moopi

MASS-CUSTOMIZED 3D PRINTED HOME OFFICE DESK CHAIR

Maximiliaan Morres

Master Thesis

Graduate
Maximiliaan Morres
5279046

Master Thesis
MSc. Integrated Product Design
Faculty of Industrial Design Engineering
March 2023

Supervisory Team
Chair: **Peter Vink**
Department: Sustainable Design Engineering

Mentor: **Lyè Goto**
Department: Human-Centered Design

Company Mentors: **Leon Zondervan** & **Koen Hoofd**
Zon & Hoofd Design

University
Delft University of Technology
Faculty of Industrial Design Engineering
Landbergstraat 15
2629 CE Delft, the Netherlands
info@tudelft.nl
www.io.tudelft.nl

Company
Zon & Hoofd Design
Volmarijnstraat 144b
3021XX, Rotterdam

Acknowledgements

Many people have supported me during the completion of my graduation project. This project would not have been possible without their help. I would like to thank the following people for all their support and meaningful involvement in the project.

Leon Thank you for being such a kind and helpful mentor throughout my internship and Master Thesis. Your excitement really helped me stay motivated throughout my project and in moments of self-doubt. Your ability to say the right things at the right moment is one of the reason why I appreciated your input. I always enjoyed to exchange thoughts, brainstorm on ideas, learn from the way you look at problems and prototype the test chairs together with you.

Koen Thank you for being such a kind and helpful mentor throughout my internship and Master Thesis. Although we only have met online, I enjoyed the brainstorm sessions and discussions we had. Your sharpness kept me on my toes throughout the whole project, motivated me to not cut corners and think of every detail of the chair. I have experienced your critical thinking and structural approach as helpful and inspiring.

Peter Thank you for your support and guidance throughout my Master Thesis. Despite your crazy schedule, you still managed to find the time to give valuable input, share your creative way of thinking and your enthusiasm for everything related to sitting with me.

Lyè Thank you for your support and guidance throughout my Master Thesis. Your knowledge and expertise on anthropometry were incredibly helpful for the development of the chair. You helped me to connect with various professors and experts which were of great value.

Bert Thank you for your support and patience. You helped me tremendously with my user tests and setting up the kyphometer.

My parents Thank you for all the support throughout my years of studying. You gave me the opportunity, freedom and help to develop myself to the person I am today.

Machteld and Raph Thank you for always being there for me. I could always rely on your support in stressful times and you pushed me stay motivated.

Executive summary

As remote work becomes increasingly popular, many people are working or studying at their dinner table while seated in a chair that does not adequately support them or is not appropriately sized, leading to various physical complaints. Traditional office chairs are often big and bulky, and their design does not complement home environments. Additionally, adjusting these chairs correctly can be challenging since users often lack knowledge on how to do this and how to maintain a healthy posture.

The objective of this project is to design a parametric chair that is both simple and beautiful, using customer body characteristics to create a mass-customizable 3D printed chair. This chair should fit seamlessly into the user's home environment while being personalized to their body. It is essential to obtain a thorough understanding of the home office worker's context and the definition of a healthy posture. This ergonomic knowledge is used to convert body measurements into a bucket chair design that provides the user with support in various postures while maintaining a comfortable and healthy posture.

The first step of the project involves analyzing the context of the home office worker. This includes studying the basis of chair design, conducting market research, and studying literature and expert interviews to understand what constitutes a healthy posture and what user characteristics must be considered. The findings from this analysis are then validated through a questionnaire to gain a better understanding of the user's context. A chair prototype is also developed to perform various user tests and to develop the backrest shape of the chair using a variety of different back shape measuring methods. Once all the important chair parameters are identified along with their corresponding body measurements, an algorithm is developed to create a personalized bucker chair shape. The resulting chair shape is 3D printed and user-tested.

It is crucial for a chair to allow for posture variation and provide support and comfort in forward, upright, and slouching postures while maintaining a natural spine curve to promote healthy posture. Due to time constraints, the backrest and support have been prioritized in development as they are crucial factors in achieving this goal. By positioning the lumbar support at the top of the pelvis, reducing the height to the underside of the shoulder blades, and limiting the width of the chair to not extend beyond the arms, users have enough freedom of movement of the upper body while rotating the pelvis forward to maintain a natural spine shape. The backrest angle and lumbar support are crucial in achieving balance while sitting, which is also a fundamental factor for healthy posture and sitting comfortably.

The algorithm generates a functional 3D-printed prototype with all elements personalized to the body dimensions of the intended user. Future research and testing should focus on validating the backrest design, improving the body measuring method, developing the seat pan and buttock bowl, addressing the comfort aspect of the chair, and creating a customer journey for ordering the chair.

moopi

Figure 1: moopi prototype chair in a home office environment

moopi

Table of contents

1 Introduction

This chapter serves as an introduction to the project and its context. It provides details about the project's scope, main objective, and focuses on the design topic.

1.1 Project introduction

As our homes and workspaces have evolved, so has the design of our interiors. From the old, static wooden interiors of the past, our homes now reflect a mix of old and new design movements, infused with innovative technologies (Rathore, 2022). This applies to our workspaces as well, with office chairs having advanced from simple, flat wooden seats to adjustable, material-advanced, and ergonomic designs (Figure 2 and Figure 3). This because we have gotten more aware of the importance of our health and posture variation which is evident in the development of office chairs.

The recent pandemic has resulted in even more workers transitioning to home offices. While remote work can create challenges for work-life balance and lower organizational connections (Robertson & Vink, 2012), it also offers benefits such as improved work-life balance, greater work efficiency, less commuting, and improved work control (Ipsen et al., 2021). This means we are spending more time sitting in various chairs in our homes, including kitchen chairs, office chairs, sofas, floors, stools, and anything else with a relatively flat surface. However, not all seating options are designed with comfort and health in mind, and often people choose chairs based on design rather than ergonomic benefits (Hendren, 2022). There is a need for office chairs that provide the necessary support while still fitting into the aesthetics of our living environments.

Figure 2: Vintage office chair and

Figure 3: Herman Miller Aeron office chair

1.2 **The assignment**

As many people are working from home nowadays, many people spend long periods of time sitting at their kitchen or dining table. While ergonomic office chairs are designed to provide proper support and promote healthy postures, their bulky design and difficult adjustments often makes them a less attractive option for those who want to maintain the aesthetics of their home environment. As a result, many people end up working on chairs that are not suitable for extended periods of use, increasing the risk of musculoskeletal disorders such as back pain (Putsa et al., 2022).

To address this issue, this project aims to create a beautiful, yet functional, parametric chair that is mass-customizable and can be 3D printed later. The chair will be designed based on the body measurements of the user and will take into account ergonomic principles to ensure healthy posture and comfort while working in the home office environment.

The technical and design aspects of the chair have already been researched and developed in a previous graduation project. This project will therefore focus on the ergonomic aspects of the chair and how to translate body measurements into a 3D printable design. The research will start with a review of existing literature on chair design and healthy posture, and will be followed by studies specific to the home office environment, including the behaviours, needs, and requirements of the users. A series of protype types will be created to explore different chair shapes to evaluate which method and shape is most effective. The findings from this research will inform the design of the chair, including the shape and algorithm that will be used to create a 3D printable model. The final product will be tested for effectiveness and comfort.

moopi - Chapter 1: Introduction

Figure 4: moopi prototype chair used by user in home office environment

2 Context

This project revolves around five main topics which set the context for the study. These topics are home office workers, sitting posture, office chairs, ultra-personalization, and 3D printing. In this chapter, each topic is briefly introduced along with their relevance. In the subsequent chapters, these topics will be discussed and researched in more detail.

2.1 Home office worker

The concept of a home office refers to a designated area within a person's residential space that is designated for work purposes. This concept has gained popularity in recent years, particularly with the rise of self-employed individuals and remote workers, who have been increasingly prevalent as a result of advancements in technology and the global Covid-19 pandemic. In addition to shift in workforce, there has also been a trend towards smaller living spaces in urban areas (Studio FA Porsche, 2020). This might be driven by factors such as the rising cost of living and housing (Walton, 2022) and has resulted in a need for more flexible and multi-functional living spaces that are better suited to individual needs.

However, for those living in smaller living spaces or shared residences, the lack of a dedicated room for work purposes can pose a challenge. As a result, individuals may be forced to work from their bedrooms or other shared spaces, such as the kitchen or dining room (Figure 5). This is a common experience for many remote workers, who may not have access to a dedicated office space and must instead work from a living area. For example, I am currently writing this report from a shared home, where I am working at the kitchen table due to the absence of a dedicated office space.

Figure 5: The home environment of a home office worker

2.2 Sitting posture

As our homes become more multi-functional, our furniture needs to adapt as well. Home office workers often work at kitchen or dining tables and sit in chairs that may look aesthetically pleasing or be inexpensive but are not designed ergonomically (Kotowski et al., 2022). These chairs are designed only for comfort and basic sitting functionality. However, with the increasing use of kitchen chairs for both work and leisure activities, it is important that they support our bodies in maintaining a healthy posture.

Maintaining a healthy posture is crucial when sitting for extended periods. The traditional definition of a healthy posture involves sitting upright, as this is what is taught in our upbringing and schools (Tilman, 2022). When individuals are younger, they may not pay much attention to their sitting habits, as their bodies are still adaptive and can tolerate more (Alexander et al., 1991) (Figure 6). However, as individuals grow older, posture and support become increasingly important. This is because their bodies age and become more sensitive to discomfort and pain, making it more challenging to maintain good posture without support (Alexander et al., 1991).

Figure 6: An example of a younger invidual sitting with poor posture for a long period of time

Individuals may not have been formally taught how to sit correctly, but they can educate themselves by searching for information online. Recommendations found through internet searches often suggest maintaining a static posture, sitting upright, facing forward, relaxing muscles, and taking regular breaks (Huizen, 2022). While there is nothing inherently wrong with maintaining an upright posture, little emphasis is placed on the importance of posture variations. The significance of posture variation is discussed later in this report.

2.3 (Office) Chairs

As more individuals work from home, they have a variety of seating options. Chairs come in all kinds of different variations with each their own characteristics and features. The type of chair that is best suited to a user is dependent on factors such as personal preference, physical condition, and work requirements. Normal chairs and office chairs tend to encourage a passive posture, whereas dynamic options like stools, balancing balls, and knee chairs require the user to maintain their balance and promote posture changes, reducing the negative effects of sedentary behaviour (Ellegast et al., 2012).

Kitchen and dining chairs, as well as simple office chairs, are commonly found in home offices (Kotowski et al., 2022) (Figure 7). However, they tend to have limited adjustability and have rigid structures with varying degrees of padding for comfort (Scholten, 2022). Office chairs, in particular, can range from basic chairs with armrests, adjustable height, and an office chair leg frame to advanced ergonomic chairs with customizable lumbar support and other features. Unfortunately, research shows that many users are not properly instructed on how to adjust their office chairs to their specifications, leading to poor posture and discomfort (Tilman, 2022; Scholten, 2022). However, these experts also indicate that if an office chair is set up correctly, it should not require further alterations afterwards.

Figure 7: Basic kitchen and dining chairs and a simple office chairs

2.4 Ultra-personalization

Ultra-personalization is a trend in which products and services are designed to meet the specific needs and lifestyle of consumers, for example creating bespoke clothing tailored to the size and shape of user (Figure 8). With the advancements in digital technology and manufacturing techniques, user data can be rapidly transformed into customized designs.

In the context of office chairs, ultra-personalization offers an interesting approach, given the wide variety of options available and the diversity of human bodies. Each individual is unique, with differences in size, weight, shape, and sitting habits (Kroemer & Kroemer, 2016), making personalization a valuable solution to accommodate these variables.

By collecting user data, such as body measurements and sitting preferences, and incorporating an algorithmic-aided design method, it is possible to develop a mass-customizable chair that can be manufactured efficiently and cost-effectively (Van den Dikkenberg, 2022). This approach not only considers the distinctive characteristics of the user but also facilitates the production of a chair customized to their individual requirements.

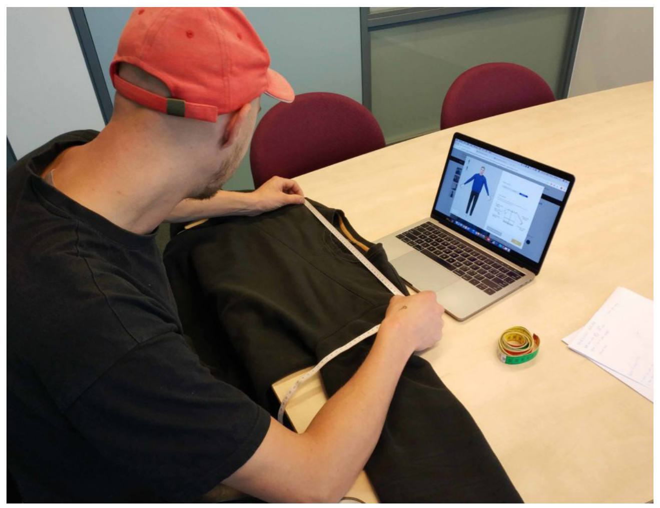


Figure 8: Ultra-personalized product that meets specific requirements

2.5 3D Printing

3D printing is a manufacturing technique that is interesting for this project. This method, known as additive manufacturing, involves the creation of a three-dimensional object from a digital 3D model. There are various methods of 3D printing, but for this project, we will be using a large Fused Deposition Modeling (FDM) printer (Carneiro et al., 2015), which allows us to print large objects (Figure 9).

The FDM printer uses a technique that deposits molten thermoplastic material from a computer-controlled moving head onto the XY plane of the print bed, and then extrudes in the Z-axis to build the object layer by layer. This approach offers precise control and a high degree of freedom in the printing process. Using an algorithm that converts user data into a 3D model, 3D printing enables the rapid production of a chair. Simplifying the design of the chair will decrease the printing duration and decrease the post-processing necessary to finish the chair.

In addition to its functional advantages, 3D printing also offers sustainability benefits. For instance, recycled plastic can be used for printing, and there are initiatives that repurpose consumer plastic waste to create filament for 3D printers, thereby reducing the need for new plastic and promoting recycling efforts (Mikula et al., 2020).

Figure 9: Large FDM printer capable of printing chairs

3 Analysis

This chapter provides an analysis of important topics for developing a personalized office chair, aimed at gaining a deeper understanding of the context. The topics covered include office chair design, market research, healthy posture, and user characteristics. The outcomes of this analysis will form the foundation for further research.

3.1 Design and technical aspects

Zon & Hoofd previously collaborated with another student on a project that focused on the technical and design aspects of the home office desk chair (Dikkenberg, 2022). This project was driven by the potential and limitations of digital manufacturing and 3D printing. By creating printing strategy, it aimed to demonstrate the feasibility of these techniques in creating a chair for the start-up client. The project included a focus on how to manufacture a chair through 3D printing, how to add comfort, and developing a brand and design identity that would fit well in the home office environment.

The final design of the project was a one-piece bucket-style chair with padding for comfort and a stylish, non-adjustable leg frame. However, the lack of adjustability or movement in the leg frame could limit the user's freedom of movement while using the chair. The current project will therefore research the value of adding an office chair frame to the design. The previous project conducted some research on how to adjust the chair to the user's dimensions, but this was limited to general dimensions found in the DINED database, rather than ultra-personalization.

The bucket-style chair, with its smooth transition between the seatpan and backrest, will serve as the starting point for the design of the chair in the algorithm (Figure 10). This chair already boasts an attractive design and has been shown to be feasible for 3D printing, so the focus of this project will be on the ergonomics of the chair and how to translate measurements of the human body into an algorithm that creates a personalized chair for each user.

3.2 Designing an office chair

Designing an office chair is a challenging task, making it essential to have a comprehensive understanding of the most critical aspects related to office chair design.

3.2.1 The purpose of an office chair

The office chair is a chair designed for use at a desk, typically in an office setting. Its design is crucial to support the user in maintaining good posture and comfort, especially during extended periods of sitting. This requires an ergonomic design and adjustment to the user's anatomy so that it fits correctly to their body dimensions. Additionally, the chair should be appropriate for the user's intended activities, ensuring that all tasks can be performed comfortably without issue. Although initially designed for office use, office chairs are now commonly used in home environments as well, requiring them to be multifunctional and visually appealing.

Figure 10: Chair design from previous design project (Dikkenberg 2022)

3.2.2 Main components

When designing a chair there are five main components that need to be considered (Jindo et al., 1995). These are the backrest, the back support, seat pan, armrest and supporting shaft (Figure 11). Each components plays an important role in the design of the chair and their function should be carefully considered. The backrest supports the user's weight, and the lumbar support stabilizes the lumbar spine and the upper body (Staarink, 1995). This decreases the muscle activity of the muscles supporting the posture, increasing comfort and reducing back pains (Groenesteijn et al., 2009). The seat pan stabilizes the pelvis and distributes pressure (Fiorillo et al., 2021). The height of the seat pan should be adjusted to the user's leg to allow for proper blood flow, and the angle of the seat pan and backrest influences stability, posture, and comfort (Staarink, 1995). In this project, armrests and supporting shafts will be disregarded despite their importance in providing support to the arms and hands and reducing spinal disc load (Rohlmann et al., 2011), as the chair design does not feature them.

Figure 11: Five main compontents of an office

Jindo et al. (1995) also identified 16 other relevant factors to consider in chair design, including whether the back rest and seat are attached or separated; the back rest form; the shape of the backrest; curve of backrest; backrest thickness; backrest fabric cover; shape of the seat; aspect ratio of the seat; seat area; curve of the front of the seat; seat cushioning; shape of armrest; cross-sectional shape of shaft; base geometry; thickness of base pieces; back support design. While all these factors should be considered when finalizing the chair design, this project will only address the factors relevant to the chair's ergonomics.

3.2.3 Not only the chair

The focus of this project is mainly on the ergonomic aspects of designing and personalizing a home office desk chair, but it is important to consider that this is only one component in a complex work environment. There are other factors that can influence posture and the performance of the chair, and if these factors are not taken into account, the chair will not perform optimally and could result in poor posture (Kroemer & Kroemer, 2016). One of these factors is the visual interface, which refers to the positioning of computer peripherals, including the monitor screen, mouse, and keyboard. It is important to adjust these correctly to ensure that the user maintains a healthy posture. For instance, the monitor should be adjusted to eye level to prevent the user from looking down, as this places extra stress on the upper back and neck (Kotowski et al., 2022) (Figure 12).

Another important factor that should not be overlooked is the desk. The height and thickness of the desk also have an impact on posture and must be adjusted to fit the user. For example, a desk that is too low will force the user to bend forward, placing stress on the spine, while a desk that is too thick will force the user to sit too low and be unable to correctly position their feet, which can also put extra pressure on the spine (Kroemer & Kroemer, 2016).

Another factor that influences posture is the specific task being performed at any given moment (Ellegast et al., 2012). The type of task being performed affects how we sit and how our body is positioned. For example, focus-oriented tasks such as writing often pull us forward, while passive tasks like watching are typically performed in a more relaxed, backward-leaning posture.

3.2.4 Comfort and discomfort

The importance of comfortable chair design in office work cannot be overstated as individuals typically spend most of their time sitting. While it is recommended to take short walks and standing intervals during work (Davis & Kotowski, 2014), a fundamental principle of comfortable chairs is that they should support the body weight of the sitting bones while keeping the feet unloaded and the spine in a natural position (Kapica and Grbac, 1998). Various factors influence the level of sitting comfort, including the shape, angle, and hardness of the seat pan and backrest, deformity of the seat surfaces, and characteristics of the upholstery such as thermal conductivity (Kapica and Grbac, 1998).

Debate exists in the literature on the difference between comfort and discomfort in seat design. Early research defined comfort as the lack of discomfort and vice versa, with comfort being a state of a person involving a sense of subjective well-being, in reaction to an environment or a situation (e.g., Floyd and Roberts 1958). However, other researchers consider comfort and discomfort as two opposite points on a continuous scale that ranges from extreme discomfort through a neutral state to extreme comfort (e.g., Shackel et al. 1969). Recent studies have suggested that the absence of discomfort does not automatically result in an experience of comfort (Vink, 2016). Comfort is associated with luxury, relaxation, or a sense of being refreshed, while discomfort is linked to physical characteristics of the environment such as posture, stiffness, and fatigue (Zhang et al., 1996; Helander and Zhang, 1997). This implies that they are different from each other and should be measured on a different scale.

In an interview with Molenbroek (Appendix D), it noted that the concept of comfort is a summary of both objective and subjective assessments of a chair. Designers can influence the objective assessment by creating chairs that accommodate the anatomical needs of the population, including appropriate body shapes and suitability for different age groups. In contrast, the subjective assessment is based on the personal preferences of the user, such as a preference for soft or hard surfaces, specific colours, thick or thin support, and the size of the seatpan. These factors are particularly crucial when designing for plus-size body types.

Research by Helander (2003) indicates that chair users have a poor understanding of chair 'comfort', and it is necessary to define the concept when evaluating comfort levels. Therefore, Vink's model (2016), which is based on the research of Zhang et al. (1996) and Helander and Zhang (1997), is recommended for measuring the comfort level of a chair. Discomfort, on the other hand, is a well-understood concept that is associated with pain, tiredness, soreness, numbness, and fatigue due to the passage of time (Helander, 2003).

Figure 12: Influence of the pheripherals on posture: monitor not at eye level and desk too low

3.3 Market research

Conducting market research helps to gain a better understanding of the types of office chairs available on the market, as well as their strengths and weaknesses.

3.3.1 Conventional office chairs

The conventional office chair is the most commonly used chair in the working environment. These chairs can either be classified as static, dynamic or synchronized. Even though they are the most popular chair, they can have a negative effect on the user as they maintain a static posture which leads to discomfort, fatigue and block the movement of bodily fluids and with it the supply of nutrients (Staarink, 1995). Dynamic chairs, on the other hand, allow users to rock backwards and forwards and prevent postural fixation, reducing discomfort and back muscle activity (Kroemer & Kroemer, 2016). Adding a swivel function (rotation) allows for even more posture changes which has a beneficial effect on low back pain by reducing pressure on the nucleus pulposus (Van Deursen et al., 2001). Synchro-tilt chairs are becoming more popular due to their ability to tilt the backrest and seat assembly at the same time (Figure 13). Today's office chairs are more adjustable and dynamic, which enables users to work for longer periods without discomfort (Groenesteijn et al., 2012).

Figure 13: Conventional office chair with sychro-tilt

3.3.2 Knee (balancing) chairs

The knee chair is designed with a tilted surface where the body weight is mainly supported by knee supports (Figure 14). Its purpose is to promote an erect spine and 'natural' lumbar curve by tilting the pelvis and supporting the knee and lower leg (Vaucher et al., 2015). Balancing knee chairs allow the user to balance their posture, and when their body weight shifts backward, the chair reclines, while it moves forward when the user leans forward. This promotes a more active sitting experience. However, the effect of gravity causes the user to slide forward which leads to pressure on the knees and can cause pain, and muscle fatigue (Vaucher et al., 2015). As a result, this chair does not promote a relaxed leg posture which is required for ergonomic sitting (Kroemer & Kroemer, 2016).

Figure 14: Knee (balancing) chair

3.3.3 Saddle chair

The saddle chair is designed to enable the user to maintain an open hip-trunk angle and knee angle to support an erect posture similar to being on a horse, hence the name (Figure 15). Like the knee chair, the saddle seat promotes a forward rotation of the pelvis and a 'natural' curvature of the spine, which has been shown to reduce the risk of musculoskeletal problems (Gandavadi & Ramsay, 2005). Other research supports this claim, that saddle chairs are beneficial for promoting a healthy posture, particularly lumbar lordosis, which is associated with reduced disc pressure (Silva et al., 2017). However, it is also noted that the use of saddle chairs may cause discomfort in the buttocks and knee region, as these areas need to support the weight of the user (Silva et al., 2017).

Figure 15: Saddle chair

3.3.4 Ball chair

Stability balls have become increasingly popular as an alternative to office chairs to help to reduce the prevalence of lower backpain (Figure 16). One purported advantage is that they increase the trunk muscle activity, which then enhances core stability and strength. However, research indicates that there are no benefits in terms of postural or muscular activation, except for a reduction in pelvic tilt while sitting on the ball as opposed to an office chair. Additionally, sitting on an unstable surface only led to increased discomfort and potential safety issues (Gregory et al., 2006).

Figure 16: Ball chair

3.4 **Healthy Sitting**

Research on office chairs and posture has shed light on the fundamental principles of healthy sitting and the potential problems associated with incorrect sitting posture. There are various sitting positions and seating options available for users, as discussed earlier.

3.4.1 **Posture variation**

Sitting in a static posture for extended periods of time has been shown to be one of the unhealthiest ways to sit as sedentary work is related to musculoskeletal disorders (Todd et al., 2007). Static sitting postures negatively affect the fluid flow into the intervertebral discs, leading to disc degeneration, increasing the risk for lower back pain and causing muscle fatigue due to lack of activation (Wilke et al., 1999; Van Dieën et al., 1993). Additionally, sitting for long periods has been linked to increased risk for diabetes, weight gain, and discomfort (Davis et al., 2020). By varying the posture, the load on different parts of the body can be distributed, avoiding these problems.

One way to motivate posture variation is to add active elements for movement to the chair, such as a tilt and swivel mechanism. These have been proven to be effective elements to stimulate posture variation (Ellegast et al., 2012). Another way is to design the chair to enable the user to take different postures without adding complex features, for example, a lower and narrower backrest that allows the upper body to move more, or a chair profile that permits different postures for different activities. An example of this is the Wotzka auditorium chair (Figure 17), which has a curved seat that allows for various sitting positions and makes it easy to change position while the backrest provides support in every posture (Staarink, 1995).

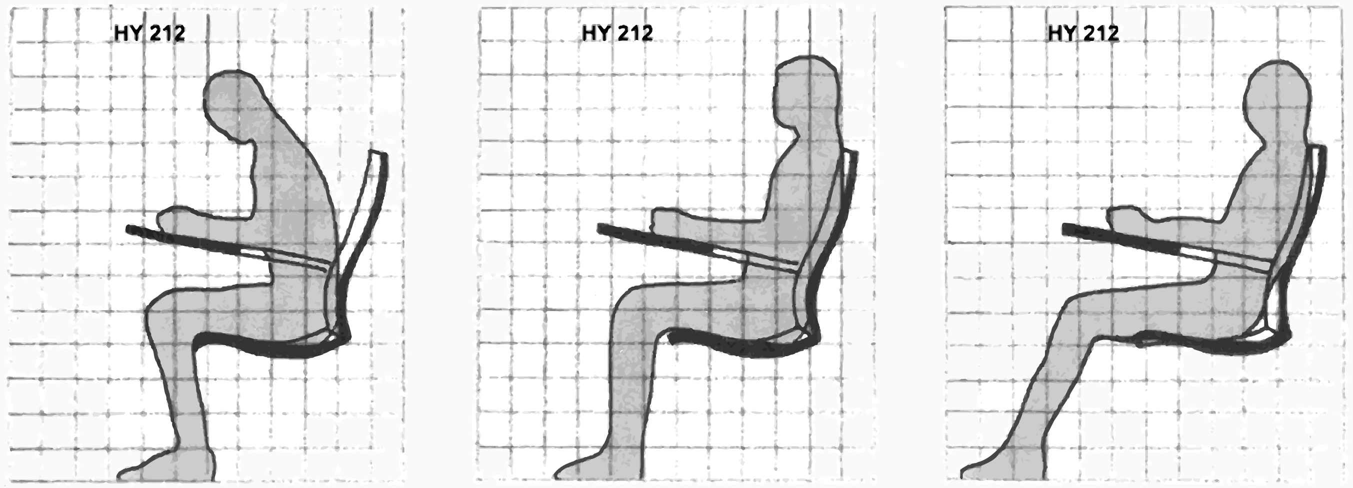


Figure 17: Wotzka auditorium chair posture variation: forward, upright, slouching postures (Staarink, 1995)

3.4.2 **Reclined seating**

Chairs were originally designed for users to sit in an upright position at 90 degrees, which is the reason why people might still think this is the best posture. However, this posture is now considered unnatural as it places the centre of mass of the body in front of the pivot point of the pelvis (Figure 17). This pulls the body forward by gravity, placing extra stress on the back muscles (Staarink, 1995). A tilted seat pan and an inclined backrest balance opposing muscle groups, help to maintain a 'natural' spinal curve, and ensure a trunk-thigh angle greater than 90 degrees, allowing for greater mobility and reduced pressure on the lungs and stomach (Staarink, 1995). Sitting in a reclined position also reduces pressure within the spinal column and shear forces on the intervertebral discs (Rohlmann et al., 2011).

3.4.3 **Size and fitting of the chair**

Office chairs are designed to accommodate the general population based the NEN 1812 and 1335 guidelines (Goossens, 1997). However, individuals with unique body dimensions or special needs may not find these chairs suitable, even with adjustable lumbar support or seat pan. The NEN guideline specifies functional requirements for the dimensions and design of office chairs. Incorrect chair setup or unfitting chairs can cause bad posture and discomfort (Kroemer & Kroemer, 2016). There are initiatives (Lodewijks, 2017) that create custom setups for people with special conditions, for example for people that are extremely short or have a very large hip circumference (Figure 19). Although most chairs are suitable for the general population, this project will also develop a chair that is suitable for those outside of norm. Finally, research has shown that if an office chair is set up correctly, there is no need to make any changes to its configuration (Coleman et al., 1998). This means that by personalizing the office chair to suit the user's needs, the chair can be set up correctly from the outset and will not require any further alterations.

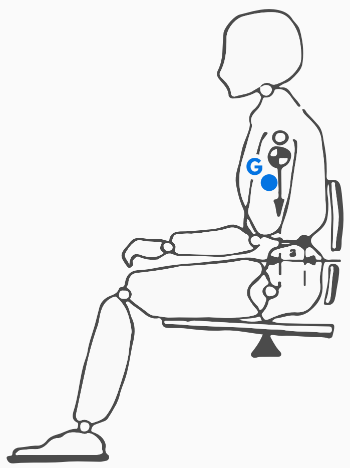


Figure 18: Centre of mass placed in front of the pelvis pivot point when sitting straight up in 90 degrees(Staarink, 1995)

Figure 19: Example of a customized office chair for large body size (Lodewijks, 2017)

3.5 **Tilman Interview**

After conducting literature study on chair design, it became clear that there are multiple approaches to creating a chair. As a designer interested in developing meaningful products, my goal is to design a chair that encourages healthy posture and sitting behaviour, not just customize the dimensions of the chair to fit the user‘s anatomy. In order to gain further knowledge on healthy sitting, an interview was conducted with Frank Tilman, founder of the ‘Zitacademy’, who has extensive experience and knowledge on the subject. The full transcript of the interview can be found in Appendix E.

3.5.1 **Pelvic balance**

Tilman’s approach to sitting correctly is centred on achieving pelvic balance and maintaining an active posture. This involves focusing on the sitting bones in the pelvis and rotating the pelvis forward to achieve a ‘natural’ spine curvature, with the muscles in the body helping to balance the spine on the pelvis (Figure 20). The position of the pelvis determines the position of the spine, and the sitting bones provide the basis for chair support. By maintaining an active posture, the user has more freedom of movement while sitting. Tilman teaches people how to find their sitting bones and balance their posture on them, as he believes that sitting healthily is not taught in schools. The final product of his project should therefore also include instructions on how to use the chair and maintain good posture.

3.5.2 **Chair balance**

For a comfortable office chair experience, it is crucial that the chair is balanced and moves naturally with the user‘s body movements. The sitting bones and balance are interconnected, with the user‘s movement being guided by these principles. The chair‘s centre of gravity also plays a crucial role in achieving balance. If the pivoting point of the chair is in the centre of the sitting bones and the centre of gravity on the seat pan, the user should experience maximum freedom of movement as the chair follows the position of the body. This balance helps maintain an active posture, reduces muscle fatigue, and prevents slouching. These components are located relatively close on the seat pan, so a large sitting area is not necessary. Only a small lumbar support is needed, and larger components surrounding the support are primarily for comfort and not essential for healthy sitting (Figure 21). Tilman emphasizes that the user needs to follow these principles for a healthy sitting experience.

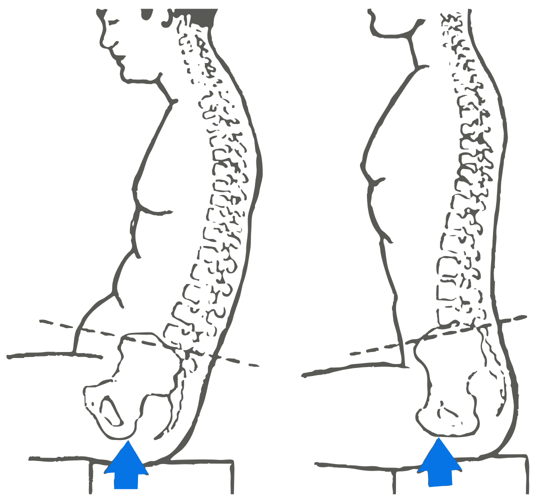


Figure 20: Example of rotating the pelvis forward to an achieve natural upright posture balancing on the sitting bones

3.5.3 **Chair design**

Tilman emphasizes that the design of a chair should start with the determination of the position of the sitting bones. This will enable other body parameters to easily be measured and translated to dimensions of the chair, for example the popliteal length for the length of the seat pan. Although his approach is debatable, using the sitting bones as the starting point will enable the development of a chair that is balanced and promotes a healthy posture. This is important because an imbalanced chair can cause discomfort and the pelvis to compensate. The centre of gravity and pivoting point can be calculated using existing research. Tilman states that the lumbar support should be positioned at the same height for every person, regardless of their height or size. It is also important to keep the chair design simple as this is more sustainable and better for the environment.

3.5.4 **Other elements**

Tilman showed a rubber pivot mechanism that is an effective and inexpensive way to add a dynamic element to a chair (Figure 22). According to Tilman, armrests are unnecessary as they disturb the sitting balance, and the user should be able to move from their pelvis. For a bucket-shaped chair, the seat pan should be convex to prevent the user‘s legs from getting cut off and to enable tilting the legs forward for better blood flow. While a soft surface may be perceived as more comfortable, it can cause the user to slouch. Therefore, harder surfaces with minimal padding are better as they allow the user to locate their sitting bones more accurately.

Figure 21: Width of finger indicate the only amount of lumbar support needed for healthy sitting according to Tilman (2022)

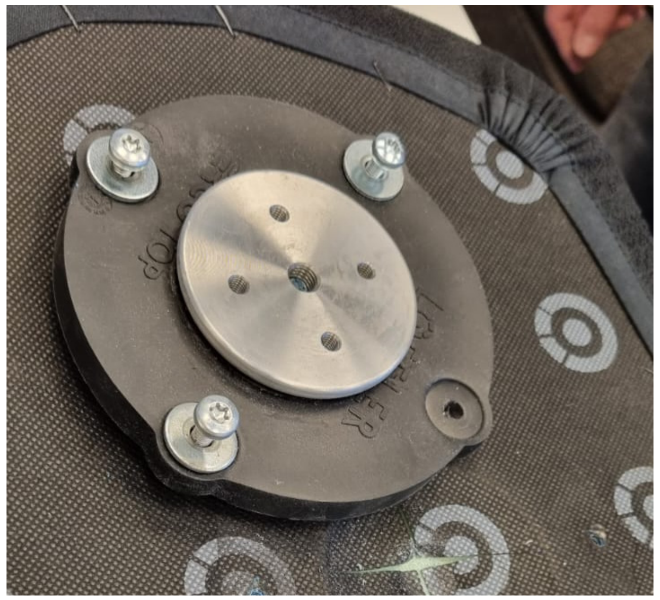


Figure 22: Rubber pivot mechanism presented by Tilman (2022)

3.6 Scholten Interview

To gain a better understanding of chairs for ergonomic sitting, a visit was made to Scholtens Werkplek, an ergonomic specialist for office chairs. While at the showroom, various chairs were tested and an interview was conducted with Hans Scholten, the owner, to obtain his perspective on office chairs. The full transcript of the interview can be found in Appendix F.

3.6.1 Balance

Scholten and Tilman share a similar vision on chair design and posture, emphasizing on the balance being the main objective of the chair. Scholten refers to this as a "biomechanical force balance", and believes that proper breathing is crucial for sitting correctly. Bad breathing will lead to a lack of oxygen to the muscles, which resulting in discomfort. In contrast to Tilman, Scholten recommends avoiding the muscle activity while sitting, as they can be overloaded, reducing blood flow and breathing. To prevent slouching, Scholten advocates for tilting mechanisms in chairs, rather than fixed seating. With a biomechanical force balance and dynamic office chair, the chair will move naturally with the body's movements.

3.6.2 Lack of knowledge

Similar to Tilman, Scholten also emphasizes that many people lack knowledge about what healthy sitting is. Due to the overload of adjustable options in chairs nowadays, people do not know how to adjust them properly, which can result in poor posture and complaints. It is crucial to invest time in educating users on how to use and adjust an office chair. The project's chair should be linked to knowledge and potential customers should be made aware of the problems associated with bad sitting and the solutions that this project provides.

3.6.3 Focus on the pelvis

To promote a 'natural' upright posture, it's essential to prioritize supporting the pelvis rather than the lower back. A saddle chair is one example of a seating option that can facilitate proper posture by enabling users to rotate their pelvis. The 'butt' curvature of the chair should follow the contours of the user's buttocks to help position the pelvis against the backrest for optimal support (Figure 23). The backrest support shouldn't fully lock the spine in one position, as it needs to be able to move. Using mesh or a similar flexible fabric will provide enough support and freedom of moment. Scholten also states that the upper part of the backrest is not as significant, as it mainly provides comfort when relaxing.

3.6.4 Other elements

Scholten emphasizes the importance of not neglecting the table, as it is just as crucial as the chair and will determine the project's success. The thickness of the table is often a problem for home office workers, as it is often too thick, forcing the user to sit too low, raising their shoulders and causing stress on their back and neck. Fabrics used on home office chairs should also be durable, as they can quickly become dirty from dirty hands after eating. Lastly, 3D printing technology has come a long way, and new design methods allow for new ways of designing chair elements, such as printing variable stiffness in the chair and variable support for weight distribution. While these methods were already discussed internally, it was chosen to keep the chair design simple to reduce the project's cost and complexity.

3.7 Interview conclusion

After conducting interviews, there were some similarities in the views of Tilman and Scholten regarding chair design and sitting. Although they used different terms, both agreed that balance is essential for sitting. The balance in both the body and the chair enables the user to sit in the best posture with the least amount of energy. The pelvis plays a vital role in achieving balance, and the chair's support should be placed on top of the pelvis to stabilize it.

They also agreed that people lack knowledge on how to sit healthily, and education is necessary. It is essential to teach users how to use the chair properly for its success. Posture variation is also crucial, and the chair design should facilitate this. This does not mean that the chair needs a complicated tilting mechanism, but movement and variation can be encouraged through the chair's design, such as the shape of the seat or by using innovative 3D printing techniques.

Figure 23: Butt curve example of an office chair with flexible fabric during Scholten interview (2022)

3.8 User characteristics

When designing the optimal office chair, the user characteristics must be considered and these include the following: anthropometry, discomfort, circulation, pelvic stability, blood flow, lower back pains and emotions (Kroemer & Kroemer, 2016). Most of these have already been address but anthropometry is an on of the main focusses of the project and getting more familiar with the topic is of the personal learning goals. When using Anthropometric Design (Van Boeijen, 2014) in the design process will ensure an optimal fit of the chair for the user using them. Doing this will help to make decisions on adjustability, size and shape to accommodate the variation in users.

3.8.1 Persona

To apply the Anthropometric Design Method, the first step is to define the user group of the chair in order to gain a thorough understanding of their needs and preferences, abilities and disabilities, and context of use (Van Boeijen, 2014). In this case, the target group of users is home office workers who work from home for at least a few days a week and wishes to have a healthy sitting solution. These users typically reside in urban areas where space is limited, and as a result, they often have to use multi-purpose spaces in their homes, such as the kitchen table and chair, for both work-related and leisure activities (Kotowski et al., 2022). Moreover, this group places high importance on design and aesthetics of their living environment and the furniture they select. Therefore, they may prefer not to have a large and bulky office chair in their living space, as it may not complement their existing interior (Studio FA Porsche, 2020). Additionally, this group is typically highly educated and interested in technology and ergonomics; without this knowledge, they may not understand the idea behind this chair or the benefits it provides over a basic dining chair. Finally, this group can be categorized as having a mid to high income, given that the chair is relatively expensive, with a price range of €500 to €750 (Van den Dikkenberg, 2022), as compared to an entry-level ergonomic chair priced at around €300 (Bureaustoel Express, 2023).

The user group for this chair can be divided into three age categories, each with their own distinct characteristics, abilities, disabilities, and demographic variables (Figure 24). The biomechanical needs of each group are the most interesting as this change significantly as individuals age. Younger (24-30 years old) are able to adapt to a new chair quickly, as their bodies have a high tolerance for sitting for extended periods of time (Alexander et al., 1991). However, in the middle age group (30-45 years old), users may start to experience physical complaints and become more interested in healthy sitting practices, with greater knowledge of how to achieve it. Finally, the last group (45+ years old) consists of experienced adult workers, who are most likely to experience physical complaints and have a lower tolerance for poor posture. As such, they require a comfortable and supportive chair (Alexander et al., 1991).

3.8.2 Home office worker observation

The context of use relates to posture, movements, sequence of movements, socio-cultural influences, artefacts, and the physical environments of the user. These were studied by conducting user observations of home office workers while they were at work. Two participants, age 30 and 51, were observed for duration 6 and 3 hours without intervening or distraction them from their work. During the observation, notes were taken and afterwards these could be clarified in a conversation with the participant. The aim of this user observation was to get a better understanding of home environment in which these participants work, the activities they perform and how these influence their postural behaviour and their sequence of movements in their chairs. The full results can be found in Appendix G.

Target group	Characteristics	Abilities	Restrictions (dissability)	Demographic Variables
24 - 30 years	• End of studies • Starters with work • Young adults • Young couples living together (small living spaces) • Part-time / full-time workers • Fitter, younger bodies	• Get adjusted quickly to a chair • Can sit for longer periods of time in a 'bad posture' • Higher body tolerance	• Might not be able to afford the chair	• Urban smaller areas where they need a multi-purpose chair • More fashionable type of interiours
30 - 45 years	• Adult workers • Home buyers (bigger environments) • Family starters • Start having physical • complaints towards the end • Full-time workers • Big diversity in bodies, from small to big	• Less of a body tolerance for bad sitting postures • Have more knowledge on how to sit healthy • Sit for medium periods of time	• Might already need decent support to sit	• Starting to furniture own houses with bigger living spaces • Urban and suburban areas
45 - 67 years	• Adult workers (experienced) • Home owners • Families or leaving houses • Physical complaints • Part-time / full-time workers • Older, worn out bodies, starting to generate older men bodies	• Having physical body com-plaints • Little body tolerance for bad posture • Need comfortable and supportive chairs • Short periods of time seating	• Not able to sit in own natural position • Constant discomfort pains or other physical problems	• Larger living spaces • Already have furniture • Country side, suburban areas

All	• **Mid to high income**
	  ▪ Mid to higher class working society
	• **Design-oriented**
	• **Tech / gadget savy**
	• **Ergonomic interests and needs**
	• **Lack of space**
	  ▪ Urban areas
	  ▪ Multi-purpose space usage (e.g. chair)			

Figure 24: User group devided in three groups with their abilities, disabilities, demographic variables and overall characteristics

Artifacts and environment
Both participants set up their workspaces cleanly and made efforts to ensure they were as ergonomic as possible. They placed an external monitor at eye level, and one participant used an external mouse and keyboard. However, despite having an external monitor, one participant tended to look down at her laptop screen on the desk while working, which resulted in neck flexion (Figure 25). Both participants fit correctly under the desk, but the top surface was too high because of thickness of the desk and a poor setup, causing their shoulders to raise to fit their arms over the desk. Finally, both participants were concerned about the aesthetics of their home environment and therefore used this as consideration when purchasing their chairs.

Activities
Both participants primarily performed in computer work, occasionally interrupting their work with phone use or light snacking. No leisure activities were observed during the test, which may have been because the observations were being conducted during work hours. Additionally, neither participant engaged in any physical work, such as physical writing or reading, as these activities were solely performed on the computer. This highlights the significant role technology plays in our lives and the impact of the workstation setup on our behaviour.

Posture and movement
During the test, both participants mainly worked on the computer and made very few posture changes. They typically maintained their preferred posture and only made small movements, such as stretching or repositioning themselves back to their original position. The upper body and legs were the areas where most of the movement happened, with changes in position occurring approximately every 30 minutes, as the user transitioned from between working activities (such as reading forward, browsing upright, or thinking while leaning against the backrest). Both participants positioned their pelvis against the backrest so that the backrest support could effectively, helping them to maintain their natural spine curvature (Figure 26). However, they tended to sit with their upper bodies loose from the backrest since they rested on their arms and elbows while performing forward-oriented work activities. When they got comfortable, such as when using their phone, they would lean backwards into the backrest. It became clear that phone usage heavily influenced their posture, as it caused them to look down and bend their neck and upper body forward, resulting in poor posture and extra stress on these areas (Gerding et al., 2021).

