.

Figure 20. User test seat variants.

Ideally, all variants should have been tested in the same environment and under the same conditions. Since the fact that they are not, as the medium-sized variant has to be tested in the context of the truck cabin, may influence the participants to choose their preferred variant. This is something that should have been taken into account before carrying out the experiment, but for this project it was difficult to implement due to lack of material, as only two foam variants were available.

3.2.2 Subjects

Six subjects were selected to perform the user test, 3 females and 3 males with an average age of 21 ± 1 years. All participants were students at the University of Skövde and none of them had any injury that would prevent them from performing the user test. As mentioned in the limitations, none of them are truck drivers, but all of them had a driving license with an average duration of 3 ± 1 years. Nevertheless, they have been given all the necessary instructions to perform the user test correctly.

At the beginning of the test, they were asked to fill in a table with their weight and height data and from this data their BMI was calculated (Table 3).

Table 3. Participant's measurements.

Participant	Gender	Stature (mm)	Weight (kg)	BMI (kg/m^2)
Subject 1	M	1980	100	25,5
Subject 2	F	1660	80	29,0
Subject 3	F	1670	80	28,7
Subject 4	F	1740	78	25,8
Subject 5	M	1890	87	24,4
Subject 6	M	1740	65	21,5

From the measurements of each participant the percentiles have been calculated (Table 4) using the ANSUR II database to get a view of how extreme the subjects participating in the experiment are.

Table 4. Participant's percentiles.

		Percentiles (%-ile)		
Participant	**Gender**	Stature	Weight	BMI
Subject 1	M	99,9	84,9	30,2
Subject 2	F	69,1	87	84,7
Subject 3	F	73,7	87	82,6
Subject 4	F	94,9	83,3	56,1
Subject 5	M	96,9	56,9	21,1
Subject 6	M	41	5,6	5,3

3.2.3 Equipment

- **Test variants of seat bolsters**

To create the different test variants, first, some different factors had to be taken into account. In this case, three variants have been created, taking the current design as one of them. So apart from the already existing one, two foam models were provided for use in the project, which via cutting, were transformed in the other two variants. Only the width was modified in these foam bolster structures. The material available was only the two foam structures, so the piece of foam that was removed to create the narrow variant was the same that was added to make the wide variant.

Now the question of how much to cut came along, to figure it out, different sources were checked, the ANSUR II survey (Paquette, 2009) and the Swedish population data (Hanson *et al.*, 2009) . Once both were reviewed, it was decided to take into account the ANSUR II survey, which's population consisted in 4.082 men and 1.986 women of the U.S. Army, to cover its 5th and 95th percentile when creating the variants. The information taken from the data in both surveys is shown below (Table 5).

Table 5. ANSUR II and Swedish Population percentiles.

Population	**Percentiles**		
Hip width (mm)	5%-ile	50%-ile	95%-ile
ANSUR II Female	358	397	456
ANSUR II Male	333	378	431
Swedish Population Female	342	415	488
Swedish Population Male	310	391	473

Considering that the market research tells that the widest models go up to 584 mm, and as the 95% measurements are 456 mm, the incision will be six centimeters wide in the foam models. In this way, it is possible to test a seat bolster with a width of 460 mm, another with a 520 mm width (the current design) and another with a 580 mm width. The following graph (Figure 21), shows the representation, with a gauss bell chart, of the hip breadth in a sitting position for the ANSUR II participants (male and female) together with three vertical lines that represent the value in millimeters of the width chosen for the variants.

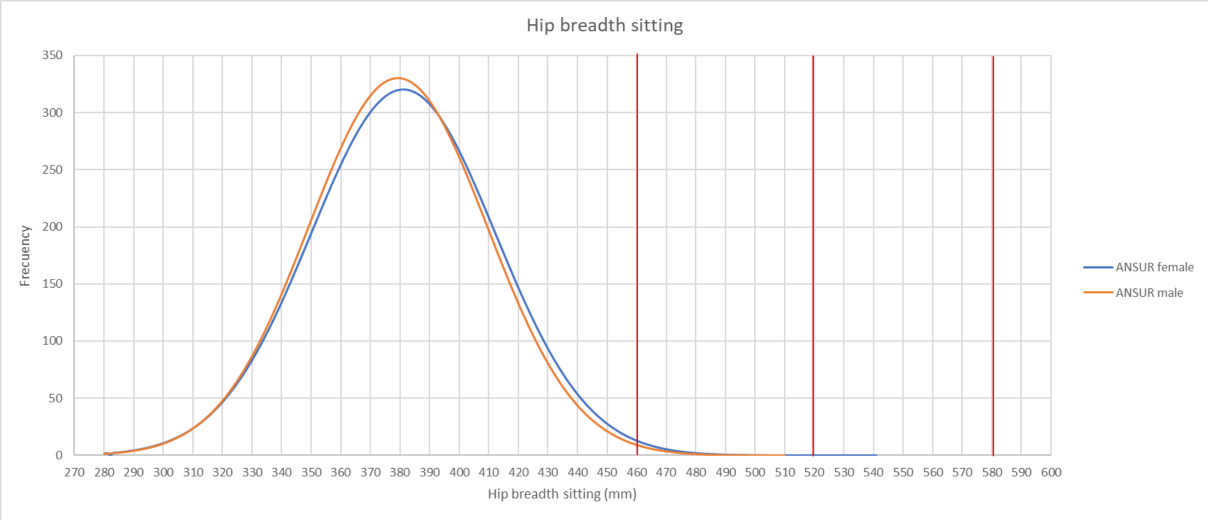

Figure 21. Gauss bell graph for ANSUR II survey.

In the graph it can be seen that the narrowest variant contains the percentile sought and that the widest one is much bigger than anyone's hip breadth in the survey, but this is something that has been done for the purpose of testing right or wrong the comfort of using really wide seats. It is also noted that the middle red line, which is the current design measuring 520 mm.

In the following list explains the process that has been followed to create the variants with pictures to help understanding the prototyping process.

- First, draw some lines to guide the cut in each foam, one line for which the foam was to be added between and two lines where it had to be removed (Figure 22).

Figure 22.Creation of variants: measuring.

- Second, take a handsaw that was able to cut the entire length of the foam model and then take gloves for security. After that, cut through the guiding lines (Figure 23).

Figure 23. Creation of variants: cutting.

- Third, after cutting, gluing the parts, for that hot glue guns were used. Following this step, the variants (Figure 24) were finished and ready to test the participants in user test.

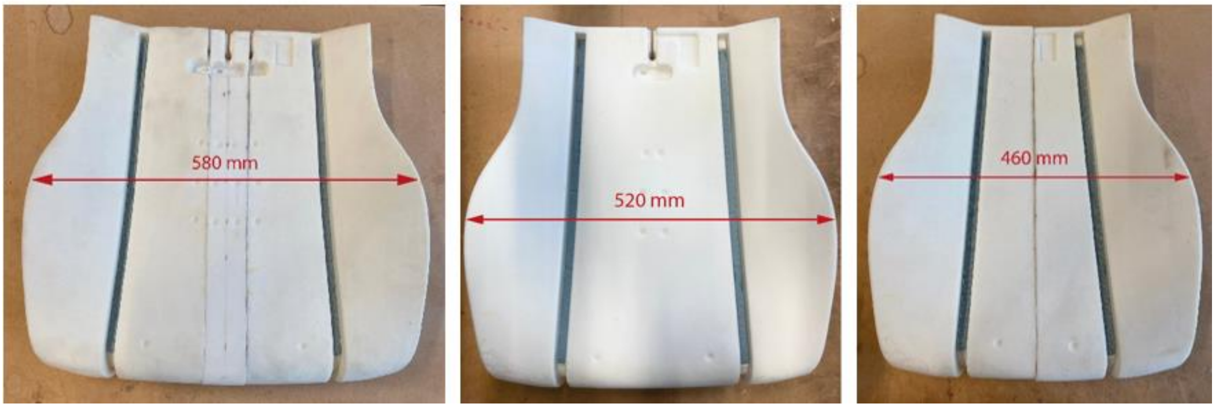

Figure 24. Test variants.

- **3D Scanner: EINSTAR Shinning 3D**

Einstar 3D scanner generates high-quality 3D data that can be used for multiple purposes. In its package is found a handheld 3D scanner with Exstar software and carrying case which included some accessories and necessary features for the use of the scanner (Figure 25). For example, the power supply wires, a board with different kind of points and white background for calibration, cloth to wipe the lenses, etc. As the technical specifications of the product show, the main characteristics to consider during the use of it are: 160 mm - 1400 mm of effective working distance and 400 mm for optimal working distance, scan speed up to 14 Frames per Second (FPS), and maximum FOV (Field of View) of 434 mm * 379 mm.

*Figure 25. Einstar 3D scanner and its package (*Einstar Portable Handheld 3D Scanner | New 3D Scanner by SHINING 3D*, 2024).*

The way it works is simple, first it has to be plugged in the computer and an electricity supply, then it is necessary to have the software necessary downloaded and then proceed with the calibration of the scanner. It is done by doing certain tasks that the software tells you, all of them interacting with the board of points mentioned above. This calibration has to be done periodically, because after half a month from the first calibration, the software notifies the user suggesting calibrating it again.

After having the calibration done, it can proceed to do the scanning processes, what is asked next is to choose the mode and resolution to scan in and then scanning can start. The program gives the user a lot of setting in order to improve the quality of the scan depending on the conditions it encounters.

The scanning activity does not involve much difficulty, but it has to be done in a slow manner so that the device is able to correctly process all the information that is being processed in real time. There are areas where the scanner needs to pass more time or more than once, such as areas where two surfaces touch each other like the seat and the legs, as can be seen in the indicated area in the figure below (Figure 26).

Figure 26. Challenging area to scan.

