



4D DIGITAL HUMAN MODEL FOR DESIGNERS

BASED ON VIRTUAL REALITY AND 3D SCANNING TECHNIQUES

MASTER THESIS
DESIGN FOR INTERACTION & INTEGRATED PRODUCT DESIGN

M.E.A.M. Kroonen

CHAIR
APPLIED ERGONOMICS DESIGN

Dr. Ir. J. F. M. Molenbroek

MENTOR
COMPUTER AIDED DESIGN ENGINEERING

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FACULTY OF INDUSTRIAL DESIGN ENGINEERING

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ANGENIET KAM

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AREND-JAN KROONEMAN

VR EXPERT TU DELFT ARCHITECTURE

ARNO FREEKE

VR EXPERT TU DELFT ARCHITECTURE

BERTUS NAAGEN

INDUSTRIAL DESIGN SUPPORT TU DELFT INDUSTRIAL DESIGN ENGINEERING

DORIS ASCHENBRENNER

POST DOC RESEARCHER TU DELFT INDUSTRIAL DESIGN ENGINEERING

JESPER VERHOEF

VR EXPERT TU DELFT ARCHITECTURE

LYÈ GOTO

PHD TU DELFT INDUSTRIAL DESIGN ENGINEERING

RENATE DE BRUIN

FREELANCE DESIGNER SPECIALISED IN ERGONOMICS

COMPANIES

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ABSTRACT

3D Digital Human Models (DHMs) provide industrial designers 3D and 4D information on the dimensions of the human body and its range of motion. Current models are based on outdated data from research on military populations making them unrepresentative for civilian populations. Available DHMs require experience to properly use them, are vague on what they represent and positioning them is demanding.

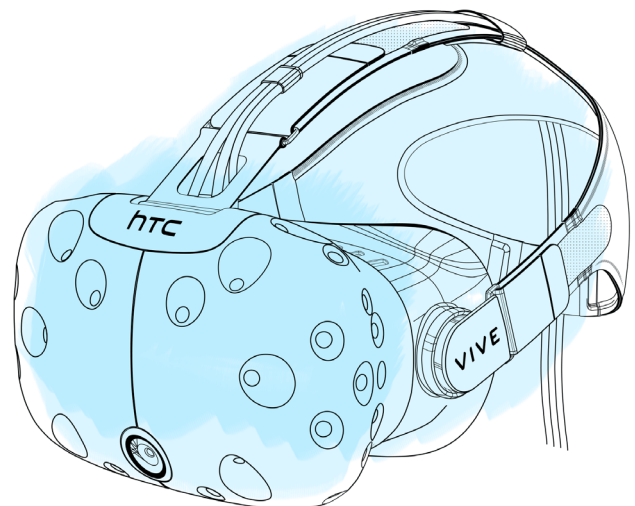
3D scanning is gaining importance in the field of human factors engineering as personalized products can accurately be formed to match the users body and movement. Examples are the Exo-L, MeshLingerie and numerous cast- and prosthetic designs.

Measurements extracted from 3D scans are currently equal or better than measurements done by hand, offering a quick and easy way to renew outdated data. yet no translation of 3D scans into DHMs has been made.

In order to create an easy to use, intuitive ergonomic tool based on full body 3D scans, the medium of Virtual Reality (VR) was chosen. VR has proven itself an intuitive computer interface, promising for the handling of a 4D DHM, as well as increasingly affordable.

Based on a literature study and field research requirements for a 4D DHM were put up. A functional prototype was built based on the found requirements and results from creative sessions.

The effectiveness of the new tool was investigated through usability research. From this research it can be concluded that 3D scans can be used for creating 4D DHMs and that VR is a good medium to position such DHM for ergonomic assessment. All eight participants succeeded in positioning the DHM to their liking within ten minutes after first introduction to the tool.



0.1 | GLOSSARY

explaining used terminologies

3D SCAN

Digitizing a person, object or space through creation of a point cloud representing the outer surface of the scanned object which can then be post processed for further use.