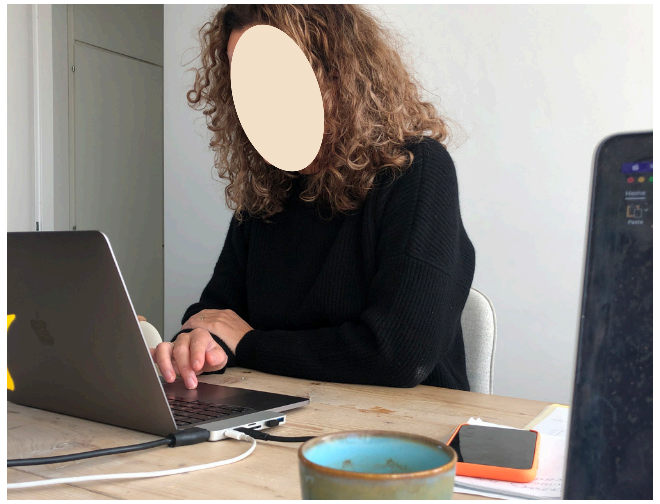


Figure 25: Participant with bad posture by looking down on screen at desk level

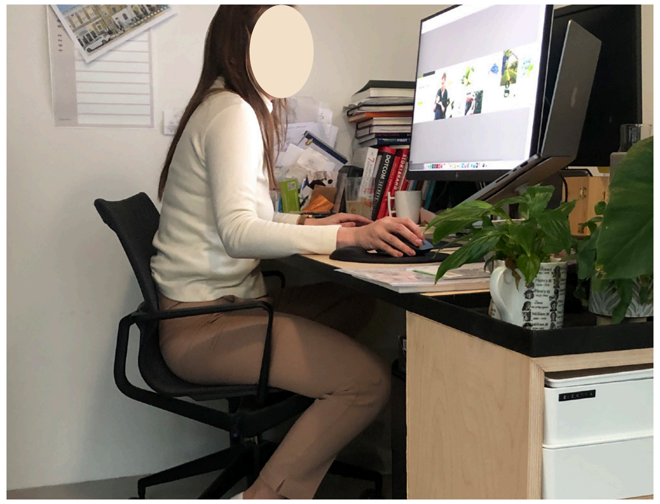


Figure 26: Participant with upright posture but with loose trunk

Conclusion
The main insights from this user observation are that participants change their activities and posture less frequently than anticipated, preferring to sit in their desired posture, such as sitting on one leg and upright. The study confirmed that the table and monitor significantly influence the user's posture. Additionally, the study revealed that the user's activity heavily influences their sitting position. Forward-oriented activities results in the user leaning forward and resting on their arms, while more relaxing activities motivate the user to lean back in the backrest to relieve spinal pressure after prolonged active upright postures that require muscle usage (Rohlmann et al., 2011). Although these insights are valuable, future research should involve observing more participants across all target user categories to validate the results.

3.8.3 Activities and postures

In the user observations it became clear that the posture of a user is heavily influenced by the activity they are performing at the moment (Ellegast et al., 2012). Activities that require a forward orientation tend to pull the user forward, while relaxing activities tend to push them backwards. During the research process, no clear information was found on the specific work and leisure activities performed by home office workers, and their corresponding sitting behaviour during these activities. Figure 27 was created to visualize the possible activities that home office workers may perform, categorized as work-related or leisure-related. Although there may be an overlap in the activities and postures for work and leisure, work related activities generally require focus and are therefore more upright and forward-oriented, while leisure allows for a more relaxed posture, often leaning backwards. This finding was further confirmed with Molenbroek (2022), who identified three primary postures while working: forward for writing, neutral for reading, and backward for listening. As a result, the project must aim to create a chair that facilitates these three postures while still providing adequate support and stability.

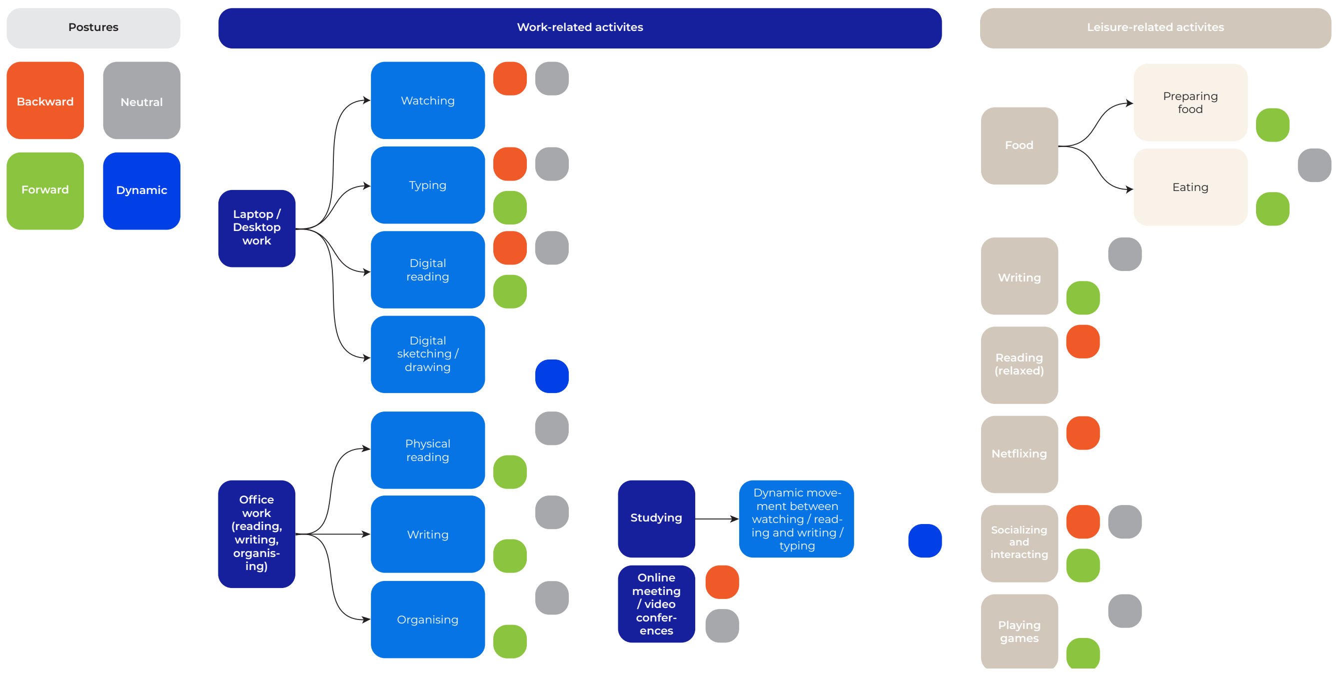


Figure 27: Work and leisure related activities and the postures individuals take while performing specific activities

3.8.4 Analysis of back curves

The final step in the Anthropometric Design Method (Van Boeijen, 2014) in the analysis phase involves researching anthropometric data. Since UPPS is a partner in this project, they were able to provide a large CAESER dataset of 3D models with a diverse range of people and body types in both standing and sitting postures (Robinette et al., 1999). The DINED database lacks extensive measurements on sitting postures, making the CAESER dataset valuable for analysing specific body types and sizes in order to gain a better understanding of human anatomy.

For the analysis, 6 male and 6 female models were selected based on specific body types, including tall and short, average, skinny and heavy, and those with a strong natural spine curve and a flat spine curve (Figure 28). These body types were chosen as they represent the diversity within the target user group and are particularly relevant for the development of the chair shape. Both standing and sitting models were aligned in Rhinoceros program and the back curves were measured. There is no available information regarding the instructions given to the models while standing or during 3D scanning, but it is assumed that they maintained natural, relaxed postures.

Standing vs. sitting
After comparing all the models, it became clear that they have different spine shapes with varying degrees of curvature while standing (Figure 28). When comparing their standing positions to their sitting positions, it is noticeable that the spine curve flattens. This is supported by research, which shows that when transitioning from a standing to a sitting position, the pelvis rotates backwards and the spine flattens (Hey et al., 2017).

After examining the models and their measured curves, no relation was found between the amount of standing curve and sitting curve. The standing spine curve shape may therefore not be useful for the chair development. However, there is a correlation between stature and sitting height, as models with a taller stature tend to have a greater sitting height. Additionally, models with a larger waist and hip circumference tend to have a larger butt size.

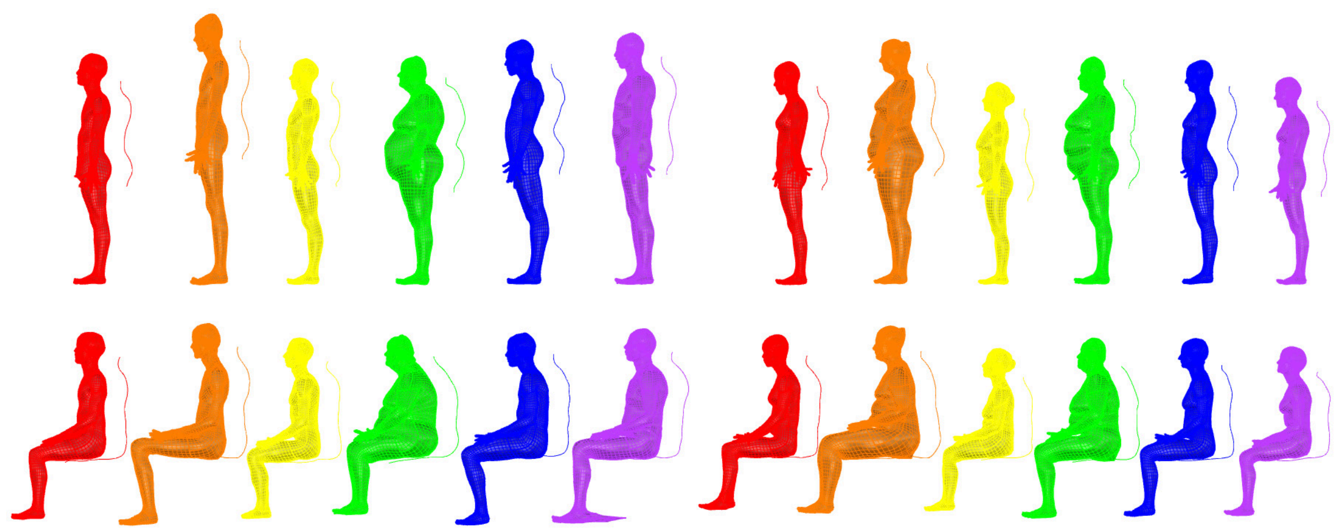


Figure 28: 12 different CAESAR models (left male, right female) with different body characteristics and their back curve measured

Popliteal depth and width
During the measurement of the spine curve of the models, the curves were drawn until the popliteal, which is the back of the knee. Aligning the curves on the buttocks shows a wide variation in popliteal-buttocks depth (PBD). This highlights the importance of carefully adjusting the seat pan length to fit the user. The DINED database indicates little correlation between the PBD and sitting height, so it is crucial to measure the PBD individually when designing the chair.

Similar to the PBD, there is a wide variation in hip breadth among the models (Figure 30). This also highlights the need to adjust the seat pan width to fit the user properly. A correlation between hip breadth and BMI is evident, as individuals with a higher BMI tend to have a larger hip breadth.

Backrest
After comparing all sitting measurements, a difference in the height of the top of the pelvis was observed (Figure 29). The measurement was taken by visually marking the iliac crests. It is evident that models with a higher BMI have a higher measured pelvis height, which contradicts the assertions made by Tilman (2022), Scholten (2022), and Molenbroek (2022). All three recommended that the lumbar support should be positioned at the top of the pelvis, which is approximately the same height.

When comparing the curve measurements, it is evident that all spines have approximately the same s-shape, but the centre of the back, the apex, and shoulder height differ and are related to the sitting height. This highlights the need for different sizes of backrests to accommodate these differences. Aligning all the buttocks of the models also reveals that they are not significantly different, and most people will fit in a chair with enough room, except for individuals with a substantial amount of fat in the region.

3D Model Max
As part of this analysis, I created 3D models of myself while standing and sitting in natural postures (Figure 31). Upon comparing my models to the UPPS models, the results were similar. The height of my pelvis and the size of my buttocks were comparable, and the comparison of my PBD and hip breadth all fell within the range of the UPPS models. Incorporating my own 3D model will help in translating digital explorations into physical prototypes when developing the chair.

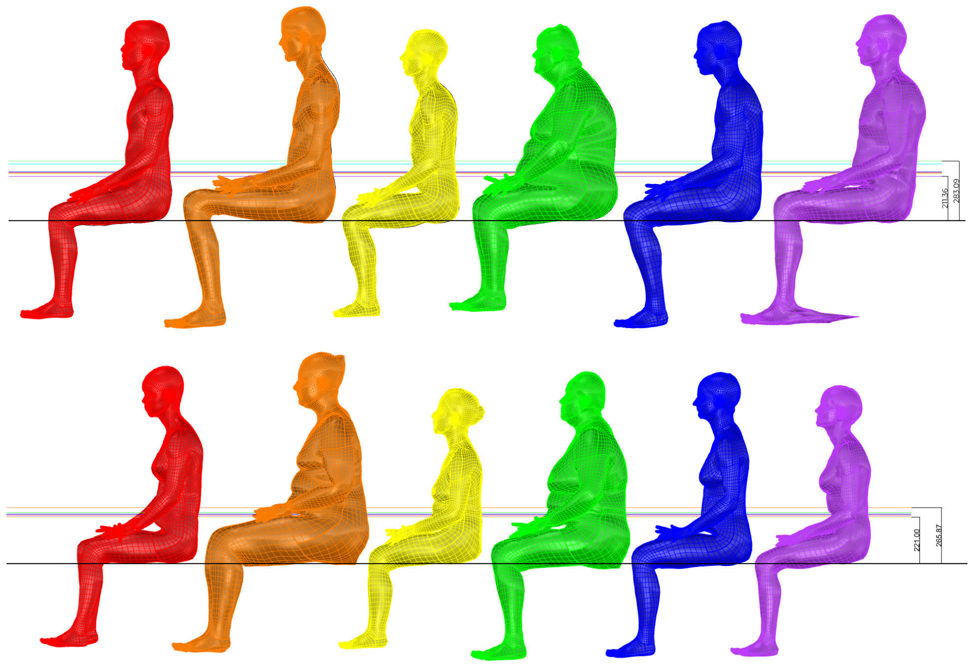


Figure 29: 12 different CAESAR models Itop male, bottom female) with the top of the pelvis measured (max and min)

3.9 Takeaways

Going into the next phase of the project, there a few important takeaways until now that will influence the design of the chair:

Posture variation

- The chair should be multi-functional and suitable for different activities and postures, including forward, neutral, and backwards positions. Inspiration can be drawn from the Wotzka chair.
- Consider incorporating movement into the design to address the rigidity of the bucket-style seat.
- Reclined sitting is important, and the seat pan and backrest angles should be personalized to provide optimal benefits.

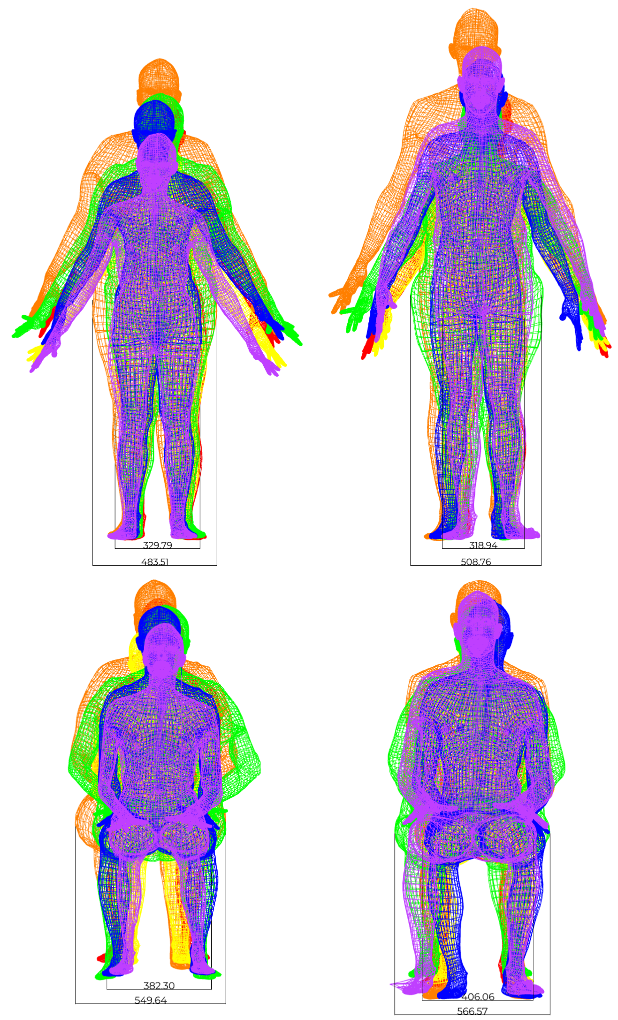


Figure 30: The hip breadth of the 12 CAESAR models with max and min measurements

Backrest design

- Pelvic support and stability are essential for achieving a natural spine curve, which is the best posture for the spine.
- The support of the backrest should focus on the pelvis and not 'fill up' the back.
- The backrest height, chair width, and seat pan length should be personalized to the user's body dimensions.
- The diversity in back shapes and curves of the human body makes the backrest a complex and interesting component of the chair.

Chair success factors

- Personalizing the chair to the user's body will ensure its comfort in terms of objective assessment and its suitability for users outside of the general population.
- Teaching users how to sit healthily and use the chair properly will contribute to their subjective assessment of the chair and, ultimately, the chair's success.
- Use the sitting bones as a starting point when designing the chair and ensure it is balanced.
- Consider all three target user groups when prototyping the chair. These are 24-30, 30-45 and 45+ years old.

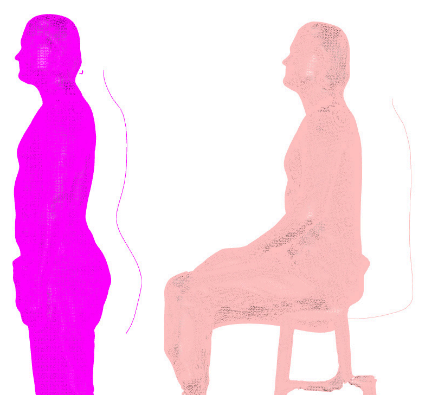


Figure 31: Comparision of 3D Model of Max while standing and sitting, and both curves measured

4 Research

The aim of this chapter is to focus the research on the most important aspects of designing a home office desk chair. This research will enable the generation of insights and knowledge that will assist in defining the essential parameters and how to incorporate ultra-personalization into the chair's design process.

4.1 Context research: Questionnaire

According to the context chapter, the success of the chair depends not only on its design but also on the entire complex home office environment that the user operates in. Therefore, the questionnaire's objective is to obtain a better understanding of the context in which home office workers operate, including their working environment and the challenges they may face.

4.1.1 The respondents

As previously mentioned, limited information is available about their work and leisure activities. The complete results of the questionnaire can be found in Appendix H.
A total of forty respondents completed the survey, with an equal distribution of male and female respondents. Their ages ranged from 19 to 61 years old (Figure 32). The majority of respondents, 59%, reported using some sort of office chair, while 33% used a kitchen or dining chair (Figure 33).

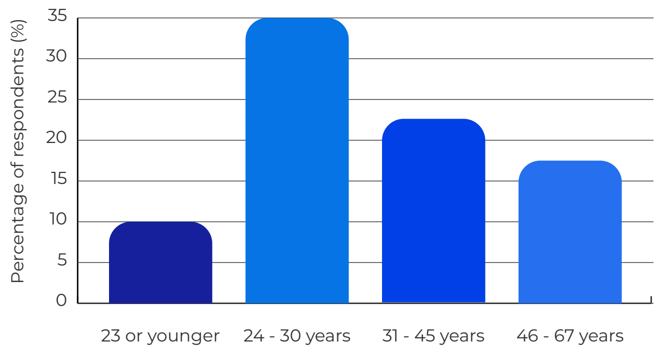


Figure 32: Percentages of respondents in the target user age categories

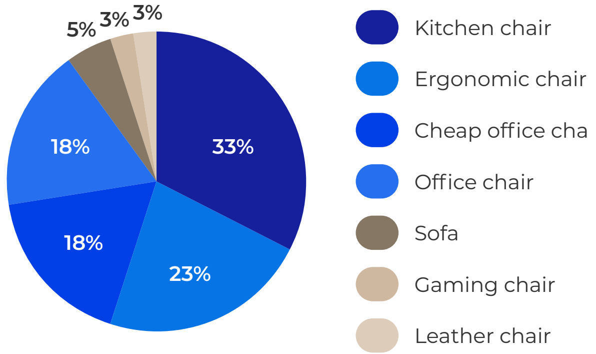


Figure 33: Percentages of type of chair use from the respondents

4.1.2 Dedicated office area

According to the results, 56% of the respondents reported having a dedicated office area in their homes where they work (Figure 34). Among these respondents, a majority reported having their office areas setup ergonomically. Specifically, 91% of these respondents reported using some type of office chair, while 82% of these reported using a monitor to improve their viewing angle while working in their dedicated office area (Figure 35). Additionally, 73% of the office chair users reported sitting with their backs fully pressed against the backrest, which is considered good practice as it increases the effectiveness of the backrest support and helps to maintain proper posture and decrease the risk physical complaints, such as lower back pain (Coleman et al., 1998).

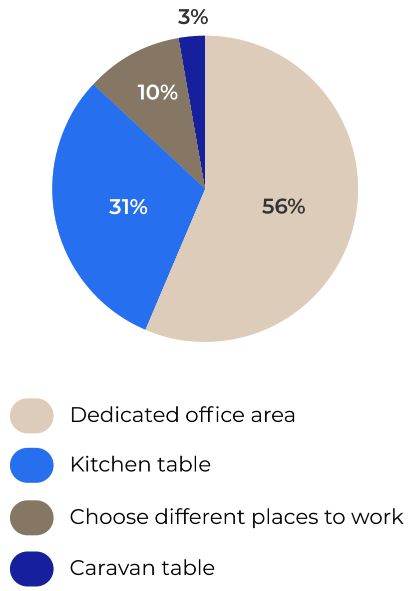


Figure 34: Percentages type of home office spaces

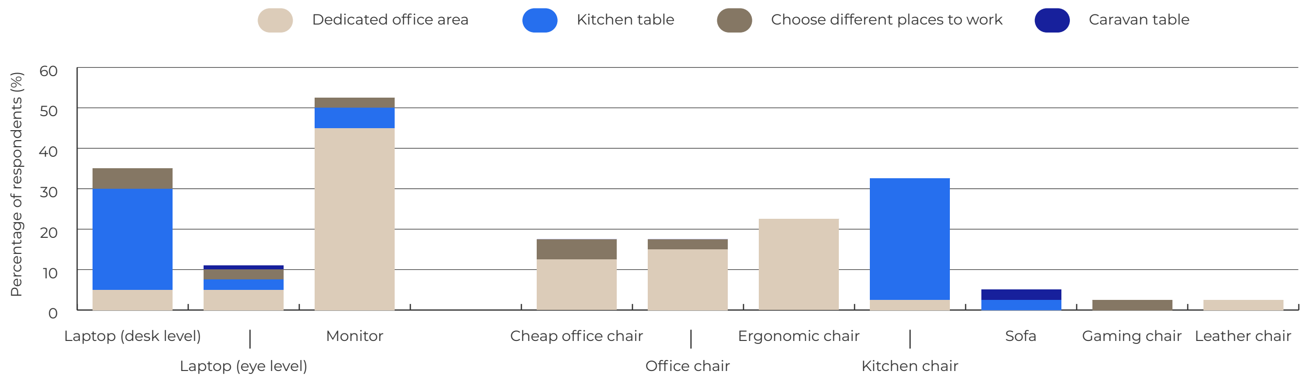


Figure 35: Percentage of respondents laptop setup, and type of chair usage in specific home office environment

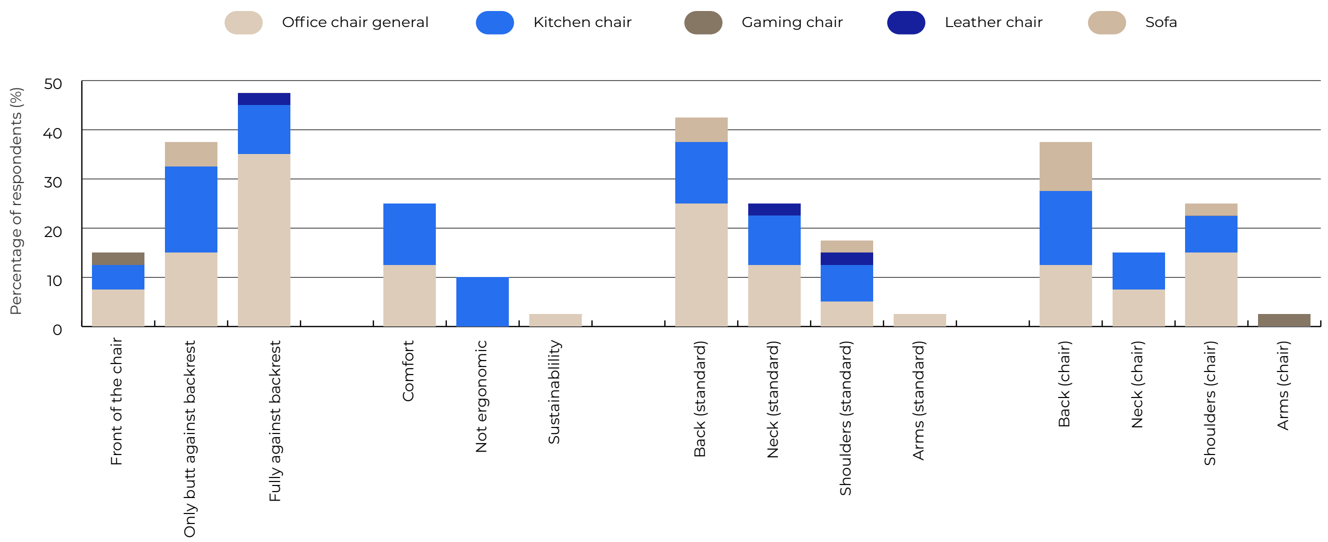


Figure 36: Percentage of respondents sitting position, chair complaint and phyisical problems with type of chair used

moopi - Chapter 4: Research

4.1.3 Kitchen and living area

The second most popular location for working is at a kitchen or living room table, with 31% of respondents working in this area (Figure 34). This may be because many respondents do not have access to a dedicated office space. In this environment, very few respondents use an office chair, opting instead to sit in a kitchen chair or on a sofa. The vast majority of this group (83%) uses a laptop on a desk or table for work and leisure activities (fFigure 35). However, these factors may have a negative impact on their sitting posture, as over two-thirds of this group (67%) reported experiencing pain in their backs, necks, and shoulders while sitting in kitchen chairs. This could be due to an incorrect ergonomic setup and the fact that they sit with only their buttocks against the backrest, leaving their upper body unsupported. This requires the pelvis to provide all the body's stability which might cause fatigue while sitting for an extended period (Staarink, 1995). The two most commonly reported problems among respondents who used kitchen chairs were the lack of ergonomic support and discomfort (Figure 36).

4.1.4 Sitting knowledge and behaviour

When asked about their knowledge of how to sit correctly and healthily, the most common answer among respondents (60%) is sitting with their arms and legs at a 90-degree angle, with a straight back and looking horizontally (Figure 37). Only two respondents mentioned sitting actively, with only one stating that they constantly change their sitting position. While research and websites about sitting do mention the importance of changing posture and taking breaks, the emphasis is often on maintaining a single correct posture (Huizen, 2022). A fairly significant number of respondents (38%) reported having no knowledge of how to sit in a healthy way, suggesting that simply providing an appropriate chair may not be enough, and that people need to be taught how to sit properly. This was also noted by Tilman (Tilman, 2022).

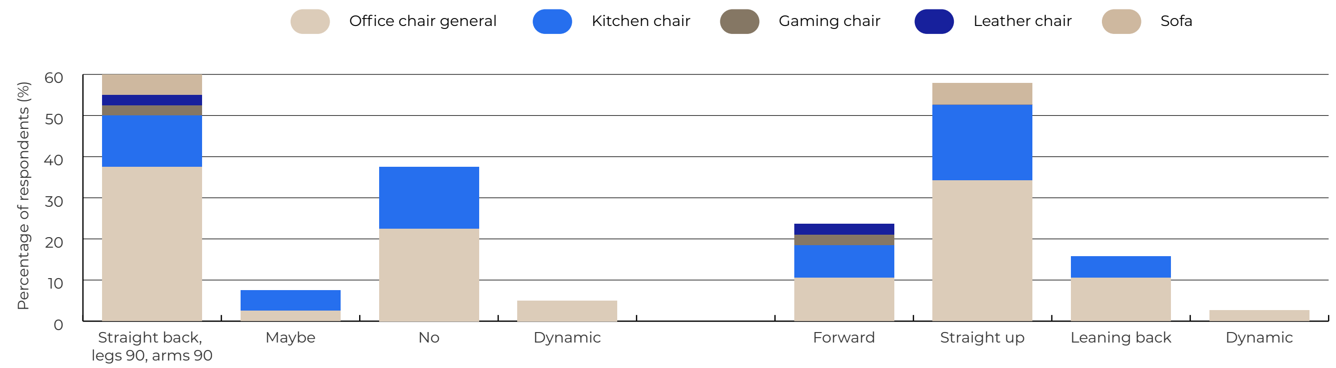
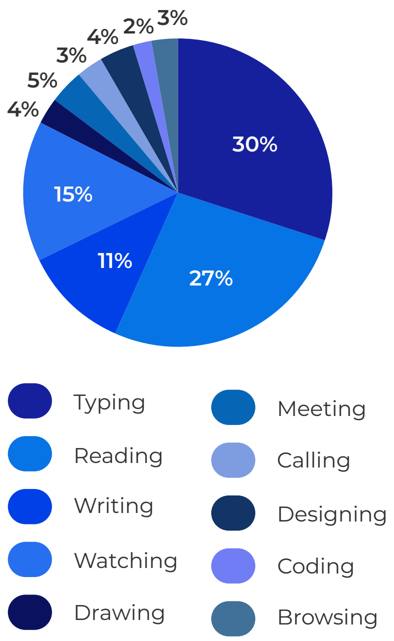


Figure 37: Percentage of respondents sitting behaviour and sittting position on the type of chair used

4.1.5 Activities

In the questionnaire, respondents are asked about the types of activities they perform while working and during leisure time in their home office chairs. The most common work activities are reading, typing, watching, and writing (Figure 38), all of which are computer-based tasks. This highlights the dominant role of computers in our work lives and how the setup of the screen, keyboard, and mouse influences our posture. Most work activities require a focus-oriented posture, with respondents likely leaning forward towards their screen or sitting upright.

The most common leisure activities reported are watching, eating, reading, and socializing (Figure 38). These activities are typically performed in a comfortable position, with respondents likely sitting upright against the backrest or in a reclined position. However, as the majority of activities performed in home offices are work-related, 21% of respondents reported not engaging in any leisure activities in their chairs. This indicates that the chair's primary function should be to support the user while working in a focus-oriented position, with less emphasis on comfort for leisure activities.



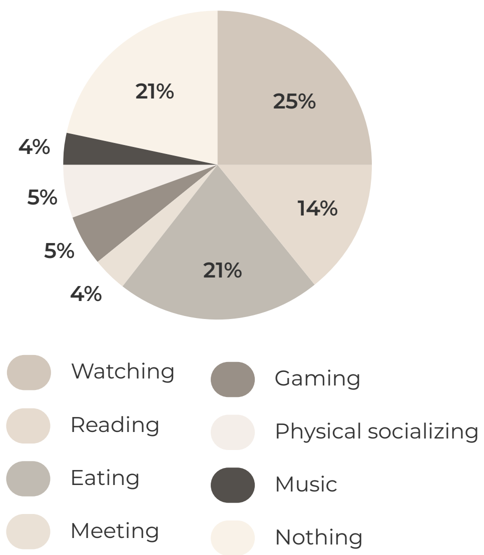


Figure 38: Percentage of respondents that participate in work and leisure related activities

4.2 Backrest design

Designing a chair is a complex and intricate task that involves careful consideration of numerous components, especially when creating a personalized chair. However, due to time constraints in this project, the focus will be on the backrest and its support (Figure 39), which is a challenging part of the chair because people have varying body sizes, spine curves, and support needs. As previously explained, the NEN guidelines specify functional requirements for the dimensions and amount of adjustability of office chairs, same goes for the backrest (Goossens, 1997). However, these guidelines do not provide any information about the lumbar support and may not be suitable for users with exceptional body types and sizes. According to Coleman et al. (1998), Tilman (2022), and Scholten (2022), an office chair only needs to be set up once, if done correctly. Thus, it is reasonable to personalize the backrest and its support to the user of the chair without needing to add adjustability. The most crucial parameters of the backrest are the lumbar support, backrest angle, and the backrest height and width (Coleman et al., 1998; Goossens, 1997; Scholten, 2022; Tilman, 2022). These parameters will be personalized to the user's specific body dimensions and are therefore crucial to measure correctly. These factors will ultimately determine if the chair fits the user's dimensions, support needs, and comfort. Adapting these factors to individual's sizes are not extensively described in the NEN guidelines

4.2.1 Lumbar support

Lumbar support is one of the fundamental requirements of an office chair as it functions as a support for the lumbar area of the body (Figure 40). The lumbar support carries the upper body's weight, thereby reducing the load on the spine, and pushing the lumbar area into lumbar lordosis, which forces the spine into a natural curvature (Kroemer & Kroemer, 2016). The lumbar support and the backrest stabilize the lumbar spine and the upper body, thereby decreasing the muscle activity of the muscles supporting the posture (Groenesteijn et al., 2009). Therefore, designing the lumbar support correctly is very important to maintain a healthy posture, especially when sitting for long periods of time.

Height placement
There are varying views among literature and experts regarding the requirements of lumbar support. The appropriate location and depth can be a maze of conflicting recommendations. Recent research suggests that lumbar support should be adjustable to allow for correct positioning at the user's preferred height. Coleman's (1998) research concluded that after testing 250 employees, the average preferred height of the lumbar support is 190 mm (110 mm min and 231 mm max). An important note is that lumbar support height is less associated with stature and more related to BMI. More obese users tend to prefer a higher lumbar support compared to slimmer users, as they have more fat around the waist that functions as support. Kroemer & Kroemer's (2016) research recommends an adjustable lumbar support within a range of 120 to 220 mm when designing an ergonomic chair. They also emphasize that the user's buttocks should have enough space to fit underneath the support.

Figure 39: The backrest of a chair with lumbar support

Other research focuses on the specific lower lumbar vertebrae the support should target. Staarink's (1995) research suggests that the support should be focused on top of the pelvis to create slight lordosis but doesn't give exact height dimensions. Tilman (2022) states that he adjusts the lumbar support to the top of the pelvis when helping a client, which is approximately the same height for most people, with only a small deviation in height difference, except for people with higher BMIs. However, he also does not give exact height dimensions. Openshaw and Taylor's (2006) study suggests placing the lumbar support from the L2 to the L5 vertebrae to allow adequate movement while the pelvis is supported. Molenbroek (2022), on the other hand, recommends positioning the support over the lumbar region within the limits of the L3 and L4 vertebrae.

While the exact placement may vary, it is clear that the lumbar support should focus on the user's lumbar area. In this project, user research will focus on studying how to personalize the placement based on the user's anthropometry.

Depth and shape
The depth of lumbar support is determined by the depth of the lumbar curve in the backrest (Figure 40). Defining this parameter is difficult and depends on the chair design and the reference point for measurement. For instance, in a bucket chair design, the lumbar support is integrated into the shape of the backrest, making it challenging to define the depth of the curve as the lumbar support and backrest are one continuous shape. However, ergonomic office chairs like the Herman Miller Aeron (Figure 2) have an adjustable lumbar support system that can be adjusted in height and depth separately from the backrest.

Previous research has used different reference points to define the depth of the lumbar support, such as a point on the backrest (Korte, 2013; Pynt et al., 2001) or the front edge of the seat pan (Coleman, 1998). Although they provide varying recommendations for the optimal lumbar support depth, it is crucial that the lumbar curve follows the convex shape of the lumbar area and pushes the lumbar area into lumbar lordosis (Kroemer & Kroemer, 2016). The research in this project will focus on personalizing the lumbar support, including its depth, to accommodate individual lumbar lordosis.

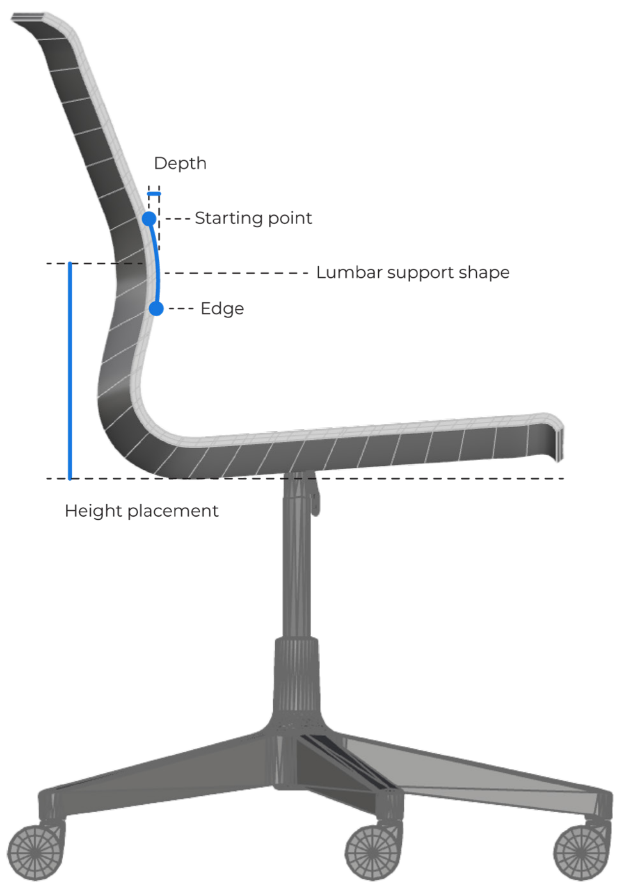


Figure 40: Chair side view with all important parameters for designing the lumbar support

4.2.2 **Height**

The height of the backrest is a crucial parameter of a chair (Figure 41), as it supports the upper body while leaning against the backrest and plays a role in promoting a healthy lumbar posture. Merely bending the pelvis forward is not sufficient, as pointed out by Vergara and Page (2000). This is contrary to what Tilman (2022) stated about only the pelvis requiring support, which may be true for an active sitting posture and shorter sitting intervals. However, supporting the upper body is important as it balances the forces on the body and reduces intervertebral disc pressure (Rohlmann et al., 2011). In contrast, the absence of back support, like in saddle chairs, forces the buttocks to bear all the user's weight, causing discomfort in the buttocks (Silva et al., 2017).

Figure 41: All important backrest parameters to consider when designing a chair

The height of the backrest must consider the chair's intended use and the environment in which it will be used. As the chair in this project is multi-functional, enabling work and leisure activities, it is important to allow free shoulder space (Goossens et al., 2003) and lateral movements around the sitting environment. This permits dynamic posture and freedom of body movement. A tall backrest that extends to the user's head will hinder these requirements. Therefore, the backrest height will be personalized to the underside of the shoulder blades.

4.2.3 **Width**

The width of the backrest is an important parameter that affects the support and comfort of the chair by distributing the pressure from the body weight along the width of the back (Kroemer & Kroemer, 2016) (Figure 41). In the previous project, it was concluded that variable widths of the chair could not be 3D printed due to constraints, and the width of the backrest depended is on the hip breadth, which is usually larger than the width of the back (Korte, 2013). However, it is important to note that the width of the chair should not extend beyond the width of the elbows as it would hinder the freedom of movement of the arms along the body.

4.2.4 Angle

The angle of the backrest is a critical parameter in chair design (Figure 42), as it determines the angle of the upper body and the posture of the user when leaning against the backrest, which subsequently affects the comfort level of the chair. The most important task of the backrest is to stabilize the weight of the upper body on top of the pelvis. This is achieved when the centre of mass of all the elements of the upper body is positioned above or behind the pivot of the pelvis, which is typically in the region of the armpit (Staarink, 1995). When the centre of mass is located in front of the pivot point, the user will be pulled forward by gravity, requiring the back muscles to compensate, which is why more reclined postures tend to be more comfortable (Staarink, 1995).

Research by Staarink (1995) also indicates that the angle of the backrest affects the effectiveness of the lumbar support and thus how well the pelvis is supported. A smaller backrest angle (<100 degrees from horizontal) is best for more active postures but leaves the upper body and pelvis unstable and unsupported. Pelvis stability starts at an angle of >100 degrees. Larger backrest angles (between 115 and 125 degrees) promote more relaxed postures where the pelvis and upper body are supported and stable. Other studies also support a backrest angle of 113/114 degrees for office work (Gscheidle & Reed, 2004) and active sitting (Smulders et al., 2016), and an angle between 121 and 123 degrees for passive (relaxed) sitting (Staarink, 1995; Smulders et al., 2016). The backrest angle also affects the amount of intervertebral disc pressure in the spine, and excessive pressure over extended periods can result in musculoskeletal disorders (Rohlmann et al., 2011). Sitting in a more reclined position reduces disc pressure and muscle activity required to maintain posture. A backrest angle of 120 degrees has been shown to produce the lowest EMG when testing different angles (Hosea et al., 1986).

It is clear that the backrest is crucial in providing posture stability, and the user's activity determines the preferred backrest angle. Adjustable office chairs allow the backrest to flow with the body of the user as they switch between activities and postures. However, as the project focuses on developing a non-adjustable bucket chair design, research will need to be conducted to find the best backrest angle that balances the need for active and relaxed postures in a multi-functional chair design.

4.2.5 Shape

As previously mentioned, the lower region of the backrest in the bucket chair, referred to as the lumbar support, should have a convex shape to fit the natural curve of the lumbar spine. Above the lumbar support, the surface should be almost straight but tilted backwards to support the upper body (Kroemer & Kroemer, 2016) (Figure 40). Additionally, it is crucial that the upper edge of the backrest is rounded or slopes away from the user to prevent it from cutting into the back or causing discomfort when leaning against the backrest or slouching.

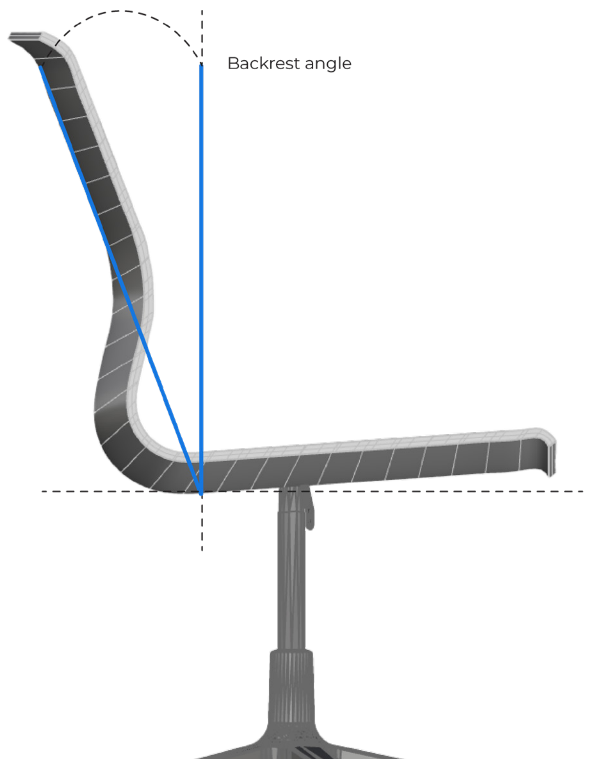


Figure 42: Backrest angle explained

4.3 Explorative user test

As previously mentioned, the project's primary goal is to personalize the backrest and its support to a specific user by focusing on essential parameters such as lumbar support, backrest angle, height, and width. The personalized parameters aim to promote a healthy posture and a comfortable sitting experience. This exploratory user test aims to integrate the previously conducted research into a backrest prototype with a shape that can be easily modified to create personalized backrest setups for the test participants. The purpose of this user test is to investigate on a small scale how to take body measurements and determine the feasibility of quickly generating realistic backrest setups using the existing research knowledge.

4.3.1 Prototype

The prototype of the office chair features a removable and customizable backrest plate, which can be adjusted to create a specific shape by stacking wooden slats of varying thicknesses. This design allows for quick and easy modifications to test different setups. The slats are secured to the backrest with long bolts, and the board can fit up to 11 slats with a height of 44 mm and thicknesses of 3, 9, 18, and 22 mm (Figure 43). The backrest plate is positioned at a 100-degree angle from horizontal to promote an active posture (Staarink, 1995), while the seat pan is kept horizontal and has a 60 mm foam for comfort. The backrest also has a 20 mm foam padding. The chair frame is a simple wooden chair with its legs removed to fit an office chair frame underneath, adding tilt, rotation, and other functionalities to the prototype.

4.3.2 Method

In this exploratory user test, six participants (four male and two female) were photographed while sitting in a natural upright posture on a flat surface (Figure 44). The photos were taken at a distance of 3 m at belly height and then scaled to the correct size in the Rhinoceros program, using the sitting object as a scale reference. After scaling, a curve was drawn along the contour of the upper body, around the buttocks, and along the legs until the popliteal to measure the back shape of the participant. It is important to draw a perspective grid on top of the sitting surface and ensure that the measured curve follows along the centre of this grid. If done incorrectly, the measured curve will be too big, as it will be measured over the contour of the leg and not along the centre of the whole body.

Figure 43: Prototype backrest with wooden slats of varying thicknesses

This curve is then transferred onto a simple 2D schematic layout of the prototype chair and rotated into position where the buttocks and shoulders touch the backrest (Figure 45). The schematic representations of the wooden slats are used to fill up the space between the curve and the backrest to create a personalized backrest setup that fits and supports the natural upright posture. This schematic setup is then replicated with the wooden backrest and slats in the prototype.

The participants were instructed to use the chair as they would normally use their office chair (Figure 46), and personalized setups were tested for at least three days. Afterward, the participants filled out an online questionnaire, which gathered general information such as age, height, and weight, as well as context information and assessed the shape, support, comfort, and balance of the backrest. The results of the questionnaire can be found in Appendix I.