- **EXStar Software**

Once the software is running, a calibration of the scanner is required in order to start using it. With the calibration, the scanner parameters are recalculated and thus the accuracy and high quality of the scan is guaranteed. To carry out the calibration, it is necessary to use the calibration board, which is the white board with black dots, which can be seen in the scanner accessories of the Figure 27. The calibration process consists of pointing the scanner at the centre of the board and moving it upwards slowly with different inclinations, following the manufacturer's instructions accordingly. Once calibration is complete, the scanner is ready for use. To start the scanning process, the resolution and the scanning mode has to be selected. Regarding the resolution, it was decided to set the resolution suggested by the manufacturer and by the software, 1.00 mm. Finally, as for the scanning mode, both portrait mode and object mode were tested and finally the portrait mode was chosen, for better quality results.

Once the mode and resolution have been selected, the scan screen shows up, it contains a lot of settings that can be changed depending on the environment conditions or the aim being searched for. The one thing that was changed was the brightness depending on how close the scanner could be to the scanned person or how dark the place was, for example the truck cabin where light was not that optimal, and the space was quite reduced.

Activation of the scan is done or clicking in the button of the scanner itself or clicking in the screen, scanning process can be paused while doing it to check for mistakes or how it is going and then continue. This is because of the ability it has to continue the scan from a previous scanned point, in fact, during the process the scanner losses track sometimes, and it is possible to go back to a scanned part to continue normally. It is also possible to edit the scan, removing some unnecessary parts, for example.

After editing comes an optimisation phase, which involves the following steps:

1. First, a point cloud is created, this phase takes some time as the computer has to work on generating all the points. At this point, the scan can be edited and saved, but to be able to measure it or convert it into other file types another processing step is necessary.
2. A mesh is created from the point cloud, the mesh parameters need to be chosen to optimize and process the scan. A window appears on the screen to choose the different mesh types (Figure 28).
3. The most suitable mesh is chosen, in this case the middle one has been chosen, which covers some small holes that exist through the scan but does not cover it completely, mostly due to the long processing times it would take.

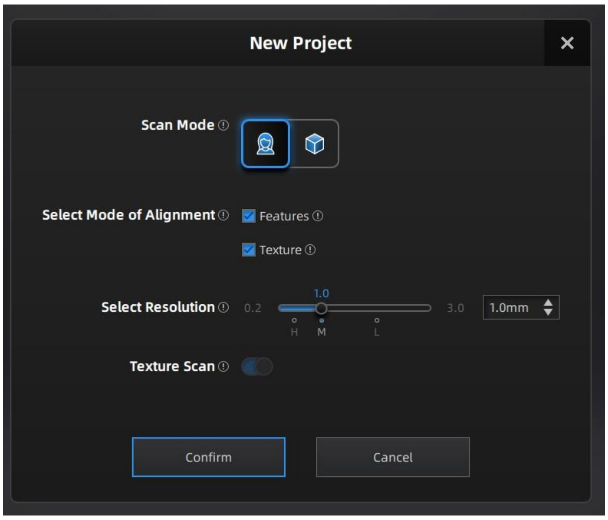

Figure 27. Scan mode selection window.

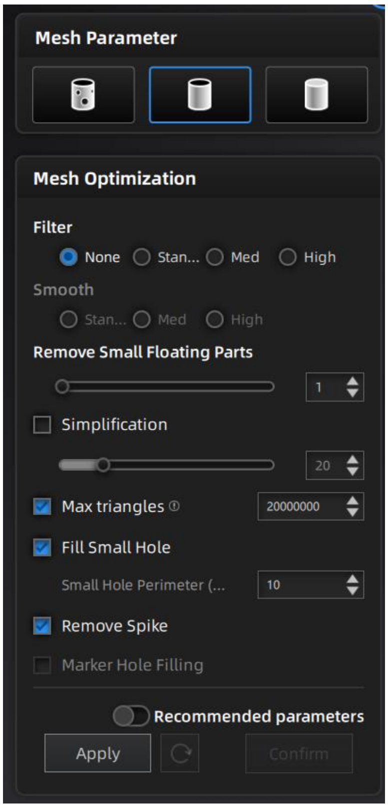

Figure 28. Mesh parameter selection window.

Then, it is possible to proceed with the measurement or use of the tools that the software gives you, also it is possible to save the scan as another type of file like. stl, .obj or .asc.

- **Metric tape**

Apart from just using the scanner to measure, a metric tape has also been used to take measurements of the hip breadth in the different postures asked to the participants in order to compare them with the ones given by the scans (Figure 29).

Figure 29. Metric tape.

3.2.4 Subjective evaluation

Aiming to be aware of the opinions of the evaluated participants, a subjective evaluation questionnaire was generated for the different seats to test. The questions were the following ones:

Q1: How does your hip and thigh posture feel? (For each seat) Rate it from 1 to 5, with 1 being very tight and 5 being very wide.

The purpose of this question is to make the participant think and rate how suitable every variant for them was. They were told that the rating was not that 1 is the worst and 5 is the best, it was said that they might find a seat very wide or very tight but suitable for them.

Q2: Which one did you find most comfortable, why, and could you rank them in order of how comfortable they were?

The aim of this one is to find the participant's preference and scan the one where they are supposed to be more comfortable, which should be the best variant for them. Also, the ranking is helpful for extra analysis information.

Q3: Do you think a change in the density of the padding would make you change your mind about the previous question?

This question aims to check that the participant is not thinking in the how the foam is and to get the awareness on if the foam has a nice density or if it would be nice to change it. Also, from this it can be concluded if a narrower seat could be better than a wider or vice versa if the density of the padding is different.

Q4: Would you like to have padding on any other part of the seat that this one does not have, and would you change the angle of the current one?

Facing a possible redesign concept of the seat, the answer to this question would help a lot.

Q5: Would you suggest a different variant to the ones you have tried, affecting only the width of them?

This question looks for feedback on if the measurements selected were enough or not and to see if a conclusion of a different solution is gotten, a redesign concept with it could be interesting.

3.2.5 Procedure

This section explains the procedure followed in the user test. For the best results, the participants were instructed at every moment in which positions to adopt, following continuous and clear indications.

First. Greeting the participant and making him an introduction to what the test is going to consist in and what the project is about, including the use of the 3D scanner and the tasks to be performed. Then, participants are asked to take a seat and read the consent form (Appendix B) and sign it. Once signed, a computer is handed to the subject with a document they could fulfil with some data that is useful for the project (exposed in the subject's section).

Second. Measuring the hip breadth with the metric tape and scanning, in a standing position. With the mark on the ground, participants were told to put the tip of their feet touching it and in the width of the shoulders. Also, they were asked to put the hands over the shoulders while crossing the arms. This is for the hands to not disturb while the scanning process is being carried out (Figure 30).

Figure 30. Standing position.

Third. Measuring the hip breadth with the metric tape and scanning, in a sitting position with a hard seat underneath. Participants were told to have the entire upper leg in contact with the surface of the seat, again the hands were asked to be in the same position as before (Figure 31).

Figure 31. Sitting position on hard surface.

Fourth. Displacement of the different variants, then offering the participant to test indistinctly and in a random order, each participant was told to start in a different variant to the others in a random order as well. Setting them in context is necessary due to the fact that the next step is to ask about comfort, so they were told them to just consider how the width affects the thigh and hip, because the models had some hard parts due to the silicone of the prototypes, whilst the current design in the cabin is upholstered and has back support.

Fifth. Proceed with the questions from the subjective evaluation while they still can try the seats. Indeed, in the first question they are asked to sit down again in each variant even if they have already tried them previously.

Sixth. Measuring the hip breadth with the metric tape and scanning, in a sitting posture on the variant that they selected as the preferred one in the second question of the subjective evaluation. This time they are also asked to put their arms and hands as in the previous scanning postures (Figure 32).

Figure 32. Sitting position in the chosen variant.

The waiting times was a fact that had to take into account during all the process of the user test. The computer needed some time to process and optimize the scan, so it was important to have a conversation with the participants during these timespans or continue with the next step if it was possible, for instance while the hard seat scan was processing, the displacement and trials of the variants could proceed.

4 Results

In this chapter the results obtained through the user test will be presented. The results obtained from the scanner will be shown in a quantitative and visual way by means of photos and tables and in a qualitative way the results obtained from the questionnaire.

4.1 Scanner Results

In this section, scanner results are shown. The following images show each of the scanned postures of one of the participants (Figure 33). These scans are already processed in the form of a 3D polygonal triangle mesh and are represented in this texture mode in order to be able to visualize the details with better quality. The results of the scans of all participants can be found in Appendix C.

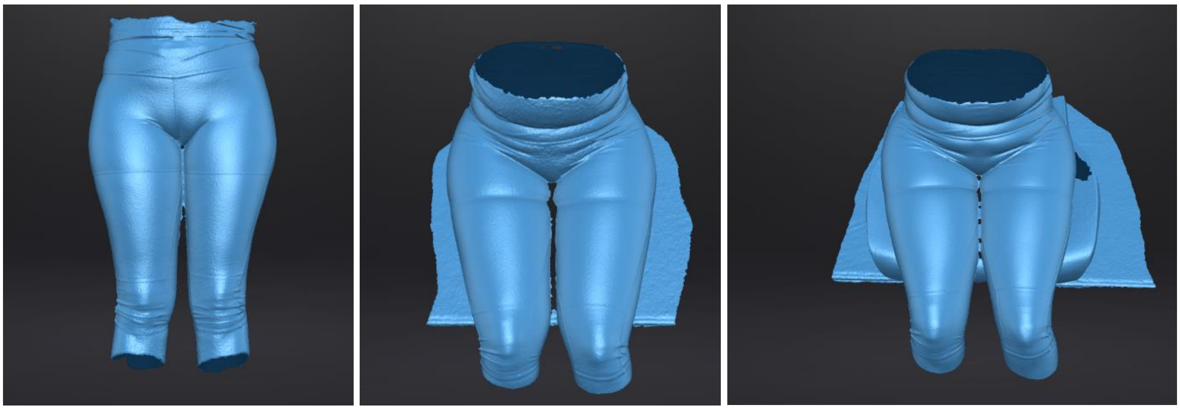

Figure 33.Visual results from 3D Scanner.