4D DATA

When an extra dimension is added to the ones we already know to determine a point in space (x, y, z) we can speak of 4D. This thesis uses 4D to present movement in time, thus the changing of x, y and z over time (t). 4D is therefore (x, y, z, t).

ANTHROPOMETRY

The scientific study of the bodily dimensions and proportions of humans.

AR - AUGMENTED REALITY

Augmented Reality (AR) covers a range of technologies or devices that provide an overlaid virtual environment to the user (Lanham, 2017). On mobile devices, the AR experience is often a result of rendering a virtual environment over the backdrop of the device's camera (like Pokémon Go).

BUMP OFFSET

Bump Offset mapping gives a surface the illusion of depth by modifying the UV coordinates in a creative way to help further displace the texels from the surface of the object, giving the illusion that the surface has more details than it really does. ("Using Bump Offset", 2017)

CREATIVE SESSION

A creative session is a gathering of people who, following some steps and rules shaped by a facilitator (or organizer), let their creativity loose.

ERGONOMICS

Ergonomics or human factors is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance (IEA, 2018).

HUMAN FACTORS ENGINEERING

Ergonomics or human factors is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance (IEA, 2018).

INTUITIVE USE

Can best be described as a highly effective, mentally efficient, and satisfying interaction with a product (Hurtienne & Naumann, 2010).

(POLYGON) MESH

A collection of vertices, edges and faces defining the shape of an object in 3D computer graphics and solid modelling (Ritchie, Callery, & Biri, 2005).

NURBS

A mathematical model for generating and representing curves and surfaces. NURBS, Non-Uniform Rational B-Splines, provide a 3D modeling framework based on geometric primitives and drawn curves ("NURBS Modeling", 2016).

POINT CLOUD

A set of data points defined by X, Y and Z coordinates, often intended to represent the external surface of an object.

RENDERING

The automatic process of generating a photorealistic image from a 3D model or scenery by means of computer programs. The results of displaying such a model can be called a render.

RIGGING / CHARACTER RIGGING

Rigging is the connection of a motion controlling skeleton to a surface or skin. The skin can be represented by various rendering methods like polygon meshes, NURBS or patch surfaces and is connected to the bone by skin weighting (Case & Högberg, 2010).

SAMPLING

Selecting a small subset of a population representative for the whole population.

TEXEL

In computer graphics, a texel (texture element) represents the smallest graphical element in two-dimensional (2-D) texture mapping to "wallpaper" the rendition of a three-dimensional (3-D) object to create the impression of a textured surface. A texel is similar to a pixel (picture element) because it represents an elementary unit in a graphic. But there are differences between the texels in a texture map and the pixels in an image display. In special instances, there might be a one-to-one correspondence between texels and pixels in some parts of the rendition of a 3-D object. But for most, if not all, of a 3-D rendition, the texels and pixels cannot be paired off in such a simple way. (Rouse, 2011)

UV COORDINATES

UV coordinates are the coordinates of a plane used to wrap a 2D image texture onto a 3D mesh. "U" and "V" are the names of the axes of a plane since X, Y and Z are used for coordinates in 3D space ("Blender 3D: Noob to Pro/UV Map Basics", n.d.).

VIRTUAL WORLD

A virtual world is a computer-based simulated environment (Bartle, 2004).

VR - VIRTUAL REALITY

VR is a computer interface that strives to immerse the user completely within a computer generated simulation, providing a much more intuitive link between the computer and the user (Mujber, Szecsi, & Hashmi, 2004).