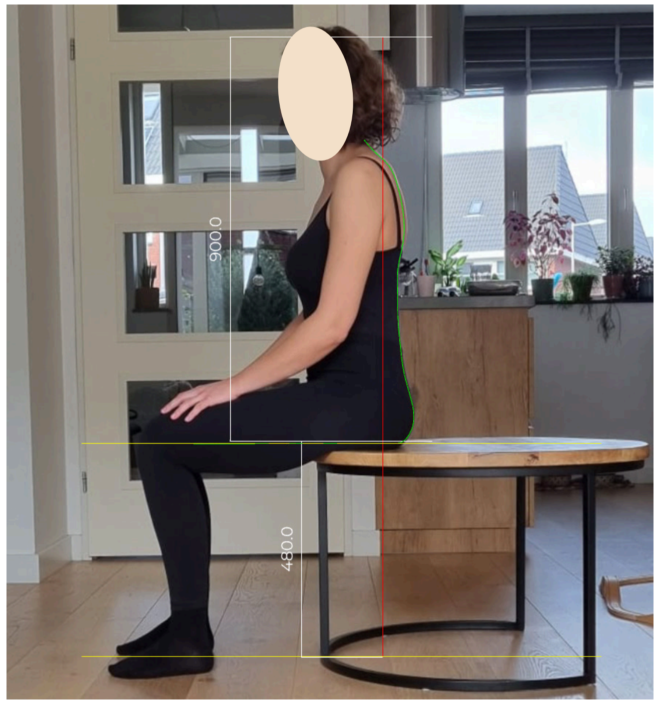


Figure 44: Curve measuring method, scaling, centreline and curve drawing (green curve)

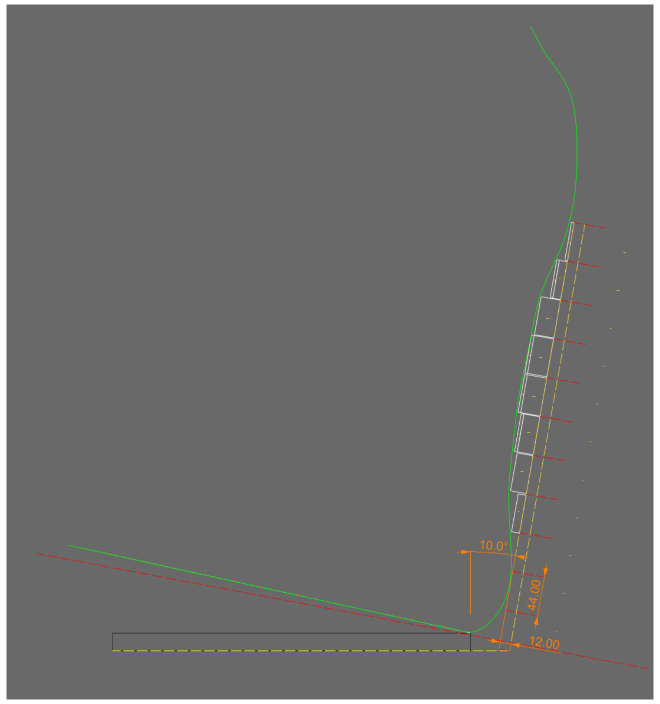


Figure 45: 2D schematic layout of prototype to create a backrest setup

moopi - Chapter 4: Research

4.3.3 Results

All participants reported that the personalized backrest shape fits well with the shape of their back, and they feel well-supported while sitting in the chair. Four participants find the backrest comfortable with the small amount of padding, while five participants state that the support of the backrest helps maintain lumbar lordosis. However, two participants report that the backrest forces them into an unnatural upright position, overloading the muscles in the lower part of the body to maintain posture, resulting in their backs feeling tired afterwards. All participants sit against the backrest while using the chair, but two report that their pelvises and upper bodies are not supported, making them feel unstable. Additionally, all participants report having enough freedom of movement, maintaining balance and feeling supported throughout all their activities. However, two participants note that the upright angle of the backrest does not allow for relaxed postures, such as slouching. Three participants state that they would prefer a higher backrest for more support of the upper body. Lastly, four participants work with their screen at eye level, while the other two work with their screen at desk level, which results in upper body and neck pain.

Figure 46: Participant testing the prototype in a home office environment

4.3.4 Conclusion

Using a photographic measuring method to measure the user's back curve is an effective way to create a backrest shape that fits the body, provides decent support, and is comfortable. The prototype offers an efficient and effective method for quickly creating personalized and realistic backrest setups. However, this method presents several challenges. Perspective distortion makes scaling the photo difficult and can impact the measurement of the curve's proportion. Different phones also have varying degrees of perspective distortion, making it challenging to scale photos accurately. Drawing a curve along the centreline of the body, which is required for an accurate and correctly sized back curve measurement, is challenging due to perspective distortion, and a different measuring method is recommended.

Participants reported feeling unsupported and unstable in their pelvises and upper bodies, which can be resolved by angling the seat pan. Tilting the seat pan increases the frictional forces and forces the user more into the backrest, preventing them from sliding forward. This increases contact with the backrest and improves the effectiveness of the lumbar support on the pelvis, resulting in increased support and stability (Staarink, 1995). The personalized backrest promotes a healthier posture while providing a comfortable sitting experience. However, additional testing is necessary with participants of different lengths, weights, and ages to compare curve measurements and research the best sitting posture to measure the back curve.

4.4 **Kyphometer**

In order to address perspective distortion challenges using a photographic measuring method and to increase the accuracy of back curve measurements, a kyphometer is introduced (Figure 47). This instrument is capable of making precise measurements of the back curve along the centre of the body, measuring the spine shape. However, the final product should not be designed around the use of a kyphometer when developing a personalized backrest, as users at home do not have access to it. Instead, the final product should integrate simple body measurements that can be easily done at home. In this project, the kyphometer enables fast and accurate back curve measurements to develop the parameters of the backrest.

4.4.1 **Concept**

A kyphometer is a medical instrument used to measure an individual's back curvature. A simple mechanical version is commonly used by healthcare professionals, such as chiropractors, physiotherapists, and orthopaedic surgeons, to evaluate the degree of spinal curvature in patients with conditions such as scoliosis, kyphosis, or lordosis (Korovessis et al., 2001). A digital kyphometer can measure the spine shape of individuals in great detail . A few years ago, TU Delft built a digital kyphometer, consisting of a rollable stainless-steel frame with Y and Z axes and a rolling ball (Figure 47). This frame can be positioned at the back of an individual, and the spine shape is measured by moving the ball from the top of the spine to the bottom while applying pressure to the back. The kyphometer measures the Y and Z positions every two cm and writes the values to a digital file that can be imported into the Rhinoceros program to draw a digital spine curve.

4.4.2 **Programming**

When the kyphometer was initially tested, it failed to take readings. After extensive troubleshooting, it was decided that the instrument needed to be reprogrammed. The Arduino software was used for this purpose, and the complete code can be found in Appendix J. However, as this report focuses on the development of the backrest, it is not necessary to provide a detailed coverage of the code.

Figure 47: Digital kyphometer from the TU Delft

moopi - Chapter 4: Research

4.5 **Backrest user test**

After completing the exploratory user test, a larger test is set up to conduct similar tests with a more diverse group of participants who represent the target group of the chair. The aim of this test is to gain a better understanding of how body measurements can be translated into a personalized backrest shape that fits correctly to the shape of the body while providing support and comfort. The results will provide guidelines on how the backrest and support should be shaped and set up, how users should be measured in terms of method and posture, and how the chair should be designed as a whole. These insights will help to define the chair parameters before developing the algorithm that will generate the chair.

4.5.1 **Method**

Before the user test, specific participants were recruited, briefed on the test procedure, and required to sign a consent form. The user test consisted of 14 participants, including 6 males and 8 females, aged between 25 and 30 years old, with one participant aged 44 years old and two participants aged 65 years old. Participants with varying heights and BMIs were also selected to represent a wide group of target users in the test. The test was conducted in a private room at the TU Delft where the measuring, testing, and observations could be done in the same space.

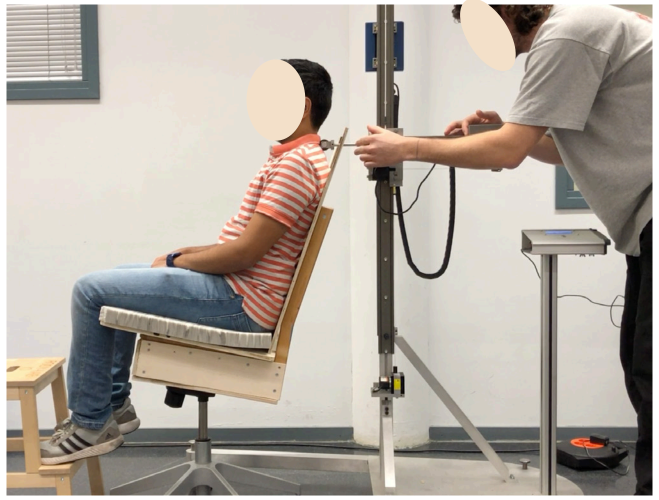


Figure 48: Measuring a participant with Kyphometer

Firstly, the participants were photographed to take body measurements for analysis of the test results. Next, their back, specifically their spine, shape was measured using the kyphometer while sitting in a measuring chair with the same seat pan and backrest angle as the prototype chair (Figure 48). The participants were asked to locate six different postures, which include forward leaning, sitting in an extreme upright posture (maximally arching the back) and maintaining this posture while leaning against the backrest, sitting naturally upright and leaning against the backrest with a normal posture, and lastly reclining with a normal posture. The measured curves were then drawn in Rhinoceros and analysed to create a backrest setup, following the same process used in the exploratory user test. The curve was placed onto a 2D schematic layout of the prototype chair and, if needed, corrected by rotating it into position where the buttocks and shoulders touched the backrest. The schematic backrest setup was then created by 'filling up' the space between the curve and the backrest with schematic wooden slats and transferred over to the prototype chair.

Figure 49: Updated prototype chair and measuring chair

Participants used the chair for a minimum of one hours, all sat behind the same desk and used a monitor at eye level with a mouse and keyboard. This was important so that the environment around the chair was consistent, and the results were not influenced by a poor desk setup. During the test, the participants were photographed and observed, and afterwards, they were interviewed via a questionnaire. These results can be found in Appendix K. Participants were told to sit and use the chair as they normally would to generate the most realistic results. For example, they were allowed to leave the room and use the tilting mechanism. The main research question to answer was how to create a backrest shape that fits the user's body, provides support for the pelvis and upper body, and allows the user to comfortably maintain all activity postures.

4.5.2 Prototype

The prototype is based on the same principle as the exploratory user test, using wooden slats of varying thicknesses to create a personalized backrest shape. However, it has been improved based on the results of that test. The seat pan has been angled up by 4 degrees to improve contact and support of the backrest. The slats are less wide, at a width of 38mm, to allow for an extra row and more detailed shape profile, with thicknesses of 5, 9, and 12mm (Figure 49). As a wide variety of participants will use the prototype, careful consideration has been given to the dimensions of the backrest and seat pan. For example, a large seat pan depth for a taller individual may be too long for a shorter individual, leading to discomfort and obstruction from sitting against the backrest. To address this, a dimension specification based on the DINED database and the research of Noshin et al. (2018) has been considered and is listed in Table 1. The backrest, seat pan, and slats are all laser cut for maximum precision and ease of assembly when changing setups. The prototype incorporates a height-adjustable office chair frame that includes rotating, rolling, and tilting features.

Table 1: Dimensions specification for prototype chair based on Noshin et al. (2018) and DINED parameters

Serial No.	Feature	Related Anthropometric Measure	Allowance		Percentile		Dimensions	Criteria
			Type	Dimensions	5th Percentile	95th Percentile		
1	Adjustable Seat height	Popliteal height	Shoe Allowance	30	397	529	**427 - 559**	*5th Percentile + Shoe Allowance to 95th Percentile - Shoe Allowance Allow everyone to sit correclty*
2	Depth of Seat Surface	Buttock- Popliteal Length	None	None	457	553	**505**	*50th Percentile So it fits a large person without it being too small, or being too big f or a small person*
3	Seat Surface Width	Hip breadth	Movement Allowance + Cloth Allowance	76,2 (Paper)	351	447	**523,2**	*95th Percentile So it is not too small for a large person*
5	Seat Surface Angle (Horizontal)	None	None	None	None	None	**'+/- 4 degree'**	*From the 'Zo zit het' Book. In the 0 or base position, enables an active posture with stabilised pelvis.*
5	Backrest Width	Breadth over the elbow	Movement Allowance	120 (own measurement of elbow breadth)	402	554	**358**	*50th Percentile - Movement Allowance So it fits a large person without it being too small, or being too big for a small person*
6	Backrest Height	Sitting shoulder height	Movement Allowance + Cloth Allowance	184	532	664	**480**	*95th Percentile - Movement Allowance + Cloth Allowance So that its not too low for a large person, so that it can lean back comfortably. But also not too high for a small person that it reaches over the shoulder. (Self measurement from test chair)*
7	Backrest Angle (horizontal)	None	None	None	None	None	**'+/- 100 degree'**	*From the 'Zo zit het' Book. In the 0 or base position, enables an active posture with stabilised pelvis.*
8	Adjustable Synchronised Seat Surface and Backrest Angle	None	None	None	None	None	**0-23 degrees**	*From the 'Zo zit het' Book. This allows the user to have freedom of movement and recline in a relaxed and stable posture. Head, trunk and pelvis in balance.*

moopi - Chapter 4: Research

To take measurements with the kyphometer, a measuring chair was created that is identical to the prototype in terms of sizing, angles, and functionality. This ensures that participants are measured in the same position as they would sit in the prototype chair, providing the most accurate back measurements. The backrest of the measuring chair is made taller than the prototype chair and features a flat surface and a slot along the centre to allow the kyphometer rolling ball to move along the spine and enable participants to rest their shoulders on the backrest while sitting in different postures.

4.5.3 Measuring the back

Participants were measured using the kyphometer in six different postures, and the resulting Y and Z values were imported into Rhinoceros. From there, curves were drawn to represent the measured spine shape in each posture, and these curves were analysed to determine the best one for creating a 2D backrest setup on the schematic prototype chair template (Figure 50).

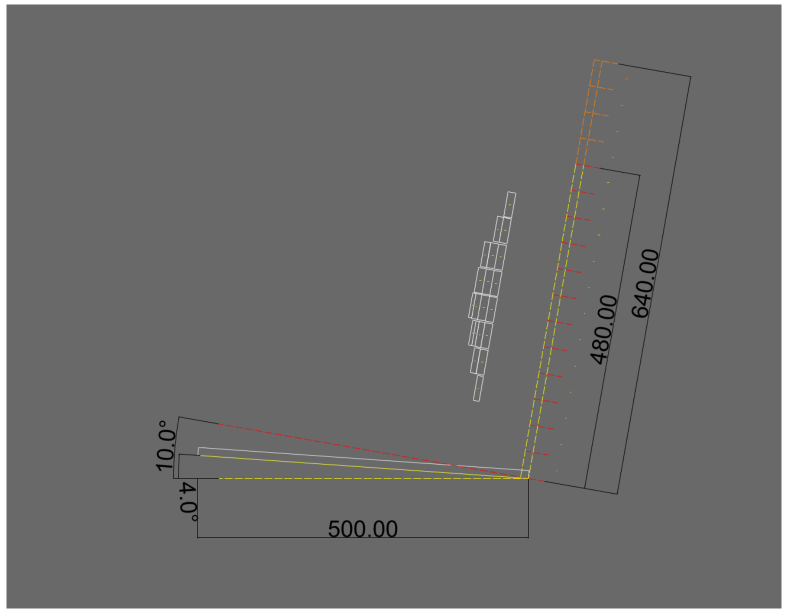


Figure 50: 2D schematic layout to create a backrest setup

4.5.4 Results

In the following results section, abbreviations are used to represent certain postures and curves. Therefore, it is important to provide an explanation for these abbreviations.

FW(1): Forward posture curve 1.
EU(2): Extreme upright posture curve 2.
EB(3): Extreme backrest posture curve 3.
NU(4): Natural upright posture curve 4.
NB(5): Natural backrest posture curve 5.
NBR(6): Natural backrest reclined posture 6.
(x out of x): How many participants out of the group the statement applies to.

BMI and spine curve
The results indicate that a higher BMI and a higher age lead to decreased spine flexibility, resulting in a less prominent curve and a flatter backrest, which offers less support (Figure 51). However, it is possible that individuals with a higher BMI do not require the same degree or type of support, as the extra body tissue may help in maintaining the sitting posture and reduce sensitivity to support (Coleman et al., 1998). Moreover, a higher BMI (along with thick clothing and belts) can make it challenging to accurately measure the spine curve and locate body areas or vertebrae, which may cause inaccuracies in measurements by the kyphometer and visual landmarking for taking body measurements.

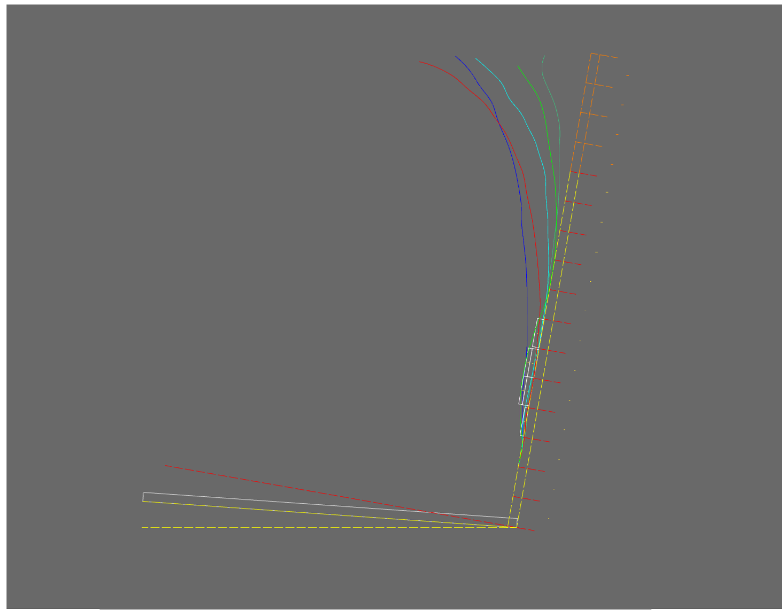


Figure 51: A flat backrest setup for a high BMI and Age

Spine flexibility and control
The results indicate a significant variability in spine flexibility and spine control among the participants (Figure 52 & 51). Spine control refers to the ability of participants to locate their natural spine position and to control and maintain their spine curve during various postures. It is an important factor, as higher spine control results in more accurate curve measurements. The assessment of spine control is based on the level of flexibility and control observed during the measuring process, as compared to other participants.

Curve selection
The best posture curves to use for creating a backrest shape are EU(2) and EB(3). However, participants with low spine flexibility and control had difficulty finding and measuring their natural spine shape. In such cases, 8 out of 10 participants had a curve that was too flat to create a supportive backrest shape. If the natural curve NB(5) was selected, it was because the participants had a normal or better spine flexibility and control score (4 out of 4).

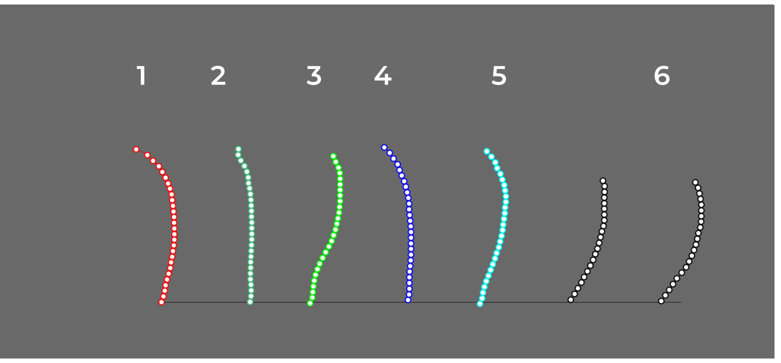


Figure 52: Stiff and bad control example

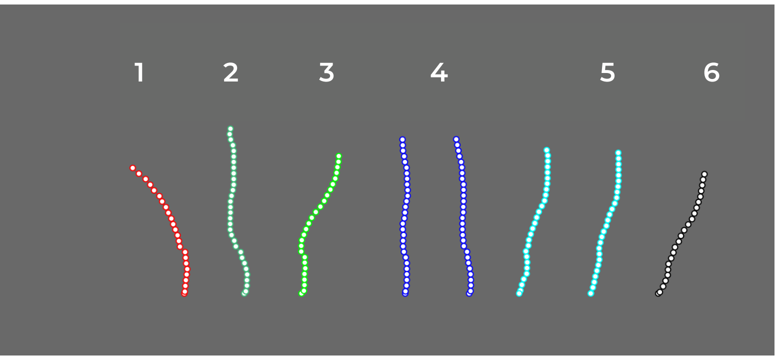


Figure 53: Very flexible and good control example

When an extreme back curve was chosen, EB(3) posture gave the best curve to create a backrest shape in 8 out of 10 cases. In one instance, the extreme upright curve EU(2) was chosen to test a setup with this curve, but feedback concluded that the buttocks needed more room, and the pelvis was not supported.

Lastly, two participants had high spine flexibility, which resulted in a very strong curve. Using this curve would risk forcing their backs into an unhealthy posture. Therefore, EU(2) and NB(5) curves were chosen for the backrest.

Support and comfort
Although the extreme backrest EB(3) posture produces the most consistent curves for shaping the backrest (Figure 54), 8 out of 14 participants found that their pelvises were not sufficiently supported and stable enough, and that they desired more support in this area. Among these 8 participants, 6 had a setup created from the EB(3) curve. Additionally, 5 participants, including 4 with the EB(3) shape, reported that the pressure was too high at the middle of their back, leading to discomfort.

Three participants reported feeling locked in the chair, stating that the stickiness of the seat pan foam prevented them from moving around and changing their postures. Additionally, four participants reported moving less in the chair than they normally would, stating that they were aware of participating in a user test and therefore sitting in 'better' postures, which they identified as upright against the backrest.

Upper body support
Participants who leaned forward, sitting only with their lower back against the backrest, and those who hunched forward but fully touched the backrest, all reported insufficient upper body support (6 out of 6). This is expected because these participants did not touch the backrest with their upper bodies (Figure 55). However, participants who sat upright with their backs fully against the backrest reported good upper body support (4 out of 5). When participants slouched, they leaned their upper bodies on the top of the backrest. This group generally found the upper body shape to be okay and/or supportive (4 out of 5).

Sitting angle
Out of the 14 participants, 11 sat in an upright posture with the chair locked to prevent reclining, while the remaining participants sat with their chairs in a reclined position. This indicates that for working activities, users prefer a chair that can be adjusted to different positions. The angle of the seat pan and backrest are based on the research of Staarink (1995), with the seat pan angled at 4 degrees and the backrest at 100 degrees, which would help users to sit in a posture that is more comfortable than a 90 degree upright position and where the pelvis is supported. Six participants reported liking this angle setup because it pushed them into the backrest and improved their posture. However, two participants commented that they did not like the feeling of being pushed into the backrest, and one participant reported that the constant pressure numbed her back after a while.

4.5.5 Discussion

Focus of the support
As 8 out of the 14 participants reported feeling unsupported in their pelvis, it is believed that simply 'filling up' the EB(3) curve is not the best way to create a backrest shape that is both supportive and comfortable. The shape should not provide equal support all over the back and should not be based solely on the posture in which the user was measured. Instead, the backrest support should focus on distributing pressure to the top of the pelvis and be comfortable in all postures the user may switch between. These postures are influenced by the user's sitting habits and preferences, as well as the specific activity they are performing at a given moment. By focusing on the top of the pelvis, the pelvis can be rotated forward, forcing the spine into a more natural upright position during focus-based activities (Staarink, 1995).

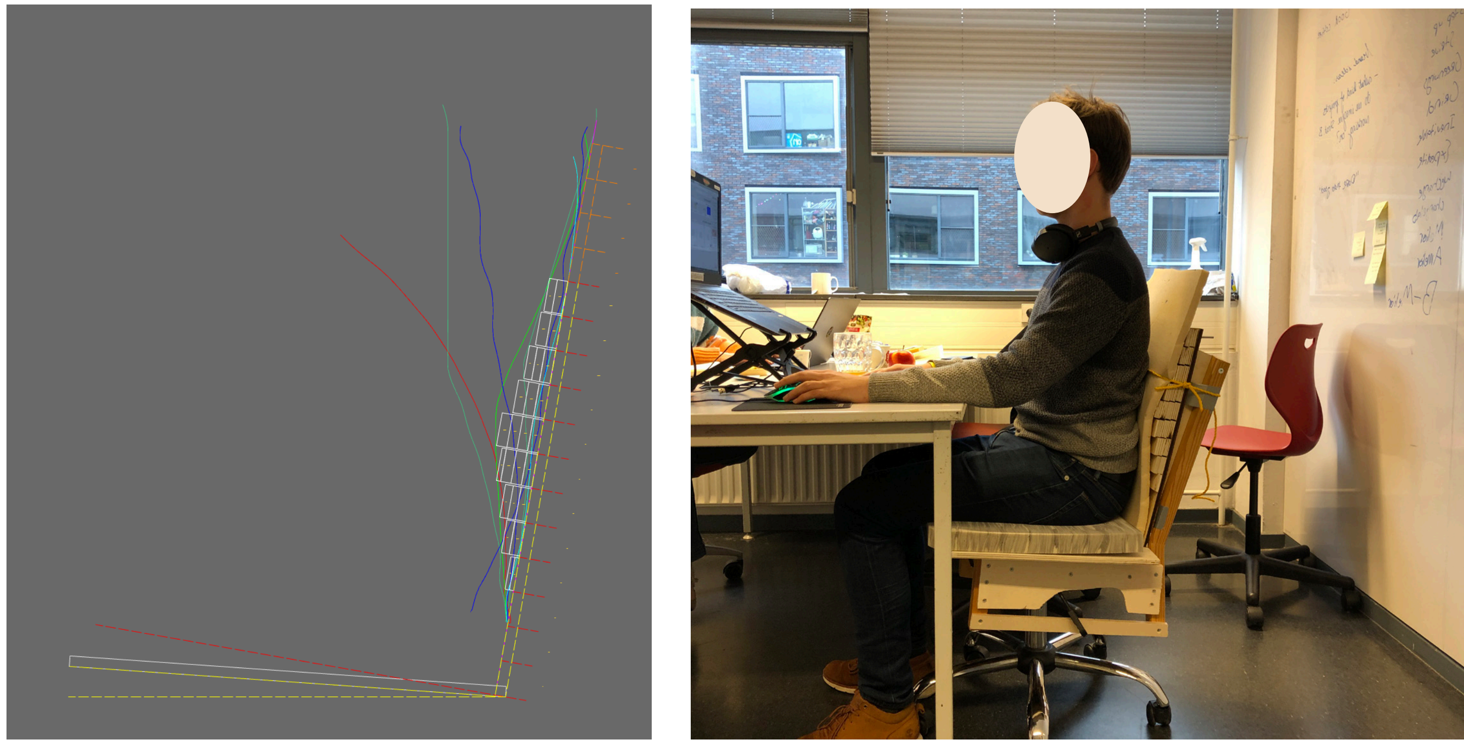


Figure 54: EB(3) curve slection and prototype backrest setup in user test

Allowing different postures
Users generally prefer to sit in an upright position while using the chair (Figure 56), but it's important to ensure that the chair also provides support for different postures and positions. Participants often switch between forward leaning, sitting upright against the backrest, and slouching, leaning with the upper body on the top of the backrest, as recommended by Molenbroek (2022). However, some participants felt locked in an upright position and found it limiting to their freedom of movement. The stickiness of the foam also made it difficult for them to move around in the chair and change their posture easily.

Forward leaning and buttocks
To maintain a natural spine position when leaning forward, it is important for the user to sit with their pelvis slightly rotated forward and supported in an upright position, while also leaning on their forearms. This helps to relieve pressure within the spine, as noted by Rohlmann et al. (2011). In order to prevent users from bending forward and increasing pressure on the spine, the backrest should provide enough pressure at the appropriate height for lumbar support. Sufficient space for the buttocks is also crucial to prevent them from pushing away from the backrest, which would result in a loss of support. Test results indicate that upper body support is dependent on the sitting posture, as leaning forward or only touching the backrest with the lower back does not provide support for the upper body (Figure 55).

Slouching is not bad
When slouching (Figure 57), it is important that the top of the backrest provides support to the upper part of the body. The ideal shape should follow the curve of the body, and the backrest should be high enough so that the upper body can rest comfortably at the top and carry part of the weight of the upper body. Slouching is not necessarily an unhealthy posture as long as the back is sufficiently supported. In fact, spine pressure in this posture is lower than when sitting upright (Rohlmann et al., 2011). Sitting in a relaxed posture may even improve focus and productivity during mental tasks (Lukits, 2015).

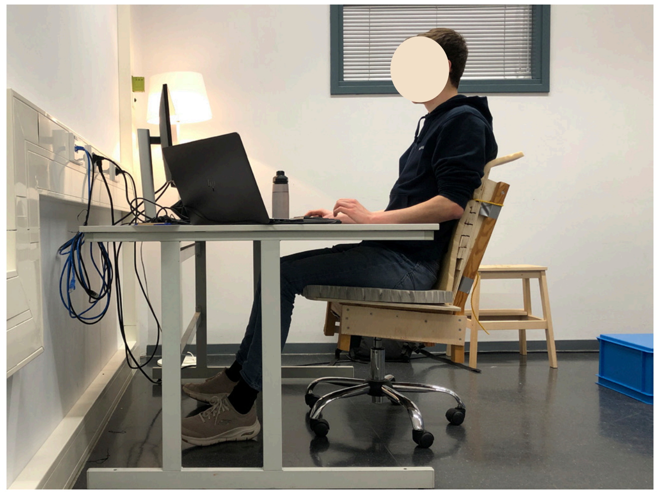


Figure 56: Upright posture against the backrest

Figure 55: Leaning forward and no trunk support

Figure 57: Slouching posture

Design of the backrest
Office chairs often have soft and flexible backrests that adapt to body movements and posture changes. However, the prototype and bucket-style chair are hard and fixed, making them less forgiving and prone to locking the body into one position. Although sitting in a fixed position may feel comfortable in the short term, prolonged sitting and constant pressure can lead to fatigue in the spine and buttocks, and cause musculoskeletal problems (Pope et al., 2002). Therefore, it is even more important that the backrest shape fits well with the user's body dimensions, as this rigid chair design highlights flaws. This is challenging, as it is difficult to obtain accurate data on people's spine shapes, which also differ from day to day (Molenbroek, 2022), and everyone has different preferences and habits, as evidenced by the test results. Therefore, the spine shape may not be the best measurement on which to base the backrest.

4.5.6 Conclusion

After conducting the user test, two backrest shape proposals can be created that integrate the results and knowledge generated so far. Both backrests have a similar shape with a buttock bowl that provides enough room for the buttocks and lumbar support, but the top part of the backrest curves back at different angles. The first proposal (Figure 58) supports the back all the way until the shoulders, providing full support when sitting straight up or reclining, but it may not be suitable for slouching or relaxed postures as it does not support the middle back and has a small backrest angle. The second design (Figure 59) features a backrest that bends away from the user above the lumbar support, providing less upper body support when sitting upright but more comfort in relaxed postures compared to the first proposal.

Figure 58: Chair shape proposal 1

Figure 59: Chair shape proposal 2

moopi - Chapter 4: Research

Because everyone has different body shapes, proportions, postures, and spine flexibility and control, it is challenging to create a consistent test chair setup using the spine shape as the basis for the backrest. Measuring spine posture is an unreliable method because participants without proper training or guidance may have difficulty achieving different postures. However, the EB(3) curve while leaning against the backrest has been proven to be the most accurate and consistent method for developing a shape, except for individuals with a highly flexible back.

It is not advisable to create a backrest and lumbar support by 'filling up' the measured curve. Instead, the focus of the support should be on the top of the pelvis, and the backrest should be less prominent from the middle of the back upward to prevent the feeling of being pushed in the middle of the back and the pelvis feeling unsupported and unstable. For the first proposal (Figure 58), the backrest shape should parallel the measured curve but with less thickness, so the primary pressure remains on the lumbar support. For the second proposal (Figure 59), the backrest should curve around the middle and bend backward, and the degree of bend should be further researched and tested.

The angle of the seatpan can remain at 4 degrees as it contributes to the amount of contact with the backrest and thereby improves support. However, the backrest angle should be larger as 10 degrees forces the body too much into an upright position, decreasing the effectiveness of the lumbar support. Lastly, choosing the right textile and foam for the chair padding is crucial. The padding should be breathable and allow for easy posture changes, balancing smoothness and sliding friction.

4.5.7 **Limitations**

There are several improvements that can be made to address the limitations discovered during testing:

Method

- The user test was conducted at a university and therefore only work-related activities were tested, which require more focused-oriented postures. No participants participated in leisure related activities and therefore the data are only related to work-related activities. Future testing should include leisure-related activities as well.
- Some tests were too short, less than two hours, which may not be enough time for younger and more adaptive bodies to experience fatigue or discomfort. Longer testing periods are needed in the future.
- Although a diverse group of participants was recruited, more testing with different people is necessary to develop a backrest shape philosophy that fits everyone.
- The scale used in the questionnaire for rating various parts of the chair should have been 1 to 10 instead of 1 to 7, as the results were too close to draw clear conclusions.

Environment

- Some participants found the test chair too high and could not reach the floor with their feet, causing discomfort and reduced control of the chair and tilt.
- The desk was too low for some participants, causing them to lean forward and putting stress on their upper body.
- Participants using a laptop experienced upper back and neck problems from looking down. Future testing should include an improved environment with a height-adjustable desk and a lower prototype chair.

Measuring

- The kyphometer used for measuring standing curves was not high enough for the 0 position to start on the seat pan.
- There was some play in the mechanism of measuring chair, causing slight variations in measuring angles depending on the weight and sitting position of the participant.
- These limitations were manually corrected in Rhinoceros by rotating the curve into the correct position and repositioning the curve by taking physical measurements on the lowest measured curve.

4.5.8 **Future steps**

To finalize the backrest shape method and create the algorithm, some future steps need to be taken, including:

- While the kyphometer is accurate, using it to measure the spine shape is not practical, as the curves produced are inconsistent due to variations in posture and spine flexibility, and potential customers don't have access to the tool. Additionally, the spine shape is not the same as the body contour that is mostly in contact with the backrest. Therefore, a new, simplified measuring method should be explored.
- The tangent line method of creating a backrest setup using a 2D schematic and the spine shape curve is not ideal, as participants did not sit consistently in the same posture. Hence, a new method of creating the backrest should be researched.
- A backrest angle of 10 degrees, with the above-mentioned setup method, seems too small and forces the participant into an overly upright posture. Therefore, a larger sitting angle should be investigated.

4.6 Photographic method

Previous research (O'Sullivan et al., 2012) has successfully applied photographic measuring methods, which are easy and accessible, especially with the current advanced mobile phone technology. Therefore, integrating this method into the algorithm could be interesting. However, this method presented some challenges during the exploratory user test, such as perspective distortion and measuring the body shape along the centreline. Since there was no information available in existing research on how to overcome these challenges, a small study was conducted to investigate how to integrate this method into the chair's design process.

4.6.1 **Method**

Two participants who had also taken part in the backrest user test sat on the kyphometer measuring chair in a normal upright posture. Several photos were taken at varying distances (Figure 60) and heights, and their perspective was corrected using the DxO Viewpoint 4 program by marking horizontal and vertical reference lines (Figure 61). These corrected photos were then imported into Rhinoceros and scaled to match the physical dimensions of the measuring chair. The back shape curve of each photo was traced by following the body contour centreline along the centre of the perspective grid of the seat pan. Finally, all the curves were compared to the curves measured by the kyphometer.

4.6.2 **Results**

Upon comparing all the curves measured from different distances, it is evident that the curves exhibit a similar shape and size from the neck down to the buttocks. However, the underside of the buttocks and legs end at different heights, as shown in the Figure 62. This poses a challenge in positioning the curve correctly on a 2D schematic chair template. This further demonstrates the difficulty in manually drawing the perspective grid and the curve along the centreline of the body.

Figure 60: Measuring back curve at 3,2 m

Upon comparing (Figure 63) the photo curves (red and pink cuves) to the kyphometer curve (other colors), it is evident that the overall shape is quite similar to that of the EB(3) curve (light green curve), despite the fact that this curve represents the spine shape and not the body contour. By accurately positioning the height of the photo's curves, it is observed that the best position would fall between the 2.8 and 3.2 m curve compared to the kyphometer curves, as illustrated in the Figure 63. The height should be at belly level to ensure that the centre of the backrest supports the back.

When drawing the curve on the photo, it is noticeable that the sharpness of the picture decreases as the photo distance increases (Figure 60). This, coupled with loose clothing that obscures the contour of the body, makes it increasingly difficult to accurately measure the back shape as the distance increases.

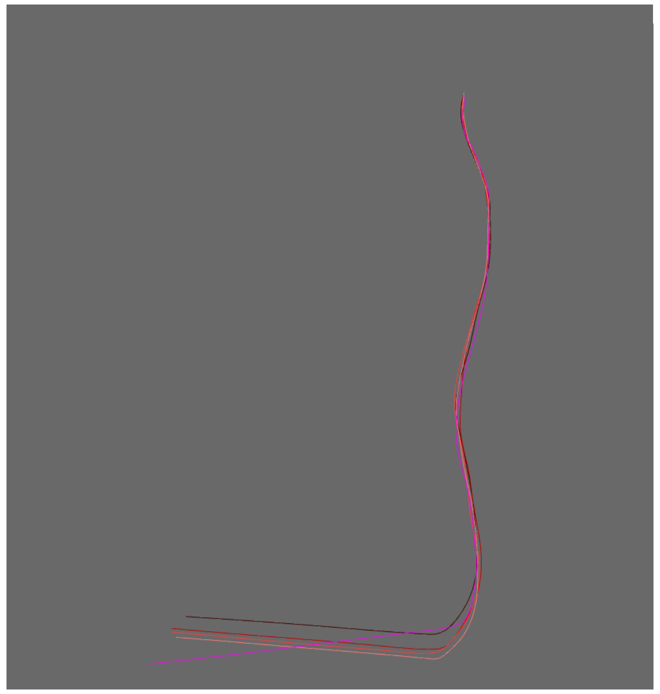


Figure 62: All curves measured from various distances

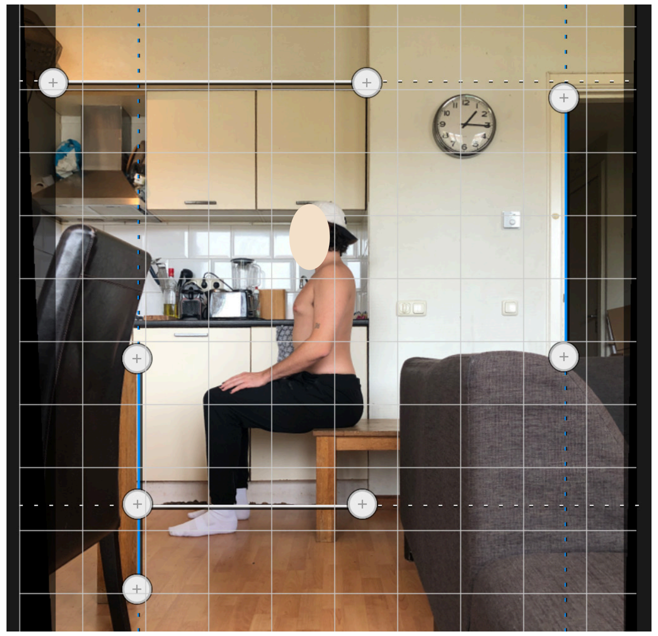


Figure 61: Correcting perspective in DxO Viewpoint 4

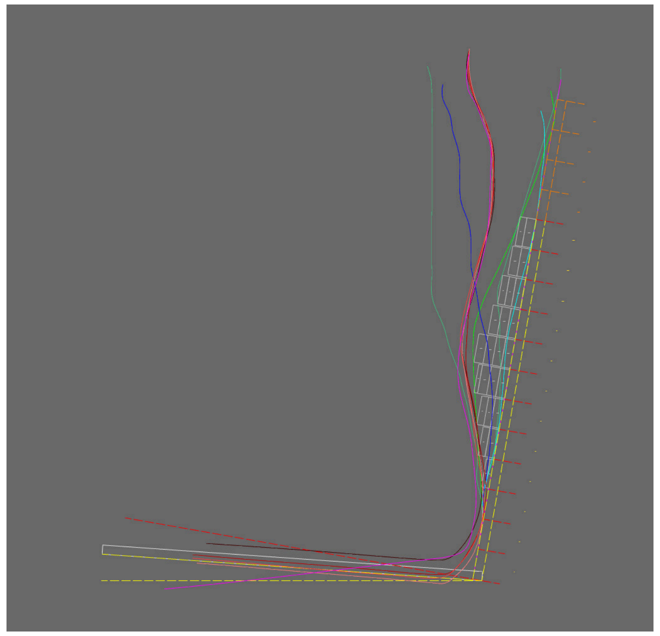


Figure 63: Kyphometer and photographic curves

4.6.3 Recommendations

This list serves as a guide for preparing, taking, and processing pictures to create accurate back shape curves or to scale photos correctly for digital measurements (Figure 64):

1. **Clothing:** Clothing makes it difficult to see the contour of the body, therefore the participants should wear tight or no clothing (or no top).

2. **Picture preparations**
- *Grid:* It is important that there are vertical and horizontal parallel references visible in the picture, such as windows or cabinets. This is for perspective correction.
- *Photo:* Use a high-quality camera in normal photo mode. Register camera model so camera corrections can be performed in post-processing.
- *Scaling:* Measure straight parts of the chair which can be used for scaling in post-processing.

3. **Picture position**
- *Distance:* Approximately 3m distance to minimize perspective distortion. After analysing all curves, this gives the best balance between perspective distortion and picture quality when accurately measuring the curve.
- *Height:* Height should be the middle of the back while sitting, this gives the least amount of distortion to the back in the photo as this happens mostly in the edges of the photo.
- *Centreline:* Touchpoint between back and backrest should be the centre of the photo, again to minimize distortion.
- *Mark spot:* Preferably using a tripod or something similar for picture stability.

4. **Posture:** Sit a chair that has the same angles as the final chair in a natural upright posture.

5. **Position:** Sit with your back fully against the backrest and look straight ahead.

6. **Post processing**
- *Camera distortion:* Correct camera distortion for the camera type which has taken the photo (DxO viewpoint 4).
- *Perspective correction:* Correct the perspective by vertical and horizontal references from the grid. This recovers the proportions of the photo (DxO viewpoint 4).
- *Scaling:* Measuring the same parts in the photo as the physical dimensions taken from the chair and re-scale photo to correct size (Rhinoceros).
- *Seatpan centreline:* Draw a perspective grid on the seat pan and the centre line in between the buttocks of the subject (Rhinoceros).

7. **Curve drawing:** Start in the neck and follow the contour of the body down towards the buttocks. From the buttocks continue with a natural shape over seat pan centre line until the popliteal (Rhinoceros).

Figure 64: Correctly measuring the back curve with the recommended steps

4.7 Measuring curve analysis

This project researched three methods for measuring the back shape and curve: photographic measurement, 3D modelling, and kyphometer. Each method uses different tools and has its own advantages and disadvantages. This section provides a brief summary of the results that can be useful for implementing these methods in future projects.

4.7.1 Photographic measurement

The first method explored for measuring back shapes was the photographic measuring method (blue curves in Figure 65). This is the most accessible of the three methods, as most people have a mobile phone that can be used for this purpose (Pew Research Center, 2021). With a mobile phone camera, photos can be easily taken and imported into a program that enables the measurement of back shape and scaling to the correct size (e.g., Rhinoceros).

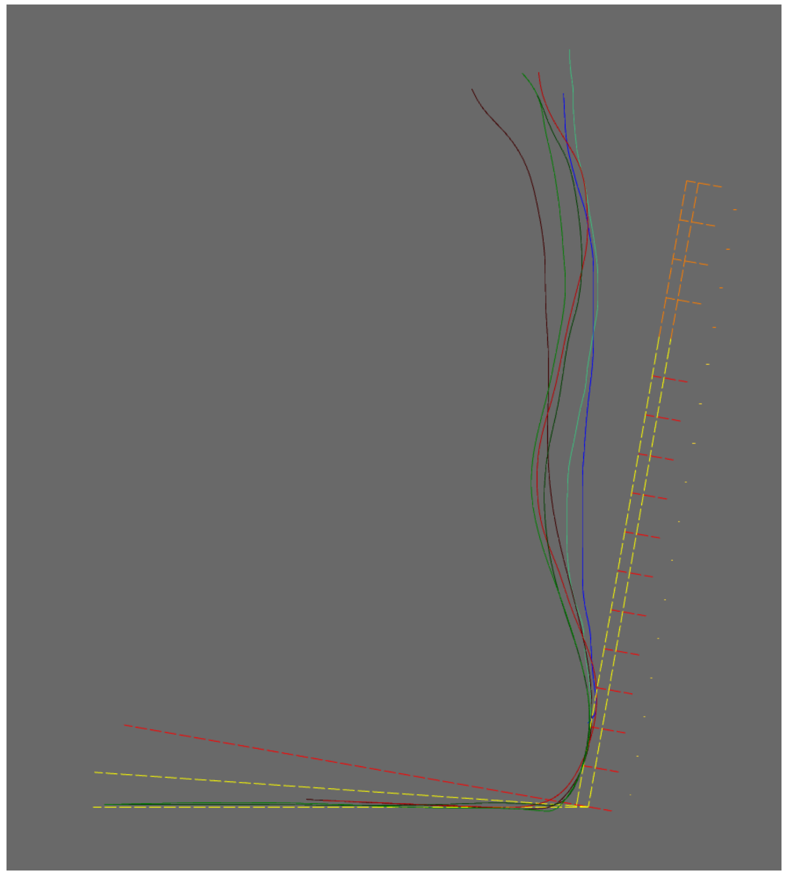


Figure 65: Kyphometer, photographic, 3D scan curves straight up (not rotated)

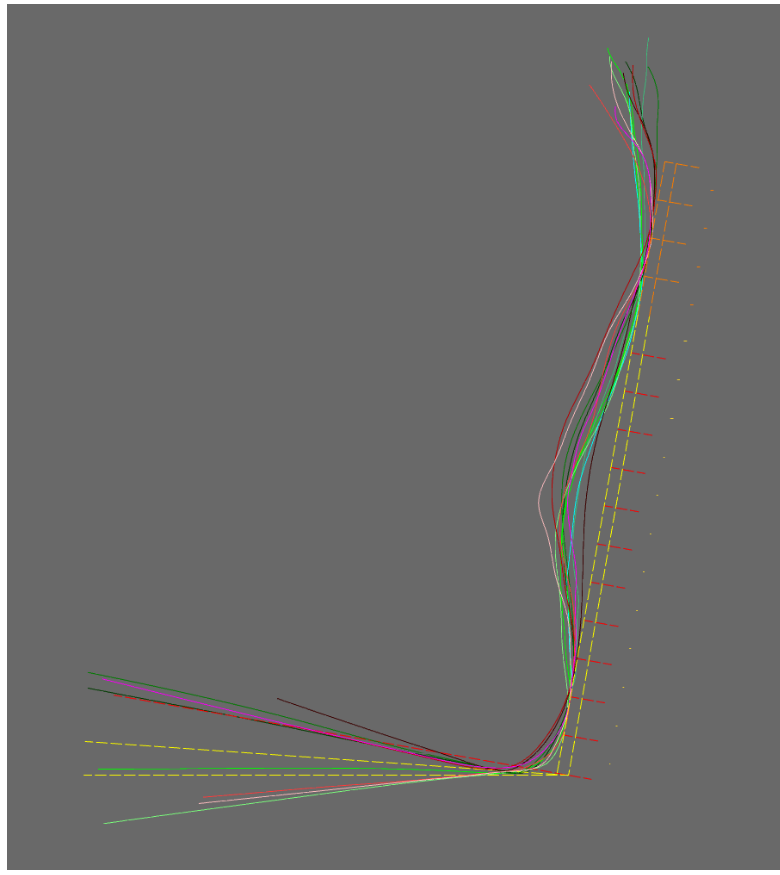


Figure 66: Kyphometer, photographic, 3D scan curves rotated against backrest

The advantage of this method is that it is relatively simple, accessible, and understandable for a normal person, provided they are properly instructed. However, photos suffer from perspective and pixelated distortion and clothing can also cause visual distortion. Therefore, photos need to undergo various post-processing steps to obtain reliable data. When done correctly, the data obtained through this method produces results similar to the other methods. The only challenge is accurately measuring the centreline of the body, especially the horizontal plane, as perspective distortion can make it difficult to measure this aspect and influence the height of the total curve compared to the horizontal plane. Lastly, it is important to note that this method measures the body contour, and clothing, skin, and fat have a significant impact on the shape of the back.