Hip width measurements have been taken through the scanner software. These measurements were taken by first aligning the scanning mesh of points with the axes and then selecting the most extreme points by matching the y, z axis coordinates at each one. Measurements were also taken with the tape measure, but have not been taken into account for this study, as the scanning extracted measurement values were more accurate than the ones obtained using the metric tape. This table (Table 6) shows the results of these measurements.

Table 6. Hip width measurements results.

Participant	Measurement in standing position (mm)	Measurement sitting on hard seat (mm)	Measurement sitting on the variant (mm)
Subject 1	399,6	434,2	467,2
Subject 2	436,5	478,9	474,4
Subject 3	411,4	472,8	469,1
Subject 4	424,9	466,7	460
Subject 5	381,1	432,7	461
Subject 6	337,8	380,4	410,3

4.2 Questionnaire results

Q1: How does your hip and thigh posture feel? (For each seat) Rate it from 1 to 5, with 1 being very tight and 5 being very wide.

Variant 1 is the narrowest, variant 2 is the middle one and variant 3 is the widest. The results are shown in Table 7.

Table 7. Values of answers to question 1 of the questionnaire.

Participant	Variant 1	Variant 2	Variant 3
Subject 1	1	3	5
Subject 2	2	3	4
Subject 3	2	3	4
Subject 4	1	2	5
Subject 5	1	3	4
Subject 6	2	4	5

Q2: Which one did you find most comfortable, why, and could you rank them in order of how comfortable they were?

To answer this question, the participants had to make a ranking between all variants and an explanation on the selection of their preference (see Table 8).

Table 8. Ranking given by participants in question 2 of the questionnaire.

Participant	Variant 1	Variant 2	Variant 3
Subject 1	2nd	1st	3rd
Subject 2	2nd	3rd	1st
Subject 3	3rd	1st	2nd
Subject 4	2nd	3rd	1st
Subject 5	3rd	2nd	1st
Subject 6	3rd	1st	2nd

Subject 1 selected the medium variant because it is an intermediate point between the other two, it holds him but does not seem loose, it does not tighten neither is there any lack of support. Then the small one because it holds quite well but it is a bit tight, and then the large one because it does not feel tight at all.

Subject 2 selected the wider variant, there is more room for movement, for longer periods of time the large one is more comfortable. She arguments choosing the small variant the second one due to its nice grip but not higher in the ranking because of it being uncomfortable in the long term. Same for the medium one but without that much grip.

Subject 3 selected medium variant, fits her more according to the hips and the padding. First the medium, then the wide, it is too wide, she does not feel the sides and then the small, it is too small and tight, many hours should be uncomfortable, she says.

Subject 4 selected that the most comfortable is the large variant, there is more freedom of movement and for a long time on the road it is comfortable, she says. The small variant is comfortable, because it supports her hips well but maybe for a long time it gets tiring because it does not allow movement. The last one, the medium seat, bothers her hips and does not support them as much.

Subject 5 selected the large wider, as the other two squeeze the sides of the hips. Then the medium and then the small, it is more uncomfortable, there is less slack, and it is too tight to spend a lot of time there.

Subject 6 the medium model because he does not feel too tight or it bothers his legs, that is to say, legs are gathered but not too tight. Then the wide one and then the small one, too tight, not comfortable for him, he prefers wider and more for longer distances.

Q3: Do you think a change in the density of the padding would make you change your mind about the previous question?

This question is about if a variation on the density of the seat would change their previous decision. All participants said it would not change theirs, it was just for subject 3 that maybe if the density was softer then she possibly would choose the smaller option because it would adjust more and be more comfortable.

Q4: Would you like to have padding on any other part of the seat that this one does not have, and would you change the angle of the current one?

Subjects 1 and 4 would not change the padding offered by the variants.

Subject 2 suggest to maybe decrease a little the angle of the lateral padding of the current seat.

Subject 3 says to remove a little bit of the front padding of the seat meaning to make it a bit shorter or lower the angle.

Subjects 5 and 6 suggest making the seats a bit longer with more padding in the front. Sixth participant also mentions lowering the angle of lateral padding for the narrowest variant.

Q5: Would you suggest a different variant to the ones you have tried, affecting only the width of them?

Subjects 1, 3, 4 and 5 suggest adding one between the medium and wide variants, but they do not see it strictly necessary.

Subject 2 says not to add any other variant width.

Subject 6 mentions to add one between the smaller and medium ones.

5 Analysis of the results

Once the results are obtained, they have to be analyzed to see if they can lead to interesting trends and conclusions useful for future truck seat designs in which body deformation must be taken into account, even though it is complicated to achieve as the sample is a very reduced number.

The following table (Table 9) summarises all the most relevant data obtained to understand and have a clearer view of the graphs shown below. In order to observe how much the hip is deformed in each of the positions and with the results of the measurement of the hip width in each position, the deformation ratio (Φ) of the measurement between each of the positions has been calculated (Columns 7,8,9).

Table 9. General data obtained from the analysis of results.

Subject	BMI (kg/m^2)	Variant selected	Hip width measure in standing position (mm)	Hip width measure sitting on hard surface (mm)	Hip width measure sitting on the variant (mm)	(Φ) Sitting on a hard seat/ Standing	(Φ) Sitting on the variant/ Standing	(Φ) Sitting in variant/ Sitting on hard seat
1	25,5	2	399,6	434,2	467,2	1,087	1,169	1,076
2	29,0	3	436,5	478,9	474,4	1,097	1,087	0,991
3	28,7	2	411,4	472,8	469,1	1,149	1,14	0,992
4	25,8	3	424,9	466,7	460,0	1,098	1,083	0,986
5	24,4	3	381,1	432,7	461,0	1,135	1,21	1,065
6	21,5	2	337,8	380,4	410,3	1,126	1,215	1,079

To see if the data obtained in the experiment follows some relationship, a series of graphs has been developed. The relations exposed in the graphs are: in Graph 1 (Figure 34), hip width with BMI and preferred variant, in the second graph, hip width ratios in all postures (Figure 35), the third graph (Figure 36), shows the hip width in all postures compared to the selected variant, and in the last graph (Figure 37), each subject is presented in relation to the variation between hip width seated hard and seated in the chosen variant.

In the following graphs, the chosen variant is multiplied by a factor of 10 with the only purpose of making it more clearly visible on the graph, as otherwise the bar would be too small and hard to see.

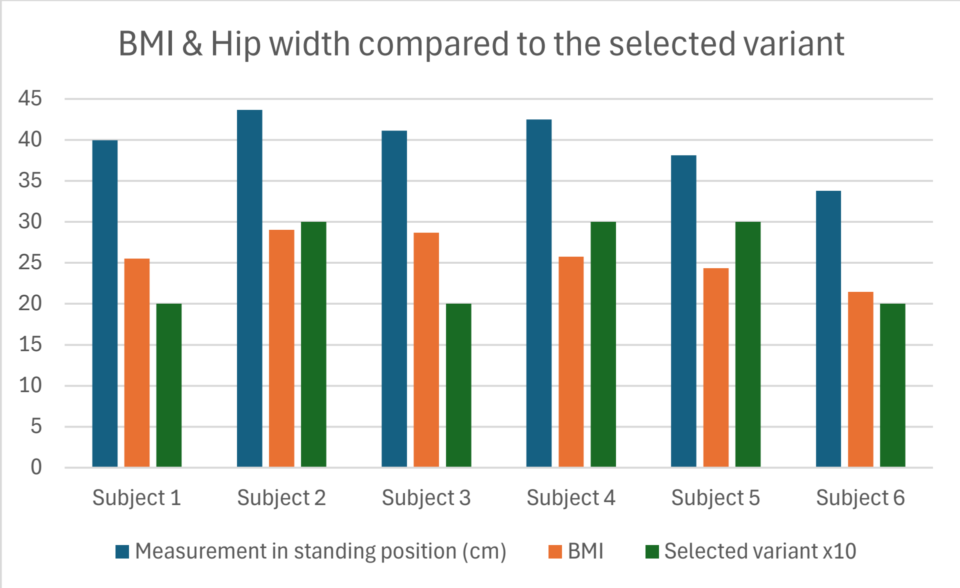

Figure 34.Hip width standing (cm) compared to BMI and the variant selected.

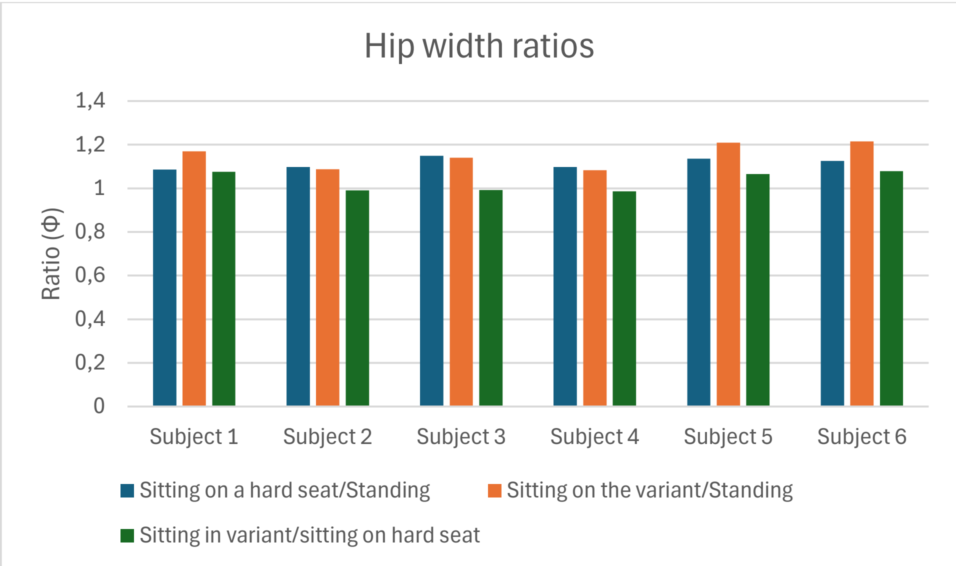

Figure 35. Φ Hip width ratios in all postures.