4.7.2 **3D modelling**

The second approach involves 3D modelling and was investigated using the CAESAR dataset (Robinette et al., 1999), as well as by conducting 3D body scans at TU Delft (Figure 67). These models can be used to measure the shape of the back (green curves in Figure 65 and Figure 66) and obtain body measurements. The advantage of this method is that the models are in 3D, providing a wealth of data on the body compared to 2D photographs, and scaling is not required, leading to high accuracy. Additionally, 3D body scans can aid in the development of crucial chair components by allowing fit testing in a digital environment. However, this method is less accessible than the photographic method, even though newer mobile phones have the capability to create 3D scans (Sink, 2021). Post-processing of scans requires some expertise, and measuring is a time-consuming manual process. This method allows measurement of both the body contour and spine shape, as well as landmarking of body parts. It is important to note that clothing, skin, and fat can affect the accuracy of measurements.

4.7.3 **Kyphometer**

The third method is the kyphometer (red curve in Figure 65 and purple curves in Figure 66), which has been explained earlier. This method is the least accessible and requires special knowledge and tools to be used effectively. The kyphometer is originally designed for measuring standing postures, and it can only measure the vertical spine shape of the body, not the horizontal plane. Although it can make highly accurate measurements, it can be challenging to determine the exact starting position of the measurement because the tool does not reach the seat pan. This limitation makes it vulnerable to inaccuracies.

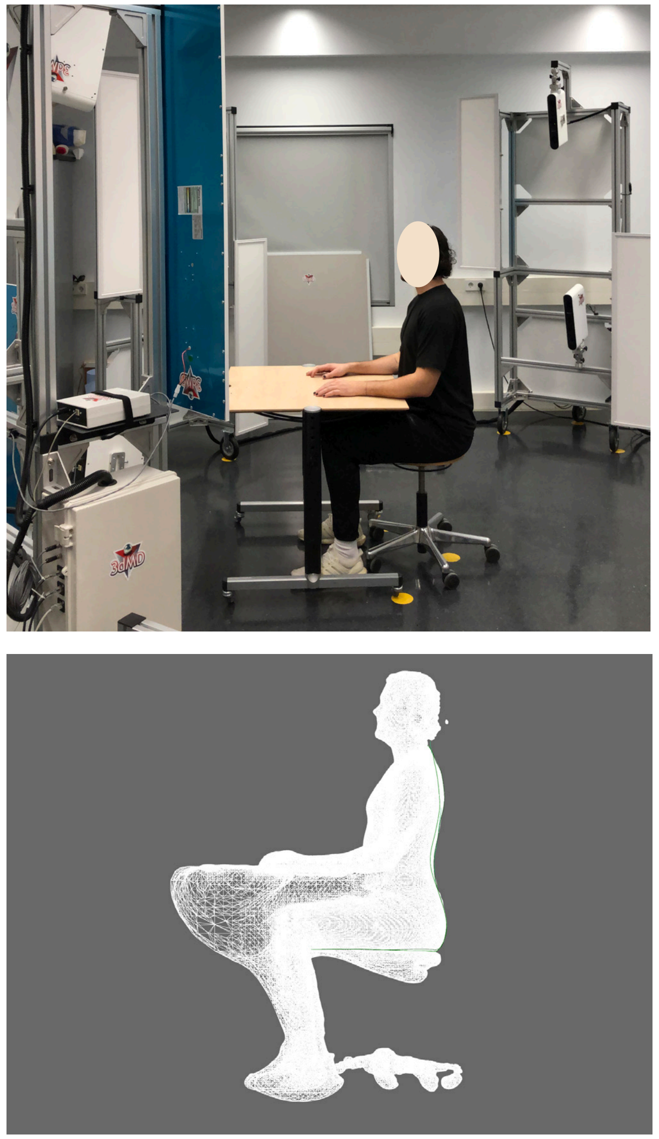


Figure 67: 3D body scanning at TU Delft + 3D model

4.7.4 **Discussion**

Upon comparing the curves obtained from the three measuring methods, it is evident that despite measuring different parts of the back, the curves have a similar shape. This indicates that all three measurement methods are accurate. Correctly positioning the photographic and kyphometer curves at the appropriate height can be challenging, but it is crucial when designing the backrest shape or taking digital measurements. Additionally, the posture of the individual has a significant impact on the curve measurement, as all curves display an s-shaped spine curve but differ in terms of curvature and overall curve angle. Therefore, using the measured curve directly as input for chair design may not be the optimal approach, and it is better to take physical or digital body measurements of specific body parts as input. To address this issue, a measuring grid with a 1 cm by 1 cm grid pattern placed on a wooden plate was created (Figure 68). This grid can be used to measure height by placing the plate vertically next to individuals, and widths and lengths by sitting on top of the grid. The use of a grid also reduces the risk of taking measurements that are not level, as may occur with a tape measure.

Figure 68: 1 by 1 cm measuring grid to measure heights

4.7.5 **3Daboutme**

Klaas Nienhuis is a digital designer who specializes in designing and building product, process, and data experiences. Nienhuis was interviewed because of his involvement in the development of 3Daboutme, a service that helps people choose the correct shoe size. The service employs an algorithm that uses three photos of the foot to generate an accurate 3D model, which is then used to determine the appropriate size for a specific shoe.

The algorithm automatically places landmarks (Figure 69) on the foot photos, and by using a method called Multi-Dimensional Statistics, it is possible to construct a precise 3D model by comparing it to other 3D foot models in a database. Nienhuis explains that 3D scanning can be challenging for the average person, which is why he opted to use an algorithm instead. This method is also interesting to be integrated in this project as photos accessible and 3D models are accurate and rich in data.

Future research should explore the potential of using the CAESAR dataset (Robinette et al., 1999) to create realistic 3D models from photos and possibly even automatic body measurements to be used as input for the algorithm. The complete interview can be found in the Appendix L.

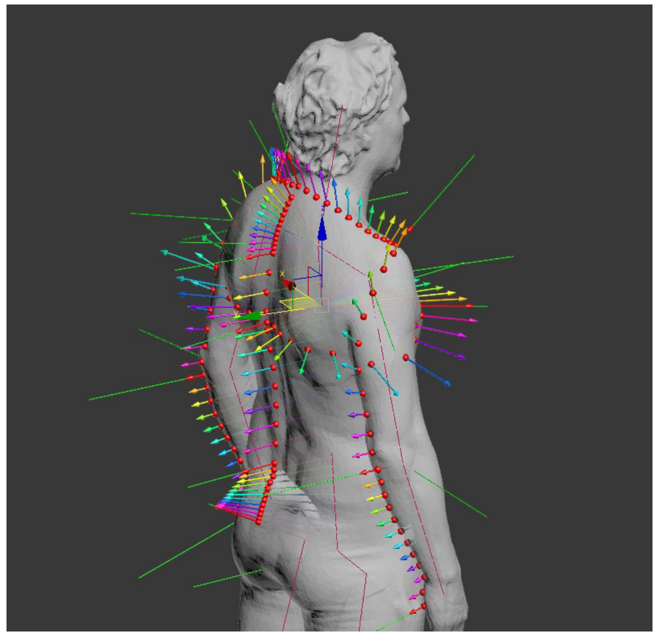


Figure 69: Landmarking to measure along surface (Nienhuis (Nienhuis, 2022)

4.8 New backrest setup method

The backrest user test found that a backrest angle of 10 degrees is too small. This angle forces users to sit too upright, reducing the effectiveness of the lumbar support and leaving the pelvis and upper body feeling unsupported. It also prevents users from sitting in relaxed postures and makes slouching uncomfortable. The study also concluded that 'filling up' the measured curve is not the best method for creating a backrest shape. As a result, a new setup method was developed to address these issues.

Staarink (1995) distinguishes between backrest angle and sitting angle. Backrest angle refers to the overall angle of the backrest, while sitting angle is the actual angle of the upper body when it is placed on the backrest. Analysis of the sitting angles from the backrest user test showed that all participants had different sitting angles due to 'filling up' the measured curve (Figure 70). This means that each participant sat in a different position while using the backrest. To address this, a new 2D schematic chair layout was created that uses the sitting angle of the upper body instead of the tangent line between the buttocks and shoulder blades.

Research suggests that a larger backrest angle between 113 and 125 degrees promotes more relaxed postures where the pelvis and upper body are supported and stable when sitting against the backrest (Staarink, 1995; Gscheidle & Reed, 2004; Smulders et al., 2016). After testing different sitting angles with the prototype chair, an angle of 111 degrees (or 21 degrees from vertical) was chosen as it balances support and comfort well between active and passive postures (Figure 71). Although more testing is necessary, this new angle will be used in the development of the algorithm and the chair it produces.

During the tests of the new backrest angle, different lumbar support methods were also tested to direct the support more towards the top of the pelvis and lumbar region, instead of overfilling the back. Different lumbar support setups suggested by research were tested (Figure 72), including placing the support on the top of the pelvis (Tilman, 2022), L2 to L5 (Openshaw and Taylor's, 2006), and L3-L4 (Molenbroek, 2022). Placing the support over the L3 and L4 vertebrae seemed to be the best option, as it provided good support, enough space for the upper body, and plenty of room for the buttocks and sacrum for the lumbar support to be effective.

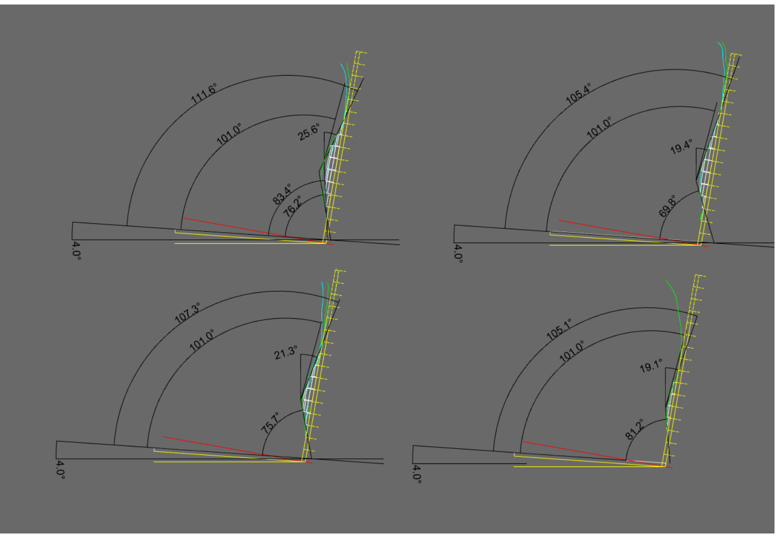


Figure 70: Actual sitting angles from the backrest user test

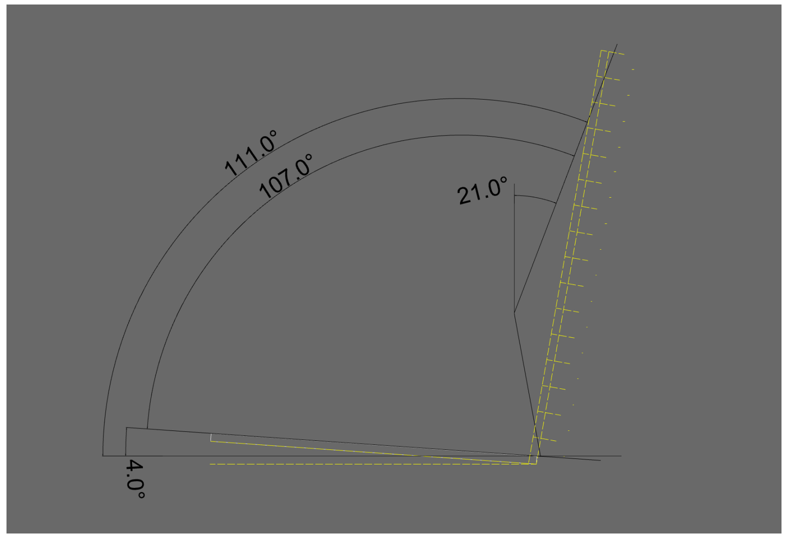


Figure 71: New 2D schematic layout with new angles

4.9 Takeaways

Going into the next phase of the project, there a few important takeaways until now that will influence the design of the chair:

Home office worker

- Home office workers often lack a dedicated office space and, therefore, work in areas such as the kitchen or dining room, sitting in those chairs.
- Home office workers usually do not have an ergonomic setup and may lack knowledge of healthy posture.

Taking measurements

- Perspective and pixelated distortion in photographic measuring methods make accurate back measurements challenging.
- Taking physical measurements is the best method in this project scope, and a measuring grid will help ensure accurate measurements.

Chair design

- The chair's design must allow for posture variation while maintaining a rigid shape.
- Slouching is not necessarily a bad posture and should be supported by the chair.
- The seat pan should have a 4-degree angle, and the backrest should be 21 degrees from vertical.
- The lumbar support should be positioned over L3-L4 and should 'fill up' the entire back.
- The backrest's height should reach the underside of the shoulder blades to support the upper body and allow for free shoulder movement.
- The chair's width should not extend beyond the arms to enable freedom of movement.
- The backrest's edge should be rounded and deflect away from the user to prevent cutting into the back.
- A new backrest setup method with a 2D schematic layout will serve as the algorithm's basis principle.

Figure 72: Focussing lumbar support on top pelvis

5 Definition

This chapter defines how all body variables are related to the chair parameters. These variables are determined by studying the anthropometry of the human body and how these influence the design of the chair. Lastly, it discusses how these variables should be measured before they can be used as input in the algorithm in the next chapter.

These two upcoming chapters have been written superficially, with certain confidential information deliberately omitted. The omitted information is available in the Confidential Appendix A, but only accessible to supervisors.

5.1 Starting point

This project focuses on how to translate the user's body dimensions into a personalized chair, while building upon the bucket style chair design from the previous project.
A bucket style chair features three main elements: the seat pan, the backrest, and the transition part connecting the two, which is referred to as the buttock bowl for ease of reference. Through research and user testing, it was concluded that the chair must enable variation in posture and allow for easy posture changes, with the most important postures being forward leaning, sitting upright, and sloughing backwards. This is achieved by creating a chair shape that takes inspiration from the Wotzka auditorium chair (Staarink, 1995).

5.1.1 Sitting bones

The sitting bones serve as the starting base of the chair as they are the balance point of the spine on the pelvis when seated (Figure 20). Previous research has proved that the sitting bones are essential for proper sitting posture and should thus form the foundation of chair design (Tilman, 2022; Lili et al., 2010).

By using the sitting bones as a starting point of all the parameters of the chair, the chair will be well-balanced and all its parameters properly interconnected, just as all body variables are connected to the sitting bones.

5.2 Seat pan parameters

Although the seat pan is not the focus of the project, it is important to define the seat pan parameters as these are necessary when creating the algorithm (Figure 73). The goal is to ensure that the seat pan design and shape are simple yet comfortable and well-fitted.

5.2.1 Angle

Similar to the prototype used in the user test, the seat pan angle will be fixed at a specific amount of degrees (Figure 74). The user test revealed that this angle enables users to comfortably take all three important postures, and research suggests that it reduces static pressure on the dorsal muscles (Lili et al., 2010) and lowers shear friction on the lower limbs, preventing the body from sliding forward (Staarink, 1995). This might result in a higher level of momentary comfort. The seat pan angle will not be personalized but rather serve as the chair identity and enables comparable results to be generated during testing of the 3D printed chair from the algorithm.

Figure 73: All the important parameters for the design of the seat pan

5.2.2 **Depth**

The depth of the seat refers to the distance between the front edge of the seat pan and the furthest point of the buttock bowl. It significantly influences the comfort of user's sitting posture. A seat pan that is too deep, exceeding the length of the thighs, will prevent users from sitting against the backrest, increase muscle activity in the legs, and stress the popliteal area (Lili et al., 2010). A seat pan that is too short leads to knee numbness due to overpressure on the knees. Therefore, the depth should be moderate so that the legs can move freely.

To determine the seat depth, the distance from the popliteal area to the back of the buttocks needs to be measured using the measuring grid. The user should sit on the grid, aligning themselves parallel to the grid lines, with the edge of the grid placed at the popliteal. At the back of the buttocks the distance can then be read.

5.2.3 **Width**

The shape of a seat pan typically features a narrower back and a wider front to allow users to adopt various sitting postures and move their legs while receiving support (Lili et al., 2010). However, due to limitations with 3D printing, it is not possible to design the seat pan in varying widths, with the backrest also needing to have the same width. Therefore, the seat pan should have a minimum width that matches the user's hip breadth to offer sufficient support to the hips and buttocks. To accommodate posture variations and lower limb movements, the width is increased by a small amount. However, the width should not exceed the arms as this would obstruct the freedom of arm movement.

To determine the seat pan's width, the same method can be used as measuring the depth, where the user sits on a measuring grid and the distance between the two furthest points on the hips is measured.

5.2.4 **Edge deflection**

For the comfort of the user, it is important that the front edge of the seat pan is not straight and instead deflects away from the seat pan surface. A straight edge is too sharp and will cause discomfort for the underside of the upper legs over time (Tilman, 2022). A drastic deflection will prevent this issue, even when the legs are tucked underneath the chair.

5.2.5 **Depth and width shape**

For the scope of this project, the shape of the seat pan is kept simple, but two important parameters need to be considered. The first is the shape along the depth of the seat pan, which should be a convex shape to improve posture by allowing the user to fall into the lumbar support while allowing the legs to move downwards to improve blood flow in the lower limbs (Tilman, 2022). The Wotzka chair also applies this principle (Staarink, 1995).

The second parameter is the shape along the width of the chair. A flat surface increases the risk of pressure ulcers in the buttock area as soft tissue is squeezed between the seat pan and sitting bones (Fiorillo et al., 2021). A curved seat stabilizes the pelvis and distributes pressure from the weight of the body on the buttocks.

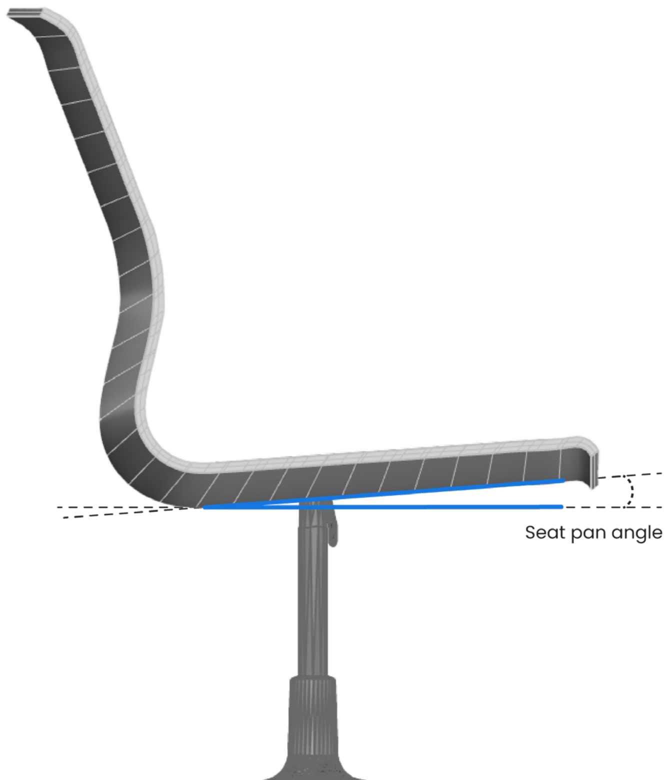


Figure 74: Seat pan angle explained

5.3 Backrest shape

The focus of the project has been the shape of the backrest and lumbar support, which have been thoroughly researched to ensure their correct design and accurate measurement. These parameters significantly impact the sitting posture and overall comfort of the chair (Figure 77).

5.3.1 **Lumbar support**

The lumbar support plays a crucial role in providing support to the lumbar area of the back, helping to maintain a healthy spine while sitting (Kroemer & Kroemer, 2016). The support should be placed in the lumbar region of the back with pressure focused on the top of the pelvis. The height positioning of the support is crucial as the user test revealed. A support positioned too high can feel pushy in the back and leave the pelvis unsupported, while a support too low can push on the sacrum, pushing the lower body forward and making it difficult to maintain posture and comfortable sitting position (Carcone & Keir, 2007). It is important that the back is not 'filled up' and the buttocks have enough room to maintain the effectiveness of the support.

Lower lumbar vertebrae identification
When designing the lumbar support, it is important to locate the position of lower lumbar vertebrae in the user's spine. To determine the top of the lumbar support, which is referred to as the starting point, the method of palpation of the iliac crests is used to identify the spinal levels (Chakraverty et al., 2007) (Figure 76). This involves palpating the intercristal line to mark the top of iliac crests on the body while seated and measuring the height using a measuring grid. As the spinal level of this line is influenced by the user's BMI and gender, the exact spinal level is determined by calculating the BMI of the user (Appendix A). After locating the position of the intercristal line, the starting point can be calculated by adding the remaining distance from the line to the desired vertebra to the measured height of the iliac crests.

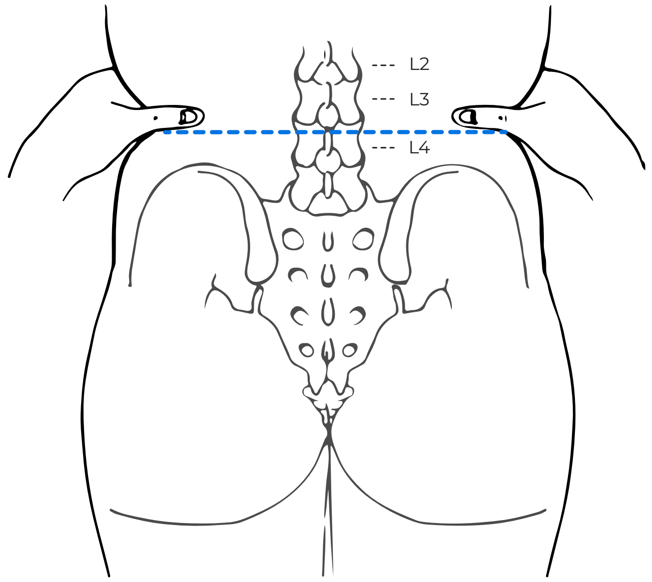


Figure 76: Identification of the intercristal line by palpation of the illiac crests and vertebrae

Figure 75: All the important parameters for the design of the lumbar support

Lumbar support starting point
To calculate the remaining distance to the desired vertebra, first the user's vertebrae and disc heights are calculated in relation to their sitting height (Zhou et al., 2000). It should be noted that these heights differ for each gender, and their deviations are related to the sitting height percentile. The user's sitting height percentage within the population on DINED is determined to calculate the deviation to the mean vertebrae and disc height. This enables precise calculation of the remaining distance to the desired vertebra and determination of the final height of the starting point of lumbar support (Figure 77).

Lumbar support edge
After calculating the user's exact vertebrae and disc heights, it becomes possible to calculate the distance to the lumbar support edge. This is achieved by subtracting the heights of the vertebrae and discs from the lumbar support starting point. The edge of the lumbar support should leave room for the buttocks. To ensure that the focus of the support is on top of the pelvis, the horizontal position of this edge must be located in front of the starting point.

Midpoint
To maximize contact surface and comfort, the lumbar support should not be a straight line, but instead should follow the curvature of the back with a small curve.

5.3.2 Angle

Based on research, the angle of the upper part of the backrest is set at specific amount of degrees, as it has been shown to balance the forces on the body and reduce intervertebral disc pressure while sitting against the backrest (Rohlmann et al., 2011). This angle also allows the user to maintain upper body support while comfortably sitting in a slouched posture. As with the seat pan angle, the backrest angle will not be personalized, as it forms part of the chair identity and enables comparable results to be generated during testing of the 3D printed chair from the algorithm.

5.3.3 Height

The height of the backrest refers to the distance to the top edge of the backrest to the surface of the seat pan. According to Tilman (2022) and Scholten (2022), the lumbar support is an essential part of the backrest for sitting and it is needed to maintain lumbar lordosis (Vergara & Page, 2000). As this office chair needs to multi-functional, it should provide comfort during breaks and leisure-related activities. Additionally, since the chair needs to fit within a home environment, the edge of the backrest should not be too high. This also allows for free shoulder space (Goossens et al., 2003) and upper body movement, enabling the user to easily perform lateral activities around their workspace. This height provides sufficient support and comfort without the backrest reaching too high above regular dining or kitchen chairs.

To determine the height of the backrest, the height of the armpits is measured as it may be difficult to locate the shoulder blades in users with higher BMI due to fat in the area. Future research will need to study the distance between armpits and shoulder blades. Currently, the shoulder blades are located through palpation, and the underside is marked while sitting in a natural upright but relaxed posture. The marked line is then measured by placing the measuring grid vertically on the sitting surface laterally of the user, and the height of the shoulder blades is measured by looking horizontally at the level of the mark.

5.3.4 Width

As mentioned previously, the width of the backrest is constrained by 3D printing limitations, resulting in a backrest that is the same width as the seat pan. Ideally, the backrest width should match the width of the upper body to provide support and maintain spinal balance (Lili et al., 2010). However, the backrest should not be excessively wide, as this would limit arm movement and freedom of motion.

5.3.5 Edge deflection

Like the seat pan, the top edge of the backrest should also have a slight deflection away from the surface. A sharp, straight edge would be uncomfortable when sitting against the backrest and slouching (Tilman, 2022).

5.3.6 Width curve

When viewing the human body from a horizontal plane, the back is also curved. To optimize the contact surface and enhance comfort and effectiveness, the shape of the backrest should also include a curve across the width of the chair. However, due to time limitations, this curve is not personalized in this project.

5.4 Buttock bowl

The last element is the buttock bowl, which connects the seat pan to the backrest. It is crucial for this element to provide enough clearance for the buttocks, especially for females and individuals with higher BMIs who typically require more space (Tilman, 2022). Therefore, the dimensions of the buttock bowl should be personalized to the user's body (Figure 78).

5.4.1 Depth

To provide sufficient clearance for the buttocks, it is necessary to measure the distance between the sitting bones and the backside of the buttocks. This is achieved by sitting on a thick cardboard sheet and aligning the edge of the sheet with the most protruding point of the buttocks. By moving back and forth on the sitting bones, an indentation will be formed on the cardboard. The distance between the sitting bones and the edge of the cardboard is then measured to determine the depth of the buttock bowl. However, the depth needs to be extended to account for the thickness of clothing. The exact amount of extension required may vary and requires further research.

5.4.2 Height

The height of the buttock bowl is a crucial factor in determining the slope of the underside of the lumbar support. If the height is too low, the slope may interfere with the user's sacrum, resulting in discomfort and reduced effectiveness of the lumbar support. The height can be measured in the same way as when measuring the underside of the shoulder blades, by placing the measuring grid in the same position and marking the most protruding point of the buttock, then measuring the height of this point by looking horizontally at the grid.

Figure 77: All the important parameters for the design of the backrest

5.4.3 **Width**

The width of the buttock bowl is designed to be the same as the width of the seat pan and the backrest, due to the 3D printing constraints and to maintain consistency in the chair design.

5.4.4 **Width curve**

The width curve of the buttock bowl is a result of the set width curve of the seat pan and backrest. Personalization of this parameter is not included in this project

A part of the usability of a chair depends on its legs, and therefore it is important to consider this aspect during the design process. There are three options available: non-adjustable and static legs, adjustable and dynamic legs (like an office chair frame), or a combination of both. In the user test, it was decided to integrate an office chair frame to promote posture variation and add a dynamic element to the chair experience. However, the user test and user observations revealed that users only made minor posture adjustments and did not make full use of the tilt functionality. To maintain consistency with the aesthetic of dining and kitchen chairs, static legs were chosen instead. The focus was shifted towards enabling posture variations through the design of the bucket.

5.5 **Other chair elements**

A dynamic rubber pivot mechanism could be an interesting addition to the chair, providing a small degree of tilt when leaning forward or backward. Such a mechanism has been developed by Tilman (2022) and is an innovative way of introducing dynamic movement to a static chair, enhancing support and comfort across different postures. Further research is needed to determine the effectiveness of this rubber mechanism in combination with the design of the bucket.

Figure 78: All the important parameters for the design of the buttock bowl

Figure 79: Backside of the backrest

6 Algorithm

Integrating algorithmic-aided design methods in the development of the chair enables personalization to the user's body dimensions and creates a mass-customizable chair concept. Algorithmic design allows easy modelling of the complex bucket shape that would otherwise be a challenge or time-consuming when done manually. The parametric modelling philosophy of algorithmic design allows for manipulation of the design through variable input parameters that are interconnected to the measured body variables, generating a chair shape model. If an input value of a parameter is changed, the entire model is generatively recreated.

This chapter has written superficially, with certain confidential information deliberately omitted. The omitted information is available in the Confidential Appendix B, but only accessible to supervisors.

6.1 Grasshopper

The project uses the Grasshopper plug-in to generate the algorithm for modelling the chair. This is a visual programming language and environment that runs within the Rhinoceros 3D modelling program (Figure 80). Grasshopper is a user-friendly and accessible plug-in that allows designers to construct generative algorithms for creating 3D components. Algorithmic scripts are created by dragging components onto a canvas and then connecting the outputs of these components to the inputs of subsequent components.

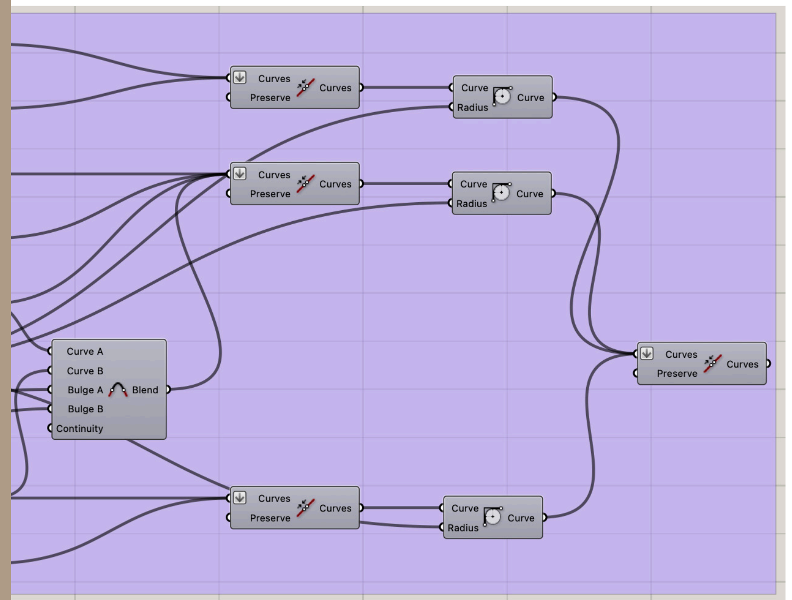


Figure 80: Example of a Grasshopper script

6.2 Algorithm principle

The algorithm is based on the principle of using points to construct the general shape of the chair (Table 2). These points define the shape of the chair along its central axis, which coincides with the centre of the user's body. The position of these points is determined by input parameters, which are derived from the user's measured body dimensions. The 2D XZ plane is used to facilitate the determination of the point's positions. Once all points are established, they are connected by a curve to create the shape of the bucket chair. This curve is then offset along the Y axis in both directions and lofted to produce the bucket-style chair shape.

Table 2: The points to construct the shape of the chair and their body dimension variable

Points	Chair parameter
Point 1	Backrest edge deflection
Point 2	Backrest height
Point 3	Lumbar support starting point
Point 4	Lumbar support midpoint
Point 5	Lumbar support edge
Point 6	Buttock bowl
Point 7	Starting base of the chair
Point 8	Seat pan depth
Point 9	Seat pan deflection

6.3 **Input variables**

Grasshopper uses input parameters to generate the chair model. Some of these parameters are body dimension variables, while others are variables used to design the chair, such as the thickness of the 3D print and smoothness of the surface of the chair.

Figure 81: Example of Grasshopper parameters to generate chair design

6.4 **Point drawing**

The points are generated by calculating their X and Z components using trigonometry (Appendix B).

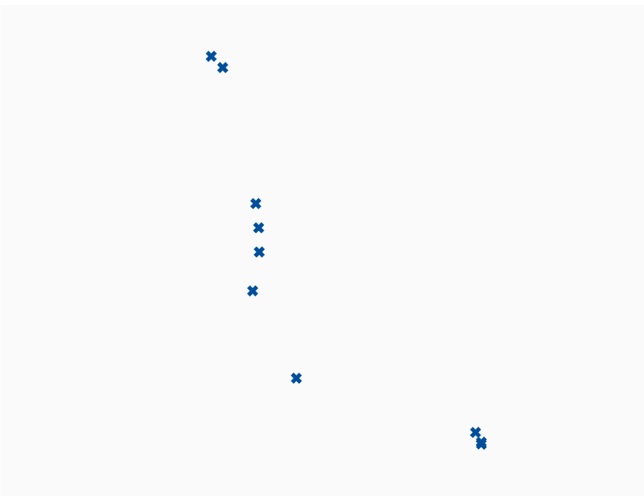


Figure 82: Point cloud after drawing all points

6.5 **Curve drawing**

After constructing all the points, they are connected by straight lines to create a curve that represents the general shape of the chair. After all lines are drawn, they are joined, and a fillet is applied to their edges to smooth the curve (Figure 83).

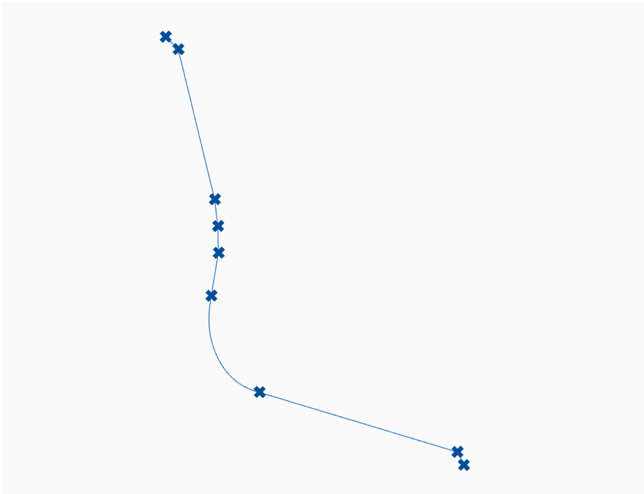


Figure 83: Central curve through all points

6.6 **Side curve drawing**

Once the main shape is drawn, the side curve can be generated by offsetting it to achieve the width curve later in algorithm (Figure 84).

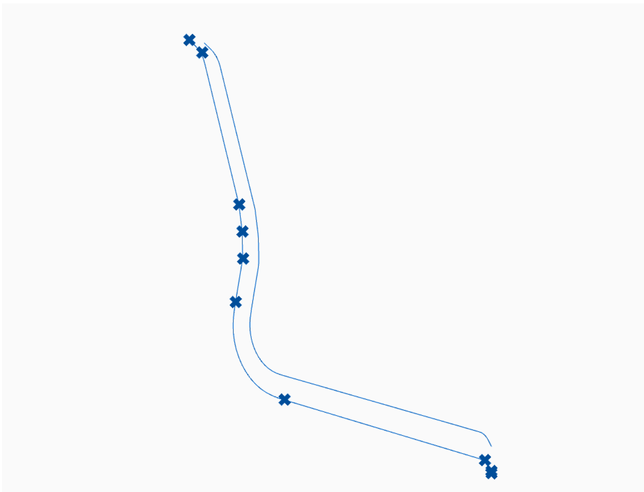


Figure 84: Side curve after offsetting the central curve

moopi - Chapter 6: Algorithm

6.7 **Surfacing and model generation**

The final step in generating the chair shape model is to create surfaces for both the central and side curves. The side curve is duplicated and moved in both Y directions to create two new side curves at half the determined chair width. The three curves (are then lofted to create the chair shape model (Figure 85). The resulting surface can be offset to create a 3D model of the chair with the desired thickness, but for 3D printing, only the surface is required.

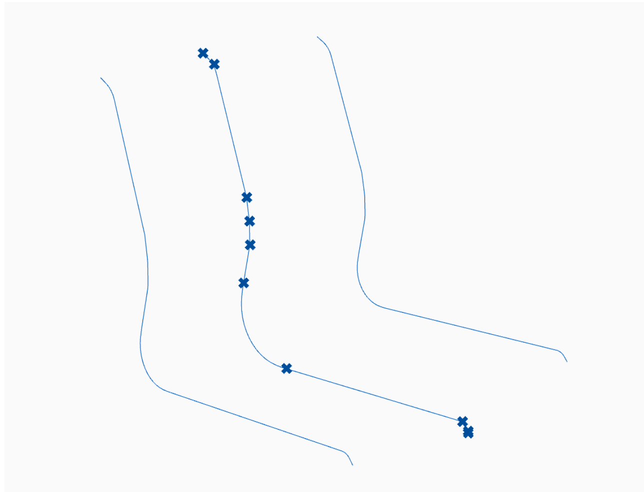


Figure 85: Moving the side curve to the desired width of the chair

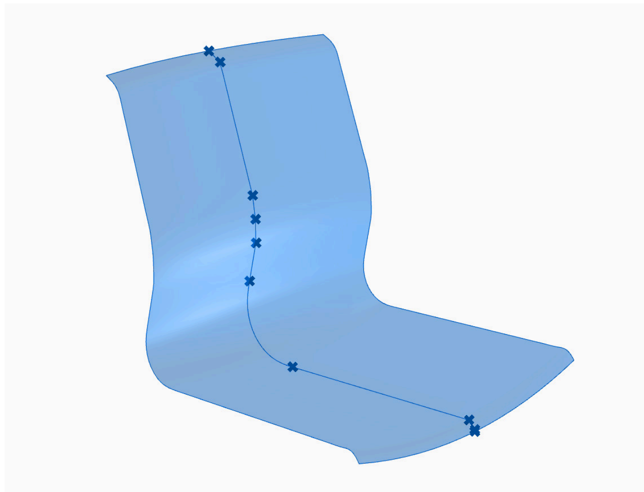


Figure 86: Lofting the surface through all three curves

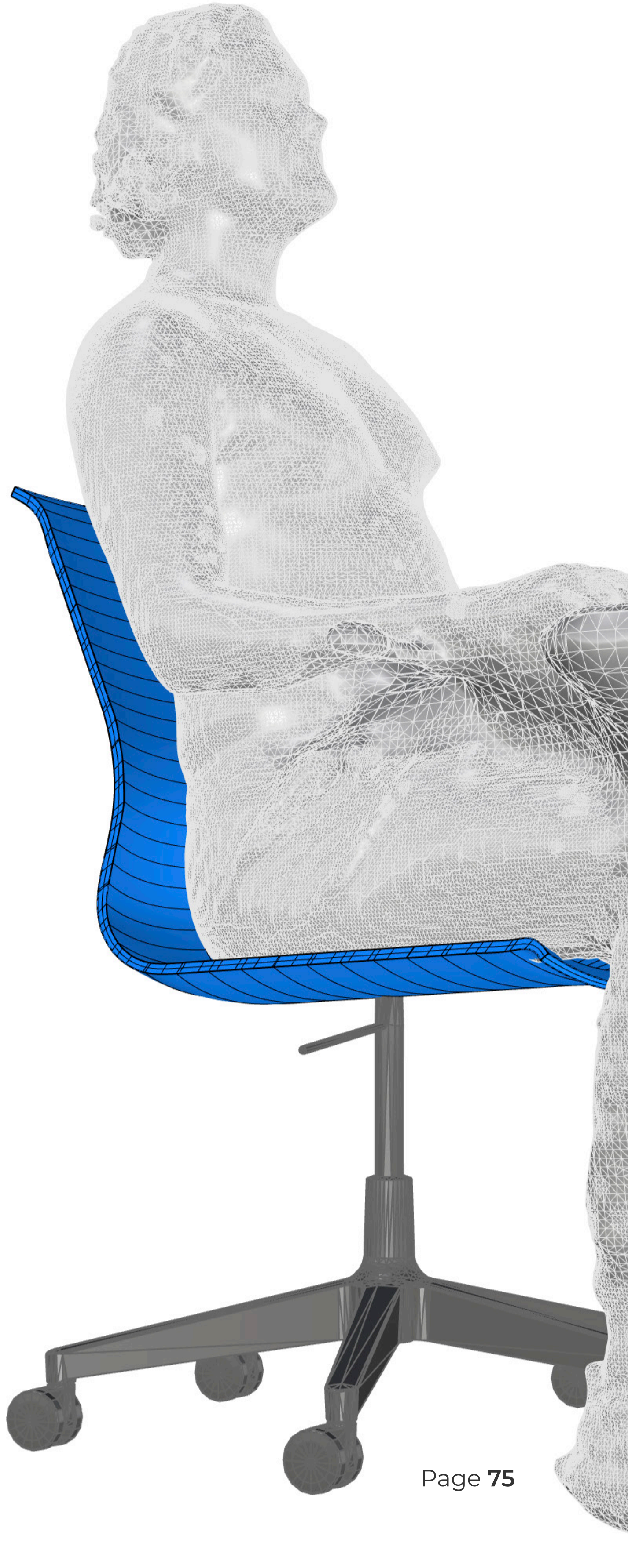


Figure 87: 3D model sitting on Grasshopper generated chair

7 Realization

In this chapter, the final steps will be taken towards realizing a prototype that represents the final product and is ready to be tested by users for evaluation. This evaluation will be used to write a discussion on the limitations and future steps that need to be taken in order to finalize the chair.

7.1 Final prototype

The algorithm can generate a personalized chair model based on the user's measured body dimensions and input parameters, which can then be 3D printed. Based on previous projects, it is recommended to print two chairs in a continuous loop to optimize print efficiency and reduce waste (Figure 89). To achieve this, the two chair surfaces are placed on the lateral side and the backrest and seat pan edges are connected by a smooth curve to create a continuous loop. The surface is then capped to create a closed object (Figure 88), which can be imported into the Cura program to generate a code that only prints the outer line of the object.

To conduct user testing on the personalized chairs, the same office chair frames used in previous prototypes are used to save time. However, mounting the chairs at the correct angle on the curved underside of the seat pan can be challenging. To address this, mounting bars with a horizontal flat surface are also created to ensure the chairs can be easily mounted at the correct angle. These are plastic welded ot the chair (Figure 92).

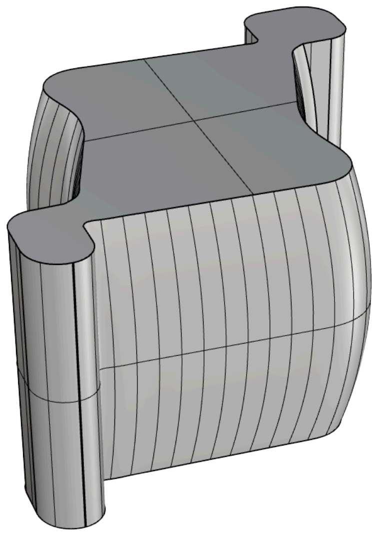


Figure 88: Two chair models surfaces connected ot create a solid which is required for pre-processing of the printer

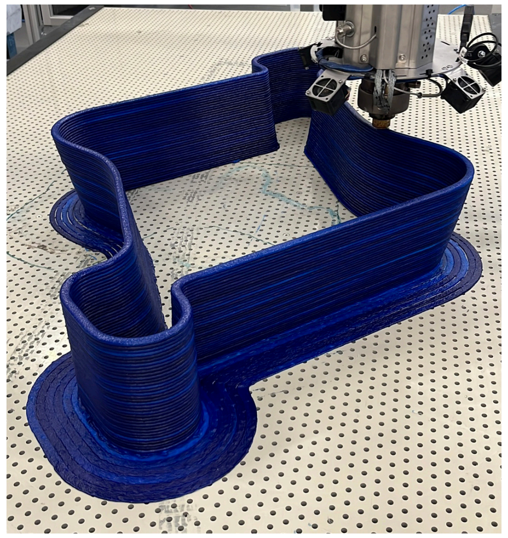


Figure 89: 3D printing two chairs in a continous loop in a single line

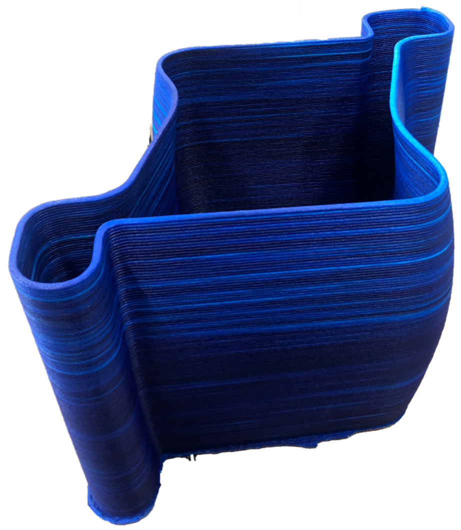


Figure 90: Final 3D printed model of two chair shapes connected

7.2 Testing

It is important to test the chairs produced by the algorithm in a realistic setting with participants who represent the target user group of the chair before finalizing this project. This will help validate the research and insights generated in this project and suggest steps for future research. Therefore, two participants, a 26-year-old male and a 51-year-old female, were measured as described in the definition phase of the project, and two chairs were generated by the algorithm from the previous chapter.

To obtain a realistic performance measurement of the chairs, the tests were conducted in the home office environments of the users. Both chairs were mounted onto office chair frames (Figure 93) that were easy to use, and other than the seat itself, the experience was similar to the office chair the participants had, which were basic non-adjustable office chairs. The chairs were then used as they normally would for three days. Afterwards, the chairs were assessed by the participants with the same questionnaire as the backrest user test. The full results can be found in Appendix M.

Figure 91: Finalized bucket chair shape after separating the the print, refining and sanding the edges

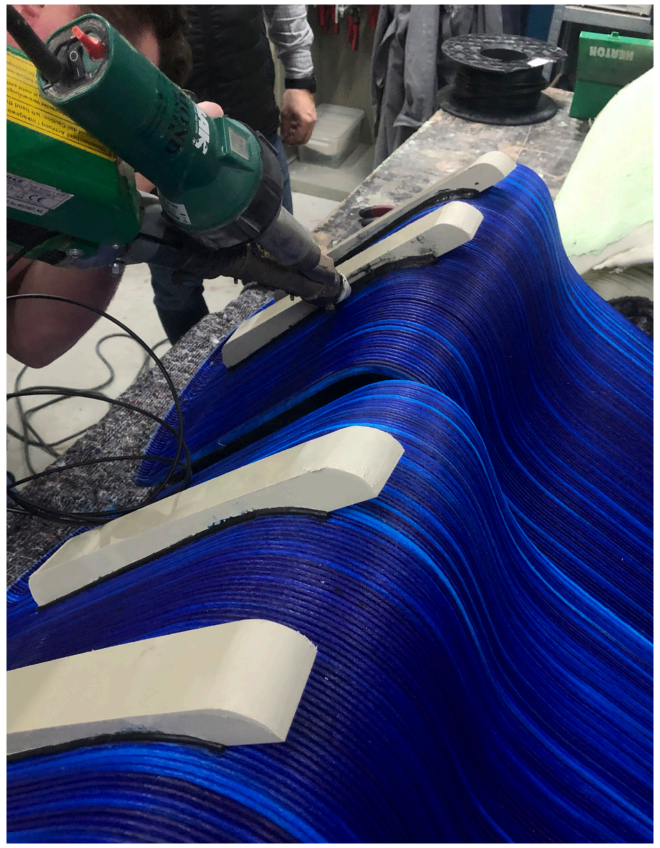


Figure 92: Plastic welding the mounting bars to the understide of the seat pan

7.3 Results & Discussion

As the project was nearing completion and time was limited, the shape of the 3D printed chairs was quickly analysed and summarised in this section. These insights can be useful for future testing, which is necessary to gain a better understanding of the performance of the algorithm and the chair shape.

7.3.1 Backrest shape

Both participants reported that the backrest shape fits well to the shape of their backs. This indicates that the overall shape and height of the backrest are well designed, resulting in a shape that is supportive and comfortable. The lumbar support shape fits well into the lumbar area of the back, and the straight upper part of the backrest follows the upper body nicely. Additionally, both participants reported that they were able to perform all activities during the test and were able to work comfortably in all three important postures: forward, upright, and slouching.

Figure 93: Two prototype chair refined and mounted to office chair frames ready for testing

7.3.2 Lumbar support and stability

Both participants expressed satisfaction with the lumbar support and its stability. The lumbar support is placed at the correct height, focusing support at the top of the pelvis. Although the curve of the support is not extreme, the buttock bowl provides sufficient room for the buttocks to be effective in supporting the lumbar region. Both participants reported not wanting more support in terms of the lumbar support curve. However, one participant mentioned that the lumbar support height could have been slightly higher as they prefer a higher lumbar support. In this case, the idea of modular padding could be interesting, as the users would be able to adjust the support to their preferences. Both participants found the back and pelvis to be stable when sitting against the backrest.

Figure 94: One prototype of the mass-customized 3D printed home office desk chair

7.3.3 Backrest angle

There is a difference of opinion between the two participants regarding the backrest angle. One participant likes the backrest angle of the chair and finds it more supportive compared to the previously used Ikea chair (LÅNGFJÄLL model). This participant stated that the combination of the lumbar support and the backrest angle resulted in a more upright posture against the backrest. Previously, in the Ikea office chair, the participant had the habit of hunching forward and losing contact with the backrest. This was noted during observations. However, the other participant found that the backrest angle was too big, resulting in the feeling of overarching the back to make contact with the backrest during focus-oriented activities, which caused lower back pain. When sitting upright and leaning forward, there was no contact with the backrest, resulting in upper back pain. This participant suggested that the backrest angle should have been less to increase the amount of contact between the backrest and the back. However, this participant found slouching postures to be very comfortable with this backrest angle, as the whole upper body was supported in this posture.

7.3.4 Seat pan

Both participants reported liking the seat pan angle, as it helped them to push their backs against the backrest and maintain good posture. However, they suggested that the seat pan length should be longer, as it felt short when slouching and moving the buttocks and legs forward. Therefore, the seat pan correction should be less in the future.

7.3.5 Backrest and seat pan width

Both participants reported that the total width of the chair was too large. Although the seat pan was made to match the participant's hip breadth with an extra margin, it was still too big. This resulted in the chair being too large for the home office space and aesthetically too bulky and flat. The large seat pan surface also allowed the user to sit relatively far from the chair frame centre, which caused the chair to tilt over as the surface of the wheel was smaller than the surface of the seat pan. Additionally, the backrest width was too large and hindered arm movement. Future testing should investigate how to 3D print a chair with variable seat pan and backrest widths.

Figure 95: The prototype in a home office environment next to other dining chairs

7.3.6 Comfort

Both participants reported finding the shape and cushioning of the seat pan comfortable and stable for the pelvis. However, one participant reported feeling their sitting bones after sitting for a longer period, but this was not uncomfortable or painful. On the other hand, the backrest cushioning was considered inadequate, as the hard plastic pressed too much on the lower back muscles when leaning forward. The padding used for the backrest was 1 cm thick to provide a more accurate assessment of the backrest shape, as padding dampens imperfections. One participant also reported that the clothing worn was noticeable with this backrest cushioning setup, and thick sweaters would make the backrest feel uncomfortable when clothes stack up in the back. This is something that needs to be taken into account in future research. Finally, the cushioning should be better finished in the final product as the chair looks exciting when 3D printed with the different shades of blue, but the prototype-style padding makes it aesthetically unattractive.

7.3.7 Details

Although the chair designs are prototypes, there are some small details that need to be refined when finalizing the product. The corners of the chair should be rounded off since the square shape is not aesthetically pleasing, and the corners are sharp enough to damage walls. Additionally, the edges and surface should be smoothed since the fibre reinforcement in the plastic creates a sandpaper-like texture that could also damage clothing. The chair's unique effect with different shades of blue may appeal to potential customers; however, this colour may not fit with the customers' home aesthetic, so exploring more colour options would be wise.

7.3.8 Chair construction

The manufacturing process of the chair was relatively easy but still labour-intensive. The algorithm-based customization of backrest shapes was fast and accurate. However, the preparation process of joining the surface of two chairs together to make a continuous loop for printing was labour-intensive. Post-processing was required to refine the final 3D print for use as a chair, including manual separation of the two chairs, rounding and smoothing of the edges of the backrest and seat pan, and adding mounting plates for leg to be attached. The plastic bars used in the prototypes were an ugly and inadequate solution, as the threaded inserts broke out of the plastic during use. Additionally, one chair was damaged during testing, as the two plastic layers of the print broke and separated, indicating that the 10 mm single line print was not strong enough to withstand the load of sitting activities. Future research should focus on reducing the labour and time required for preparation and post-processing, as well as developing a more robust solution for mounting legs to the chair.

Figure 96: User testing the prototype in the home office environment of a participant

8 Discussion

Due to time constraints, the final design was limited to a prototypal level, with a focus primarily on the backrest and support. However, to transform the prototype into a tangible product, it is necessary to develop other elements of the chair, such as the seat pan, buttock bowl, and legs. Moreover, the design of the backrest and support needs to be validated further, and it is crucial to take into account the business aspect and customer journey. This section will cover the areas that necessitate additional research or development.

8.1 Future reasearch and limitations

Although this is a lengthy list, it is essential as each point will contribute to the chair's success. After completing this project, the chair will be further developed into a real product, and these points must be taken into consideration before it is launched into the market.

8.1.1 Home office worker

- The target group lacks knowledge of how to sit with a healthy posture in an office chair. Therefore, this product should teach them how to do so, as it is a crucial factor in its success.
- To ensure the chair fits the needs of potential customers, a deeper understanding of their activities performed in the chair, physical conditions, extreme body dimensions, and their ability to perform body measurements and understand the concept of the chair is required.
- A better understanding of the factors that contribute to comfort assessment from potential customers is necessary. How can we manage expectations and improve satisfaction assessment when buying and using the chair?
- The personal preferences of the user have not been considered in this project. Therefore, it is unknown how these could influence the design and assessment of the chair. Future research should take these preferences into account.

8.1.2 Overall chair concept

- Posture variation is a critical aspect of healthy sitting. Therefore, more testing is required to assess whether the current design of the chair allows users to sit comfortably and be supported in a forward, upright, and slouching posture.
- Only two participants with similar body types were tested for the final prototype. Therefore, future testing should include a wider variety of body types and age categories to determine whether the overall chair concept fits all users and can be customized correctly.
- The final chair concept does not include a dynamic element, such as an office chair frame. It would be interesting to explore integrating the rubber pivot mechanism from Tilman (2022) and conduct further research on its feasibility.
- Longer and more extensive tests should be conducted with the final chair shape to study whether the design fits the user's sitting habits, movements, work and leisure-related activities, and physical environment.
- These tests should be conducted with a more realistic prototype than the one used in the user tests. HREC approval was not requested for this project. Future research should request HREC approval if tests are conducted through the university.

8.1.3 Measuring

- The measuring method proposed appears to work accurately in the final user test. However, further testing is necessary. Another issue that arises is how to translate it into a method that customers can perform at home without making mistakes.
- Spinal level identification by palpation may not be accurate due to its sensitivity to errors influenced by BMI and measuring experience (Chakraverty et al., 2007). This inaccuracy can lead to poor lumbar support setup. When using the palpation method for spinal level location, the formula created with research from Zhou et al. (2000), DINED, and Chakraverty et al. (2007) uses the relationship between stature, BMI, and the dimensions of male and female lower vertebrae to design the lumbar support. Future research should focus on validating this method's suitability for integration and investigate females with higher BMIs as there is no information available on this group.
- Future research should explore integrating the concept of 3Daboutme into this project. This involves using photographs to create a 3D model from a database and using the model to take body measurements.

8.1.4 Backrest design

- **Backrest height:** Further research is needed to determine the correct reference point for measuring backrest height. Is it the armpits or shoulder blades, and what is their anatomical relationship?
- **Backrest (sitting) angle:** The current sitting angle may be too large, reducing support during focus-oriented postures and overstressing the back over the lumbar support, resulting in discomfort. Future research should test smaller sitting angles.
- **Upper backrest shape:** The current upper backrest shape is straight, but future research could investigate a slightly curved shape as the upper body is not straight.
- **Lumbar support starting point:** Tilman, Molenbroek, and Scholten (2022) suggest that the lumbar support should be positioned at approximately the same height, but this contradicts the findings from the CAESAR database and physical measurements. Further research is needed to determine if there is a significant difference in starting point heights or if the lumbar support can indeed be positioned at approximately the same height.
- **Lumbar support edge:** Future research should also focus on validating the method used to set up the lumbar support and on determining how sensitive it is to incorrect calculations.
- **Edge angle:** The edge angle in relation to the starting point of the lumbar support has a significant impact on the pressure distribution. A 0-degree angle directs the support towards the middle of the back, leaving the pelvis unsupported and causing discomfort. A 6-degree angle pushes the edge forward, allowing the support to focus on the lumbar area and provide more support to the pelvis. Future research should aim to find a balance between the sitting angle and the edge angle that provides comfortable lumbar support and overall body support.

- **Buttocks length:** The algorithm creates a curve transition between the backrest and seat pan using the buttock length, with a large margin to ensure enough space for the buttocks and effective lumbar support. However, leaving the buttocks unsupported creates an uncomfortable amount of pressure on the lower back. In Grasshopper, the transition curve is manually drawn to provide sufficient room and be aesthetically pleasing. Future research should investigate whether the chair can support the buttocks or provide some counter pressure from the backrest/buttocks transition. The design of this transition in Grasshopper is also crucial.
- **Buttock height:** The buttock length and height both affect the angle of the buttocks to the lumbar edge that rests on the sacrum. A larger height provides enough space for the sacrum but can put too much pressure on the lower back due to the lack of counter pressure, while a lower height results in an uncomfortable amount of pressure on the sacrum and pushes the body forward, reducing the effectiveness of the lumbar support. Future research should investigate how to design this transition angle and whether measuring the 'apex' of the buttocks is sufficient.
- **Backrest width:** Due to printing constraints, the backrest and seatpan have the same width, potentially obstructing arm movement. Future research should explore different printing techniques to enable the chair to be printed in two different widths.
- **Backrest horizontal shape and curve:** The backrest curve is derived from competitor chairs, as it was not the focus of the project. Future research should investigate which horizontal backrest shape and curve are best for the chair design.

8.1.5 Seat pan and buttock bowl design and cushioning

- **Seat pan and buttock bowl design:** Although the focus of the project was the development of the backrest, the seat pan was kept simple. Future research should explore how to improve the seat pan shape to enhance comfort and pressure distribution, while considering the autonomy of the buttocks and legs.
- **Seat pan foam:** The thickness and hardness of the foam on the seat pan should be carefully chosen and included in the algorithm to ensure correct fit and sitting height.
- **Backrest foam:** The thickness and hardness of the backrest foam can affect how well the backrest shape fits the body and the effectiveness of the lumbar support, similar to the seat pan foam. Thick and soft foam may reduce the lumbar support and flatten the backrest shape. The impact of clothing should also be considered in this aspect.
- **Modular cushioning:** A modular cushioning system could be an interesting approach as it allows users to customize the support of the chair according to their personal preferences.

8.1.6 Algorithm

- The palpation and vertebrae heights method has not yet been integrated into the algorithm. If this method is proven to be accurate, it should be incorporated.
- The algorithm currently takes the sitting bones as the starting point for the backrest and seatpan. Future research should validate this design principle.
- The curves of the buttock bowl are currently created manually in the algorithm. Future research should focus on linking these curves to body measurements.

8.1.7 Realization

- Research should be conducted on a more efficient printing technique that reduces processing and finishing times.
- Development of mounting plates that are both aesthetically pleasing and can withstand forces during use is imporant.
- Future research should investigate the use of a larger printing thickness, and potentially even double layers, to prevent breaking between layers.

moopi - Chapter 8: Discussion

8.2 **Reflection**

This final section concludes the report by evaluating the project as a whole by the graduating student. It provides the personal insights of the graduating student as a reflection on the overall project and process.

8.2.1 **Project evaluation**

My assignment for this project was to research the ergonomic requirements for creating a mass-customizable home office desk chair, which involved translating body measurements into a parametric chair shape. I identified several important topics to research and integrate into this project, as my goal was to deliver a complete and comprehensive final master project. This means that I aimed to gain a thorough understanding of the design topic I was working on, and that my decisions were informed by either literature research or my own findings. As a designer, I find it important to develop a product that is meaningful and healthful, so I focused not only on the physical product itself but also on understanding the context of the chair, healthy sitting habits, and the requirements for personalizing a complete chair through a parametric method.

Understanding the context
I took the first step in delivering a complete project by gaining a good understanding of the context of the home office worker. I was interested in what their work environments look like, how they behave in these environments, their experiences with their current chairs, and how they sit in these chairs. I found this step important so that I could get a realistic understanding of how chairs are used, rather than a generalized picture influenced mainly by my own habits and environment. Although I am satisfied with the level of my understanding of the context through research and the questionnaire, I wanted to have done more observations of the home office worker as I believe two does not provide a complete picture of the target group. Also, these observations were conducted during work hours, so no leisure-related activities were done, and therefore, my understanding lacks in that regard.

Healthy sitting
The second step in my project was to gain a good understanding of healthy sitting is. Initially, I believed that healthy sitting was mainly related to maintaining a 'good' static posture while sitting, but I quickly realized that this was a superficial idea and that there was much more to sitting than I had anticipated. Therefore, I devoted a significant portion of the project to researching and interviewing experts on the different ways of sitting, how the body reacts to different sitting positions, good postures, and how chair design can facilitate maintaining a healthy sitting posture. I learned that posture variation, supporting the body, and maintaining a natural spine curve are the most crucial aspects of healthy sitting. I am highly satisfied with the level of knowledge I have acquired on this topic and feel confident in my ability to design and evaluate chairs that meet these important criteria. I also believe that the knowledge I have generated through my research efforts can be valuable for future academic projects and debates related to sitting, as detailed in this report.

Chair design
At the beginning of the project, my aim was to design a fully personalized chair with all elements tailored to anthropology the user. However, as the project progressed, I realized that chair design is much more intricate and challenging than I had initially anticipated, particularly when it comes to personalization within the constraints of a rigid and unforgiving structure. Given the scope of the project, it was not possible for me to completely research and design the entire chair, so I decided to focus solely on the backrest, specifically the lumbar support. This is a critical aspect of the chair and fundamental to healthy sitting, as it supports the body and maintains a natural spine shape. Although my perfectionistic side is disappointed that I was unable to fully personalize the chair, my realistic side is satisfied with my level of understanding of how to define and design the parameters of a personalized chair.

Ultra-personalization and algorithmic design
Before starting this project, I had prior experience with ultra-personalization and algorithmic design, and I enjoyed working with these topics to create physical products. Therefore, I was excited to take on the challenge of developing a mass-customizable chair through an algorithmic-aided design process. Through this project, I was able to improve my skills and efficiency in working with these topics. Although there are areas for improvement in future research, particularly in the measuring process of the body, I believe that I have provided valuable insights for the company to integrate and plan their next steps. Furthermore, I think that the information presented in this report on these two topics can be useful for future academic projects related to parametric chair design.

Figure 97: Finalized bucket chair shape

8.2.2 Personal experience

My main goal of my graduation was to set up a project where I would get excited about and could integrate my knowledge and skills I developed over the last years as a designer, and especially the ones from my Masters. To achieve this, I established personal learning goals right from the start. It was important for me to pick a project that would maintain my interest throughout the entire process, unlike some previous projects that left me feeling drained towards the end. I am pleased to say that I managed to select a project that I found very interesting, and this reflected in the end results. The company was happy with my work and requested my assistance with further development of the chair.

Before my Masters, I had no experience with the Delft Design Guide, and I was eager to use the various methods in the book during the design process of my project. Thus, I set it as one of my personal goals. I employed Anthropometric Design methods, user observations, and interviews, as well as a list of requirements in the definition phase of my research to aid me in acquiring knowledge and designing the chair. I believe that the Delft Design Guide is a valuable tool for designers, and I will definitely continue using it in future projects. Another personal goal was to improve my Grasshopper skills, which I did significantly. I can now comfortably integrate these skills into my projects. Furthermore, these skills allowed me to create a functional 3D printed prototype, which I can use as a showcase for my project. This was another personal goal that I am happy to have achieved, as it was very rewarding to conclude the project with a physical product that I could test and showcase in my portfolio.

Unfortunately, I was unable to accomplish my final goal of investigating the business aspect of the chair due to time constraints. However, I do have suggestions on various aspects of the chair, such as how the order and measuring process could be designed, which I will discuss after the completion of this project.

Project management
As a designer, I have always struggled with project planning and management, particularly as a project becomes more complex. I tend to lose track of the planning and find it challenging to manage priorities. Therefore, I deliberately chose a project that had defined boundaries from the start, as I find such projects more suitable and exciting. I set clear goals and research topics right from the beginning, with the ultimate objective of delivering a functional 3D printed prototype. I am pleased to say that I was able to achieve this goal successfully. However, my planning was not very efficient, as I did not use a proper planning method such as a sprint planning for example. As a designer, I need to develop this skill further, as it would significantly improve the efficiency of the design process.

In terms of project management, I can confidently say that I did well. I organized the process effectively using Miro and Rhinoceros, prepared all the meetings and interviews, and kept my files organized on my laptop.

Client communication
I believe that the success of this project was largely due to the relationship and communication that I had with the client. Right from the start, they were actively involved in the project, and this helped me to manage the project effectively and create real value for both the company and the product. We held weekly meetings and sparring sessions, which played a crucial role in keeping me within the project boundaries and preventing me from feeling isolated while working from home.

Additionally, I conducted interviews with several experts as I wanted to go beyond literature research and tap into their knowledge and expertise to discuss various aspects of the project, my ideas, and specific topics.

Figure 98: Two 3D printed prototype chairs after refining

9 References

This section lists all references used in the report.

Bureaustoel Express. (2023). BENE bureaustoel. Bureaustoelexpress. https://www.bureaustoelexpress.nl/bene-bureaustoel-black-black.html

Carcone, S., & Keir, P. J. (2007). Effects of backrest design on biomechanics and comfort during seated work. Applied Ergonomics, 38(6), 755–764. https://doi.org/10.1016/j.apergo.2006.11.001

Carneiro, O. S., Da Silva, A. A., & Gomes, R. (2015). Fused deposition modeling with polypropylene. Materials & Design, 83, 768–776. https://doi.org/10.1016/j.matdes.2015.06.053

Chakraverty, R., Pynsent, P., & Isaacs, K. (2007). Which spinal levels are identified by palpation of the iliac crests and the posterior superior iliac spines? Journal of Anatomy, 210(2), 232–236. https://doi.org/10.1111/j.1469-7580.2006.00686.x

Coleman, N., Hull, B. P., & Ellit, G. (1998). An empirical study of preferred settings for lumbar support on adjustable office chairs. Ergonomics, 41(4), 401–419. https://doi.org/10.1080/001401398186900

Davis, K. G., & Kotowski, S. E. (2014). Postural variability: An effective way to reduce musculoskeletal discomfort in office work. Human Factors, 56(7), 1249–1261. https://doi.org/10.1177/0018720814528003

Davis, K. G., Kotowski, S. E., Daniel, D., Gerding, T. J., Naylor, J. C., & Syck, M. (2020). The Home Office: Ergonomic Lessons From the "New Normal." Ergonomics in Design, 28(4), 4–10. https://doi.org/10.1177/1064804620937907

Ede, F. (2020, July 15). Correct Sitting Posture. Body Care Health & Chiropractic. https://www.bodycarechiro.com.au/blog/2019/5/31/correct-sitting-posture (report picture)

Ellegast, R. P., Kraft, K., Groenesteijn, L., Krause, F., Berger, H., & Vink, P. (2012). Comparison of four specific dynamic office chairs with a conventional office chair: Impact upon muscle activation, physical activity and posture. Applied Ergonomics, 43(2), 296–307. https://doi.org/10.1016/j.apergo.2011.06.005

Fiorillo, I., Song, Y., Vink, P., & Naddeo, A. (2021). Designing a shaped seat-pan cushion to improve postural (dis)comfort reducing pressure distribution and increasing contact area at the interface. Proceedings of the Design Society, 1, 1113–1122. https://doi.org/10.1017/pds.2021.111

Floyd, W. F., & Roberts, D. F. (1958). Anatomical and physiological principles in chair and table design. Ergonomics, 2(1), 1–16. https://doi.org/10.1080/00140135808930397

Gandavadi, A., & Ramsay, J. (2005). Effect of two seating positions on upper limb function in normal subjects. International Journal of Therapy and Rehabilitation, 12(11), 485–490. https://doi.org/10.12968/ijtr.2005.12.11.20058

Gerding, T., Syck, M., Daniel, D., Naylor, J., Kotowski, S. E., Gillespie, G. L., Freeman, A. M., Huston, T. R., & Davis, K. G. (2021). An assessment of ergonomic issues in the home offices of university employees sent home due to the COVID-19 pandemic. Work, 68(4), 981–992. https://doi.org/10.3233/wor-205294

Gerding, T., Syck, M., Daniel, D., Naylor, J., Kotowski, S. E., Gillespie, G. L., Freeman, A. M., Huston, T. R., & Davis, K. G. (2021). An assessment of ergonomic issues in the home offices of university employees sent home due to the COVID-19 pandemic. Work, 68(4), 981–992. https://doi.org/10.3233/wor-205294

Goossens, R. (1997). NEN 1812. Norm kantoorstoelen is aan aanpassing toe. Erasmus University Rotterdam. https://pure.eur.nl/en/publications/nen-1812-norm-kantoorstoelen-is-aan-aanpassing-toe

Gregory, D. E., Dunk, N. M., & Callaghan, J. P. (2006). Stability Ball Versus Office Chair: Comparison of Muscle Activation and Lumbar Spine Posture During Prolonged Sitting. Human Factors, 48(1), 142–153. https://doi.org/10.1518/001872006776412243

Groenesteijn, L., Ellegast, R., Keller, K. M., Krause, F., Berger, H., & De Looze, M. P. (2012). Office task effects on comfort and body dynamics in five dynamic office chairs. Applied Ergonomics, 43(2), 320–328. https://doi.org/10.1016/j.apergo.2011.06.007

Groenesteijn, L., Vink, P., De Looze, M. P., & Krause, F. (2009). Effects of differences in office chair controls, seat and backrest angle design in relation to tasks. Applied Ergonomics, 40(3), 362–370. https://doi.org/10.1016/j.apergo.2008.11.011

Gscheidle, G., & Reed, M. P. (2004). Sitter-Selected Postures in an Office Chair with Minimal Task Constraints. Proceedings of the Human Factors and Ergonomics Society. https://doi.org/10.1177/154193120404800802

Helander, M. G. (2003). Forget about ergonomics in chair design? Focus on aesthetics and comfort! Ergonomics, 46(13–14), 1306–1319. https://doi.org/10.1080/001401303100 01610847

Helander, M. G., & Zhang, L. (1997). Field studies of comfort and discomfort in sitting. Ergonomics, 40(9), 895–915. https://doi.org/10.1080/001401397187739

Hendren, S. (2022, October 19). The tyranny of chairs: why we need better design. The Guardian. https://www.theguardian.com/artanddesign/2020/aug/25/the-tyranny-of-chairs

Hey, H. W. D., Teo, A. Q. A., Tan, K. A., Ng, L. W. N., Lau, L. L., Liu, K. P. G., & Wong, H. K. (2017). How the spine differs in standing and in sitting—important considerations for correction of spinal deformity. The Spine Journal, 17(6), 799–806. https://doi.org/10.1016/j.spinee.2016.03.056

Hornsby, M. (2022, February 23). A History of Remote Work: From Hunter Gatherers to the Industrial Revolution to the Internet to Wifi - And. TelNet Worldwide. https://www.telnetww.com/blog/remote-work/a-history-of-remote-work-telecommuting/

Hosea, T. M., Simon, S. R., Delatizky, J., Wong, M. A., & Hsieh, C. C. (1986). Myoelectric Analysis of the Paraspinal Musculature in Relation to Automobile Driving. Spine, 11(9), 928–936. https://doi.org/10.1097/00007632-198611000-00013

Huizen, J. (2022, August 26). Sitting positions for good posture. https://www.medicalnewstoday.com/articles/321863

Jindo, T., Hirasago, K., & Nagamachi, M. (1995). Development of a design support system for office chairs using 3-D graphics. International Journal of Industrial Ergonomics, 15(1), 49–62. https://doi.org/10.1016/0169-8141(94)00056-9

Kapica, L.; Grbac, I., (1998) Construction principles of ergonomic furniture intended for sitting and lying (in Croatian). In: Grbac, I. (ed.): Furniture and healthy habitation. Proceedings of international conference. University of Zagreb, UFI-Paris, Zagreb, 53-58.

Kingma, I., Van Dieën, J. H., Nicolay, K., Maat, J., & Weinans, H. (2000). Monitoring water content in deforming intervertebral disc tissue by finite element analysis of MRI data. Magnetic Resonance in Medicine, 44(4), 650–654.

Koskelo, R., Vuorikari, K., & Hänninen, O. (2007). Sitting and standing postures are corrected by adjustable furniture with lowered muscle tension in high-school students. Ergonomics, 50(10), 1643–1656. https://doi.org/10.1080/00140130701587236

Korovessis, P., Petsinis, G., Papazisis, Z., & Baikousis, A. (2001). Prediction of Thoracic Kyphosis Using the Debrunner Kyphometer. Journal of Spinal Disorders, 14(1), 67–72. https://doi.org/10.1097/00002517-200102000-00010

Korte, J. (2013). South African anthropometric dimensions for the design of an ergonomic office chair. Doctoral Dissertation. https://core.ac.uk/download/pdf/145047188.pdf

moopi - Chapter 9: References

Kotowski, S. E., Davis, K. G., & Gerding, T. (2022). Almost a year in: Virtual offices remained an ergonomic trouble spot. Work, 71(2), 319–326. https://doi.org/10.3233/wor-211052
Kroemer, A. D., & Kroemer, K. H. (2016). Office Ergonomics. Ease and Efficiency at Work, Second Edition. https://doi.org/10.1201/9781315368603

Lili, W., Tao, S., Zheng, Y., & Yixiong, L. (2010). The Parametric Design of Office Chairs Based on Ergonomics. 2010 International Conference on Computing, Control and Industrial Engineering. https://doi.org/10.1109/ccie.2010.96

Lodewijks, M. (2017, December 6). Een bureaustoel op maat. Wat is dat? EMTEK Ergonomics Ergonomische Bureaustoelen Op Maat. https://www.emtek.nl/

Lukits, A. (2015, October 12). Why It Can Help Children to Slouch. WSJ. https://www.wsj.com/articles/why-it-can-help-children-to-slouch-1444662618

Mikula, K., Skrzypczak, D., Izydorczyk, G., Warchoł, J., Moustakas, K., Chojnacka, K., & Witek-Krowiak, A. (2020). 3D printing filament as a second life of waste plastics—a review. Environmental Science and Pollution Research, 28(10), 12321–12333. https://doi.org/10.1007/s11356-020-10657-8

Molenbroek, J. (2022, November 14). Personal communication [Personal interview].
Pope, M. H., Goh, K. L., & Magnusson, M. L. (2002). Spine Ergonomics. Annual Review of Biomedical Engineering, 4(1), 49–68. https://doi.org/10.1146/annurev.bioeng.4.092101.122107

Noshin, L., Gupta, H. S., & Kibria, M. G. (2018). Office chair design: a systematic approach of ergonomic design based on the anthropometric measurement of Bangladeshi people. International Journal of Research, 7(2), 224–234. https://doi.org/10.22105/riej.2018.128451.1040

O'Sullivan, K., O'Sullivan, P., O'Sullivan, L., & Dankaerts, W. (2012). What do physiotherapists consider to be the best sitting spinal posture? Manual Therapy, 17(5), 432–437. https://doi.org/10.1016/j.math.2012.04.007

Pew Research Center. (2021, April 7). Mobile Fact Sheet. Pew Research Center: Internet, Science & Tech. https://www.pewresearch.org/internet/fact-sheet/mobile/

Publishing, O., Editors, Stevens, B., Michalski, W., & Miller, R. (1999). 21st Century Technologies: Promises and Perils of a Dynamic Future. Organization for Economic Cooperation and Development.

Putsa, B., Jalayondeja, W., Mekhora, K., Bhuanantanondh, P., & Jalayondeja, C. (2022). Factors associated with reduced risk of musculoskeletal disorders among office workers: a cross-sectional study 2017 to 2020. BMC Public Health, 22(1). https://doi.org/10.1186/s12889-022-13940-0

Pynt, J., Higgs, J., & Mackey, M. (2001). Seeking the optimal posture of the seated lumbar spine. Physiotherapy Theory and Practice, 17(1), 5–21. https://doi.org/10.1080/09593980151143228

Rathore, S. (2022, October 4). How Has Interior Design Changed Over the Years? A Journey From the 1970s to the 2020s. Livspace Magazine. https://www.livspace.com/in/magazine/how-has-interior-design-changed-over-the-years

Reynolds, B. W. (2022, July 20). The Complete History of Working from Home. FlexJobs Job Search Tips and Blog. https://www.flexjobs.com/blog/post/complete-history-of-working-from-home/

Robertson, M., & Vink, P. (2012). Examining new ways of office work between the Netherlands and the USA. Work, 41, 5086–5090. https://doi.org/10.3233/wor-2012-1042-5086

moopi - Chapter 9: References

Robinette, K. M., Daanen, H. A., & Paquet, E. (1999). The CAESAR project: a 3-D surface anthropometry survey. Digital Identity Management. https://doi.org/10.1109/im.1999.805368

Rohlmann, A., Zander, T., Graichen, F., Dreischarf, M., & Bergmann, G. (2011). Measured loads on a vertebral body replacement during sitting. The Spine Journal, 11(9), 870–875. https://doi.org/10.1016/j.spinee.2011.06.017

Scholten, H. (2022, October 6. Personal communication [Personal interview].

Shackel, B., Chidsey, K. D., & Shipley, P. (1969). The Assessment of Chair Comfort. Ergonomics, 12(2), 269–306. https://doi.org/10.1080/00140136908931053

Silva, V., Fonseca, P. C. D., Pinho, M. J., Góis, J., Vaz, M., & Campos, J. C. (2017). Biomechanical study of dentists posture when using a conventional chair versus a saddle-seat chair. Revista Portuguesa De Estomatologia, Medicina Dentária E Cirurgia Maxilofacial. https://doi.org/10.24873/j.rpemd.2017.05.005

Sink, A. (2021, September 24). How to scan objects in 3D with your iPhone. Input. https://www.inverse.com/input/guides/how-to-scan-objects-in-3d-with-your-iphone

Smulders, M. J. M., Berghman, K., Koenraads, M., Kane, J. A., Krishna, K., Carter, T. K., & Schultheis, U. (2016). Comfort and pressure distribution in a human contour shaped aircraft seat (developed with 3D scans of the human body). Work-a Journal of Prevention Assessment & Rehabilitation, 54(4), 925–940. https://doi.org/10.3233/wor-162363

Staarink, H. (1995). Sitting posture, Comfort and Pressure: Assessing the quality of wheelchair cushions | TU Delft Repositories. https://repository.tudelft.nl/islandora/object/uuid:c71e326e-f0a6-47d7-a641-6fe41e82c6c7?collection=research

Stevens, B., Michalski, W., & Miller, R. (1999). 21st Century Technologies: Promises and Perils of a Dynamic Future. Organization for Economic Cooperation and Development.

Studio FA Porsche. (2020, October 29). Urban Trend: The Rise of Small Space Homes. Studio F. a. Porsche | Premium Design Services. https://www.studiofaporsche.com/en/blog/urban-trend-the-rise-of-small-space-homes/

Tilman, F. (2022, October 14). Personal communication [Personal interview].

Todd, A. C., Bennett, A., & Christie, C. J. (2007). Physical implications of prolonged sitting in a confined posture - a literature review. Ergonomics SA : Journal of the Ergonomics Society of South Africa, 19(2), 7–21. https://journals.co.za/content/ergosa/19/2/EJC33263

U.S. Bureau of Labor Statistics. (2021). Employed persons working at home, workplace, and time spent working at each location by full- and part-time status and sex, jobholding status, and educational attainment, 2021 annual averages. https://www.bls.gov/news.release/atus.t06.htm

US Census Bureau. (2017, October 8). 2017 ACS 1-year Estimates. Census.gov. https://www.census.gov/programs-surveys/acs/technical-documentation/table-and-geography-changes/2017/1-year.html

Van Boeijen, A. (2014). Delft Design Guide: Design Strategies and Methods. Welcome to DTU Research Database. https://orbit.dtu.dk/en/publications/delft-design-guide-design-strategies-and-methods

Van den Dikkenberg, L. (2022). Coopi: a custom fitted chair for the modern home workspace combining manual processes with robotic 3D printing.

Van Deursen, D. L., Snijders, C. J., Van Dieën, J. H., Kingma, I., & Van Deursen, L. L. (2001). The effect of passive vertebral rotation on pressure in the nucleus pulposus. Journal of Biomechanics, 34(3), 405–408. https://doi.org/10.1016/s0021-9290(00)00210-4

Van Dieën, J. H., Vrielink, H. H. O., & Toussaint, H. M. (1993). An investigation into the relevance of the pattern of temporal activation with respect to erector spinae muscle endurance. European Journal of Applied Physiology and Occupational Physiology, 66(1), 70–75. https://doi.org/10.1007/bf00863403

Vaucher, M., Isner-Horobeti, M. E., Demattei, C., Alonso, S., Hérisson, C., Kouyoumdjian, P., Van Dieën, J. H., & Dupeyron, A. (2015). Effect of a kneeling chair on lumbar curvature in patients with low back pain and healthy controls: A pilot study. Annals of Physical and Rehabilitation Medicine, 58(3), 151–156. https://doi.org/10.1016/j.rehab.2015.01.003

Vergara, M., & Page, Á. (2000). System to measure the use of the backrest in sitting-posture office tasks. Applied Ergonomics, 31(3), 247–254. https://doi.org/10.1016/s0003-6870(99)00056-3

Vink, P. (2016). Vehicle seat comfort and design: With special attention for aircraft seats. Pumbo. https://research.tudelft.nl/en/publications/vehicle-seat-comfort-and-design-with-special-attention-for-aircra

Walton, D. (2022, February 14). How tiny living spaces affect our wellbeing – individually and societally. Connecting Research. https://research.reading.ac.uk/research-blog/how-tiny-living-spaces-affect-our-wellbeing-individually-and-societally/

Werth, A. J., & Babski-Reeves, K. (2012). Assessing Posture While Typing on Portable Computing Devices in Traditional Work Environments and at Home. Proceedings of the Human Factors and Ergonomics Society . . . Annual Meeting, 56(1), 1258–1262. https://doi.org/10.1177/1071181312561223

Wilke, H., Neef, P., Caimi, M., Hoogland, T., & Claes, L. E. (1999). New In Vivo Measurements of Pressures in the Intervertebral Disc in Daily Life. Spine, 24(8), 755–762. https://doi.org/10.1097/00007632-199904150-00005

Zhang, L., Helander, M. G., & Drury, C. G. (1996). Identifying Factors of Comfort and Discomfort in Sitting. Human Factors, 38(3), 377–389. https://doi.org/10.1518/001872096778701962

Zhou, S. H., McCarthy, I. D., McGregor, A. H., Coombs, R. R. H., & Hughes, S. P. F. (2000). Geometrical dimensions of the lower lumbar vertebrae - analysis of data from digitised CT images. European Spine Journal, 9(3), 242–248. https://doi.org/10.1007/s005860000140

10 Appendix

This section contains all appendixes for this report, including the confidential appendixes.

Appendix C: **Design Brief**

TUDelft

Personal Project Brief - IDE Master Graduation

3D Printend & Mass Customized Home Office Desk Chair — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 04 - 10 - 2022 — 07 - 03 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

This project focuses on designing a 3D printed ultra-personalized home office desk chair. Many people are working and/or studying at their dinner table while sitting on a chair that doesn't correctly support the user during these activities or is sized wrongly. This has also become worse because of the pandemic and results in all kinds of physical complaints. Traditional office chairs are big, bulky and the designs don't fit well into home environments. These chairs are also difficult to adjust correctly.

This project aims to create a simple but beautiful parametric chair that translates body characteristics of the customer into a mass-customizable 3D printed chair. This chair needs to fit into the home environment of the user and is personalized to their body. Ergonomic knowledge will be used to translate the body measurements to a chair shape that supports the customer to have a healthy and comfortable seating posture while they are working in their home office.

In a prior gradation project, the technical- and design aspects of the chair were researched and developed. Therefore this project will focus on the ergonomic aspects of the chair and how to make the translation of body measurements into a 3D printable chair shape. Firstly, focusing on conducting desktop research on how to design an (office) chair, in general and ergonomically. These results will be the starting point to conduct more studies in the specific context of the home office environment. Examples of these studies could be how people behave in this context, what their needs are and how these translate into the requirements of the chair. Secondly is the design of the chair, converting those requirements into an algorithmic model that is creates the chair shape and then testing if it actually works.

The main stakeholder in this project is the home office worker that is interested in an integrated and comfortable chair to put at their (kitchen) table. This is because they are currently sitting on chairs that are uncomfortable to sit on for longer periods or have ugly desk chairs in their living environments. The second stakeholder is Zon & Hoofd Design and their ultimate goal is developing this project in an actual product that is able to be sold. To reach this goal, research needs be conducted first. This is where the other stakeholders get involved. Peter is interested in this knowledge about chair design in terms of comfort and seating position and Lyè is interested 3D scanning and anthropometry. This project is also part of the UPPS Fieldlab. They are interested in the learnings from this project and can also offer support and facilities throughout the project.

A big opportunity in this project is that there is a lot of knowledge in the team surrounding the topics that are related to this project and together with the involvement of the UPPS Fieldlab team, there are plenty of resources available. Because of the prior project, the focus can be directed towards the ergonomic aspects and shape development of the chair. This will hopefully allow this project to generate in-depth knowledge and finished with a 'working' prototype. In terms of limitations, the parametric design phase of the chair shape could be a bit challenging as I am not an expert in algorithmic design, but I am eager to learn. I believe with the resources at the TU Delft and UPPS team, this will not be a problem.

space available for images / figures on next page

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 — Page 3 of 7

Initials & Name MJJ Morres — Student number 5279046

Title of Project 3D Printend & Mass Customized Home Office Desk Chair

Personal Project Brief - IDE Master Graduation

TU Delft

introduction (continued): space for images

image / figure 1: Home office desk chair 1

image / figure 2: Home office desk chair 2

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 4 of 7

Initials & Name MJJ Morres Student number 5279046

Title of Project 3D Printend & Mass Customized Home Office Desk Chair

Personal Project Brief - IDE Master Graduation

TU Delft

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

This project focusses on a new direction of research in ergonomics, namely, how to translate a body shape into the right chair shape. Home office desk chairs or chairs in general, never have been mass-customized and were always fully adjustable or a one-size fits all, so the answer can't be found in literature or existing research. In car seats and aircraft seats 3D scanning is used, but not in office seats. Therefore this project will focus on generating ergonomic knowledge on how to design such an office chair, creating a list of requirements that will help to set variables for the parametric design of the chair.

The research topics to answer this project's main question are:
- What is the seating behavior, posture and activities performed in an office chair?
- How to facilitate body movement during longer periods of sitting? (Posture variation)
- The seat characteristics influenced by touchpoints, target group and body sizes
- The seat dimensions: width, seatpan length and angle, height, and seat pan and backrest contour
These topics need to be researched through literature research, talking to experts and conducting observations, 3D-scanning and physical tests.

The final solution is a parametric home office desk chair that can be mass-customized. A variety of specific body measurements will be collected and then processed through an algorithm, that also needs to be developed, to a chair shape that is personalized to its user. This chair shape is then able to be realized by 3D printing with the knowledge that was generated in the previous project.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

I am going to research what the ergonomic requirements are to create a mass-customizable home office desk chair presented in the brief of Zon & Hoofd. And with this knowledge create an algorithm that translates these ergonomic requirements (including body measurements) into a parametric chair shape. This chair will then be 3D printed and tested with participants (customers) which the chair is designed for.

The project deliverables will consist of three parts. The first is research knowledge on everything related the ergonomics of such a chair. The second is an algorithm that can translate body measurements of a customer and create a chair shape that complies to all the knowledge generated and requirements that are set. And the third is a final working product or prototype that I can use to showcase and validate all the findings. This prototype will be 3D printed and be tested and used by the person it was designed for.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 5 of 7

Initials & Name MJJ Morres Student number 5279046

Title of Project 3D Printend & Mass Customized Home Office Desk Chair

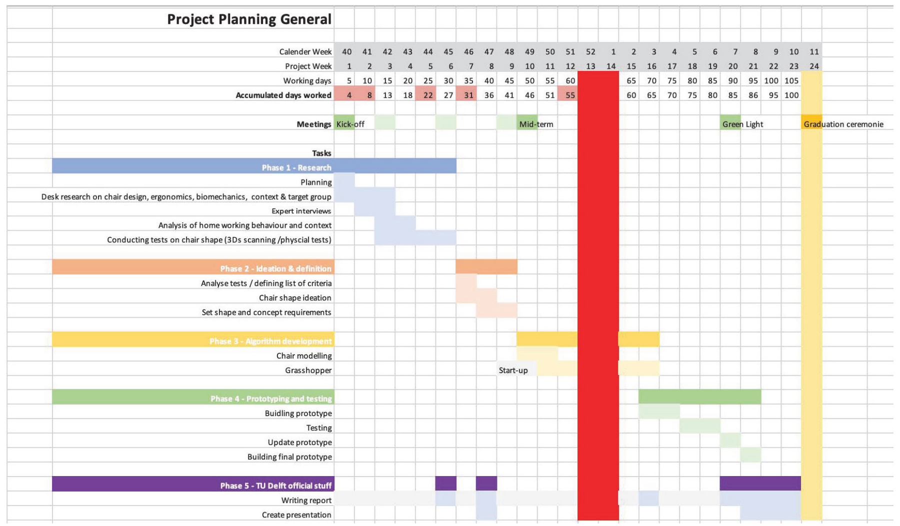
Personal Project Brief - IDE Master Graduation

TU Delft

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 4 - 10 - 2022 7 - 3 - 2023 end date



Red marked accumulated days worked means that I will probably only work 4 days instead of 5!