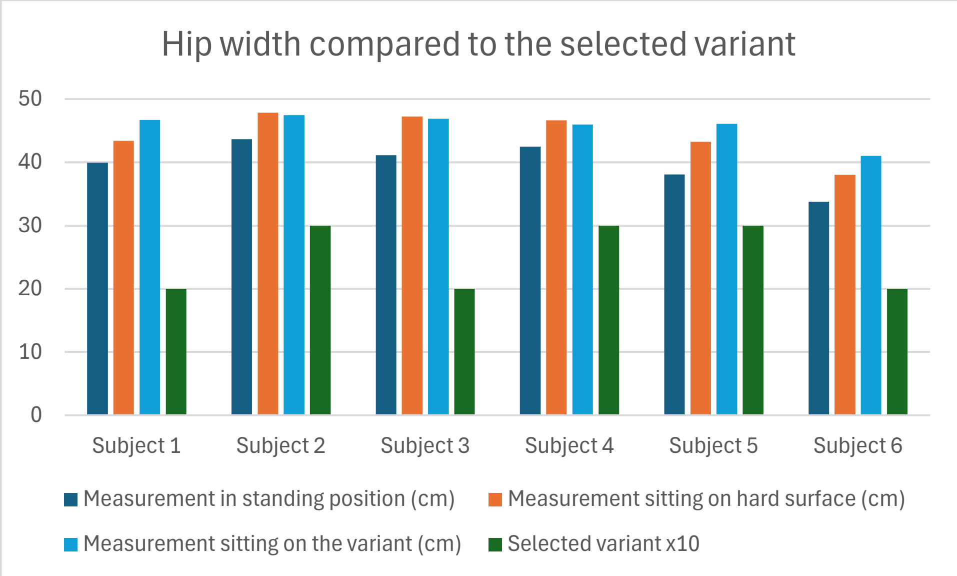

Figure 36. Hip width (cm) in all postures compared to the selected variant..

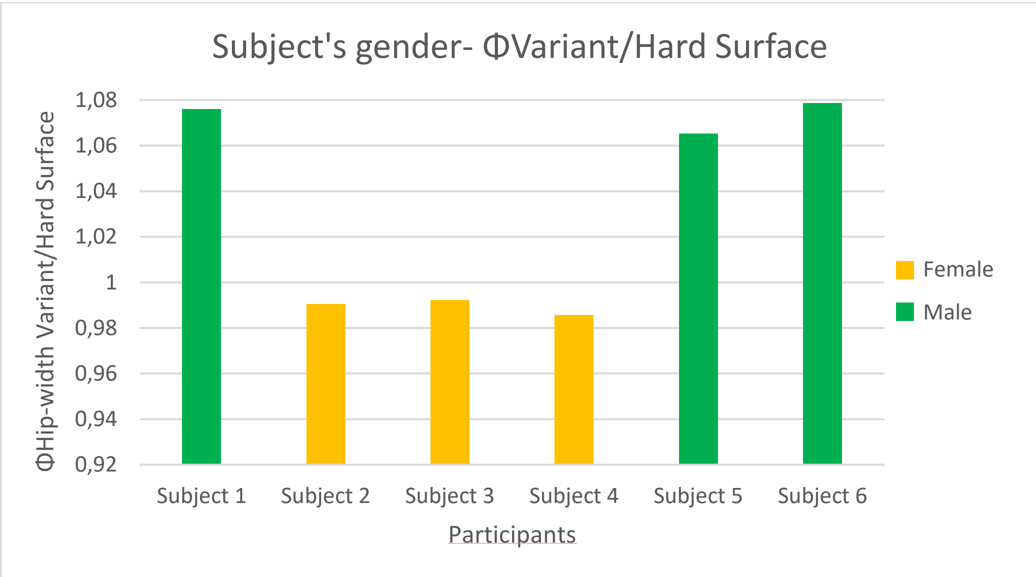

Figure 37. Subject compared to Φ hip-width sitting on variant/hard seat.

A bigger number of graphs have been done in order to analyze the data correctly, despite that, the four ones exposed above are the most representative ones for the study, as the aim of the project remains to measure hip width deformation depending on the seat used and the anthropometry of each person. Taking this into account, Figure 37 compares the subject to the variation of hip width between both seats, this is done with the purpose of exposing that the female subjects get less deformed when sitting in the variant chosen, while the male subjects are the opposite. As can be seen in the legend of the graph, subjects 2,3,4 are female and subjects 1,5,6 are male.

In addition to the graphs, analyzing the results obtained from the subjective evaluation, it can be seen that in terms of the subjects' preference for their favorite seat variant, none of them chose the narrowest variant, number 1. The widest variants were the most popular, with three people choosing the medium variant as their favorite and three others selecting the widest variant as their first choice.

5.1 Redesign guidelines

Having analyzed the results obtained from the user test, the final purpose of the project is to establish guidelines for vehicle seat cushion design based on these results. According to the Oxford English Dictionary (1996), a guideline is "a principle or criterion guiding or directing action". When it comes to design, the definition suggests a specific direction by excluding many other possible, and by implication, less suitable ones (Brink *et al.*, 2016). A guideline offers transferable and abstract knowledge which works beyond a specific case to a more generalizable set of situations.

Previously to the production of a guideline, a study is necessary, so the qualitative and quantitative data obtained in the user test will be used to fulfill it. These are the guidelines that have been subtracted:

- Concerning the width of the cushion, it needs to fit the population's whole hip. It is important for a long-time use, as a truck seat is, so to embed every user's hip it needs to be wide enough depending on the target population.

- Regarding the padding, the side angles need to have an inclination which does not disturb or compress the hips of the driver. An overly tight angle in the seat cushion may cause a very uncomfortable driving experience.

- The density of the foam is related to the width of the cushion. It needs to be soft for any type of width, but the narrower it is, the softer it needs to be.

If this redesign guidelines would be expressed as design specifications in order to be ready to an implementation into a PDS document, for the current model, the seat width should be at least 520 mm, thus covering more than the 95 percentile of both the ANSUR II population and the Swedish population. Moreover, none of the participants chose the narrowest variant, being the widest hip width taken from subjects in sitting position 480 mm. So, considering that the BMI of the truck drivers is significantly higher than the participants, in a general way, and the populations considered in the study, the seat width does not have to be narrower than the proposed measurement of 520 mm as there was just one participant that suggested a variant below it, which was the one with the narrowest hip, and as probably a wider seat width of 580 mm should not be seen as too wide.

6 Discussion

During this chapter, a discussion about the assumptions, processes, development, and results of the project is carried out. Also, recommendations about the study and its future possibilities and work are commented. The most important of the recommendations is to conduct the user test with a survey sample big enough to obtain clear trends. This addition would potentially improve the results a lot in terms of clarity and implementation to actual truck seats.

Several obstacles have been faced alongside the development of the project, in order to overcome them some skills have been developed, like deeper use of Microsoft Excel to process data and analyze the results or the 3D scanning tools like the software EXStar, which helped to process and measure all the scans performed. Throughout the sections of this chapter, the mentioned obstacles will be exposed and discussed.

6.1 Problem statement and objectives

At the beginning of the project, the problem definition was very general as it set out to evaluate the driver's posture with 3D scanning technology without specifying which areas were to be evaluated or how it was to be carried out. In addition, the objectives were very general and did not define very well what was to be achieved with this thesis.

Considering that the scanner used for this project is completely new, it was somewhat more difficult to define the objectives and the problem adequately from the beginning.

It was throughout the project, when it came to getting into the method, that modifications had to be made in the definition of the problem and the objectives, as it was difficult to know how to move forward with the thesis, due to lack of information and concepts that were too abstract. Once these modifications were made, the definition of the problem was completely established and it was based on evaluating the deformation of the hip width, as well as the objectives were more defined and concise.

The project has developed well for the aims and objectives finally set, however, in the course of the study, it became apparent how wide-ranging the topic is. Talking particularly about the interaction of body shape with a truck seat, there are many factors that affect driving posture, so it is very difficult to approach them all in the same study, but it is worth being aware of this for future developments.

The project had to be slightly modified in its extent, as a redesign concept for the seat cushion was intended, but due to lack of trends between results and time limitation for the project, this part had to be disregarded.

In the following, the main objectives of the project will be argued as to whether they have been met:

- The first objective was to perform the user test, studying the hip width when sitting using 3D scanning technology. This objective has been completely fulfilled since in this thesis a user test has been carried out, consisting of two parts, the recording of hip width measurements both standing and sitting on different surfaces, and the part where the users answered some questions by means of a subjective test in the form of a questionnaire (see Chapter 3. Design of experiment).
- The second objective of the project is to analyze and compare the data obtained from the user tests, focusing on hip width deformation. This objective has been fulfilled as the results obtained from the user tests have been represented in this thesis and subsequently analyzed and compared by calculating the hip width deformations between the different postures and by plotting graphs in order to find trends between the data.
- The final objective of the project is to develop specific guidelines for the design of vehicle seat cushions, focusing on seat width. This objective has been fulfilled as guidelines have been established based on the analysis of the results. However, due to the little conclusive information obtained from the analysis of the results, these guidelines are general and not very extensive.

6.2 Methodology

Methods are a crucial part of a project, as it dictates how the work is going to be done and provide a structured approach to the study. When it comes to design, there exist a lot and diverse methods for evaluating, comparing, decision-making and creativity.

At the beginning, this project was going to contain the creation of a new concept for the truck seat, therefore it was going to have some methods regarding the points exposed before, like the list of requirements based on top-level requirement (Wright, 1998) or brainstorming through thumbnails for the creative part. To clarify, these chapters have not been addressed owing to the limited time and a lack of firm conclusions in terms of sure trends that could provide me with the proper information to state such things as requirements.