Initials & Name MJJ Morres Student number 5279046

Title of Project 3D Printend & Mass Customized Home Office Desk Chair

moopi - Chapter 10: Appendix

Personal Project Brief - IDE Master Graduation

TU Delft

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

My main goal of my graduation was to set up a project where I would get excited about and could integrate my knowledge and skills I developed over the last years as a designer, and especially the ones from my Masters. Picking a project that excites you might sound self-explanatory, but there have been ones that ended up being very draining to finish. I have a personal interest in designing physical products that contribute to the quality of life of its user, products that are meaningful and/or healthful. I enjoy creating these products within a digital and physical space, meaning working with digital creative tools to create physical products.

After reading the opportunity for this chair, I got excited to address a personal problem and it ticks boxes of certain topics that I am interested and the skills the company is looking for. As my height almost reaches two meters, I also have struggles working from home while sitting on bad chairs that cause neck and back pains. I believe that (ultra-) personalization is a very powerful method to create valuable (and mass producible) products while still taking specific user needs into account. I have already created an algorithm in Grasshopper during my Final Bachelor Project that takes measurements from 3D scanned feet and translate these into perfect fitting shoes. I enjoyed that project, so I am convinced that this project will be a similar experience. During my Masters at the TU Delft, I followed the elective Biomechanics where I used DINED and the CEASARS dataset to complete ergonomic design assignments. I also created a game controller for boys with Duchenne muscle disease in which I had to develop a controller that would adapt to the constantly to changing ergonomic needs of the users as the disease develops over time. Here I worked plenty with 3D printers to create different iterations of the controller and test these with the targeted user. These are all subjects that I have an interest in and want to explore more in this project.

The personal ambitions I have for this project are:
- I want to integrate the Delft Design Guide into my project. As a new student to the TU Delft and the book having such a prominent status, I want to use this book to my advantage in my final project. Anthropometric design (approach), user observations and interviews (method: discover) and list of requirements (methods: define) are all interesting topics for my project that are featured in the book.
- I want to continue to develop my skills with Grasshopper in this project. I already have experience, but I want to continue to develop my skills and create a working algorithm to create a chair shape. This algorithm doesn't have to be fully developed but I want to make a functional one.
- I want to investigate the business aspect of the chair. How the ordering service might look like, how customers order a chair with their measurements and what limitations could be of such a service. This is not going to be a big study, but I want touch upon this topic in my project.
- Finally I want to be able to showcase a functional and 3D printed prototype at my graduation ceremony. The goal is to have a final prototype finished that is functional, thus personalized to a user.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Let's go :)

Initials & Name MJJ Morres Student number 5279046

Title of Project 3D Printend & Mass Customized Home Office Desk Chair

moopi - Chapter 10: Appendix

Appendix D: **Johan Molenbroek interview**

Vragen
- Wat is de natuurlijke rug houding / curve tijdens het zitten?
- Kunnen mensen zelf natuurlijke rug houding aannemen?
o Wanneer doen ze te overdreven of te laf aannemen?
o Hoe kun je die gemakkelijk en consistent van mensen vragen?
o Is het principe van de loodlijn goed? Oren, schouder en bekken op 1 lijn en dan curve meten?
o Is het overdreven aannemen van een holle rug, een goede curve om pakken? (Kan lumbale deel overstrekken?)
- Is er een overeenkomst tussen staande en zittende ruggencurve?
- Is de natuurlijke rug houding een goed uitgangspunt voor vorm de rugleuning van een stoel?
- Hoe kun je deze rug curve gemakkelijk, eenvoudig en nauwkeurig opmeten bij mensen, zonder daar 3D scannen of andere dure apparatuur bij te betrekken?

- Wat is uw advies over hoe de ruggencurve kunnen opmeten en vertalen naar de rug curve van een stoel?

- Andere dingen die nog binnen springen die relevant zijn voor dit project?

Notulen
- Rug heeft niet 1 curve, dat ligt er maar net aan hoe iemand uit bed is gestapt
o Het ligt ook aan de bekken, of je op een horizontaal vlak zit of niet
- Johan denk dat via foto's de rugleuning / curve bepalen wel een interessante benadering is aangezien cameras en technieken in telefoons (3D scans maken) steeds beter worden
o Voor de echte curve moet je op verschillende dagen een foto maken van de rug (ma, di, wo)
o Op een vast moment van de dag
o Gelijke omstandigheden
o Belangrijk om de cameraopstelling te standaardiseren (hoogte, afstand, opstelling
  Wellicht kunnen zij de opstelling eerst leasen
o Voor- en zijaanzicht foto maken
o Meetstaaf ernaast voor Schaling
- Met telefoon een foto maken is een interessante benadering, 3D scan van de rug maken met telefoon kan ook interessant zijn.
o Er zijn ook al app die 3D scans van het hoofd kunnen maken
- 3D about me is een interessant voorbeeld op gebied van schoenen
o Klaas nienhuis
o 3 Fotos van voet, dan wordt er een 3D model gemaakt en vanuit daar krijg je advies over maat en type schoen
o https://www.klaasnienhuis.nl/portfolio/3daboutme/
- Swedese Lamino stoel (hoog) 1954 hebben een goed rug profiel
o Maar ook alleen maar voor de gemiddelde mensen, lange of kleine mensen zitten niet goed
- Normale bureaustoel heeft twee krommingen, een verticale en een horizontale
o Hoogte van de gemiddelde lumbale steun is 23 cm (L3-L4 Wervel)
o Bij ouderen is holling weg, kunnen moeilijker lordose krijgen
- Hoogte van de lumbale is vrij gelijk bij mensen
o De hoogte en breedte van mensen is misschien nog wel interessanter om te gebruiken om de ruggensteun te bepalen omdat die meer verschillen
o Bij gemiddelde afmetingen en geen bijzonderheden aan het lichaam is de lende steun gemiddeld
o Bedenk een paar personas voor je stoel, daarin kun je stoelen ontwikkelen
- Mensen willen niet in een te zachte en een te harde stoelen zitten
o Maar de voorkeur ligt wel richting zachtere
- Dikke mensen hebben moeite om op te staan zonder armleuningen
o Gasveer moet ook bestand zijn tegen het gewicht van dikke mensen
o Veel producten gaan niet verder dan 100 kg
o Ook in DIned niet verder dan 100 kg
o Maak de stoel stevig genoeg
- Mensen hebben eigenlijk maar 3 houdingen als ze werken
o Schrijven (vooruit)
o Luisteren (achteruit)
o Lezen (neutraal)
- Comfort = een objectieve + subjectieve beoordeling van de stoel
o Objectief kun je maken: voldoen aan de verhoudingen van de mensen
  Vorm van het lichaam
  Leeftijd
o Subjectief: Of het aan de individuele voorkeur van de mensen voldoet
  Zeker bij dikke mensen belangrijk
  Zacht of harde stoel
  Kleur
  Hoge, lage of dikke, dunne steun
  Grote van zitvlak etc.
o Bifono is een voorbeeld van bedrijf die rekeninghoud met subjectieve voorkeur van klanten
  Overhemden
  Stelt 10 vragen vooraf aan de bestelling om een gebruikersprofiel op te stellen
  Minder klachten / retourzendingen
  Goede vragen vooraf stellen is belangrijk
- Ga testen want voor dat je het weet zijn je project dagen voorbij

moopi - Chapter 10: Appendix

Appendix E: **Frank Tilman interview**

Questions
- Project uitleg
o Een kuipstoel voor aan de keuken- / eettafel
o 3D scan en/of afmetingen nemen of de design van de stoel te bepalen
o Rugcurve waarschijnlijk het belangrijkste om de lenden- / bekkensteun te bepalen
o Mass-customizable stoel die ge3D-print word
o Werken met DINED database, waar we meer dan 1000 staande en zittende 3D scans hebben
- Huidige status van het project
o Onderzoek naar de probleemdefinitie
Eerst het zitten aan een keukentafelstoel
Daarna de vertalen van maten/curves naar stoeldesign
o Hoe moet je goed zitten? De definitie van goed zitten.
o Activiteiten die mensen thuis doen en hoe deze vertalen in het design van de stoel
Vragen
- Wat is de definitie van goed zitten?
o Ligt het aan de stoel?
o Of ligt het aan de manier waarop wij zitten?
o Rechtop zitten is ouderwets, maar hoe doet je dat dan bij een kuipstoel
- Pelvic balans is waarschijnlijk het belangrijkste, mensen moeten dit leren.
o Maar hoe kan een stoel hieraan bijdragen?
o En hoe kan in een kuipstoel zoals in dit project dat doen?
o Hoe kan een kuipstoel ervoor zorgen dat je toch je balans vindt via je zitbeenknobbels?
o Biomechanisch krachten evenwicht, is een tilting/freeflowing mechanisme zo belangrijk?
o Moet de bekken recht staan of iets naar voren gebogen in de stoel?
- Hoe kan het design van de stoel eraan bijdragen dat mensen er goed en gezond in gaan zitten zonder dat mensen daar uitleg bij krijgen? (Bij online bestellen gaat dat niet)
o Waar moet je rugsteun zitten?
o Hoe breed en diep moet de zitting zijn?
o Curve van het kont deel?
o Hoek van zitting?
o Zijn er nog andere cruciale afmetingen
- Wat zijn de belangrijkste afmetingen van een persoon om te bepalen wat voor stoel je nodig hebt?
o Of ligt dit ook aan persoonlijke voorkeur?
o Dikke, dunne, kleine, grote, afwijken?

- Wat zijn de activiteiten die mensen thuis doen in home office chair of keukentafel stoel?
o Zitten mensen vaker naar voren, neutraal of naar achteren?
o Bewegen zij dynamisch een en heer?
o Zijn hier nog dingen waar ik op moet letten qua design?
- Wat zijn de dingen of houdingen die ons het meeste last geven tijdens het werken?
- Wat zorgt ervoor dat we het comfortabelste kunnen zitten/
- Wat zijn de meest voorkomende klachten van het verkeerd zitten in een stoel?
- Wat vind je van het idee om afmetingen van mensen te nemen en deze doormiddel van een algoritme te vertalen naar een op maat gemaakte stoel?

Transcript
The reason why I wanted to do this interview was because I read an interview with Frank in the previous report and I was fascinated by the knowledge he has about sitting correctly and his vision on how we should do that. My drive as a designer is not to create just a chair that is personalized to the anatomical characteristics of the user, but I also want to make the chair meaningful in a sense that it also promotes the user to sit healthy and/or helps them to do so. Frank has extensive knowledge and experience helping and learning people how to sit correctly. I assumed that he also has worked with or researched countless chairs and that he will definitely have an interesting opinion on this project's bucket seat type chair and is able to help me with finding the chair parameters.

Max legt het project uit en laat het startpunt van de stoel zien.

Grootste deel van je massa dit achter je kantelpunt van je stoel, maar waar zit je te werken en waar zit je eten? Je zit naar voor te werken. Als je een korte zitting gebruikt die op je kantelpunt zit zal deze veel beter meebewegen. Veel mensen moeten met hun lichaam meebewegen en dus spierkracht gebruiken om te bewegen en de stoel naar voren te krijgen en dit kost energie. Als het zwaartepunt goed zit moet je alleen maar vanuit je zwaartepunt, dat hoog in je bekken zit, meet te bewegen.

Ik heb geen oordeel over zitten, iedereen mag kiezen wat hij wil. Zolang je het maar doet vanuit kennis. Als je een stoel gaat maken vanuit parameters gaat maken en techniek eronder, dan kan ik je zo vertellen welke je nodig hebt. Maar het gaat erom wat voor bewegingsvrijheid je dan nog hebt. Als je een kuipstoel maakt dat wordt dat een kort traject. En naar voren gaat je niet lukken met een kuipstoel, tenzij je een heel duur mechanisme eronder steekt.

Max legt NOHO Move stoel uit en de tijdlijn hoe mensen in een stoel zitten.

Het verschil hier met alle andere stoelen is dat het materiaal meebeweegt. Het lijkt een beetje op wat jullie willen gaan doen met de stoel. Laten we eerlijk zijn, jij bent ook geen wonder aan het doen en eigenlijk zou je deze stoel op de kop moeten tikken (Pendulum Stokke). Dan ben je ook meteen klaar qua maatvoering.

Max zegt dat het een stoel moet worden waar veel verschillende activiteiten in gegaan moeten worden en je daardoor de parameters ruim moet interpreteren zodat je mensen nog wel de mogelijkheid houdt om in verschillende posities te zitten. Dit klopt helemaal daarom ben ik ook fan van minimalisme. Als je veel erbij verzint dan moet je ook met veel verschillende dingen rekening houden. Eigenlijk moet je op een heel klein vlak kunnen zitten, namelijk je zitbeenknobbels en je bekkenrand. Meer heb je niet nodig. Het bewegingsmechaniek zit er om ervoor te zorgen dat je niet naar voren schuift. Het vette aan de NOHO is dat het probleem in het materiaal wordt opgelost, dat is een extra dimensie om het op te lossen. Alles wat er boven de bekken gebeurt qua stoel zit alleen maar vreselijk in de weg als je rechtop wilt zitten. Net als Hans Scholten zei, alles boven de onderrug is eigenlijk overbodig, alleen voor comfort.

Max: het is wel de bedoeling dat het een kuipstoel blijft want dit is de start geweest van dit project en waar ik mee verder ga. Goed dat je dat zegt want dan is het een verkanteling om het voor en achterwaarts op te vangen die aansluit bij de vorm van de kuip. Max: Ja klopt, want men zit dynamisch aan een keuteltafel en die stoel moet dat wel allemaal ondersteunen. Ik ben dus opzoek naar waar je op moet letten bij een mens (Laat de Dined database zien). Vanuit deze database wil ik gaan werken om te kijken wat voor soorten mensen er zijn. Ik moet lachen want toe hoever moet je proporties opvangen? Er zijn zoveel verschillende soorten mensen en de uitschieters zullen wel een probleem zijn. Maar je kunt inderdaad wel voor deze uitschieters allemaal een stoel maken, dat is interessant.

De vraag is nu hoe je ertoe gaat komen om al die verschillende anatomische verhoudingen die erin zitten te krijgen en welk punt ga je nemen om je parameter te bepalen? Dat is waar het over gaat. Max: Mensen kunnen thuis geen 3D scan van zichzelf maken, maar wel 2D foto's en/of afmetingen nemen en dan zal het bedrijf (of algoritme) moeten gaan bepalen waar bekkenpunt zit, waar de steun moet komen, hoe breed de heupen zijn en hoe breed de zitting moet zijn. Dat is de core van het project. Ja ik hoor je, maar je hebt het jezelf niet makkelijk gemaakt om voor een kuip te kiezen. Max: Er is gekozen voor een kuipstoel omdat die esthetisch mooi de huiskamer past. Dat vind ik toch zo'n bullshit, daar krijg ik echt ruzie mee met designers en architecten.

Waarom kan jullie creativiteit niet gebruiken om de vertrekpunten die iemand goed Laten zitten, om die in een model te zetten. Waarom kan dat niet? Daar ben je juist in opgeleid om zo functioneel mogelijk een vorm aan te reiken, die technisch maar zo vertaald hoeft te worden dat hij zo gemaakt kan worden. En het liefste zo goedkoop mogelijk en alle duurzame aspecten mogelijk. Waarom ga je niet eerst zorgen dat je eerst iets goeds en functioneels bouwen en dan je creativiteit gebruiken om er iets moois van te maken. Zo zou het moeten zijn. Max: Er is waarschijnlijk voor een kuipstoel gekozen omdat de huidige stoel in de woonkamer vaak een kuipstoel is en deze ertussen moet passen. Zoals je zegt dan ga je vanuit iets moois werken en moet je het functioneel maken, want de omgekeerde wereld is. Ik ben blij dat je het doet hoor maar zoals ik een stoel maak is veel gemakkelijk dan vanuit een kuipstoel gaan werken. Zoals ik het doe (voorbeeld stoel van Frank), is het veel gemakkelijker om maatwerk te leveren als in dat idee (kuipstoel). Max: De foto zegt wel dat het een kuipstoel moet worden, maar dat hoeft natuurlijk helemaal niet. Ik mag als ontwerpen zeggen dat het anders moet zijn als ik ergens anders op kom. Het idee is het een rugleuning heeft en een zitten met een doorlopend kont deel. Wat denk je dat je gebeurt als je in een kuipstoel zit met je onderbeen? Die wordt afgekneld door de opwaarts krullende rand van de stoel. Wat je eigenlijk zou moeten doen is de stoel bij de zitbeenknobbels afzagen en dan het voorste deel omdraaien. Dan zou goed zitten in de stoel.

Het bewegingsmechaniek dat onder mijn stoelen zit is van rubber met een hang erin en dat kan alle kanten op bewegen. En dat moet jij ook gaan oplossen, jij moet gaan oplossen wat makkelijk beweegt en dat wordt in een kuip waarschijnlijk erg moeilijk en zul je een veer nodig hebben.

Het gaat om de punt, punt (zitbeenknobbel punten), vorm. Misschien moet je zeggen vorm, punt, vorm, punt. Nu is de vraag waar je iemand gaat laten zitten, waar ga je zijn zitbeenknobbels neerzetten? Waar gaat hij nou daadwerkelijk op de zitting zitten? Het is belangrijk dat mensen op die zitbeenknobbels gaan zitten als vertrekpunt voor je parameters. De kunst is om iets te maken dat mensen wel dat zit punt pakken om op te gaan zitten, anders heb je geen vertrekpunt voor je parameter. Dan praat je over dat harde gedeelte in je billen. Er is een truc om ze altijd te voelen in een stoel is door op bijvoorbeeld een hard boek te zitten. Het boek nodigt uit om goed te gaan zitten en een zachte ondergrond laat je onderuitgezakt zitten. Harde ondergrond is beter voor je houding, maar je moet ervoor zorgen dat je randen niet in je benen snijden. Door bijvoorbeeld naar beneden te laten buigen.

Een schommelslede onder een stoel nodigt je uit om op je balans punt te zitten in een stoel. Als je naar voren buigt om iets te pakken kantel je naar voren, als je naar achteren leunt ga je naar achteren. Maar je moet wel balans houden want anders kantel je op je kin bijvoorbeeld.

Het is grappig als ik een stoel moet instellen, zet ik hem voor iedereen hetzelfde qua rugsteun hoogte. Of je nou lang, klein of groot bent, maakt geen moer uit. Deze positie verandert bijna niet. Rug zo ver mogelijk naar, bekken vrij en de schenen in de middenstand (schommelstoel). Als ik recht zit, zit ik netjes in het midden. Zak ik door, dan kantelt hij naar achteren, strek ik op, dan val ik naar voren. De stand van je bekken bepaalt waar je heen gaat. Het gaat om je waar je steun zit, je bewegingspunt en je zwaartepunt. Het mooie is als iets in balans staan, dan ga je reageren op elke verstoring. Als je dus bijvoorbeeld te veel naar achteren zit in een kuip, dan moet je een hoop kunst en vliegwerk gaan doen om goed te gaan zitten. Nogmaals de punten zijn: De zitbeenknobbels (denk aan het boek, waar we vanuit gaan dat we op onze bekken rechtop zitten), vanaf dat moment heb je gewoon op je balans te zitten (als dat niet zo is, ga je met je bekken compenseren), de uitnodiging is van het mechanisme techniek om daarop (zitbeenknobbels) te blijven zitten (dan heb je een goed vertrekpunt). Zitbeenknobbels en je balans gaan altijd tijd samen, maar dan heb je een mooi standpunt voor je parameters. Dan kun je vanuit daar gaan kijken want je van voor, naar achteren en zijwaarts nodig hebt. Je zou kunnen zeggen dat je door de vorm van de stoel op je zitbeenknobbels gaat zitten, maar dat is een dwangbuis. Want als je balans niet klopt, dan je kan niet weg.

Voor jou een hele grote motivatie om die stoel te veranderen van een kuip naar een omgekeerde vorm. Ga je een stoel aanrijken die helemaal qua maatvoering op maat gemaakt is, maar qua comfort van zitten nooit eruit van wanneer je het bekken en zwaartepunt als vertrekpunt gebruikt en daar dan parameters aan gaat hangen. Dus als je een goed zwaartepunt vindt, dan heb je een goed vertrekpunt voor je balans. Wat ik zou doen is de stoel bij de zitbeenknobbel as afzagen en dan de kuip omdraaien.

(Frank legt uit wat het minimale is wat je nodig hebt om op te zitten, zie Miro)

Ik zou zeggen, je gaat of met parameters werken. Ik denk dat dat best moet lukken, ik denk dat je anatomisch alles best goed voor elkaar gaat krijgen. Maar ik denk niet dat je je dan tot goed zitten komt.
De meeste creatieve mensen willen liever iets hoger werken.

Max: Wil je nog eens uitleggen hoe je die rug instelt?
De rug zet ik bij iedereen in dezelfde stand, behalve bij de mensen die uitzonderingen zijn qua lichaam.

Je moet je overgeven het balans gevoel. Dat is ook het leuke, net als mensen die zonder handen op de fiets zitten. Balans is leuk, balans is speels, balans is uitnodigend.

Zitbeenknobbels, balans (dat houdt in plek zwaartepunt, waar pak je het kantelpunt, waar maak je het zwaartepunt), en als je ervan af gaat heb je steun nodig.

De vraag is nu, hoe bepaal je het zwaartepunt van een persoon. Ik denk dat dat in de parameters te vinden is. Maar dan moet je met een biomechanicus man gaan praten. Met iemand gaan praten die de bekken helemaal bestudeerd heeft. Waarschijnlijk weet hij wel iets over de afmetingen van de bekken en steunpunten.

De bil curvateur maakt het wel erg moeilijk voor je stoel. Soms zaag ik het er wel eens uit, want het zorgt er snel voor dat je niet goed kan zitten. Je moet ruimte maken voor de billen, alleen houdt het wel een keer op als je een grote bil partij hebt. Dan zou je kunnen zeggen, zwaartepunt, zitbeenknobbels en dan de afstand naar de rug. Ik denk dat daar een concaaf voor te vinden is. Ik denk dat daar een bepaalde verhouding voor te vinden is. Ik laat mensen vaak een boek achter zich zetten op een rechte rug en dan wil ik de horizontale maat weten van dat punt naar de knieholte en neem ik dat als vertrekpunt. En dan denk ik dat het mogelijk om een bovenbeen lengte te nemen, voorkant knie tot voorkant heup. Als je daar de verhoudingen van gaat nemen van mensen, dat je er wel een verhouding tussen kan vinden.

Als je dus de verhouding van de voorkant van de knie tot aan de rechte rug (bil) neemt en knie tot aan voorkant bekken (bovenbeen), kunt je waarschijnlijk wel de positie van de zitbeenknobbels bepalen en dat kun je dan als startpunt gebruiken om je stoel de gaan ontwerpen. Hier is waarschijnlijk wel een formule voor. Dit wordt ook een grote uitdaging voor mensen die meer volumineus zijn. De vorm van de billen verandert ook als je gaat zitten, qua vorm. Voor je rug ben ik niet zo bang, want het zitten gebeurt op je billen. Je rug staat op de tweede plek, zijn genoeg mensen die goed zitten op een kruk.

Als je je zitbeenknobbels hebt, kun je waarschijnlijk in die dezelfde parameters wel gaan kijken hoe lang iemand zijn bovenbeen is. Dat er een koppeling te leggen is aan de afstand van de lende. Het wordt wel een puzzel, eigenlijk ben je alleen maar met antropometrie bezig. Jij moet iemand vinden die onderzoek heeft gedaan naar de bekken.

Max: Het doel is dus, waar zitten de zitbeenknobbels. Hoe vertaalt zich dat naar de andere maten erom heen van die bekken. Hoogte van de rugsteun op de juiste plek en de holling. Dat maak je ook een gezond product.

Als het puur op de curvatuur zou doen en de maatvoering van de stoel, dan durf ik het wel aan. Pak 30 mensen en doe wat metingen en dan kom ik er wel uit. Dit is alleen te doen als het een statische stoel is. Als de stoel naar voren moet bewegen wordt het een ander verhaal, dan moet je een ander vertrekpunt nemen.

(Max vertelt over nogmaals over stoel, zijn motivatie reden voor he project en waarom kennis net zo interessant is in dit project)

Dan kom je terug bij, zitbeenknobbels, bewegingspunt, zwaartepunt. Hoe ga je al die punten bepalen. En ontdekken of het kantelpunt ertussen ligt, maar dat zal liggen aan de proporties van de mens. Die verschuiving zal nihiel zijn. Alleen extreem forse mensen, maar je lijf corrigeert ook al uit zichzelf waarschijnlijk. De natuur zoekt de balans van zelf wel weer op.

Er is iets te bouwen hoor (maar dan wel het omgekeerde design). Ik zou beginnen met zitbeenknobbels nemen als referentie punt, een referentie punt in de rug en dan nog gaan werken met volume en beenlengte. De industrie noemt het zwaartepunt wel, maar niet in relatie met het bekken. Het bekken rechtop houden is het probleem omdat het niet in mensen hun gedrag zit. Alles erom waar je op zit is opvulling. Het is belangrijk om ervoor te zorgen dat de stoel ook simpel blijft, niet te veel aan een stoel. Materiaal beperken is ook duurzamer, beter voor de natuur.

moopi - Chapter 10: Appendix

Max: 'Ik realiseer mij nu ook dat het allemaal niet zo gek moet zijn met curves en een hoop poespas. Een vlakke zitting en simpele rug.'

Als jij de stoel in deze richting op (wat Frank tekende produceert), dan ben ik geïnteresseerd in de uitkomst. Dan kunnen we gaan kijken of het aansluit bij dit verhaal en dan neem ik een rubber voor je mee zodat we kunnen zien wat dat doet. Het rubbermechanisme is een effectieve en goedkope manier om beweging erin te krijgen (patent is verlopen trouwens).

Als je naar echt naar goed zitten wilt komen, dan is vanuit maten echt wel iets goed te maken. Als je alleen naar achteren wilt zitten, dan zou ik zeggen maak 3 modellen en dan ben je klaar. Zorg dat mensen die gaan testen, pas je hem aan en dan ben je klaar. Doe je zo 30 mensen dan ben ik er wel. Max: Maar het gaat niet om alleen maar naar achteren te zitten. Nee maar dan heb je wel cijfers. Dus laat je 30 mensen in de kuip, bepaal je de maatvoering van wat zijn bil en been is. En dan laat je mensen ook het comfort bepalen. Dus je doet een meting en comfort test, waarin mensen een suggestie doen wat er verandert of goed is. Dit is geen parametrisch model want je hebt geen referentie.

Ja een parametrisch model kan wel vanuit die zitbeenknobbels. Eerst die zitbeenknobbels als referentie, die werk je uit. En dan ga kijken wat er gebeurt als je er beweging onder gaat zetten. Dan heb je wel een verhaal te vertellen. Dan ga je het model aanpassen en dan gaat het waarschijnlijk het comfort omhoog.

Het rubber kantel mechaniek zorgt ervoor dat bij een normale kantelstoel ook iets naar voren kan bewegen want normaliter niet zou kunnen. Als je gaat zitten en je gaat meteen op dat balans punt zitten, dan heb je niet het gevoel dat je onderuitgezakt wil gaan zitten. De stoel vormt naar je lichaam en als je gaat bewegen, dan beweegt de stoel met je mee. Je hebt dus geen behoefte om onderuitgezakt te gaan zitten. Het rubber van de zitten zorgt ervoor dat de stoel een beetje mee naar achteren buigt als je op het kantelpunt gaat zitten. Dus je blijft zitten. Het is belangrijk om wel op het balans gevoel te zitten.

Ik zie jij (Ik, Max) ook iets met je bekken naar achteren staat en dit wordt alleen maar versterkt als je zit. Dit van je op in je benen. Hier moet je vanaf, ander blijf je rugklachten houden. Ik weet als ik dit mechaniek pak (rubber kantel mechaniek), je zit veel dus ik kan je veel aanrijken, ik kan je op die balans zetten dat je dat gevoel meemaakt. Dat doe ik door de stoel iets hoger te maken dan de standaard stoel. Armleuningen eraf, alle verstoringen eraf, dan ben jij zo vrij om als een vogel om vanuit je bekken je beweging te maken. Als je dan echt lui wilt zitten, doe je de stoel naar beneden, dan kantel je automatisch naar achteren, maar als je je dan weer aan het werk gaat, krik je de stoel weer op.

De kern blijft: Je hebt de zitbeenknobbels nodig om de maatvoering te bepalen. Dat kun je laten maar dan ben je niet in de opdracht bezig. Dan kan je geen parameter maken. Dan laat je dat los en dan ga gewoon werken met maten. Dan zou mijn advies zijn om 3 maten stoel te maken (als je in de huidige bucket vorm blijft). Dat moet je dan wel kunnen aantonen met metingen die je gedaan hebt.

Maar als je het omgekeerde bucket vorm gebruikt en je zet er een fatsoenlijk mechaniek onder en je gaat ook werken vanuit de zitbeenknobbels. Dan gaan we het zwaartepunt en het kantelpunt erbij betrekken. En dan gaan we daarvanuit redeneren hoe de zitting moet zijn.

Appendix F: **Hans Scholten interview**

Notities
Een opmaat gemaakt gemaakte stoel maakt nog geen goede stoel
- Wat onderscheid goede en slechte stoel?
- Slecht bioscoop stoel ga je ook telkens verzitten en onderuit gezakt zitten

Interessante bedrijven:
Emtek: opmaat gemaakte stoelen
Specialised: 3d geprintte fietszadel
Workwear: 3d geprintte vergaderstoel
7.5 stoelen: uniek kantelmechanisme, produceert ook voor Herman Miller (misschien connectie naar producent)

Probleemdefinitie is het allerbelangrijkste!!
- Wat is de definitie van goed zitten?
- Wat is het hogere probleem? Mensen weten niet wat goed zitten is.

Belangrijkste aspecten van een stoel
Goed kantelmechanisme, ondersteuning juiste plekken, comfort
Biomechanisch krachten evenwicht daar streef je naar in je stoel, zodat het meebeweegt met je lichaam zodat je eigenlijk geen spierkracht moet gebruiken
1rste wet van newton
Bekken steun ipv rugholling opvullen, de bekken naar voren duwen zorgt ervoor dat je in een rechte en gezonde positie komt te zitten.

Npr1813 is onzin

Transcript
Ademhaling
Goed zitten heeft allemaal met je ademhaling te maken. Als je niet goed kunt ademhalen dan krijgen je spieren geen zuurstof en krijg je klachten. Bij goed zitten wil je ten alle tijden voorkomen dat mensen hun spieren gebruiken, dat is essentieel. Wat is de consequentie van je spieren wel gebruiken? Op termijn lijdt dat tot overbelasting, mindere bloedsdoorstroming en een slechtere ademhaling. Lichaam op spanning, is minder goed ademhalen.

Probleemstelling bepalen
Het is belangrijk dat je begint bij een hele duidelijke probleemstelling. Wat wil je fysiek met die stoel bereiken? Wat is het hogere probleem dat je wilt oplossen, welke klachten hebben de thuiswerkers, welke problemen hebben de thuiswerkers. Wat doen de thuiswerkers precies allemaal voor activiteiten in de stoel. Niet alleen simpel werken met een stoel op maat om een opportunity te vullen.

Mensen ontbreekt kennis over zitten
95% van de bureaustoelen die geproduceerd worden, daar zit geen vorm van research in. Er zit geen kennis in van ergonomie en hoe je moet zitten. Meeste stoelen die worden verkocht, worden maar gewoon verkocht om geld te verdienen. Het is een keten van onnozelen. Het is een fabrikant die geen idee heeft, een importeur die geen idee, een dealer die geen idee heeft die geen idee heeft en een klant die geen idee heeft. Klant heeft geen enkele kennis of idee hoe ze goed moeten zitten. Dit komt omdat het hun nog nooit verteld is. Een bedrijf dat veel stoelen levert hebben zelf geen idee hoe het werkt en dus hun klant ook niet. Het is alleen maar dozen schuiven. 98% (ervaringsgetallen) weet niet hoe die zijn stoel moet instellen. Laat dit percentage maar eens in een auto rijden.

Leer hoe je in de basis moet zitten
Het zal lastig zijn om in 20 weken een hele nieuwe fysieke stoel te ontwerpen. Als jij kennis wilt vergaren of de fysieke kant, dan kan je gaan praten met een fysiotherapeut etc. Alleen die hebben allemaal niet de kennis over hoe je moet zitten. Ze weten niks van zitten en maken uitspraken gebaseerd op niks, ook artsen. Een stoel die je niet instelt is per definitie al een compromis. De allerbeste stoelen die wij hebben staan (hier in de showroom) hebben 12/13 instelmogelijkheden. Er is geen mens die daar uitkomt. Dat werkt alleen als je wij die klant daarin begeleiden en dat kost tijd. Tijd is er niet en tijd kost ook geld, klant is niet geïnteresseerd. Wat ik denk wat heel belangrijk is en waarmee je je kunt onderscheiden is door je product te koppelen aan kennis. Door de klant te vertellen wat het probleem is en dan te vertellen waarom jouw stoel de oplossing is. Mensen moeten het wel begrijpen, dat is essentieel. Er is geen kennis, ook niet bij bedrijven. Er zijn al veel initiatieven geweest om een perfecte stoel te ontwikkelen. De markt is dominant en tot op dit moment zijn goede stoelen heel erg duur.

Specialized
Kijk eens naar Specialized 3D geprintte zadels. Het leuke is aan fietsen, maar in mindere maten bij stoelen, een zadel 1 cm hoger of lager kan het verschil maken tussen rugklachten of niet. Bij fietsen wordt alles uitvergroot omdat je inspanning levert. Fietsen is eigenlijk een uitvergroting van zitten. Bij fietsen speelt alles op maat nog een grotere rol dan bij zitten. Daarom is het een leuke vergelijking.

Mesh en flexible stoffen om de druk te verdelen
Volgens mij heeft het bedrijf Workwear een ge-3D printte vergaderstoel. Dat zit hier in het Gooise. Gewoon omdat het kan, niet op maat gemaakt of iets dergelijks. Het leuke aan 3D printen is dat je zones kan creëren met meer of minder support. Dit hebben bijvoorbeeld ook gedaan bij deze stoel (Herman Miller Aeron). Op het zitgedeelte heb je een stof die op verschillende plekken anders is qua stijfheid. Als je op verschillende plekken drukt, dan voel je een verschil in stugheid. In het stugge deel zijn extra draden verwerven die voor extra spanning zorgen. Hierdoor zak je minder in de stoel, bijvoorbeeld aan de voorkant, zodat je je benen niet klemt/afscheid op de framerand en je zitting meer kan vormen naar je billen. Dit zorgt ook voor een beter gewichtsverdeling.

Je hebt verschillende soorten mesh. Je hebt high end mesh, carbonfiber (zonder carbon) mesh van Herman Miller, en een gewoon stoffen mesh. Over 20 jaar zit de spanning van de carbonfiber mesh er nog op en het gewone stof rekt veel te veel uit. De carbonfiber mesh is veel innovatiever dan de andere.

De Herman Miller hierboven besproken en de goedkopere mesh zijn anders qua prijsklasse alleen zijn het alle twee goede stoelen en kunnen klachten voorkomen. Als een klant komt vraag ik daarom altijd eerst: wat ga je ermee doen dan? Het is belangrijkst om te weten hoe ze de stoel gaan gebruiken en waar. Max: “Peter Vink zei ook al dat de activiteit heel bepalend is voor de het design van de stoel”. Dat is een goede opmerking. Thuiswerkers willen ’s avonds ook wel eens naar Netflix kijken in de stoel met een biertje. Heel veel thuiswerkers hebben weinig ruimte en willen een stoel hebben die er leuk uit ziet. Deze stoelen (Herman Miller Aeron) zijn daar succesvol omdat het zich nog voor wat meer leent dan alleen kantoor werk.

Bewegingsmechanisme
Het bewegingsmechanisme hier hiervoor essentieel. Een vaste rugleuning impliceert een hoop problemen (mensen gaan onderuitgezakt zitten en dit is heel slecht voor de rug. Dat is ook het probleem in de bioscopen, mensen gaan continu verzitten. De truc van een goed mechaniek is dat je in balans blijft zitten. De balans moet je instellen. Als je je slap maakt val je naar achter en naar voren komt helpt de stoel je. Belangrijke termen: Biomechanische krachten evenwicht (menselijke mechanica) en de eerste wet van newton. Daar streef je naar bij het zitten, dan gebruiken je spieren zo min mogelijk krachten. Als er geen evenwicht is dan zijn jouw spieren niet in rust. Als je dan vanuit een liggende positie naar boven komt wil je zo min mogelijk spierkracht gebruiken, de stoel helpt je daarbij. Als je onderuitgezakt gaat zitten en je armen steunen op een goede hoogte, dan gaan je schouders omhoog en dat geeft spanning. Ook je romp gaat omlaag, terwijl je romp omhoog moet staan. Dit gebeurt vanuit je bekken.

Bekken focus ipv onderrug
Moet je lendensteun dan ook op je bekken zitten ipv je rug? Dit klopt, de stand van je rug wordt bepaald vanuit je bekken. Ruggensteun is heel erg stom, je moet iets hebben dat je bekken ondersteunt. Kussen in de rug zorgt ervoor dat je bekken nog steeds naar achteren kunnen draaien. Het is essentieel dat je normale ruggenwervels nog kunt bewegen. Met een ruggensteun zet je je wervels vast, dan zit er geen beweging meer in je onderrug. Wat gebeurt er op een zadelstoel. Als op zo'n stoel zit, trek je je bekken naar voren en dan zit je automatisch rechtop.

Ruggenwervelsteun
Bij de Herman Miller Aeron zit in het midden een ruggenwervelsteun en een mesh achterkant. Het flexible mesh zorgt ervoor dat het naar de rug vormt en dan de rug nog kan bewegen. De stoel geeft door de rugvorm al veel rugsteun, maar het mesh kan ervoor zorgen dat je iets wat doorzakt en dit voorkomt de ruggenwervelsteun. Bij een andere stoel steek de rugleuning (RH Logic 400) uit en dat kun je op de goede hoogte instellen zodat het op de juiste plek drukt. Het zou super zijn als je dat kan moduleren op een manier. Maar noway, dan zou je een gips afdruk maken. Mensen zouden op een betonnen stoel nog goed kunnen zitten als je in hun zit vorm giet, als de gewichtsverdeling goed is.

Zithoek benen
Deze wordt bepaald door het kantelmechanisme. Het zitgedeelte MOET met rug gedeelte meebewegen. Een vast zitgedeelte zorgt ervoor dat je onderuitgezakt gaat zitten, dit kan niet! Mensen hebben het over actief zitten en dit kan alleen als je je spieren aanspant en dit is niet comfortabel zitten. Comfortabel zitten kan alleen als je iets achterover gekanteld zit. Een stoel met horizontale zitting kan niet, de zitting moet iets naar achteren kantelen. (RH Logic 400) Heeft het beste kantelmechanisme, het werkt als een soort exoskeleton. Het beweegt helemaal natuurlijk met het lichaam mee. Van alle 100en stoelen, zijn er maar 3 die dat goed doen. Als je vanuit een 0 wilt werken en ontspannen wilt zijn is dit de beste. Perfect voor mensen met bijv. een hernia.

Vorm van rug zitting
Er is hier veel verschil in. Sommige zijn uit de gedachte van het design ontwikkeld, ene jaren 90 andere jaren 70. Maar beide zijn zo goed dat ze nog steeds bestaan, welliswaar verbetert. Er hangt alleen prijskaartje aan. Max: 'Er bestaat dus geen goed of fout aan het ontwerp van de rugleuning?' Boven in de rugleuning gebeurt helemaal niks, het is niet interessant. In het gebied van de onderrug gebeurt het allemaal, de rest erboven kan bij wijze van spreken afzagen. Alleen wat je niet meer kan is lekker naar achteren hangen. Het gebeurt allemaal in onderrug area, dit zit je bekken goed en dat je rechtop komt zitten. Jonge mensen zijn behoorlijk belastbaar, dus die kunnen goed op een slechte stoel zitten. Oudere mensen krijgen op dezelfde stoel klachten, tenzij ze hele hun leven goed en sportief geleefd hebben. In een samenleving waar mensen hun lichaam steeds slechter onderhouden, wordt de rol van stoel steeds belangrijker!

Thuiswerken
Scholten heeft veel kennis over wat thuiswerkers motiveert om een stoel te kopen. Een van die dingen is dingen is is dat de stoel niet alleen voor kantoorwerk geschikt moet zijn. En dat het er leuk uit moet zien omdat het een deel van je inrichting is.

Markt
Ik zou de stoel veel duurder maken dan 500 euro, maar dat is afhankelijk is van de markt waar je opricht. Wat is de markt waarvoor je het gaat doen. Ik zou heel hoog inzetten, misschien 2000 euro, en dan in de loop van je jaren verminderen. Ik vind het in ieder geval heel goedkoop voor de technieken en technologie. Wij zitten in de top van de markt, wij doen veel vanuit kennis en tijd investeren in klanten, dan moeten wij dure producten verkopen. Wij hebben veel marktkennis.

Je moet uiteindelijk de stoel ook gaan verkopen en dat is vaak wel heel erg lastig. Misschien een idee voor Zon&Hoofd eens met hun te gaan praten.

Geeft uitleg over opdracht en Dined
NPR1813. Het target was om naar Dined tabel te kijken en een stoel te maken die voor 95% van de mensen past. Dus dat bekent dat het zit gedeelte enorm veel moet kunnen bewegen (naar voor en naar achteren). De aanname is dan dat we de zitting altijd 3cm korter willen hebben dan de knieholte. Dat is leuk maar waar is dat op gebaseerd, op het Dined tabel? Dat is totale onzin. Het maakt helemaal niet uit wat de ruimte is tussen de zitting en knieholte. Je zit helemaal niet op dat gedeelte van been. NPR is bedacht om nieuwe stoelen te ontwikkelen die volgens een norm weer konden verkopen. Ontwikkeld door een bedrijf om te cashen. Mensen ging stoelen maken aan NPR norm maar steeds goedkoper en goedkoper en die stoelen werden heel slecht.

Basis van de stoel
Het uitgangspunt moet zijn biomechanische kracht evenwicht, lage spierspanning en goede houding. Als je dat bereiken, dan heb je een goede stoel. Je moet kunnen ademhalen, dat is een basisbehoefte. Dat is uitgangspunt op een hoger niveau van de stoel. Kantelmechaniek is heel duur. Vele hebben een actief, maar er bestaat ook een passieve (Herman Miller Setu). De kracht zit hem hier in de integreerde veer. Dit is voor hem comfort, een vergaderstoel. De zit heel erg goed. Dit is een stoel zonder instelmodus, een multi purpose stoel.

De Herman Miller Setu kan je goed je kont duwen en uit de holling komt de steun in de bekken. De juiste holling is belangrijk dat je kont erin valt. Stoelen die die holling niet hebben, voor je kont, zijn glijbanen. Daar zak je heel snel onderuit.

Armsteunen
Veel stoelen hebben een armleuning die scheef staat in de verstelling. Dat wil zeggen dat je dat als je de armsteun hoger zet, de armsteun ook meer naar voren zet. Daar zit een kromme gedachte achter. De gedachte is dat mensen die hogere armsteunen nodig hebben, ook veel groter zullen zijn. De hoogte van de armsteun heeft niks met je lichaam te maken. Er zit geen

correlatie tussen de elleboog hoogte en je bovenbeen hoogte. Ook dat als je groter wordt, je ook dikker wordt. Dit is onzin. Goede stoelen gaan recht op en neer, de armsteun. Er is wel een correlatie tussen dikke en dunne mensen.

Tafeldikte
Als jij in ontspanning, rechtop, zit dan is je elleboog je steunhoogte. Maar als je tafel te hoog is dan gaan je schouders nog steeds om hoog. Dan kan je tafel omlaag of stoel omhoog. Een leuke voor je onderzoek is ook om te kijken naar de dikte van de tafel. Ze hebben het altijd over de hoogte maar niet over de dikte. Er zit maar een kleine ruimte tussen je elleboor (en armen horizontaal en je bovenbeen. Anders aan armen wijd zitten. Deze ruimte bepaalt de dikte van je werkblad nodig. Ook als je dikke benen hebt is dit ook een probleem. Als je stoel zakt dan ga je nog lager met je bekken. (Minuut 17:00) Dus bij mensen die laag uitkomen moet de bekken nog verder naar voren komen. Dus bij lage mensen, moet de kont goed naar achter zodat de bekken naar voren komen. Problemen bij thuiswerkers: tafel te hoog en te dik.. dan moet de tafel weg. Dit is ook belangrijke factor in het succes van je stoelen. Daarom is het belangrijk om je product te koppelen aan kennis. Je moet dan uitleggen hoe het moet (het gezond rechtzitten) en niet een boekje meegeven. Tafel kan echt een dealbreaker zijn! Beoordeel je tafel, heb ik wel een goede tafel?

Mag je de tafel voor lief nemen?
Max: "De tafel een bepalende factor maar die zouden we voorlief nemen in dit project". NEE! De tafel mag niet vergeten, is deel van je succes is een complete oplossing. Laten we uitgaat van integriteit. Ik houd van integriteit. Als je uitlegt hoe die stoel omhoog en omlaag moet dan wordt het een bende net als iemand in een Ferrari laten rijden zonder uitleg. Ik vind dat daar een pakket bij hoort, van hoe je dat gaat toepassen in de praktijk. Waar moet je nog meer opletten. Ook voor het succes van je product en klant tevredenheid. Maar het allerbelangrijkste is dat jezelf (Max) over die kennis beschikt. Het probleem goed in kaart brengen, probleemstelling moet heel erg duidelijk zijn! Wat is de definitie van goed zitten? Dit is essentieel.

Wat ik mij afvraag, als je al die moeite gaat doen voor thuiswerken, dan heb je toch ook een goede stoel voor op kantoor?

Stoelen die thuis worden gebruikt, worden ook smerig dan op die van kantoor (door eten bijv.) Moet je dan nog wel stof willen? Daarom zijn mesh stoelen (Aeron) is daarvoor goed.
Ga je met zones werken met de print dikte?

Zit er nog bekleding op? Ja er komt padding op te zitten. Je moet ff kijken naar Specialized zadel met 3D structuur. Een ruimtelijke structuur met alle beweging, dus waardoor je geen materiaal meer nodig hebt. Nu ben je maar een 'schaal' aan het maken. Dat is meer mijn visie die ik heb op 3D printing. Met 3D printen kun je allerlei functionaliteiten uit je 3D print halen, zachtheid, vorm. Door een geraamte van cellen te printen heb je geen schuim meer nodig. Zo kun je eindigen met een oppervlaktelaag die semi dicht is. Ik voel heel erg voor die 3D structuur, het zal gecompliceerd zijn. Maar wel heel interessant. De truc van 3D printen is dat je er veel functionaliteiten erin kan steken. Schuim op een bucket plakken is boring, daarin zit geen innovatie. Dan ga je een kuipje maken op een andere manier.

Max: "De innovatie zit hem in het 3D scannen, afmetingen nemen van mensen en die vertalen naar afmetingen van een stoel." Dat is helemaal niet nodig, daardoor maak je het alleen maar onnodig complex. Is he-le-maal niet nodig. Deze als je uitgaat van one-size-fits-all met 3D

moopi - Chapter 10: Appendix

technologie. Dat is een veel mooier principe en interessanter. Max: "legt concept nog eens uit" Wat nu als je iemand hebt die nu 120 kg weegt en volgend jaar 90 kg? Of andersom? Hoe ga je mensen ook 3D scannen thuis? Kijk hiervoor naar mode-industrie. Wat gebeurt er als mensen de verkeerde maten doorgeven of verkeerd meten. Ik vind het risky business het idee. Bij kleding word mass-customization wel al veel gedaan. Dit project klinkt meer als 5000 euro dan 500 euro. Als je een mooi product wilt maken voor thuiswerkers, doe er dan geen stofje overheen.

Mijn theorie is als je maatwerk gaat leveren, iets afgaat stemmen op het volume van de persoon, dan heb je alleen de schaal nodig. Als die schaal goed is dan ben je al heel ver. Zeker als jij met je 3D technologie nog een beetje flexibiliteit in die schaal te krijgen. Niet door alleen een platte schaal te maken, maar die schaal een beetje volume te geven waardoor de nog wel een beetje kan bewegen. Kijk net als hier (Herman Miller Mirra 2 Triflex) maak je gaten in de rugleuning om de stijfheid van de rug te bepalen. Veel gaten is slap, minder gaten is minder stijf.

moopi - Chapter 10: Appendix

Appendix G: **Home office worker oberservations**

	Questioned	Observed
Participant information	*Participant 1*	
Sex	Female	
Age	51	
Body characteristics	Tall, normal, 1,80m	
Job information	Freelance photographer	
Physical complaints	Lower back Is a weak point, therefore bought the current chair from ikea	
Context information		
Space around desk		Has a lot of stuff on the tables, papers, notepads and stores maps around her
Desk height / thickness		Very thick living room table, can fit legs under the table but not table too high
Monitor		Uses monitor above her laptop, but this uses this as secondary screen
Keyboard and mouse		Laptop keyboard, external mouse but mainly uses keyboard trackpad
Drawers, books		Uses notepad to write stuff on
Aesthetics of environment		Very concerned about the aesthetics of her living room, same colors, bought specific chair to fit into the home environment
Current chair		
Type		**IKEA LÅNGFJÄLL** Conference chair, Gunnared beige/white
Correctly setup or fixed		Fixed
Features (tilt, swivel, wheels, adjustability)		Tilting mode active, but has high resistance so sits naturally up straight. Has wheels
Personal		Heavy tilting mechanism, doesn't work naturally

Activity timeline	Laptop work (photoshopping	Phone	Eating	Back to laptop work	Phone	Phone (texting clients)
Work or leisure	Work	Work	Leisure	Work	Leisure	Work
Physical or digital	Digital	Digital	Physical (socializing)	Digital	Digital	Digital
Body posture during activity	-Upright with arms next to body, elbows a bit wide (leaning against backrest in an upright position) -Leaning on one elbow forward looking down at screen -Leaning head on hand while leaning on elbow while working on trackpad (3 main positions)	-Upright with arms next to body, elbows a bit wide (leaning against backrest in an upright position)	-Leaning forward far from table while leaning on forearms -legs crossed	-Upright with upper body leaning forward looking down at laptop screen - Switching between working with two arms and using one. Using the other the lean on, lean head on -Legs forwards (ankles crossed)	- Relaxed backwards position - Upper body follows the backrest - Does NOT tilt chair	- Relaxed backwards with a slight tilt - upper body against backrest - Tilts chair a bit
Seating position during activity	-Body following contour of seat but upper body leaning forward with neck to look at laptop -Sitting very close to the table to lock her body in place	-Body following contour of seat but upper body leaning forward with neck to look at laptop -Sitting very close to the table to lock her body in place	-Sitting on the front of the chair - Not touching backrest	**-Body firm against backrest following contour, but upper not touching back because leaning forward**. -Close to table, locking	-Butt is free from backrest / butt curve, this allows the user to relax backwards against backrest **Without tilting chair (therefore is the butt moved forward**	- Butt free from back rest - tilts back for more comfort
Forward, neutral, backwards	Forwards, with neutral pauses	Neutral	Forward	Forwards, with neutral pauses	Backwards	backwards
Movements	- Only small movements between neutral and forward seating position. -When moving away from table, rolling and turning chair		Normal movements while eating (cutting, eating, drinking)	-Often makes very small sitting adjustment -Rolls back and forward to reposition against the table -Every 30 min makes a big adjustment by lifting and repositioning butt and back against chair **But constantly tries to reposition in same position**	- No	- Doesn't really move a lot during this activity. Sits still
Sequence of movements	Switching between different upper body postures, lower body stays in static position		Moving in and out of chair to get stuff out of the kitchen			
Time duration of each activity	1 hour	10 min	15 min	30 min	10 min	15 min
Complaints during activity						

	Questionned	Observed
Other remarks		
Ergonomic complaints		None
Do they know how to sit well?	Has knowledge how to sit well but forgets automatically	
Time observed		From 12 till 6

	Questionned	Observed
Participant information	*Participant 2*	
Sex	Female	
Age		
Body characteristics	Average height, normal posture	
Job information	Digital marketing creative	
Physical complaints		
Context information		
Space around desk	Has little space as her desk is full of stuff, typing area and mouse area are free for movement	
Desk height / thickness	Desk is fairly high as her shoulders are raised up while leaning on the table during typing / writing	
Monitor	Uses monitor as main screen, laptop on stand also on eye level	
Keyboard and mouse	External keyboard and ergonomic mouse	
Drawers, books	Uses sheet of paper to take notes on	
Aesthetics of environment	Has a dedicated office space in her house, chose chair as it also aesthetically is nice. Looks like quality.	
Current chair		
Type	Vitra	
Correctly setup or fixed	Legs in 90 degrees, tilting mode active but sits naturally up straight. CANT LOCK CHAIR	Chair base position is the seat pan is horizontal (0 degrees) and the curve for the lumbar is 20 degrees both ways
Features (tilt, swivel, wheels, adjustability)	Tilt, wheels	

Activity	**Had meeting before this observation, so she hasn't been sitting at her desk the whole day**	**Laptop work (browsing and designing)**	**Calling**	**Walks to kitchen after 20 min of calling**	**Back to laptop work**	**Conversating**	
Work or leisure		Work	Work			Leisure	
Physical or digital		Digital	Physical				
Body posture during activity		-Up straight with forearms on the desk typing and using mouse -Sits fully against the backrest with buttocks pressed in the but curve of the chair -Sits on one leg with foot under the others' leg upper leg - Not leaning back, so upper body doesn't touch the backrest	Same but leaning on elbow and scrolling at the same time	Reposition back into sitting on one leg, fully pressed against backrest	-Up straight looking horizontally to her monitor screen - Doesn't have an extreme up right posture but sits neutral, pelvis rotated back I guess -Sits a bit rotated behind her desk, this has to do with that she looks to the right at her laptop monitor	-Sits relaxed back fully tilted -also sits normally with legs crossed -rotates towards	
Seating position during activity		-Body follows backrest -Sits nice up straight as if body is in natural spine position -Sits close the desk, but doesn't clamp between chair and seat	Same as previous	Presses herself against backrest (see the chair tilting) to get a good support	Sometimes roles a tiny bit forward to write stuff down, then also bents her upper body forwards	-Butt doesn't touch the back of the chair -dorsal area of the back rests on top of the chair -slouching comfortable pose	
Forward, neutral, backwards		neutral	neutral				
Movements		Switches between: -Sitting on one leg -Sitting crossed legs -Sitting with both feet on the ground	Same as previous		None in her under body		
Sequence of movements		Switches every 5-7 min of position	Same as previous		After 30 min switches to crossed leg seating position from sitting on op of one leg		
Time duration of each activity			20 min	1,5 hour		Depends on conversation (Up to 15 min)	
Complaints during activity							

	Questionned	Observed
Other remarks		
Ergonomic complaints	Says that she has NO complaints of the chair, has more problems with sleeping	
Do they know how to sit well?		

Time observed	2,5 hours	

Appendix H: **Questionnaire results**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Tijdstempel	Do you work in home offi	Gender?	Age?	Country of residence?	Body length? *(e.g. 1,97m*	Body size type?	Type of job or study?	Do you already have phy	How often do you work a	What does your work en	Space on the desk *(stuff,*	Can you fit your legs und	Is your desk thicker than	What is your main comp	Keyboard and mouse?
2	11/2/2022 18:56:24	Yes	Female	23	Italy	1,65	Skinny	Marketing	No	2	Choose different places t	Moderately crowded	Yes	No	Laptop screen (on eye le	Keyboard
3	11/3/2022 8:37:51	Yes	Female	22	The Netherlands	1,67m	Regular	Hbo	Back pain	3 times per week	Kitchen table	Moderately crowded	Yes	No	Laptop screen (on desk l	Mouse
4	11/2/2022 16:01:10	Yes	Male	24	The Netherlands	1,86	Regular	Marketing	Yes, pain on my upper ba	2/3	Kitchen table	Empty / clean	Yes	No	Laptop screen (on eye le	Mouse, Keyboard
5	11/2/2022 15:59:20	Yes	Female	25	The Netherlands	1m70	Regular	Office job, 100% comput	Nope	2 days	Kitchen table	Moderately crowded	No	Yes	Laptop screen (on desk l	Mouse, Keyboard
6	11/2/2022 23:07:48	Yes	Female	30	Portugal	1,72	Regular	Engineering	Lower back often hurting	1	Dedicated office area	Moderately crowded	Yes	Yes	Laptop screen (on desk l	None of the above when
7	11/2/2022 16:07:29	Yes	Female	27	The Netherlands	1,8	Regular	Leger Counsel	No	3	Dedicated office area	Moderately crowded	Yes	Yes	Laptop screen (on eye le	Mouse, Keyboard
8	11/3/2022 17:45:22	No	Male	28	The Netherlands	191	Large	Procesoperator	Yes my knee	0	Factory	Full of stuff	Yes	Yes	Laptop screen (on desk l	Mouse, Keyboard
9	11/2/2022 18:14:53	Yes	Male	33	Portugal	1,83m	Regular	Designer	Spinal irritations	5	Dedicated office area	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard
10	11/3/2022 9:44:54	Yes	Male	20	The Netherlands	2,00m	Regular	Study, leisure and events	Lower back problems	4	Dedicated office area	Moderately crowded	Yes	No	laptop and monitor scree	Trackpad
11	11/3/2022 15:37:18	Yes	Female	31	The Netherlands	1,65m	Regular	Administratief medewerk	Nek en schouderklachter	1	Kitchen table	Moderately crowded	Yes	Yes	Laptop screen (on desk l	Mouse, Keyboard
12	11/2/2022 16:24:56	Yes	Male	44	The Netherlands	189	Regular	Industrial Design Engine	Nee, na een dag werken	4-5 dagen	Dedicated office area	Full of stuff	Yes	No	Monitor	Mouse, Keyboard
13	11/2/2022 17:31:05	Yes	Male	61	The Netherlands	1,8	Regular	Wholesaler	No	60 hrs	Office at home	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
14	11/2/2022 20:28:10	Yes	Female	30	Portugal	1,67m	Skinny	Digital Design	Not yet fortunately	4 days	Living room table	Moderately crowded	Yes	No	Laptop screen (on desk l	Keyboard, Trackpad
15	11/2/2022 21:53:26	Yes	Female	58	The Netherlands	1,69	Regular	IT	No	4 times per week	Dedicated office area	Empty / clean	Yes	Yes	Monitor	Mouse, Keyboard
16	11/3/2022 9:53:19	Yes	Female	59	The Netherlands	1.74	Regular	Office	No	5 days	Choose different places t	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
17	11/3/2022 10:19:44	Yes	Male	32	The Netherlands	181cm	Skinny	Engineering	Not really	2 days	Bedroom	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard
18	11/3/2022 12:20:21	Yes	Female	36	The Netherlands	1,73 m	Regular	Consultant in life science	No	3	Dedicated office area	Full of stuff	Yes	No	Monitor	Mouse, Keyboard
19	11/3/2022 15:44:04	Yes	Female	25	The Netherlands	1,74	Skinny	Office job	No	3	Dedicated office area	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
20	11/3/2022 17:38:17	Yes	Male	29	The Netherlands	1,81	Regular	Finance	No	4	Dedicated office area	Moderately crowded	Yes	Yes	Monitor	Mouse, Keyboard
21	11/2/2022 23:14:50	Yes	Male	28	The Netherlands	1,82	Regular	Handelaar	Gebroken sleutelbeen	5	Kitchen table	Moderately crowded	Yes	Yes	Laptop screen (on desk l	Mouse, Keyboard
22	11/2/2022 16:16:45	Yes	Female	30	The Netherlands	168	Skinny	Office job, creative medi	Back and shoulder pain	2 or 3 times	Dedicated office area	Moderately crowded	Yes	No	monitor + laptopscreen a	Mouse, Keyboard
23	11/2/2022 18:18:22	Yes	Female	19	The Netherlands	1.63	Skinny	Graphic design	No I don't have	2 times a week	Choose different places t	Empty / clean	No	Yes	Laptop screen (on desk l	Keyboard
24	11/3/2022 7:56:23	Yes	Female	52	The Netherlands	1,84	Regular	Management	Back issues	3	Kitchen table	Moderately crowded	Yes	No	Laptop screen (on desk l	Mouse, Keyboard
25	11/3/2022 8:33:07	Yes	Female	23	The Netherlands	1,68	Skinny	Graduation internship on	No	2 tot 3 times	Choose different places t	Moderately crowded	Yes	Yes	Laptop screen (on desk l	Mouse
26	11/2/2022 22:16:44	Yes	Female	57	The Netherlands	1,6	Regular	job	schoulders	4	Kitchen table	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard
27	11/3/2022 21:08:49	Yes	Male	26	The Netherlands	1.87m	Regular	Healthcare consultancy	Neckpain	3 days	Studio apartment	Full of stuff	Yes	No	Monitor	Mouse, Keyboard
28	11/2/2022 17:53:54	Yes	Female	32	The Netherlands	180	Skinny	Video Production	Yes, scoliosis	3	Dedicated office area	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
29	11/2/2022 22:41:27	Yes	Male	32	Portugal	1,76m	Regular	Digital design		4 days	Caravan table	Moderately crowded	Yes	Yes	Laptop screen (on eye le	Mouse
30	11/3/2022 11:23:08	Yes	Female	29	The Netherlands	162	Regular	Office administrator	no	2 times per week	Living room	Moderately crowded	No	Yes	Laptop screen (on desk l	Mouse
31	11/3/2022 17:38:32	Yes	Male	25	The Netherlands	1,80m	Regular	Kantoorbaan/uni	Nee	1	Dedicated office area	Empty / clean	Yes	Yes	Laptop screen (on eye le	Mouse, Keyboard
32	11/3/2022 17:49:11	Yes	Male	27	The Netherlands	1,79	Regular	Tech Specialist/solution	Yes back and shoulders	3	Dedicated office area	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard
33	11/2/2022 16:25:01	Yes	Female	23	The Netherlands	1,7	Regular	Social Media Manager	Frequent headaches	2	Kitchen table	Moderately crowded	Yes	Yes	Depends where I'm work	Mouse, Keyboard
34	11/3/2022 10:29:42	Yes	Male	38	The Netherlands	190	Skinny	Entrepeneur	no	1	Dedicated office area	Moderately crowded	Yes	No	Laptop screen (on desk level)	
35	11/2/2022 16:23:06	Yes	Male	34	The Netherlands	192	Skinny	architect	yes, upper back	3-5 days	Dedicated office area	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
36	11/2/2022 16:41:05	Yes	Male	25	The Netherlands	1,68	Regular	Web developer	Stijve nek	all the time	Dedicated office area	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard, Track
37	11/4/2022 14:48:22	Yes	Male	49	Denmark	1,79m	Regular	Product development	No	3 days	Dining table	Long table, i am at clutter	Yes	Yes	Laptop screen (on desk l	Mouse, Keyboard
38	11/4/2022 18:02:27	Yes	Male	26	The Netherlands	1,87	Regular	Tax advisor	No	2	Dedicated office area	Empty / clean	Yes	Yes	Monitor	Mouse, Keyboard
39	11/5/2022 15:37:11	Yes	Male	26	The Netherlands	1,83m	Regular	Planner	Ja, regelmatig rug en arr	2	Bedroom	Moderately crowded	Yes	Yes	Monitor	Mouse, Keyboard
40	11/9/2022 18:49:11	Yes	Female	57	The Netherlands	1,77	Regular	Administrative	No	7	For the time being, a “ bu	Empty / clean	Yes	Yes	Monitor	Mouse, Keyboard
41	11/18/2022 8:06:15	Yes	Male	27	The Netherlands	1,9	Regular	Business Development	Sometimes. My back or	3	Dedicated office area	Moderately crowded	Yes	Yes	Monitor	Mouse, Keyboard

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Tijdstempel	Do you work in home offi	Gender?	Age?	Country of residence?	Body length? *(e.g. 1,97m*	Body size type?	Type of job or study?	Do you already have phy	How often do you work a	What does your work en	Space on the desk *(stuff,*	Can you fit your legs und	Is your desk thicker than	What is your main comp	Keyboard and mouse?
2	11/2/2022 18:56:24	Yes	Female	23	Italy	1,65	Skinny	Marketing	No	2	Choose different places t	Moderately crowded	Yes	No	Laptop screen (on eye le	Keyboard
3	11/3/2022 8:37:51	Yes	Female	22	The Netherlands	1,67m	Regular	Hbo	Back pain	3 times per week	Kitchen table	Moderately crowded	Yes	No	Laptop screen (on desk l	Mouse
4	11/2/2022 16:01:10	Yes	Male	24	The Netherlands	1,86	Regular	Marketing	Yes, pain on my upper ba	2/3	Kitchen table	Empty / clean	Yes	No	Laptop screen (on eye le	Mouse, Keyboard
5	11/2/2022 15:59:20	Yes	Female	25	The Netherlands	1m70	Regular	Office job, 100% comput	Nope	2 days	Kitchen table	Moderately crowded	No	Yes	Laptop screen (on desk l	Mouse, Keyboard
6	11/2/2022 23:07:48	Yes	Female	30	Portugal	1,72	Regular	Engineering	Lower back often hurting	1	Dedicated office area	Moderately crowded	Yes	Yes	Laptop screen (on desk l	None of the above when
7	11/2/2022 16:07:29	Yes	Female	27	The Netherlands	1,8	Regular	Leger Counsel	No	3	Dedicated office area	Moderately crowded	Yes	Yes	Laptop screen (on eye le	Mouse, Keyboard
8	11/3/2022 17:45:22	No	Male	28	The Netherlands	191	Large	Procesoperator	Yes my knee	0	Factory	Full of stuff	Yes	Yes	Laptop screen (on desk l	Mouse, Keyboard
9	11/2/2022 18:14:53	Yes	Male	33	Portugal	1,83m	Regular	Designer	Spinal irritations	5	Dedicated office area	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard
10	11/3/2022 9:44:54	Yes	Male	20	The Netherlands	2,00m	Regular	Study, leisure and events	Lower back problems	4	Dedicated office area	Moderately crowded	Yes	No	laptop and monitor scree	Trackpad
11	11/3/2022 15:37:18	Yes	Female	31	The Netherlands	1,65m	Regular	Administratief medewerk	Nek en schouderklachter	1	Kitchen table	Moderately crowded	Yes	Yes	Laptop screen (on desk l	Mouse, Keyboard
12	11/2/2022 16:24:56	Yes	Male	44	The Netherlands	189	Regular	Industrial Design Engine	Nee, na een dag werken	4-5 dagen	Dedicated office area	Full of stuff	Yes	No	Monitor	Mouse, Keyboard
13	11/2/2022 17:31:05	Yes	Male	61	The Netherlands	1,8	Regular	Wholesaler	No	60 hrs	Office at home	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
14	11/2/2022 20:28:10	Yes	Female	30	Portugal	1,67m	Skinny	Digital Design	Not yet fortunately	4 days	Living room table	Moderately crowded	Yes	No	Laptop screen (on desk l	Keyboard, Trackpad
15	11/2/2022 21:53:26	Yes	Female	58	The Netherlands	1,69	Regular	IT	No	4 times per week	Dedicated office area	Empty / clean	Yes	Yes	Monitor	Mouse, Keyboard
16	11/3/2022 9:53:19	Yes	Female	59	The Netherlands	1.74	Regular	Office	No	5 days	Choose different places t	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
17	11/3/2022 10:19:44	Yes	Male	32	The Netherlands	181cm	Skinny	Engineering	Not really	2 days	Bedroom	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard
18	11/3/2022 12:20:21	Yes	Female	36	The Netherlands	1,73 m	Regular	Consultant in life science	No	3	Dedicated office area	Full of stuff	Yes	No	Monitor	Mouse, Keyboard
19	11/3/2022 15:44:04	Yes	Female	25	The Netherlands	1,74	Skinny	Office job	No	3	Dedicated office area	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
20	11/3/2022 17:38:17	Yes	Male	29	The Netherlands	1,81	Regular	Finance	No	4	Dedicated office area	Moderately crowded	Yes	Yes	Monitor	Mouse, Keyboard
21	11/2/2022 23:14:50	Yes	Male	28	The Netherlands	1,82	Regular	Handelaar	Gebroken sleutelbeen	5	Kitchen table	Moderately crowded	Yes	Yes	Laptop screen (on desk l	Mouse, Keyboard
22	11/2/2022 16:16:45	Yes	Female	30	The Netherlands	168	Skinny	Office job, creative medi	Back and shoulder pain	2 or 3 times	Dedicated office area	Moderately crowded	Yes	No	monitor + laptopscreen a	Mouse, Keyboard
23	11/2/2022 18:18:22	Yes	Female	19	The Netherlands	1.63	Skinny	Graphic design	No I don't have	2 times a week	Choose different places t	Empty / clean	No	Yes	Laptop screen (on desk l	Keyboard
24	11/3/2022 7:56:23	Yes	Female	52	The Netherlands	1,84	Regular	Management	Back issues	3	Kitchen table	Moderately crowded	Yes	No	Laptop screen (on desk l	Mouse, Keyboard
25	11/3/2022 8:33:07	Yes	Female	23	The Netherlands	1,68	Skinny	Graduation internship on	No	2 tot 3 times	Choose different places t	Moderately crowded	Yes	Yes	Laptop screen (on desk l	Mouse
26	11/2/2022 22:16:44	Yes	Female	57	The Netherlands	1,6	Regular	job	schoulders	4	Kitchen table	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard
27	11/3/2022 21:08:49	Yes	Male	26	The Netherlands	1.87m	Regular	Healthcare consultancy	Neckpain	3 days	Studio apartment	Full of stuff	Yes	No	Monitor	Mouse, Keyboard
28	11/2/2022 17:53:54	Yes	Female	32	The Netherlands	180	Skinny	Video Production	Yes, scoliosis	3	Dedicated office area	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
29	11/2/2022 22:41:27	Yes	Male	32	Portugal	1,76m	Regular	Digital design		4 days	Caravan table	Moderately crowded	Yes	Yes	Laptop screen (on eye le	Mouse
30	11/3/2022 11:23:08	Yes	Female	29	The Netherlands	162	Regular	Office administrator	no	2 times per week	Living room	Moderately crowded	No	Yes	Laptop screen (on desk l	Mouse
31	11/3/2022 17:38:32	Yes	Male	25	The Netherlands	1,80m	Regular	Kantoorbaan/uni	Nee	1	Dedicated office area	Empty / clean	Yes	Yes	Laptop screen (on eye le	Mouse, Keyboard
32	11/3/2022 17:49:11	Yes	Male	27	The Netherlands	1,79	Regular	Tech Specialist/solution	Yes back and shoulders	3	Dedicated office area	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard
33	11/2/2022 16:25:01	Yes	Female	23	The Netherlands	1,7	Regular	Social Media Manager	Frequent headaches	2	Kitchen table	Moderately crowded	Yes	Yes	Depends where I'm work	Mouse, Keyboard
34	11/3/2022 10:29:42	Yes	Male	38	The Netherlands	190	Skinny	Entrepeneur	no	1	Dedicated office area	Moderately crowded	Yes	No	Laptop screen (on desk level)	
35	11/2/2022 16:23:06	Yes	Male	34	The Netherlands	192	Skinny	architect	yes, upper back	3-5 days	Dedicated office area	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
36	11/2/2022 16:41:05	Yes	Male	25	The Netherlands	1,68	Regular	Web developer	Stijve nek	all the time	Dedicated office area	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard, Track
37	11/4/2022 14:48:22	Yes	Male	49	Denmark	1,79m	Regular	Product development	No	3 days	Dining table	Long table, i am at clutter	Yes	Yes	Laptop screen (on desk l	Mouse, Keyboard
38	11/4/2022 18:02:27	Yes	Male	26	The Netherlands	1,87	Regular	Tax advisor	No	2	Dedicated office area	Empty / clean	Yes	Yes	Monitor	Mouse, Keyboard
39	11/5/2022 15:37:11	Yes	Male	26	The Netherlands	1,83m	Regular	Planner	Ja, regelmatig rug en arr	2	Bedroom	Moderately crowded	Yes	Yes	Monitor	Mouse, Keyboard
40	11/9/2022 18:49:11	Yes	Female	57	The Netherlands	1,77	Regular	Administrative	No	7	For the time being, a " bu	Empty / clean	Yes	Yes	Monitor	Mouse, Keyboard
41	11/18/2022 8:06:15	Yes	Male	27	The Netherlands	1,9	Regular	Business Development	Sometimes. My back or	3	Dedicated office area	Moderately crowded	Yes	Yes	Monitor	Mouse, Keyboard

1	Tijdstempel	Do you work in home offi	Gender?	Age?	Country of residence?	Body length? *(e.g. 1,97m*	Body size type?	Type of job or study?	Do you already have phy	How often do you work a	What does your work en	Space on the desk *(stuff,*	Can you fit your legs und	Is your desk thicker than	What is your main comp	Keyboard and mouse?
2	11/2/2022 18:56:24	Yes	Female	23	Italy	1,65	Skinny	Marketing	No	2	Choose different places t	Moderately crowded	Yes	No	Laptop screen (on eye le	Keyboard
3	11/3/2022 8:37:51	Yes	Female	22	The Netherlands	1,67m	Regular	Hbo	Back pain	3 times per week	Kitchen table	Moderately crowded	Yes	No	Laptop screen (on desk l	Mouse
4	11/2/2022 16:01:10	Yes	Male	24	The Netherlands	1,86	Regular	Marketing	Yes, pain on my upper ba	2/3	Kitchen table	Empty / clean	Yes	No	Laptop screen (on eye le	Mouse, Keyboard
5	11/2/2022 15:59:20	Yes	Female	25	The Netherlands	1m70	Regular	Office job, 100% comput	Nope	2 days	Kitchen table	Moderately crowded	No	Yes	Laptop screen (on desk l	Mouse, Keyboard
6	11/2/2022 23:07:48	Yes	Female	30	Portugal	1,72	Regular	Engineering	Lower back often hurting	1	Dedicated office area	Moderately crowded	Yes	Yes	Laptop screen (on desk l	None of the above when
7	11/2/2022 16:07:29	Yes	Female	27	The Netherlands	1,8	Regular	Leger Counsel	No	3	Dedicated office area	Moderately crowded	Yes	Yes	Laptop screen (on eye le	Mouse, Keyboard
8	11/3/2022 17:45:22	No	Male	28	The Netherlands	191	Large	Procesoperator	Yes my knee	0	Factory	Full of stuff	Yes	Yes	Laptop screen (on desk l	Mouse, Keyboard
9	11/2/2022 18:14:53	Yes	Male	33	Portugal	1,83m	Regular	Designer	Spinal irritations	5	Dedicated office area	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard
10	11/3/2022 9:44:54	Yes	Male	20	The Netherlands	2,00m	Regular	Study, leisure and events	Lower back problems	4	Dedicated office area	Moderately crowded	Yes	No	laptop and monitor scree	Trackpad
11	11/3/2022 15:37:18	Yes	Female	31	The Netherlands	1,65m	Regular	Administratief medewerk	Nek en schouderklachter	1	Kitchen table	Moderately crowded	Yes	Yes	Laptop screen (on desk l	Mouse, Keyboard
12	11/2/2022 16:24:56	Yes	Male	44	The Netherlands	189	Regular	Industrial Design Engine	Nee, na een dag werken	4-5 dagen	Dedicated office area	Full of stuff	Yes	No	Monitor	Mouse, Keyboard
13	11/2/2022 17:31:05	Yes	Male	61	The Netherlands	1,8	Regular	Wholesaler	No	60 hrs	Office at home	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
14	11/2/2022 20:28:10	Yes	Female	30	Portugal	1,67m	Skinny	Digital Design	Not yet fortunately	4 days	Living room table	Moderately crowded	Yes	No	Laptop screen (on desk l	Keyboard, Trackpad
15	11/2/2022 21:53:26	Yes	Female	58	The Netherlands	1,69	Regular	IT	No	4 times per week	Dedicated office area	Empty / clean	Yes	Yes	Monitor	Mouse, Keyboard
16	11/3/2022 9:53:19	Yes	Female	59	The Netherlands	1.74	Regular	Office	No	5 days	Choose different places t	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
17	11/3/2022 10:19:44	Yes	Male	32	The Netherlands	181cm	Skinny	Engineering	Not really	2 days	Bedroom	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard
18	11/3/2022 12:20:21	Yes	Female	36	The Netherlands	1,73 m	Regular	Consultant in life science	No	3	Dedicated office area	Full of stuff	Yes	No	Monitor	Mouse, Keyboard
19	11/3/2022 15:44:04	Yes	Female	25	The Netherlands	1,74	Skinny	Office job	No	3	Dedicated office area	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
20	11/3/2022 17:38:17	Yes	Male	29	The Netherlands	1,81	Regular	Finance	No	4	Dedicated office area	Moderately crowded	Yes	Yes	Monitor	Mouse, Keyboard
21	11/2/2022 23:14:50	Yes	Male	28	The Netherlands	1,82	Regular	Handelaar	Gebroken sleutelbeen	5	Kitchen table	Moderately crowded	Yes	Yes	Laptop screen (on desk l	Mouse, Keyboard
22	11/2/2022 16:16:45	Yes	Female	30	The Netherlands	168	Skinny	Office job, creative medi	Back and shoulder pain	2 or 3 times	Dedicated office area	Moderately crowded	Yes	No	monitor + laptopscreen a	Mouse, Keyboard
23	11/2/2022 18:18:22	Yes	Female	19	The Netherlands	1.63	Skinny	Graphic design	No I don't have	2 times a week	Choose different places t	Empty / clean	No	Yes	Laptop screen (on desk l	Keyboard
24	11/3/2022 7:56:23	Yes	Female	52	The Netherlands	1,84	Regular	Management	Back issues	3	Kitchen table	Moderately crowded	Yes	No	Laptop screen (on desk l	Mouse, Keyboard
25	11/3/2022 8:33:07	Yes	Female	23	The Netherlands	1,68	Skinny	Graduation internship on	No	2 tot 3 times	Choose different places t	Moderately crowded	Yes	Yes	Laptop screen (on desk l	Mouse
26	11/2/2022 22:16:44	Yes	Female	57	The Netherlands	1,6	Regular	job	schoulders	4	Kitchen table	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard
27	11/3/2022 21:08:49	Yes	Male	26	The Netherlands	1.87m	Regular	Healthcare consultancy	Neckpain	3 days	Studio apartment	Full of stuff	Yes	No	Monitor	Mouse, Keyboard
28	11/2/2022 17:53:54	Yes	Female	32	The Netherlands	180	Skinny	Video Production	Yes, scoliosis	3	Dedicated office area	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
29	11/2/2022 22:41:27	Yes	Male	32	Portugal	1,76m	Regular	Digital design		4 days	Caravan table	Moderately crowded	Yes	Yes	Laptop screen (on eye le	Mouse
30	11/3/2022 11:23:08	Yes	Female	29	The Netherlands	162	Regular	Office administrator	no	2 times per week	Living room	Moderately crowded	No	Yes	Laptop screen (on desk l	Mouse
31	11/3/2022 17:38:32	Yes	Male	25	The Netherlands	1,80m	Regular	Kantoorbaan/uni	Nee	1	Dedicated office area	Empty / clean	Yes	Yes	Laptop screen (on eye le	Mouse, Keyboard
32	11/3/2022 17:49:11	Yes	Male	27	The Netherlands	1,79	Regular	Tech Specialist/solution	Yes back and shoulders	3	Dedicated office area	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard
33	11/2/2022 16:25:01	Yes	Female	23	The Netherlands	1,7	Regular	Social Media Manager	Frequent headaches	2	Kitchen table	Moderately crowded	Yes	Yes	Depends where I'm work	Mouse, Keyboard
34	11/3/2022 10:29:42	Yes	Male	38	The Netherlands	190	Skinny	Entrepeneur	no	1	Dedicated office area	Moderately crowded	Yes	No	Laptop screen (on desk level)	
35	11/2/2022 16:23:06	Yes	Male	34	The Netherlands	192	Skinny	architect	yes, upper back	3-5 days	Dedicated office area	Empty / clean	Yes	No	Monitor	Mouse, Keyboard
36	11/2/2022 16:41:05	Yes	Male	25	The Netherlands	1,68	Regular	Web developer	Stijve nek	all the time	Dedicated office area	Moderately crowded	Yes	No	Monitor	Mouse, Keyboard, Track
37	11/4/2022 14:48:22	Yes	Male	49	Denmark	1,79m	Regular	Product development	No	3 days	Dining table	Long table, i am at clutter	Yes	Yes	Laptop screen (on desk l	Mouse, Keyboard
38	11/4/2022 18:02:27	Yes	Male	26	The Netherlands	1,87	Regular	Tax advisor	No	2	Dedicated office area	Empty / clean	Yes	Yes	Monitor	Mouse, Keyboard
39	11/5/2022 15:37:11	Yes	Male	26	The Netherlands	1,83m	Regular	Planner	Ja, regelmatig rug en arr	2	Bedroom	Moderately crowded	Yes	Yes	Monitor	Mouse, Keyboard
40	11/9/2022 18:49:11	Yes	Female	57	The Netherlands	1,77	Regular	Administrative	No	7	For the time being, a " bu	Empty / clean	Yes	Yes	Monitor	Mouse, Keyboard
41	11/18/2022 8:06:15	Yes	Male	27	The Netherlands	1,9	Regular	Business Development	Sometimes. My back or	3	Dedicated office area	Moderately crowded	Yes	Yes	Monitor	Mouse, Keyboard

moopi - Chapter 10: Appendix

Appendix I: **Explorative user test questionnaire results**

	A	B	C	D	E	F	G	H	I	J	K	L
1	Tijdstempel	Name	Gender	Age	Height	Weight	Any physical complaints	Is your desk at the corre	Is the top of your main r	Name again *(This is for*	Which number of chair v	Upload a side-view pictu
2	11/22/2022 14:51:20	max	Male	26	197	105	No	Desk is too low	Yes		Test	https://drive.google.com
3	11/23/2022 9:45:46	Max	Male	26	1.98m	105		Legs fit under the desk,	Yes, I have a laptop on		1 (miro, 0 seatpan and '	https://drive.google.com
4	11/24/2022 15:09:05	Niels	Male	26	1.90	75	Missing outside meniscu	Yes	No, I have a laptop from		1	https://drive.google.com
5	11/30/2022 9:56:18	Leon Zondervan	Male	34	192	90	a pain in right upper bac	yes	yes		2 (the last version you m	https://drive.google.com
6	12/12/2022 14:12:22	Sander	Male	37	189	67	Lower back problems	Yes	Yes		1	https://drive.google.com
7	12/14/2022 14:48:39	Rossouw Oosthuizen	Male	32	176cm	71kg		Roughly yes	No, I use a laptop to wh		1	https://drive.google.com
8	12/20/2022 18:51:06	Paola	Female	38	1.61	52	Low back pain/injury	Yes	yes		1	https://drive.google.com
9												

	L	M	N	O	P	Q	R	S	T	U	V	W
1	Upload a side-view pictu	Does the shape of the b	Is the backrest comforta	Does the chair support y	Do you sit with your bac	Do you feel that your pe	Do you feel that your tru	Do you feel you have er	Are you able to sit balan	Does the chair support a	Is the cushioning on the	Is the cushioning on the
2	https://drive.google.com	yes	NO	horrible	Yes	Yes	NO	yes	yes	yes	yes	yes
3	https://drive.google.com	The shape fills up the lu	No, only when reclining	Yes, it forces me into thi	Yes	No, pelvis feels very loo	Yes trunk feels supporte	Yes	Yes	No, working upright and	First impression is that it	Yes, I don't feel the woo
4	https://drive.google.com	Yes it does, especially n	Yes	Yes, my pelvis is upright	Tend to lean forward wi	Yes	A little. As I mentioned b	Enough freedom.	Yes	Yes	Yes	Yes, and supporting nic
5	https://drive.google.com	yes, but i had prefered a	yes, its very supporting.	yes	yes	yes, i can fit my but in th	yes, but a bit more curva	yes freedom, it's very co	yes	everything except loung	yes	yes
6	https://drive.google.com	Yes. It really helps me to	Yes. It follows the shape	Yes	Yes	Yes	This chair supports my t	Yes.	Yes. I can easily change	Yes. The chair design s	Yes it is comfortable eno	Yes
7	https://drive.google.com	Yes, it gave support of t	Yes it was, even with a	As mentioned, because	Lower back yes, upper b	I can't recall feeling any	again, I don't remember	It feels relatively free, I f	Yes, the only complicati	Yes	Yes, not too soft but no	Yes, I was surprised i di
8	https://drive.google.com	Yes my back feels supp	Yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
9												

	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	A
1	What is your overall impr	Do you experience any	How is this setup compared to the previous? *(Only when you are evaluating an updated backrest configuration)*											
2	good	sleepiness												
3	Back feels tired, as I nee	Back problems and neck problems because I was working on a laptop												
4	Yes, I can sit in it for a v	No	-											
5	good, i want to sit in it a	no	more straight											
6	Really good. Although i	No												
7	Yes it improved my seat	No												
8	it was good	no	i didnt have a previous one											
9														