Sacrificing the concept creating, a successful user test was done, containing its proper learning of how to use the 3D scanner and its software, the environment, questionnaire, and script in order to obtain information with the highest quality possible and provide the participants with an enhancing experience.

Moreover, the use of the 3D scanner has been found to be very advantageous compared to the use of a regular tape ruler, as the measurements provided by the scans were much more precise and clearer than the ones provided by the metric tape. In addition, the scanned information is processed to generate point clouds that can be used and analyzed for purposes such as studying the shape and deformation of the body as well as estimating sitting posture in DHM software or even to convert objects into CAD with the possibility of 3D printing.

6.3 Previous study comparison

When comparing this project to the previous investigation study by Volvo (University of Skövde, 2019), the first thing they differ in is the use of DHM tools and IPS IMMA software to fulfill their project questions stated at the beginning. This delimited the part of the study that was analyzed, so the following bullet list exposes the comparison between several similar points of both projects:

- Different measurements of interest. While in the previous study the following things were measured: Belly circumference in different sections, belly width and depth, hips width, thigh circumference in different sections, and thigh width and depth; in this project is only focused on the hip width and its variation. It would have been interesting to compare the values measured in both studies, but the ones from the Volvo's are not available.

- Different tool for measuring. The 3D scanning method is different due to both the scanner and the software used. A handhold 3D scanner has been used for the present study whilst an iPad for the previous one. When it comes down to the software, in the previous study, an external CAD software was used to generate sections in the interesting spots, whereas in the present study, the software that the scanner's firm provides was used to measure the hip width without the use of sections.

- Quality of the scan. The quality of the 3D scanner used this time is much better, it possesses a much higher resolution than the ones performed by the iPad-attached scanner camera. As the one used is unknown, it is not possible to know its resolution, but knowing Einstar 3D is 0.1 mm distance between points, the one used in the previous study must possess a longer distance between points.

- Different scan postures. The standing and sitting in anthro posture are the same in both studies, but in the previous study, the third posture is sitting on a car seat, whilst in the present one, it is in the variant of truck seat that the subject selected previously in the subjective evaluation.

- Different type of subjects. All subjects tested in Volvo's study possessed a high BMI, whereas in this project could not aim for a full sample of subjects with high BMI. In addition, in the previous study, eight people were tested, what makes a difference of two participants between experiments, as in ours six people attended the experiment.

- Results. The results concern different aspects, as they expose conclusions for all the different measurements taken. However, speaking of the previous study, quantitative data is not showed, it is visible how the measurements have been taken and which were the conclusions drawn from them, but there is no graph or table that shows the value of such measurements.

6.4 User test

As exposed in the first steps of the project, a UCD perspective has been sought through the entirety of it. With the performance of the user test, the goal was to get as much information from all the participants as possible, in order to reach the conclusions and results wanted.

For time reasons, only six participants could be gathered in the test, as aforementioned it is a small sample size to get conclusive results in the matter. Apart from this, regarding the possible sources of error faced during the user test, it is to be mentioned that two of the variants tested were outside placed over a flat surface with freedom for the legs (even though the subjects were asked not to move them), while the medium variant was the one inside the truck cabin which possessed different conditions to the rest. In spite of this, the current design is upholstered and the others not, in fact, the different parts were glued together with silicone. This was asked to be taken into account by all participants.

The user test was conducted in a very good way, no one between the subjects showed signs of fatigue. Despite that, some problems happened unexpectedly, for example, the scanner had to be calibrated again right before starting with the test. Also, there was a problem with the processing of the second scan during the second participant's test, which made it last much longer than it was supposed. Still, the user test was successful, and the participant was happy with the test.

A final recommendation to improve the user test is making its sample not only bigger, but also more accurate, meaning it to take population similar to people who work as a truck driver. It can be people who actually have this job (that is the best option) or people with similarities in the anthropometric aspects, for example having high BMI (Thiese, 2016).

6.5 Results

In Chapter 5, the raw analysis of the data is shown. There, it is visible that different coefficients were calculated off the variation between the hip width measurements in different positions, this information was also compared, by graphs, with different data obtained. The comparisons include the BMI of the participants, the variant chosen by each subject or their hip width.

At this point is where the project finds the biggest limitation, the lack of participants, the sample tested was too small to obtain clear trends in the graphs. Some appear to be possible in the long term, but there is a lack of evidence to state them as purely certain, so they remain hypotheses.

In the other hand, the qualitative data obtained subtracted from the user test is clearer and valuable for future possibilities in the aspects of truck seat designing, as they show much more similarities than the quantitative data. Which is also very valuable but, as mentioned before, it needs to be proved by a larger sample.

6.6 Recommendations for future development

Due to the different limitations of the project, it has not been possible to develop it completely, but in the future, it would be very interesting to be able to continue with a more complete and detailed study on the basis of this thesis. By providing new recommendations and suggestions, it is possible to carry out a research and design project in which, using 3D scanning technology, great advances in the field of truck seats can be achieved.

First, the sample size should be much larger, to achieve much more representative and reliable results. A larger sample size also helps to better detect problems and less frequent issues as well as more consistent statistical analyses can be conducted.

Another thing to improve in the future in terms of how to perform the user test would be to measure each person sitting on each of the variants, as in this thesis, the subjects chose their favorite variant, and were measured in that one. In this way much more information is obtained about hip width and the deformation that occurs when sitting on different seats. Also, it would be very appropriate to take more measurements of each subject, besides measuring the hip width, take the measurements of different thigh widths. With a large number of measurements, it is possible to compare the different widths taken in the various positions, both standing and sitting on the different surfaces.

The way measurements have been taken once the scan has been performed may also be something to improve in the future. For this thesis, the scanner software was used to obtain the hip width measurements of the participants. This software has been used due to the lack of time to learn how to use a new program, but with the necessary knowledge and time, it would be very interesting to take the measurements with a program that would allow making sections to the scan. Making sections on the required parts of the scan would allow to obtain more accurate measurements.

Finally, if adapting all the above recommendations leads to conclusive and substantiated results, something that could be done in the future is to convert the guidelines established, by analyzing the results, into a real product, in case variations of the current design are needed.

6.7 Industrial Design and Product Development connection

Considering ergonomic aspects, such as measuring and deforming hip width, is crucial when designing a truck seat to improve drivers' experience after long hours of driving. By knowing how hip width performs when sitting, the results obtained can be expressed in the form of technical specifications when making a list of truck seat design requirements, as well as being able to meet many ergonomic aspects related to its design.

The use of high-quality 3D scanning technology allows an accurate and detailed assessment of the interaction between the user and the product, which can facilitate the optimization of a truck seat design to meet ergonomic requirements. Furthermore, thanks to these new technologies, more accurate results can be achieved in a more efficient and comfortable way for both the researchers and the users undergoing ergonomic evaluations or measurements.

Furthermore, in the ADOPTIVE project plan: The Work package 1, Virtual human models, includes research and development actions to generate advanced virtual human models adapted for seated posture, including body mesh deformation going from a standing to a seated posture.

By making use of the scanner in this thesis project, it is possible to extract accurate measurements that can then be implemented in generating advanced virtual human models as well as having measured the deformations of the hip width when standing and sitting, it is possible to translate these accurate estimates into virtual manikins. In addition, having also calculated and analyzed the deformation that occurs between sitting on a hard surface and sitting on a soft surface, advanced virtual human models can be generated and adapted to the sitting posture but more specifically in vehicles, as in the case of this thesis, in trucks.

Therefore, it can be said that the study carried out in this project is related to industrial design and product development, since through a practical application such as user testing and the use of new and relevant technologies in the field of the study, it can contribute to improve the user experience, to the development of future research in the field of study to obtain more conclusive and reliable results, as well as to the implementation of knowledge about body measurements in DHM tools to help design engineers to access specific measurements for the development of CAD models of seats and virtual manikins.

7 Conclusion

The main objective of the project was to evaluate the deformation and interaction of the hips when sitting on a truck seat through the use of a 3D scanning technology. To achieve this, a user test was conducted, obtaining different results which were used afterwards to analyze the data that furtherly served the study with several conclusions.

- About the ergonomics user test results and analysis:
  - The hip width in males is wider when sitting on the variant than when sitting on a hard surface, while in female it is the opposite.
  - When comparing the BMI of the participants to the variant they chose in the user test, there is not a clear trend. The small variant is the only clear thing, because no one between the participants chose it. But when it comes to the selection between the current model (medium size) and the wider variant, it is not clear if there is a relation between the BMI and their selection.

    Three subjects selected each of the two variants, and their BMIs did not follow the rule expected. Despite this, two of the one who chose the widest option possessed high BMI and the one with lowest chose the medium option. So, there is a possibility that if the study was continued with a larger sample size, a correlation might be found in higher BMIs choosing the wider variant.
  - Concerning the choice of the variant relating to the hip width in standing position no clear conclusion could be drawn as no evident trend could be observed. If the sample size had been larger, it can be assumed that the wider the hip measurement in standing position, the wider variant tends to be chosen. This was reflected in some cases in the study, but in other cases, participants with a smaller hip width still selected the wider variant.
- About the subjective evaluation:
  - It can be concluded that the most favorite variant was the third one, whilst the first was the least favorite. This is mostly because of the freedom of space and the little disturbance the participants felt when using the rest.
  - The padding did not affect much in their selections as it was okay for everyone.
  - For future possible similar trials, another variant could be done between the medium and the wide options. Even though some participants thought it was enough with the ones they tried.

- Reflections about the project:
  - It has been a real enhancement for my development as future professionals to use a new technological tool, as well, I had never 3D scanned anything, even more a person. So, this was also one of the most interesting things for us, the way the scans were made and the quality of them. With more time, a lot of things could have been done with these files.
  - Something to highlight is that in the initial phase of the project a very extensive search for information on the field of study was carried out in order to acquire knowledge and focus the project in the most correct way, since for me it was a field of study in which I did not have much experience in its first stages.

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Apendix

Appendix A Work Breakdown and Time Plan

The following diagram (Figure 38) is the original Gantt Chart that was made at the beginning of the semester before starting to develop the Final Degree Project.

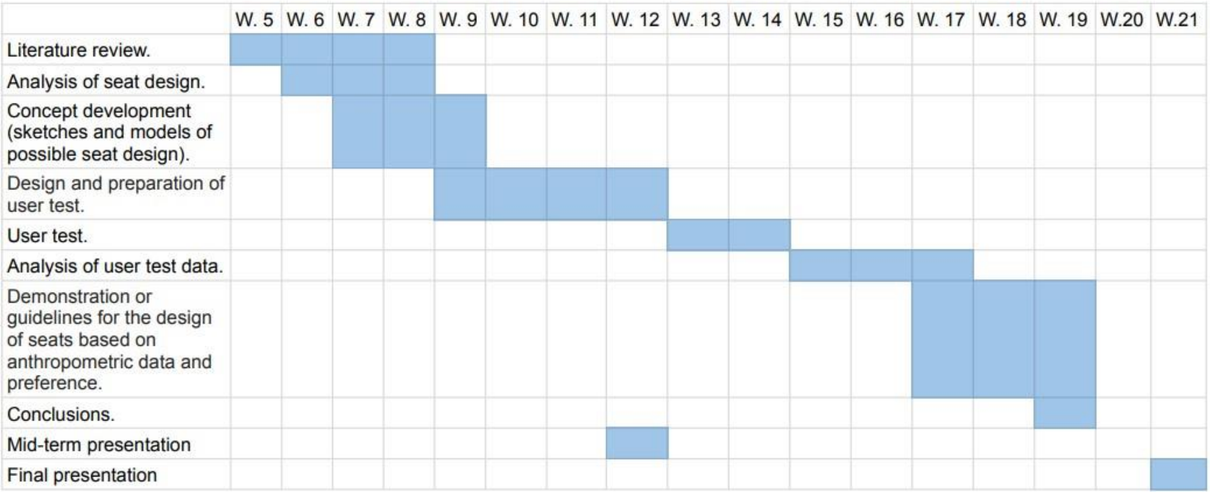

Figure 38. Original Gantt Chart.

The figure below (Figure 39) shows an updated Gantt Chart of how the project has been carried out.

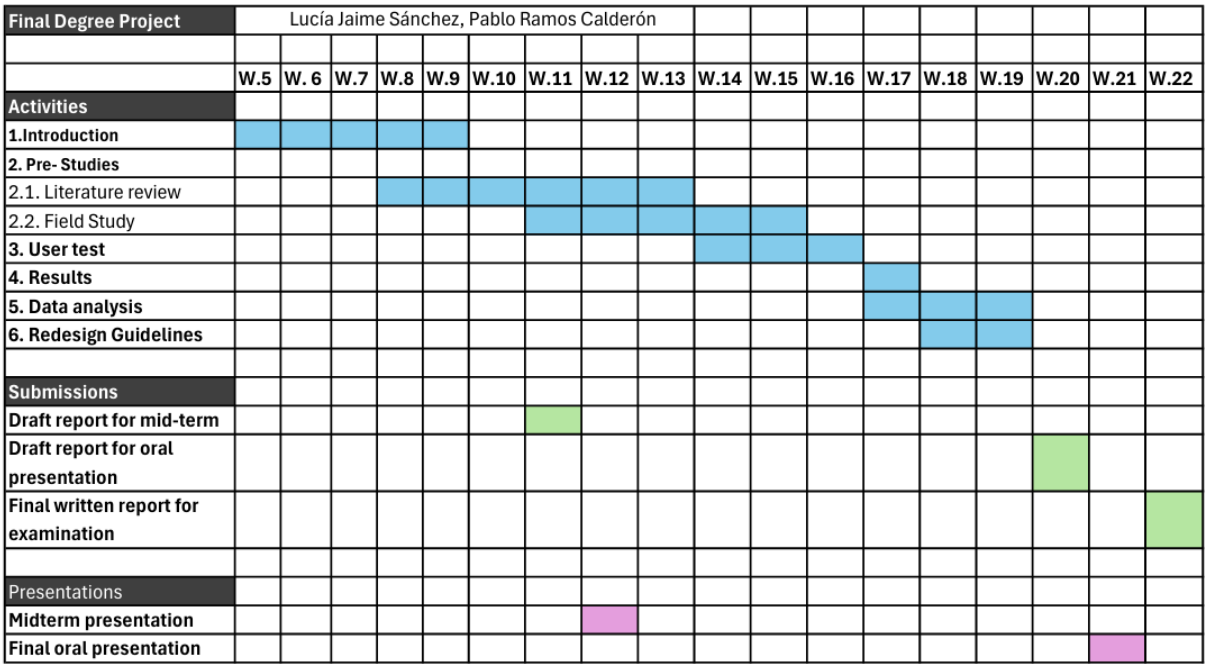

Figure 39. Updated Gantt Chart.

The project has undergone significant changes in terms of the procedure to be followed and the time dedicated to each phase, which has influenced the execution and direction of the thesis. Both the order and the steps that were established at the beginning had to be changed because they were not sufficiently adequate for a successful development of the project.

The steps to follow can be seen to be very different from those established at the beginning. Since, after the midterm presentation, it was recommended to change a little the direction of the study, establishing a more adequate methodology for my project. Therefore, after doing the field study, the user test was carried out to reach the redesign guidelines with the data obtained and analyzed from the experiment, eliminating the concept development part of my project.

In addition, the literature review required more time than expected, as it was an unknown field of study for me, I had to search and learn about different topics, so the theory phase was longer than planned, with a good purpose as it was necessary to acquire a lot of knowledge to make a good execution of the project.

Although the changes are too many from the beginning to the end of the project, I consider that they have been necessary in order to achieve successful results through a proper order of the activities.

Appendix B Consent form

Consent form for participation in User test study.

Background and purpose: The purpose of this study is to use 3D scanning technology and get understanding of user interaction with different truck seat variants from an ergonomic point of view in today's automotive industry.

Procedure: In this study, you will be asked to stand in different positions (standing and sitting on a hard surface) to take your hip width and scan your hip area in each position. In the second part of the test you will be asked to try sitting in the three variants of the truck seat and you will be asked through a questionnaire to answer questions related to the ergonomic design of the three variants. Afterwards you will choose your favourite variant and you will undergo the same measurements and scanning as in the previous positions. Video and audio may be recorded during the development of the test.

Risks and benefits of this study: It is my opinion that participation in this study is not associated with any risks, and there is no anticipated benefit of participating in this study. Your participation is completely voluntary and can stop participating at any time without explanation or negative consequences.

Results: The information collected will be solely used for research purposes. Any data collected will be de-identified and thus not associated with the individual results of each participant. Anonymous data may be shared publicly, and the final results of this study may be presented in the form of scientific publications, conference presentations, or theses works.

Contact: If you want to contact someone regarding this interview, please contact Lucía Jaime Sánchez or Pablo Ramos Calderón, who are responsible for this study.

Lucía Jaime Sánchez, Bachelor Student Product Design

School of Engineering Science, University of Skövde

b23lucja@student.his.se, +34 671251007

I have been informed about the study and <u>agree to participate</u>. I am aware that my participation in the study is fully voluntary and that I can stop my participation at any time.

Place, date	Signature	Name
	Researcher	Researcher Name
	Researcher	Researcher Name

Appendix C

This Appendix shows the visual results of each participant's scanned postures.

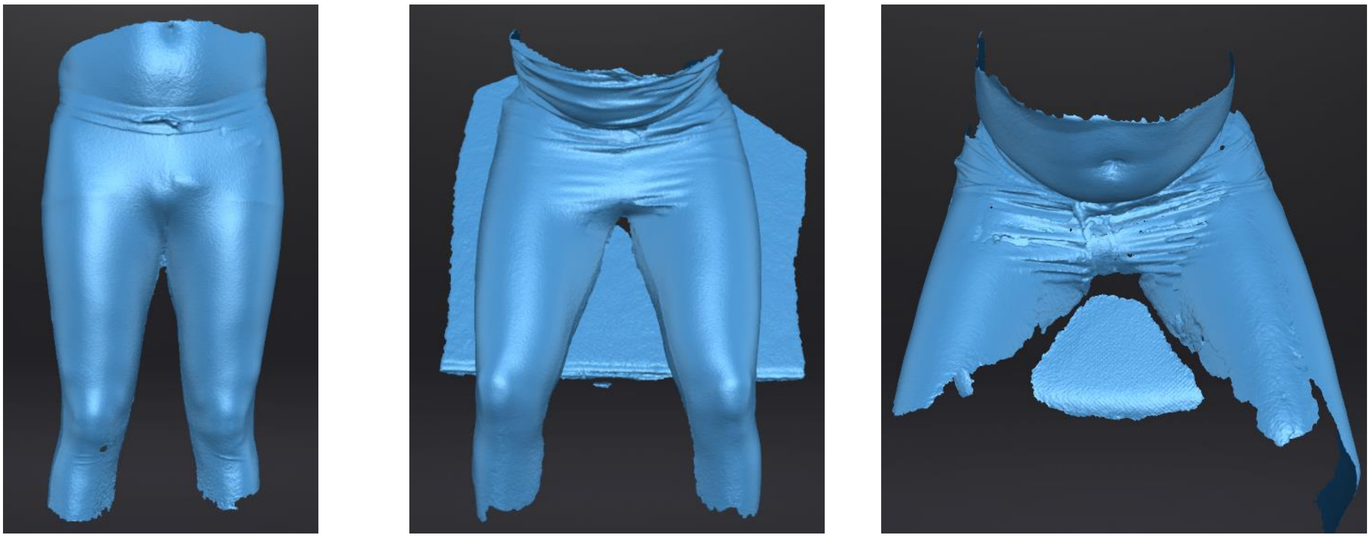

Figure 40. User 1. Scanned postures.