Appendix J: **Kyphometer Arduino code**

```
////////////////////////////////////////////////////////////////////////////////////////////////////////////
//    This version of the Kyphometer code based on the original version which did not work when reinstalled.        //
//    This why there is a lot of room for improvement, such as the button animation doesn't work but the code is there.     //
//    The horizontal axis is the X and vertical Y. (In the original code, the vertical was named Z but this was confusing).    //
//    I am not a professional code writer, but you can always contact me :) Have fun! Maximiliaan Morres           //
////////////////////////////////////////////////////////////////////////////////////////////////////////////
#include <Wire.h>              //communicate with I2C
#include <SPI.h>               //communicate with SPI devices, arduino as controller device
#include <SD.h>                //SD card libarary
#include <avr/pgmspace.h>          //storing data in flash
#include "DS1307.h"             //real time clock
#include "Pushbutton.h"           //button
#include <hd44780.h>             //main hd44780 header (LCD)
#include <hd44780ioClass/hd44780_I2Cexp.h>  //I2C expander i/o class header

const uint8_t PIN_CHIPSELECT = 11;  // LCD PIN
const uint8_t PIN_ENCODERX_A = 2;   // PIN 4 in original code, but now switched to make X horizontal and Y vertical
const uint8_t PIN_ENCODERX_B = 3;   // PIN 5 in original code
const uint8_t PIN_ENCODERY_A = 4;   // PIN 2 in original code
const uint8_t PIN_ENCODERY_B = 5;   // PIN 3 in original code
const uint8_t PIN_BUTTONLED = 12;
const uint8_t PIN_PUSHBUTTON = 6;

float XSCALE = 0.050432;        // Scaling factor for the X-axis (mm/pulse)
float YSCALE = 0.207492;        // Scaling factor for the Y-axis (mm/pulse)
const uint8_t MAX_SPINEELEMENTS = 400;  // Maximum measure elements in list (CHANGE THIS IF YOU WANT MORE OR LESS MEASURING POINTS)
float ENCY_DELTA = 10 / YSCALE;     // Measuring distance interval distance scaled(mm) (CHANGE THE VALUE TO THE DESIRED MEASURING INTERVALS)

//   Very poor solution to getting the text right on the screen
//   This is an OLD LCD and writes code in this line order: 1-3-2-4 and I was not able to correct this in code in the timeframe
const char msgMoveToInit[] PROGMEM = { "Beweeg naar nul    op de knop       positie, druk daarna " };   // Beweeg naar nul positie, druk daarna op de knop
const char msgMoveToC1[] PROGMEM = { "Beweeg naar C1    op de knop      wervel, druk daarna " };     // Beweeg naar C1 wervel, druk daarna op de knop
const char msgDoMeasure[] PROGMEM = { "Rol over de gehele  de knop        rug, druk daarna op" };     // Rol ovder de gehele rug, druk daarna op de knop
const char msgFinished[] PROGMEM = { "Meeting voltooid" };                   // Meeting voltooid

// Initalizers
float encX_count = 0;
float encY_count = 0;
float prev_encX_count = 0;
float prev_encY_count = 0;
uint16_t seconds = 0;

float spineArrayX[400];  // Array list for X values
float spineArrayY[400];  // Array list for Y values
uint8_t spineElements = 0;

unsigned long currentMillis = 0;
unsigned long secondMillis = 0;
```

```
DS1307 rtc;            // Date/time files
PushButton button(PIN_PUSHBUTTON);  // Pushbutton
File dataFile;           // Datafile so save measurements
String filename;          // Datafile name
hd44780_I2Cexp LCD;         // LCD

const int LCD_COLS = 20;  // LCD Columns
const int LCD_ROWS = 4;   // LCD Rows

/////////////////////////////////////////////////////////////////////////////
// Setup                                    //
/////////////////////////////////////////////////////////////////////////////
void setup() {
  pinMode(10, OUTPUT);
  pinMode(PIN_CHIPSELECT, OUTPUT);
  pinMode(PIN_BUTTONLED, OUTPUT);
  pinMode(PIN_ENCODERX_A, INPUT_PULLUP);
  pinMode(PIN_ENCODERX_B, INPUT_PULLUP);
  pinMode(PIN_ENCODERY_A, INPUT_PULLUP);
  pinMode(PIN_ENCODERY_B, INPUT_PULLUP);
  pinMode(PIN_PUSHBUTTON, INPUT_PULLUP);

  attachInterrupt(digitalPinToInterrupt(PIN_ENCODERX_A), EncX_
OnRisingEdge, RISING);  // Registering lowering of rising
  attachInterrupt(digitalPinToInterrupt(PIN_ENCODERY_A), EncY_
OnRisingEdge, RISING);

  Serial.begin(115200);
  rtc.begin();

  int LCDstatus;  // Starting LCD, error is faulty
  LCDstatus = LCD.begin(LCD_COLS, LCD_ROWS);
  if (LCDstatus) {
    hd44780::fatalError(LCDstatus);
  }

  button.hook_doWhenPressed(button_doWhenPressed);  // Button animation,
doesn't work at time of writing

  if (!SD.begin(PIN_CHIPSELECT)) {  // Checking if SD card is inserted
    Serial.println(F("SD Card failed, or not present"));
    LCD.print("SD Card failed,    or not present");
    while (1)
      ;
  } else {
    Serial.println(F("SD Card ready"));
    LCD.print("SD Card ready");
  }
}
```

```
/////////////////////////////////////////////////////////////////////////////
// Button states                                //
/////////////////////////////////////////////////////////////////////////////
uint8_t smBtnLedSignal = 0;
uint16_t smBtnPressedSeconds = 0;
uint8_t smCurrentState = 1;
uint8_t smPrevState = 0;
uint16_t smTimeOut = 0;

void loop() {
  button.poll();    // I don't know
  doLedAnimation();  // Call for LED animation

  currentMillis = millis();
  if (currentMillis - secondMillis >= 1000) {  // Every second
    seconds++;
    secondMillis = currentMillis;
  }

  if (smCurrentState != smPrevState) {
    smPrevState = smCurrentState;

    switch (smCurrentState) {
     case 1:          // Move to initial position
      PromptUser(msgMoveToInit);  // Write message on screen and serial

      break;
     case 2:  // Move to C1 vertibre
      // Reset both encoders
      noInterrupts();
      encX_count = 0;
      prev_encX_count = 0;
      encY_count = 0;
      prev_encY_count = 0;
      interrupts();

      PromptUser(msgMoveToC1);
      break;
     case 3:                   // Roll over patient's back
      spineArrayX[spineElements] = encX_count * XSCALE;   // Starting x value in
array list
      spineArrayY[spineElements++] = encY_count * YSCALE;  // Starting  value in
array list

      PromptUser(msgDoMeasure);

      // Compile filename for SD card logging (YYYY-MM-DD_HH)
```

```
    rtc.getTime();
    filename = String(“”);
    filename += ZeroPad(rtc.month);
    filename += ZeroPad(rtc.dayOfMonth);
    filename += ZeroPad(rtc.hour);
    filename += ZeroPad(rtc.minute);
    filename += F(“.csv”);

    // Open the file. note that only one file can be open at a time,
    // So you have to close this one before opening another.
    dataFile = SD.open(filename.c_str(), FILE_WRITE);
    Serial.println(filename);

    // Serial write measurements at time 0
    Serial.print(F(“Xmm0: “));          // X distance in mm at t=0
    Serial.print(encX_count * XSCALE, DEC);  // scale X count to mm
    Serial.print(F(“ - “));
    // Serial.print(F(“Y: “));
    // Serial.print(encY_count, DEC);
    Serial.print(F(“ - “));
    Serial.print(F(“Ymm0: “));
    Serial.println((encY_count * YSCALE), DEC);

    break;
  case 4:  // Measurement finished
    PromptUser(msgFinished);
    seconds = 0;

    if (dataFile) {
      for (int i = 0; i < spineElements; i++) {
        // dataFile.print(i);   // Writing measurement nr. (0,1,2,3,etc.) in first column
(skipped this one as I wanted accurate measurements)
        // dataFile.print(',');
        dataFile.print(spineArrayX[i]);  // Write X measurement in mm
        dataFile.print(',');
        dataFile.print(spineArrayY[i]);  // Write Y measurement in mm
        dataFile.println();
      }
    } else {
    }

    spineElements = 0;

    dataFile.close();  // Close data file

    break;
  default:  // Error
    break;
 };
}
```

```
 // Makes sure that the code only registers when moving Y down and not up
 if (smCurrentState == 3) {  // When measuring (moving along) the spine

  if (prev_encY_count == 0) {     // This makes sure that the previous Y value at
t=0 is the initial value of Y
    prev_encY_count = encY_count;  // Otherwise the previous Y value will
always be less than the current Y value (error next line)
  }

  if (prev_encY_count > encY_count) {                // Prev Y value needs to be
higher than current Y value
    if (prev_encY_count - encY_count >= ENCY_DELTA) {       // Difference needs
to be Y delta (measuring steps)
      prev_encY_count = encY_count;                  // Update prev Y value to
current Y value
      if (spineElements < MAX_SPINEELEMENTS - 1) {         // Count number of
measured elements
        spineArrayX[spineElements] = encX_count * XSCALE;    // Adding next X
value to array list
        spineArrayY[spineElements++] = encY_count * YSCALE;  // Adding next Y
value to array list
      }

      // Serial printing values to check if measurements are registered correctly
      // Serial.print(F(“X: “));
      // Serial.print(encX_count, DEC);
      // Serial.print(F(“ - “));
      Serial.print(F(“Xmm: “));
      Serial.print(encX_count * XSCALE, DEC);
      Serial.print(F(“ - “));
      // Serial.print(F(“Y: “));
      // Serial.print(encY_count, DEC);
      Serial.print(F(“ - “));
      Serial.print(F(“Ymm: “));
      Serial.println((encY_count * YSCALE), DEC);
    }
  }
 }

 if (smCurrentState == 4 && seconds >= 4) {  // Reset
  smCurrentState = 1;
 }

 // Serial printing values to check if measurements are done correctly
 // Serial.print(F(“X: “));
 // Serial.print(encX_count, DEC);   // Encoder values
 // Serial.print(F(“ - “));
 // Serial.print(F(“Xmm: “));
 // Serial.print(encX_count * XSCALE, DEC);  // Scaled values to mm
 // Serial.print(F(“ - “));
 // Serial.print(F(“Y: “));
```



```
 // Serial.print(encY_count, DEC);
 // Serial.print(F(“ - “));
 // Serial.print(F(“Ymm: “));
 // Serial.print((encY_count * YSCALE), DEC);
 // Serial.print(F(“ - “));
 // Serial.print(F(“DELTA: “));
 // Serial.println((prev_encY_count - encY_count), DEC);
}

//////////////////////////////////////////////////////////////////////////////
// Encoder X                                                              //
//////////////////////////////////////////////////////////////////////////////
void EncX_OnRisingEdge() {
 float ENCODERX_b_state = digitalRead(PIN_ENCODERX_B);

 if (ENCODERX_b_state == HIGH) {
  encX_count--;
 } else if (ENCODERX_b_state == LOW) {
  encX_count++;
 }
}

//////////////////////////////////////////////////////////////////////////////
// Encouder Y                                                             //
//////////////////////////////////////////////////////////////////////////////
void EncY_OnRisingEdge() {
 float ENCODERY_b_state = digitalRead(PIN_ENCODERY_B);

 if (ENCODERY_b_state == HIGH) {
  encY_count--;
 } else if (ENCODERY_b_state == LOW) {
  encY_count++;
 }
}

//////////////////////////////////////////////////////////////////////////////
//                                                                        //
// Returns a zero padded string based on a two-digit input value          //
//                                                                        //
// Input:  a single- or double digit number                               //
// Output: if the input was a single digit number, the output will have a //
//       leading zero. Otherwise the double digit number will be returned //
//                                                                        //
//////////////////////////////////////////////////////////////////////////////
String ZeroPad(int value) {
 String returnVal = (value > 9 ? “” : String(F(“0”))) + String(value);
 return returnVal;
}

//////////////////////////////////////////////////////////////////////////////
// Displaying text in flash memory on LCD                                 //
```

```
//////////////////////////////////////////////////////////////////////////////
void PromptUser(const char *text) {
 LCD.clear();        // Clear screen
 LCD.setCursor(0, 0);  // Position cursor at 0,0 position

 for (int i = 0; i < strlen_P(text); ++i) {  // Write text
   Serial.print((char)pgm_read_byte_near(text + i));

   LCD.print((char)pgm_read_byte_near(text + i));
 }
 Serial.println();
}

//////////////////////////////////////////////////////////////////////////////
// LED animation                                                          //
//////////////////////////////////////////////////////////////////////////////
void doLedAnimation() {
 static unsigned long _flashMillis = 0;
 static unsigned long _currentMillis = 0;
 static uint8_t off = false;

 if (smBtnLedSignal == 1) {

   _currentMillis = millis();
   if (_currentMillis - _flashMillis >= 50) {
    _flashMillis = _currentMillis;
    digitalWrite(PIN_BUTTONLED, off);
    off = ~off;
   }

   if (seconds >= 1) {
    smBtnLedSignal = 0;
    off = false;
   }
 } else {
   digitalWrite(PIN_BUTTONLED, HIGH);
 }
}

//////////////////////////////////////////////////////////////////////////////
// Button press                                                           //
//////////////////////////////////////////////////////////////////////////////
void button_doWhenPressed() {
 smCurrentState++;
 smBtnLedSignal = 1;
}
```

moopi - Chapter 10: Appendix

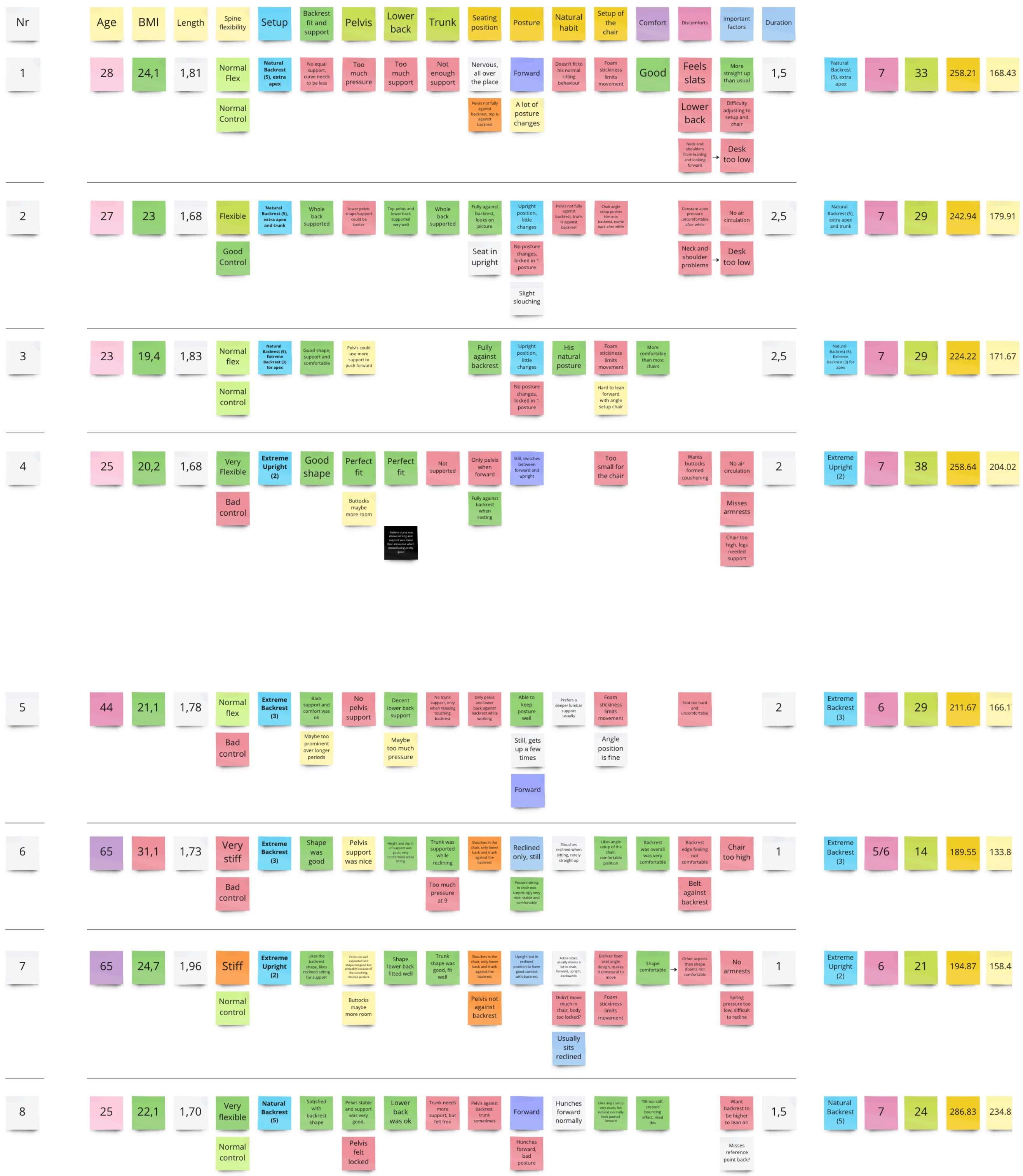
Appendix K: **Backrest setup user test results**

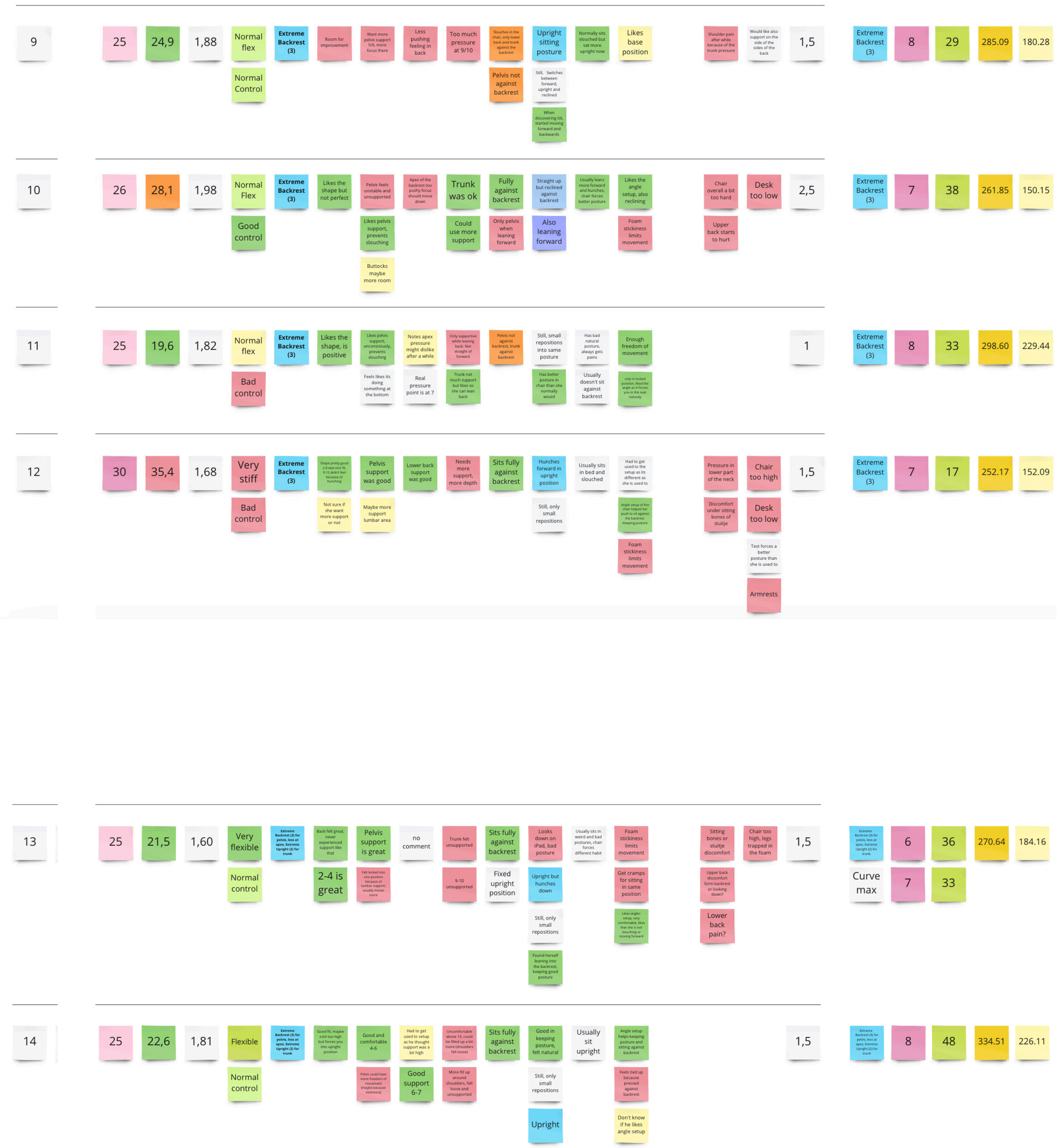
	C	D	E	F	G	H	I	J	K	L	M	N
1	Gender	Age	Height (in x.xx m)	Weight (in kg)	Any physical complaints	What type of chair do yc	How well does the shap	Please elaborate on ho	How comfortable is the l	How supportive is the ba	Please elaborate on you	How well does the chai
2	Male	28	1.81	79	broke my back 3 years a	simple office chair, often	3	I have the feeling that m	3	5	I have the feeling that th	6
3	Male	27	168	65	NA	Simple Ikea office chair	6	Points1-Points3---> may	5	6	My whole back felt supp	6
4	Male	23	1.83	65	no	simple office chair with a	7	the only (slightly) discom	6	7	after sitting on it for 2 ho	7
5	Female	25	1.68m	57kg	No	Ergonomic office chair a	6	the support on my waist	5	6	the support is nice, I car	7
6	Female	44	178	67	No	Ergonomic office chair a	5	The back support was c	5	5	comfort and support wer	6
7	Male	65	1.96	95	No	Ergonomic office chair a	5	At number 9 it pokes int	6	6	I feel the upper part of t	6
8	Male	65	1.73	93	No	Ergonomic chair mesh a	6	Sitting straight up was le	6	6	Zit op schouderbladen r	2
9	Female	25	1.70	64	No	Ergonomic mesh adjusta	7	Want the backrest to be	7	7	All good satisfied with it	5
10	Male	22	1.88	88	No	Plastic chair bucket only	5	After a while I felt the up	5	6	Druk boven aan, schouc	6
11	Female	25	1.82	65	Scoliosis, often back pa	Ergonomic office chair m	5	Notice it. Around 5/6 the	5	6	Feel stable sitting, only a	6
12	Female	30	1.68	220 lb	Bad back in general, low	Normally works in bed ar	5	Lower back was good, f	5	5	Main complain is top par	4
13	Female	25	1.60	55	Lower back sensitive, pr	Regular simple chairs, lik	6	Needed some time to ge	7	6	it is was supportive, only	7
14	Male	25	1.81	74	Nee	Ergonomic adjustable m	6	Good fit, maybe a bit hig	6	6	Good support some whe	6
15	Male	26	1.98	110	No	Simple office chair	6	Fit was good in the seco	6	5	Support should be on to	6

	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	Please elaborate on ho	How well was your pelvis	Please elaborate on ho	How well was your trunk	Please elaborate on ho	Do you sit with your pelv	Did you change betwee	Do you feel you have er	Please elaborate on you	How well were you able	Please elaborate on you	How well did the chair p
2	I find it difficult to assess	7	I don't have any issues	3	No upper body support,	No not fully against the	yes, I often change. So	5	I think the material of th	6	No more difficult than wh	6
3	I didn't feel the need to	5	Only the top part of my	7	It was supported very w	My pelvis is around ~10	Yes, The constant touch	3	It feels like I'm kinda pus	7	Was able to work on the	6
4	It did not take any effort	6	It felt stable, but my pelv	7	it felt stable, didn't have	Yes	No, didn't feel the need	5	moving wasn't needed,	3	I would like to balance a	7
5	This support is perfect fo	5	it was good, but I feel if	7	The part was very good	Sometimes yes, sometin	Yes. just like the previou	5	The cushion is big enou	6	With the armrest it would	6
6	I have the feeling that b	3	I don't feel that my pelvi	3	not really supported bec	Not fully against the bac	Only from active sitting (	6	I did not have the feelin	5	-	5
7	Yes was able to sit in th	6	Pelvis was nice. The sea	6	Very good	I think I was sitting in a v	No, sat in 1 position. Th	6	Felt the rope in the back	6	Didn't change tilt	7
8	Natural preference post	3	Niet op gelet maar was	6	Sloot goed aan de rug (	Nee, met schouderblade	No sits in reclined positio	3	Because of the smaller	3	Veerdruk was te laag du	5
9	Pelvis area felt really go	7	Very stable	5	meer pelvis dan bovenn	pelvis yes trunk sometim	wilde onderuit gezakt ga	4	Upper body felt free and	6	I believe that resistance	7
10	Normal sitting posture is	3	Was sitting upright again	6	That was fine	Van nature zit meer ond	In het begin niet laatste	6	had de behoefte aan ee	7	eerst vast om dat hij dac	7
11	Normally she would slou	4	She doesn't want more,	3	Only supportive while le	Pelvis not against backr	Few small shifts, but enc	6	Was good	4	Only sat in locked positi	5
12	Kept butt als flush as po	6	The shape was pretty go	5	Missing top part support	Yes, sat with back and t	Only small repositions, n	3	The foam was too sticky	4	Sat in a fixed upright po	4
13	Great, found herself lea	7	Great, haven't moved bu	4	Needs more support at t	Yes, sat most of the tim	Only micro readjustmest	3	Legs trapped in into the	4	Only sat in an upright po	6
14	Good but there is alway	6	Freedom of movement c	5	More fill up around shou	Fully pressed against ba	No, one position	4	Tied up because of butt	4	Only straight up position	7
15	It does keep me in the p	5	Pelvis felt stable, but no	6	Not sure anymore, but I	Yes, fully pressed again	Only moving from sitting	5	The foam on the seatpa	7	Chair was setup for me (	7

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
1	What activities did it not	What is your overall imp	Please elaborate on you	Did you experience any	Is the cushioning on the	Is the cushioning on the	How was the comfort sit	Please explain if you like	How was the comfort sitting in a **reclined** postion in general?			
2	only maybe the wheels (	3	I would change the chai	stiff shoulder and neck.	5	4	3		5			
3	I would like a neck rest	5	I like the support of the	After sitting for a while, r	7	6	6		4			
4	I was able to work witho	6	many chairs sit less com	after a few hours I felt th	4	4	7	I liked it	3			
5	I want my foot to rest or	5	The backrest is perfect f	I couldn't put my left leg	3	4	6	This position is perfect	5			
6	it supported my lower ba	5	back rest ok, but seat its	no	2	3	5	its fine	4			
7	Everything was able to b	6	Very good, very comfort	No	4	4	6	The basic seating positi	4			
8	Browsing on the interne	3	Heeft niet met de rugleu	No	3	4	4	Only sat in the reclined p	6			
9	All ok	6	Had to get used to the (	No	4	5	6	She liked the basis posi	7			
10	Kon alles goed doen ind	4	Don't want to sit in it all (	Shoulder pain and uppe	4	6	6	Chill	6			
11	It allowed everything, sta	5	Need more time testing	No	4	3	5	Like the basis seating p	5			
12	Table too low and chair	5	Lower back support is g	Lower neck discomfort	3	3	5	Wished the backrest wo	4			
13	Didn't feel like she want	5	Less friction, to move ar	Lower back pains, botto	3	6	5	Like the small reclined p	4			
14	No comment	5	It is a prototype, misses	No	4	4	6	Difficult to judge base se	4			
15	Just regular computers s	5	Needs more support/foc	upper back starting to h	4	4	5	Yes, I like the base posi	6			

Analysis of questionnaire results





Oberservation notes user test

Notes User Test
Personalised Backrest Shape

Participant 1

- Klachten aan bovenrug en schoulder na het zitten, dit heeft te maken dat bureau waarschijnlijk te laag is en hij voornamelijk naar voren gebogen, leunend op armen of elleboog, werkt.
- Moet heel erg wennen aan nieuwe manier van werken, met scherm en muis en kb, want normaliter werkt hij gewoon op een laptop op tafel hoogte
- Zit met rug weinig tegen de leuning, leunt veel voorover
- Actieve zitter, zit onrustig, snel afgeleid en beweegt veel rond
- Wieltjes rollen niet lekker, beetje irritant
- Backrest cushioning is good, but feels the wooden slats through the coushining. Ruggensteun zou meer smooth moeten zijn. Niet meer coushing nodig
- Testtijd: 1,5 uur

Participant 2
- Zit erg stil in een vaste houding, ook met rug erg goed tegen ruggensteun aan
- Gaat herzitten na 1 uur
- Locks the chair in upright position
- Likes the backrest shape asks me about the measurements of the setup so that he can replicate it at home
- His old chair at home gives him pain in the area between his shoulder blades
- Vond het eerste uur de stoel en de ruggensteun erg comfortabel, maar daarna voelde hij alsof zijn rug ging slapen (net als been die slaapt) omdat de stoel hem constant in de rugleuning drukte
  - o Dit komt wss omdat de het zitvlak naar achteren gekanteld is voor bekken steun
  - o Dit zal ook te maken hebben met het feit dat hij in de 2,5 uur dat hij in de stoel zat, 1x is gaan verzitten en continu in dezelfde houding heeft gezeten
- Didn't recline at all
- Testtijd: 2,5 uur

Participant 3
- Eerste indruk: zit goed en sluit goed aan. Zegt dat hij de lage ruggensteun fijn vind omdat zijn schouderbladen ver uitsteken en bij stoelen met een hoge ruggensteun drukt deze de schouders te ver naar voren waardoor hij last krijgt.
- Na een uur een keer opgestaan om naar de wc te gaan, daarvoor nog niet echt bewogen. Zit voornamelijk in 1 houding
- Heeft wel zijn voeten eens op de stang van het bureau gelegd
- Tussentijdse beoordeling: fijn zitten, niet de behoefte om de setup te veranderen. Zegt dat hij ook niet de behoefte heeft om te gaan verzitten of andere houdingen aan te nemen na een 1,5 uur zitten. Comfortabel dus!?
- Zit met de stoel in rechtop positie, bij opmerking dat je ook kunt kantelen zegt hij dat misschien iets verder naar voren zou willen zitten
- Testtijd: 2,5 uur

Participant 4
- Problemen tijdens het meten
  - o Participant heeft hele korte benen en een lang bovenlichaam, dit zorgt ervoor dat zij niet goed tegen de rugleuning van de kyfometer stoel kan zitten omdat haar onderbenen van tegen de rand van de stoel aan komt
  - o Probleem gecorrigeerd in Rhino, alleen hierdoor kon zij moeilijk houdingen aannemen en was het lastig om de natuurlijke s-shape te doen
  - o Participant begreep ook niet helemaal de -10% methode en leek weinig controle te hebben over haar ruggenwervel en de houdingen ze er mee kan aannemen
  - o Participant heeft korte benen en een lang bovenlichaam
  - o Participant is erg flexibel, kijk maar naar de maximale curve als ze haar bekken vooroverbuigt
  - o Participant had ook een trui aan en kon deze niet uitdoen, dit geeft ook een beetje problemen tijdens met meten omdat wat golven in de lijn geeft
  - o Participant vergeet ook houdingen vast te houden / lukt niet om dat te doen:
  - o Achterover meten ook lastig om dat ze zich moeilijk kan afzetten
- De test setup maken geeft ook problemen:
  - o Hier is het zitvlak ook te diep voor haar benen, dit is opgelost om het rugvlak verder naar voren te brengen en een minder dun foam (geel) te gebruiken. Dit zorgt ervoor dat haar benen beter over de rand kunnen curven/buigen
  - o Tevens is de stoel te hoog, dit is opgelost door planken op de grond te leggen zodat haar voeten de grond raken.
- Eerste indruk: Participant geeft aan dat ze de vorm goed vindt in eerst instantie alleen dat ze door haar trui, de ruimte en het foam+hout het heel warm heeft in de stoel. Ze zegt dat een mesh bijvoorbeeld al luchtiger zou zijn
  - o De vorm die gebruikt is, is de maximale bekken curve terwijl ze rechtop zit.
    De -10% curves waren allemaal erg inconstent (3x) gemeten
    En de maximale bekken curve terwijl ze achterover leunt was te intens, dit is niet realistisch aangezien de bekken vast gezet werden tijdens het achterover hollen.
    Op een foto is gekeken waar haar billen de leuning raken en zo is het begin punt van de curve bepaald en de schouders van de curve zijn ook geroteerd om de ruggensteun
- Wilt graag hoofd en nek steun hebben
- Switches often between forward and backwards posture, where she leans against the back rest
- User lijkt enorm flexibel, dus erg makkelijk te rug te hollen en vond daarom misschien de maximale curve fijn om te zitten

- Insight: De stoel kantelt van zichzelf al iets naar achteren, dus dat betekent dat de curves uit de kyfometer niet allemaal in dezelfde hoek zijn. Dus bij het verwerken van de curve moet hij handmatig geroteerd worden zodat de schouder en bil tegen de ruglening aan liggen

Participant 5
- Instellen stoel: Lastige keuzes maken. Bij kijken naar natuurlijke zithouding is de ruggensteun niet zo diep en niet zo hoog. Participant gaf zelf aan wel een voorkeur te hebben voor 'aanwezige' ruggensteunen. Daarom is er gekozen om naar de rechtop zittende maximiale holling houding te kijken en die te roteren en te gebruiken om te stellen. Dit was ook get geval bij Qing. De reden waarom er niet voor curve 3 is gekozen omdat ik het gevoel heb dat bij het achterover leunen dat de natuurlijke s-curve (of aangenomen) houding verandert omdat er geen steun is tijdens de verandering van zithouding.
- Participant was sitting very still, didn't move much besides getting up out of the chair a few times
- Participant found that the backrest shape was maybe too prominent, this could because the shape was based on her maximal curve while laying down

Insight: Vanaf hier erachter gekomen dat de curve niet vanaf het 0 punt wordt opgeslagen. Het laatste punt in de data is vaak nog het voor laatste meetpunt, dus dat betekent dat het startpunt in de stoel setup ook anders moet zijn voor elke curve. Dit kan een klein verschil zijn. (Op 12 December de andere curves nog checken)
- Vanaf nu 0.00,000 toevoegen aan de lijst van berekeningen om het juiste start punt te hebben

Participant 6
- Gestart met de questionnaire te vragen en zelf invullen ipv de participanten het zelf te laten. Dit geeft betere antwoorden en discussies

- Participant had moeite om de houdingen aan te nemen, dit kan komen omdat de participant wat zwaarder is en op leeftijd is
- Participant zit voornamelijk naar achteren over geleund
- Is van de stoel gevallen
- Vorm van rugleuning stoel was goed alleen hij was niet comfortabel
- Zit laag, zelfs op laagste stand zit kon hij zonder kratje nog niet achter over leunen. Ik denk dat hij enorm korte benen heeft
- Testtijd: 1 uur

Participant 7
- 7 doesn't agree that sitting in lordosis is the best way to sit. Names papers that confirm the difference. The lordosis posture is not scenically proven better. The posture on the right in the questionnaire is also good if you fill in the open space at the butt. Names papers like: Wilke, Nagarson. These have done measurements of the pressure in between the verbal discs, where the pressure is the best.
- Hij was enthousiast over de stoel en heeft er de gehele tijd op 1 positie gezet, dit betekent dat hij comfortabel was. Op zijn timelapse bewoog hij veel thuis, maar dit kan ook beïnvloed worden door de omgeving.
- Observation while measuring: mensen die ouder zijn lijken minder ver hun rug kunnen hollen. Dit resulteert in minder extreme lende steunen. Ook verandert de curve veel als ze achteroverleunen. Het lijkt er namelijk op dat ze dan minder de vorm kunnen aanhouden en de curve dan afvlakt. Jongere mensen hebben meer flexibiliteit in de ruggenwervel lijkt het (paper bevestigen)
- Riem en trui uitgedaan
- Testtijd: 1 uur
- Vragen beantwoord doormiddel van een interview stijl gesprek (vragen van de questionnaire gesteld op een beamer scherm) en gesprek opgenomen

Participant 8
- Participant had dikke trui en dikke denim broek aan, dit heeft invloed op de nauwkeurigheid van de curve
- Zat in eigen ruimte te werken maar met laptop op ooghoogte
- Max had twijfels over de vorm van de ruggensteun omdat de participant of een ander foam zat en de ruggensteun hoger begon dan bij andere mensen. Achteraf bleek dit geen probleem en werd de steun als goed en comfortabel bestempeld.
- Ruggensteun moest hoger zijn
- Hij deze meeting de stoel weer hoger gezet want bij vorige test personen was hij omlaaggegaan. Dit had volgens mij geen problemen met het instellen.
- Vond de basis positie van de stoel erg chill, niet zo voorover geduwd als de bureaustoelen van de uni
- Vooruit buigende houding kan een goede houding zijn om het startpunt van de lende steun te bepalen. Bij het voorover buigen zit je met je bekken/kont tegen de ruggensteun aan en als je dan rechtop gaat zitten of achterover kantelt je rug over de steun heen.
- Heeft wel veel gepuzzel nodig om de juiste curve te vinden, curve meten met kleding aan en test setup (stoel etc.) moet nauwkeuriger
- Jong persoon, sterke curves

Participant 9
- Grote man, verwacht dat zijn curves sterk zouden zijn
- Achteraf bleek dat curves helemaal niet zo sterk waren en dat de extreme en natuurlijk zitcurves vrij gelijk zijn.
- In eerste instantie de leuning ingesteld op zijn natuurlijke curve maar die vond hij veel te licht, doen de leuning ingesteld op zijn extreme achterover curve en vond de vorm in eerste instantie goed
- Bureau eigenlijk te laag voor 1.88m, hierdoor nek en schouders omlaag en last op het einde
- Voorkeurshouding is relaxed en onderuit gezakt daarom leunde hij veel op de bovenkant van de stoel en dit werd oncomfortabel na verloop van tijd. Wilde daarom meer steun aan de onderkant
- Tekenen ging ook in de stoel
- Testtijd: 1,5 uur

Participant 10
- Zelf als proefpersoon figureren, dezelfde meet methode en instel methode
- Begonnen met curve 5, natuurlijke houding tegen de leuning
  - o Curve lijkt vergelijkbaar met de vorige test personen qua startpunt, dikte en hoogte
  - o Eerste indruk: Niet meteen enthousiast, zoekende naar positie om te zitten en begint met last vd schouders, maar dit kan ook liggen aan vorige zit houding aan andere tafel die veel te laag is. Rug voelt opgevuld maar niet direct ondersteund.
  - o Voel eerder de druk op apex ruggenvorm 7 dan directe steun op de bekken. Dit komt omdat de steun de rug volgt natuurlijk
  - o Moet wennen aan het ontbreken van de steun van de schouders
  - o Conclusie 1 uur: Rug voelt goed gevuld maar niet het idee dat lende echt goed ondersteund wordt. De druk van de ruggensteun is goed maar zou lager moeten zitten heb ik nu het idee.
- Nu met curve 3, maximale houding tegen de leuning
  - o Eerste indruk: Voelt in eerste instantie al beter dan de vorige, rug beter gevuld en meer druk op de bekken. Misschien apex iets te hoog want ik voel die drukken. Bovenkant rug voelt nu ook ondersteund en dat was bij de vorige setup niet zo. Ik heb nu meer het idee dat ik een gezonde houding aanneem en dat was bij de vorige minder of niet zo
  - o Bekken voelen veel stabieler dan de vorige
  - o Had het idee ik hier comfortabeler in zat, was minder bezig met juiste positie vinden. Rechtop zitten zorgde voor goede focus en rust tijdens het werken.
  - o Ik zou zo verder willen zitten in deze stoel, alleen piek is het hoog
  - o Bovenrug doet wel zeer

Participant 11
- Aan de hand van eigen test, nu de ruggensteun ingesteld op de extreme rechtop curve
- Trui zat wederom in de weg
- Eerste indruk: ze vindt de ruggensteun lekker, zegt dat ze er normaal een kussentje tussen
- Participant zit zelf nooit goed en krijgt vaak aan het einde van de dag pijn in de rug, nek en schouders. Dus van nature gaat ze niet in een juiste houding zitten
  - o Zit vaak met billen van de ruggensteun af, dit zorgt ervoor dat haar bekken niet goed ondersteund wordt. Boven rug wel tegen de ruggensteun, dus die krijg wel steun.
- Conclusie: vond de ruggensteun fijn, was positief over de vorm. Echter zit net als bij mij de piek in de rug en misschien is dat niet de juiste manier voor ondersteuning. De druk moet meer op de bekken zitten om het lichaam in de juiste positie te drukken.
- Extreme rug curve zorgt wel voor een goede vorm, de ruggensteun als die ingesteld is zorgt niet voor dezelfde overdreven ruggensteun vorm. De rug blijkt wel af te vlakken. Dit komt omdat de participant niet helemaal perfect tegen de leuning zit met de kont (Kont zou meer ruimte moeten hebben voor aansluiten van de rug), en bovenlichaam zit ook niet helemaal tegen de ruggensteun aan aangezien participant(en) naar voren leunen om te werken.

Participant 12
- Participant aan de zwaardere kant en is hierdoor minder goed instaat om de rug te hollen waardoor de rug curves erg vlak zijn. Dit was vooraf al te verwachten
- Door de vlakke rug curves is de ruggensteun ook niet zo sterk qua vorm
- Participant gaf aan iemand te zijn die veel naar voren leunt en onderuitgezakt zit. Zit vaak in bed te werken met een laptop standaard en glijd dan langzaam af onderuitgezakt. Gebruikt dus niet. Vaak een bureaustoel
- Zit tijdens te test wel redelijk goed tegen de ruggensteun
- Moest wennen aan de setup en gedroeg zich ook anders dan ze normaal zou zitten

Participant 13
- Participant aan de kleine kant, dus zittende op de test stoel kan niet de grond raken met de voeten

- Doet vanaf jongs af aan aan yoga, dus heeft een flexibele rug, ondanks dat haar rechtop natuurlijke curve vrij vlak is
- Stoel ingesteld: De stoel is nu ingesteld dat de lende steun de vorm volgt van hij extreme leuning curve (3) met de gedachte dat dit de bekken zou ondersteunen / pushen naar voren zodat de rug in een goede positie komt en dan vervolgens boven de bekken zwakt de ruggensteun af naar de curve van rechtop extreme curve (2) omdat deze duidelijker was dan de natuurlijke gemeten curves. Als je krijgt naar haar rechtop natuurlijke zit curve (4) zonder hem te roteren!!, dan zie je dat de steun nu meer is dan de curve waardoor het dus extra druk zou moeten uitoefenen wanneer ze rechtop zou zitten of leunend tegen de stoel. Dit is gedaan me de gedacht dat alleen het opvullen van de rug niet genoeg steun geeft (wat max dacht) en dat de bekken dus meer steun moeten krijgen. Ben benieuwd naar de uitkomst.
- Eerste indruk: De bekken en bil hebben genoeg ruimte en zijn goed ondersteund. Bovenrug voelt wel los en niet ondersteund. Na even zitten de in stoel krijg ze last van haar bovenrug, maar dit zal te maken hebben met dat ze op een ipad werkt en naar beneden kijkt. Normaliter zou ze onderuitgezakt zitten.
- Ze geeft ook aan dat ze nu goed zit omdat het een test is, maar normaal zit in de meest gekke houdingen. Benen over elkaar, over de armleuning etc.
- June en asli kregen last van hun stuitje of de onderkant van hun ruggenwervel. Komt dit door dat ze achterover geleund in de stoel zitten en daardoor niet op de zitbotjes zitten maar op hun stuitje leunen??
- Testtijd: 1,5 uur

Participant 14
- Participant heeft heel sterke en hoge apex van zijn extreme rechtop zithouding maar zijn natuurlijke zithouding is erg vlak. Van de natuurlijke houding is geen curve te tekenen.
- Dezelfde aanpak als bij Asli gebruikt. Het lende gedeelte van de extreme rechtop houding gebruiken om het onderste deel van de ruggensteun te maken. Dit zorgt ervoor dat de bekken goed naar voren worden geduwd zodat de participant rechtop zit. De piek van de steun is NIET ter hoogte van het diepste punt van de rug curve en de dikte is ook niet gelijk aan het diepste punt maar die is minder. Dit zorgt er beide voor dat de focus van de druk niet op het diepste punt van de rug ligt, maar gericht is op de bekken. En omdat de dikte ook minder dik is, kan de participant goed zijn billen in de steun duwen / klemmen.
- Verder is de bovenkant dikker gehouden, afgeleid van de extreme curve maar dan leunende tegen de ruggensteun. Hierdoor zou de rug meer steun moeten hebben, omdat dit miste bij Asli.
- Eerste indruk: eerste reactie was dat hij wat hoog zat het diepste punt, maar na het herpositioneren met billen tegen de ruggensteun aan was de indruk goed. Voelde diep en hoog genoeg aan en was positief. Misschien dat de participant even moet wennen.
- Hoe is het om in relax modus te hangen? In de stoel is alleen getest voor rechtop zitten en actief werken, rug ondersteuning. Relaxed zitten is toch wat anders
- Testtijd: 1,5 uur

Appendix L: **Klaas Nienhuis interview**

Notulen
- 3Daboutme help bij de moeilijke aspecten van kleding online kopen, namelijk de goede maat uitkiezen
- 3Daboutme matched voeten aan de hand van 3 fotos
  - o Er worden zo'n 20 landmarks op de voeten gezocht van foto (herkenbare punten bijv. top van je teen)
  - Landmarks zetten op herkenbare plekken (voet)
  - Rig maken van het model en de voet in positie zetten. (Voet plat op de vloer is anders dan een schoen) Dit zal ook wel zo zijn als je zit, horizontaal zitten is anders dan schuin
  - o Van elke landmark wordt een vergelijkbaar 3D stuk gezocht ineen bestaande database met verschillende voeten
  - o Al deze individuele stukken worden dan samengevoegd tot 1 voet vorm die overeenkomt met degene op de foto
  - o Maakt dan een nieuwe 3D model van de voet
  - o Deze methode was uiteindelijk erg nauwkeurig
  - o Multi dimensionale statistics methode (geen AI)
- 3Daboutme scande ook de binnenkant van de schoenen en zochten dan een match met de scan van de voeten
- Belangrijk om te weten wat mensen lekker vinden zitten is niet consistent
  - o Sluitend advies geven voor kleding is lastig zonder te passen.
- Gebruikte 3Dstudio voor het algoritme, kan ook Javascript of Phython
- Vroeger (10 jaar terug) was het moeilijk om mensen te herkennen dmv. een algoritme, maar misschien is dat nu anders
  - o Full body scan maken was niet toegankelijk, maar nu zijn er wel bedrijven die dat kunnen doen aan de hand van 2 fotos
  - o IBV in Spanje doet veel in biomechanics en hadden samenwerking met 3Daboutme
- Mensen zelf 3D modellen laten maken is enorm lastig
  - o Mensen zijn domme wezens
  - o Ze hadden zelfs al moeite om 3 fatsoenlijke foto's te maken op een A4 papier
- Klaas denkt dat universeel advies voor een stoel niet mogelijk gaat zijn
  - o Je moet de voorkeuren meenemen en meewegen in het design
  - o Suggestie is om 10 vormen te maken en een algoritme de beste vorm aan te bieden aan de hand van afmetingen en voorkeuren
  - o Een slimme selectie tool maken, dit is qua commercieel oogpunt misschien ook slimmer
- Suggestie om te kijken naar een recht model riggen en dan een zithouding te reproduceren
  - o Nauwkeurig??
- Je kan ook kijken of er een overeenkomst is tussen de staande en zittende houding en die informatie gebruiken voor het algoritme om houdingen te produceren/analyseren
- Bodylabs maakt op basis van foto's en videos 3D modellen, misschien hebben zij kennis over vervorming van het lichaam
- Manier van advies is belangrijk voor de geloofwaardigheid van je product
  - o Als je je advies onderbouwt met professoren en literatuur dan geloven mensen sneller dat ze in een goede stoel zitten
  - o Als je mensen met autoriteit laat markten dan geloven mensen het ook sneller
  - o Iedereen koopt een iphone als steve jobs dat zegt

Interessante tips

- IBV (uses 3D database to create realistic human model from photos): https://www.ibv.org/en/technologies/3d-scanning-and-modeling/
- Michael Black (biomechanics guru): https://ps.is.mpg.de/~black
- Obtaining skeleton shape from outside: https://github.com/MarilynKeller/OSSO
- Bodylabs: https://browzwear.com/partners/bodylabs/

moopi - Chapter 10: Appendix

moopi - Chapter 10: Appendix

Appendix M: **Realization user test notes**

Realization user test results notes

Participant 1:
- Stoel zit niet vak, door de mounting plate zit de stoel meer naar rechts achter, dus moet het lichaam compenseren
- Vorm zit goed, sluit aan aan de rug en bovenlijf heeft goede steun
- 21 graden misschien te ver, moet iets te ver achterover buigen om goed tegen de leuning aan te zitten tijdens het werken
- Stoel verder comfortabel
- Onder doet beetje pijn na einde van de dag, oorzaak? Stoel die scheef staat, te weinig padding bij de rug waardoor harde lumbar support teveel duwt op de spieren. Trui erg goed voelbaar hier door in lumbale deel
- Mounting plate links voor insert losgekomen bij het achterover leunen. Hierop zit dus veel druk als je tegen de rugleuning aan leunt, maken op dag 2.
- 5 uur op gezeten, dan geswitch naar andere stoel
- Last van bovenrug omdat de rugleuning niet genoeg steund die is te ver naar achteren
- Stoel wederom comfortabel
- Lende voelt goed ondersteund maar niet te over dreven
- Voelt zitbeenderen lichtjes, maar niet storend, foam kan daarom wel wat dikker zijn
- Rugleuning en support qua vorm goed maar veel verstoring door kleiding (trui bijv) 1cm foam gebruikt maar dit zou dikker moeten om dit op te vangen
- Stoel kan minder wijd zijn, nu wel erg massief in de ruimte
- Stoel randen hoekig, voor design beter om deze rond te maken
- Curve van zitting goed, maar rugleuning nog te vlak, mist lateral support. Dit zou ook opgevangen kunnen worden door dikkere foam
- Zitvlak kan ook langer zijn, want met onderuit gezakt zitten is het wat kort, 60 mm is mis wat te veel
- Stoel afgebroken van mounting plate, dit moet verstevigd worden
- Onderuit gezakt zitten is heel comfortabel, Onderzoeken of kleinere zithoek ook comfortabel is

Participant 2:
- Van de stoel vallen 2x, oppervlakte van de wielen minder dan de stoel dus bij het zitten op de rand kantelt hij omver
- Ging goed tegen de rugleuning zitten tov van haar idea stoel, dit kwam door het gekantelde zitvlak
- Merkt dat het een prototype is er en daarom comfort nog niet helemaal fantastisch en de padding ook nog niet, daarom een 6
- In de prototype stoel ging beter rechtop zitten dan in de ikea stoel, en ging niet voorover gebogen zitten
- Wilde niet meer over minder steun, vond de hoeveelheid goed. Had niet zoveel last van kleding, had truien aan
- Het lichaam was stabiel en zat stevig in de stoel, alleen onderstel instabiel
- Ging minder vaak verzitten dan in de andere stoel, zat hier beter in 1 houding
- Wieltje van de stoel waren niet goed, stoel was ook iets te breed wat te veel ruimte in de ruimte in beslag nam
- Gebruikte geen kantel modus
- Kon alles perfect doen
- Zou mijn stoel verkiezen over de ikea stoel, zitvlak van ikea stoel is te klein, prototype stoel beter
- Vond zithoek en van zitvlak goed qua hoeken
- Schuim mag iets steviger, voelde zitbeenknobbels
- Rugleuning foam mag iets zachter van, voelde de achterkant van de rugleuning met zitten 1cm te dun

Armen niet genoeg bewegingsvrijheid omdat het rugvlak te breed was