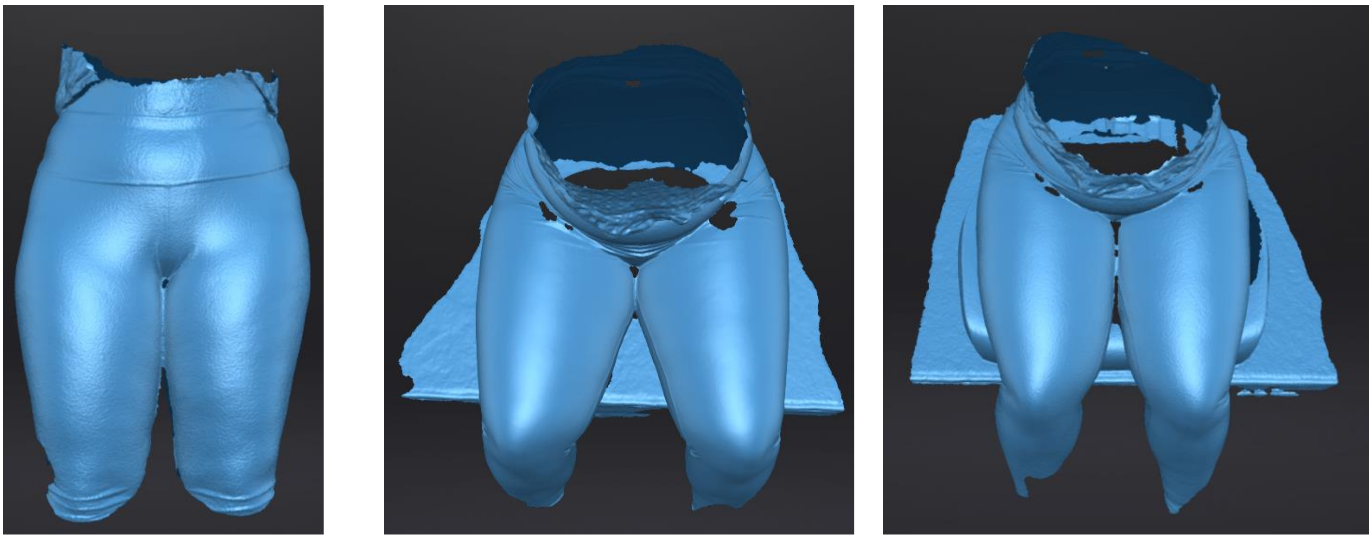

Figure 41. User 2. Scanned postures.

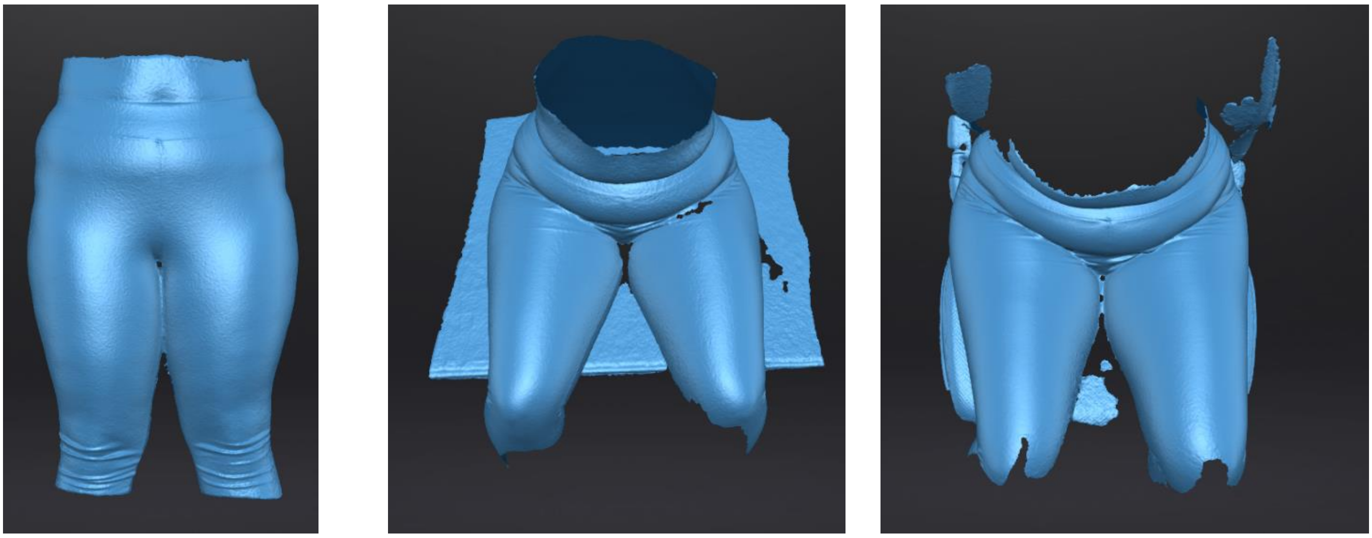

Figure 42. User 3. Scanned postures.

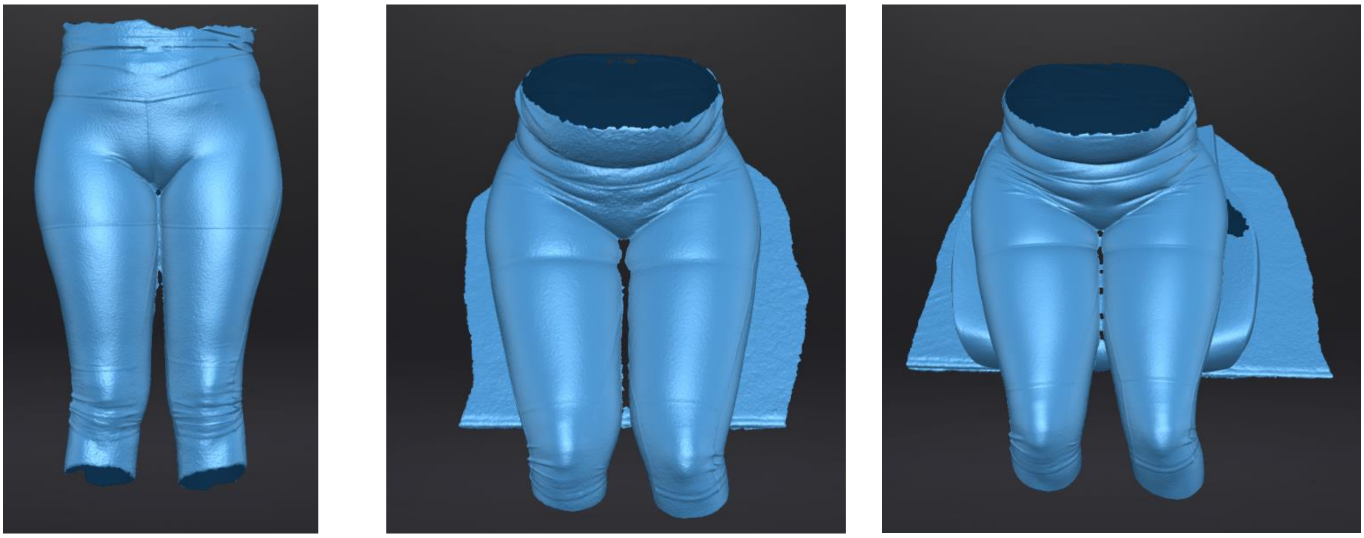

Figure 43. User 4. Scanned postures.

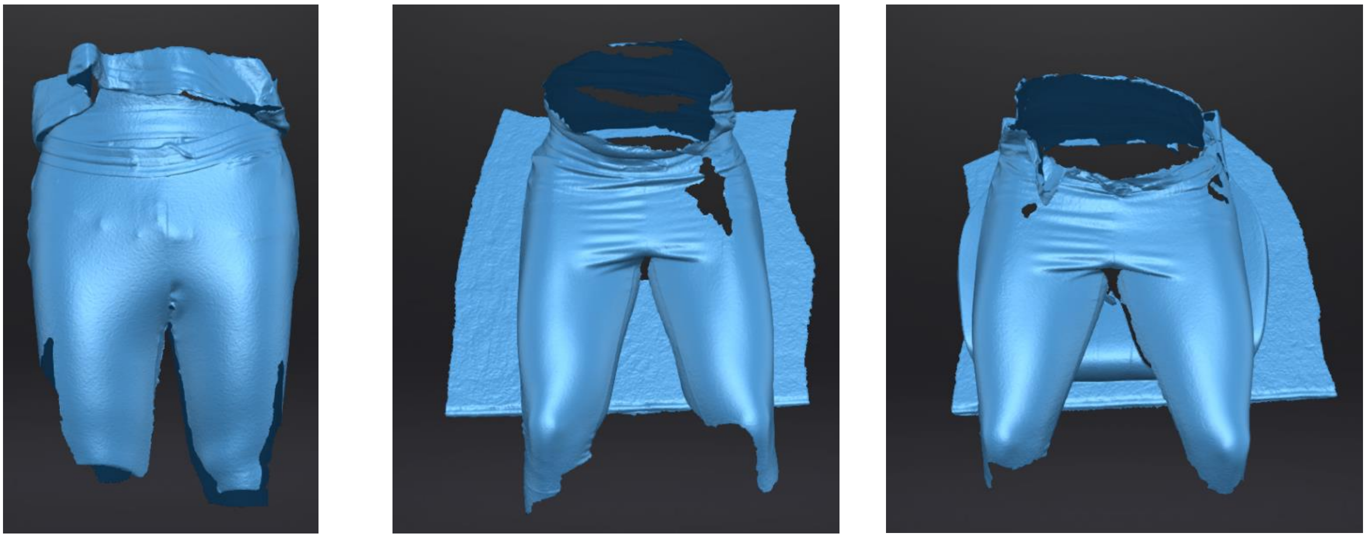

Figure 44. User 5. Scanned postures.

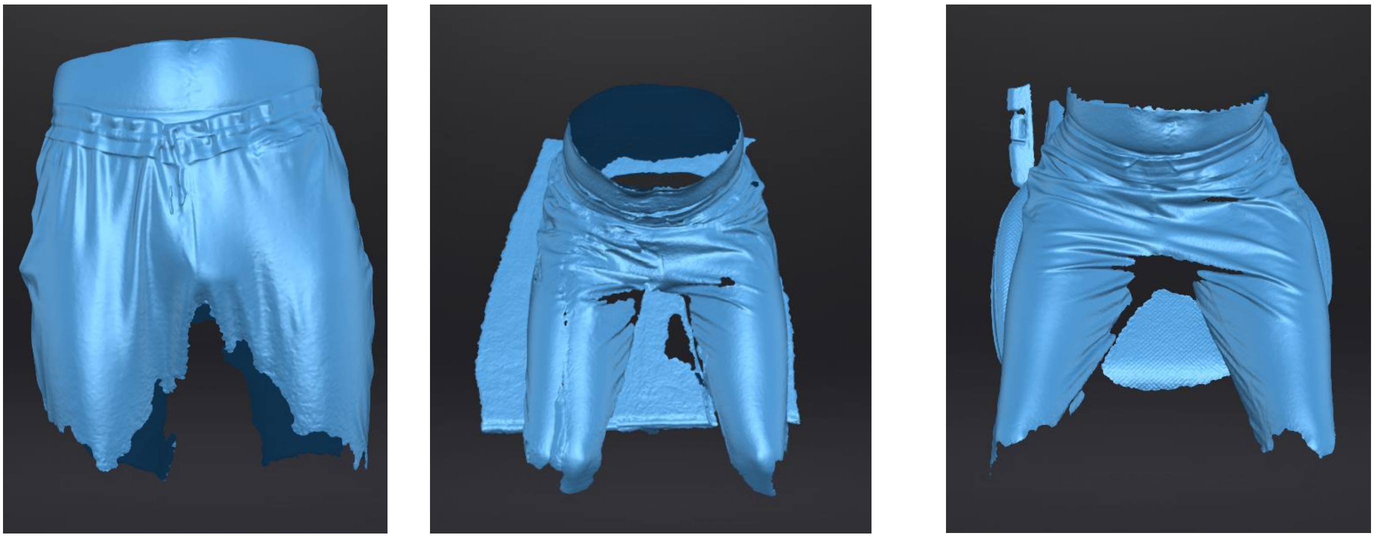

Figure 45. User 6. Scanned postures.

Appendix D

This Appendix presents the extreme points taken from the hips to get the measures.

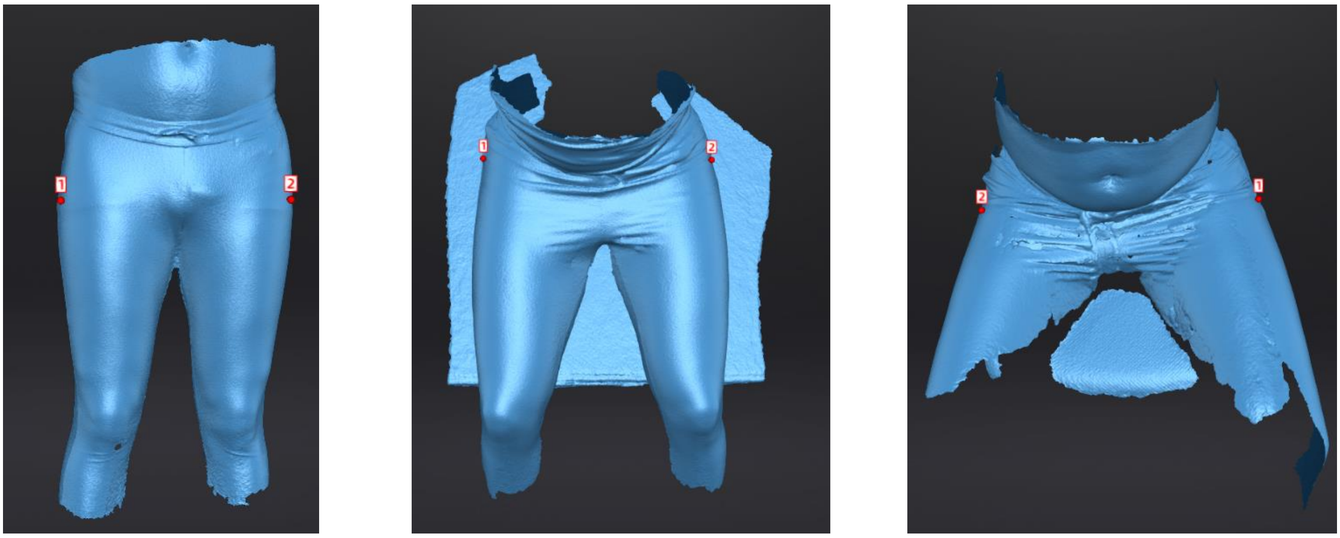

Figure 46. User 1. Hip points for measuring.

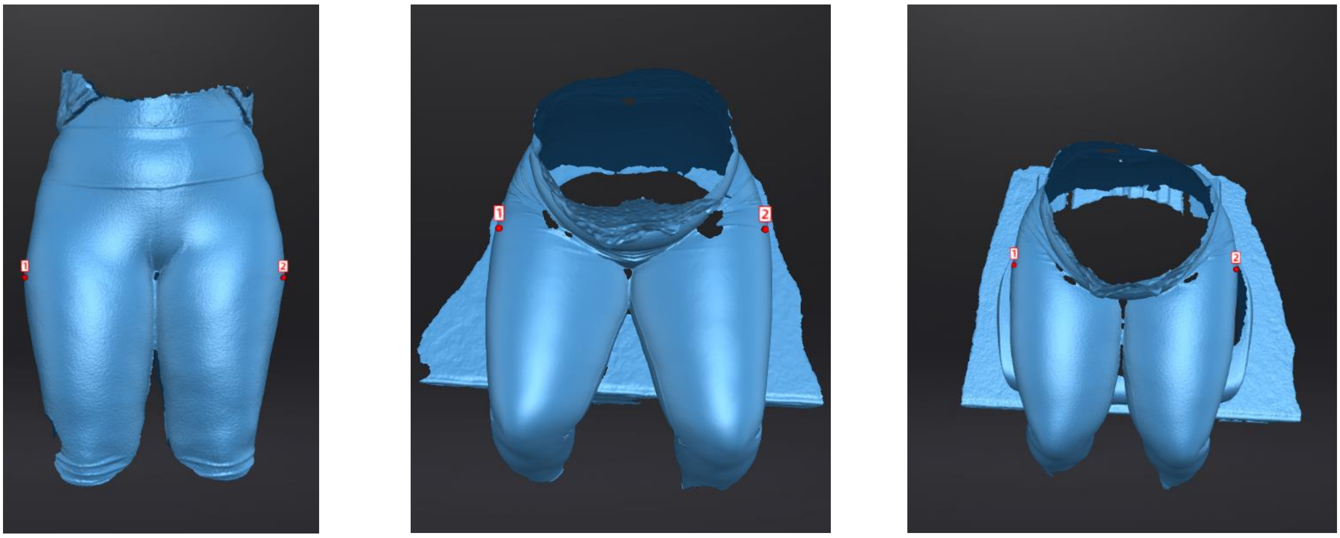

Figure 47. User 2. Hip points for measuring.

Figure 48. User 3. Hip points for measuring.

Figure 49.User 4. Hip points for measuring.

Figure 50. User 5. Hip points for measuring.

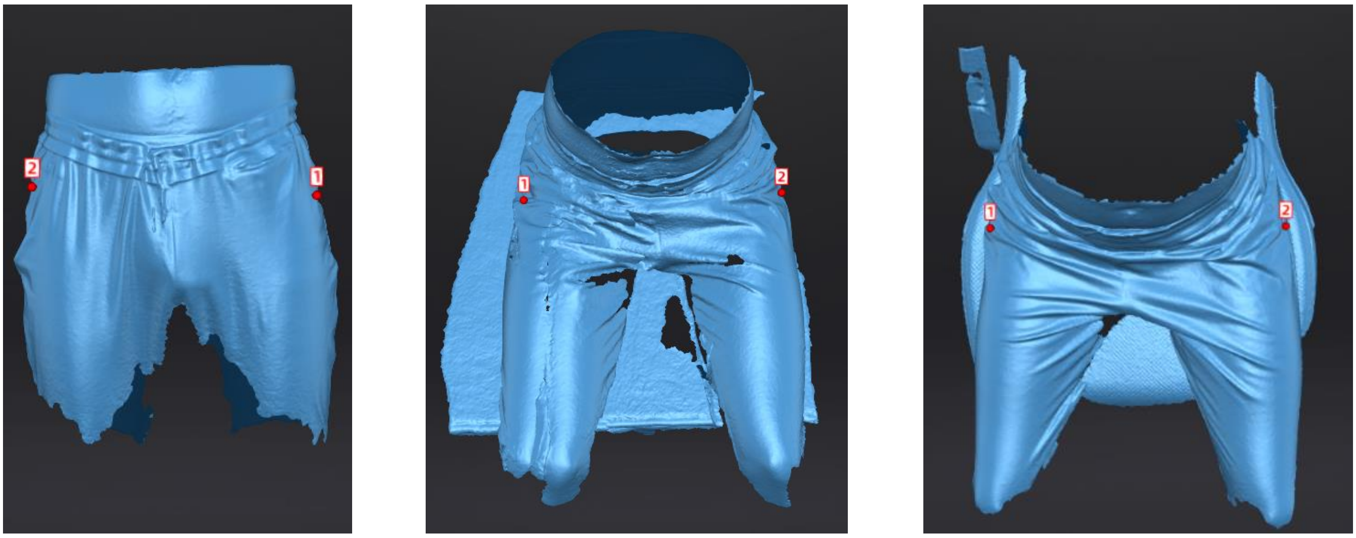

Figure 51. User 6. Hip points for measuring.