WEIGHT PAINTING / SKIN WEIGHTING

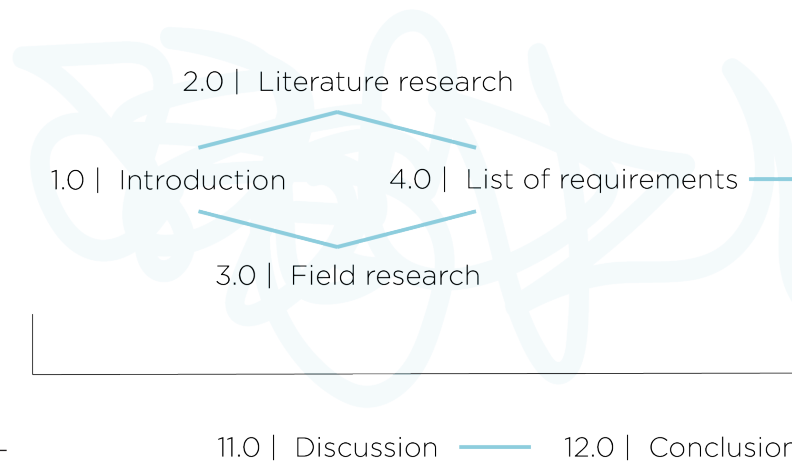
Skin weighting is the process of connecting a vertex (surface control point) to one or more controlling objects. This is achieved through relating the transformation matrix of the vertex to that of the controlling object. By this, a small number of geometries can control the movement of a larger set of vertices (Ritchie et al., 2005).

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1.0 | INTRODUCTION

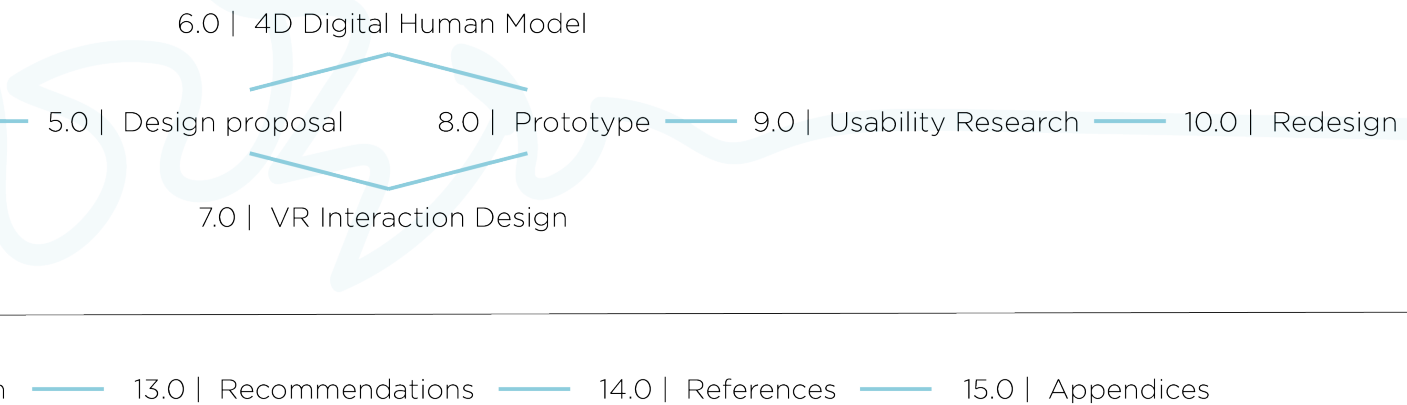


1.1 PROBLEM STATEMENT

Ergonomics or human factors is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance (IEA, 2018). For Industrial Design Engineers, ergonomic assessment of products is important because of the direct interaction between user and product (Dirken, 1997). This thesis will focus on physical ergonomics, which is concerned with human anatomical, anthropometric, physiological and biomechanical characteristics as they relate to physical activity (IEA, 2018). Anthropometry is the study of bodily dimensions and stems from the Greek words “anthropos” which means human, and “metron” which means measure.

The importance of ergonomics has grown with industrialization and mass production as the diversity within the target group, the group of people most likely to buy the product, increased. Since then globalization has furthermore widened the area of distribution, causing the need for products to cover even more diverse target groups. Consequently, designers are facing tough decisions when designing for the masses. Preventing discomfort is a main concern, according to Kuijt-Evers, who states that discomfort causes a lowered work ethic and productivity and/or physical damage (2007, p.8).

Human Centered and User Centered Design strategies, which focus on the user and usage of products when designing, are gaining popularity (Acosta & Morales, 2011). Tools



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figure 1. Thesis outline.

range from data sheets, reach envelopes or 2D manikins to advanced Digital Human Models (DHMs), real test subjects or combinations of these (Lombaers, Molenbroek, & Osinga, 1986).

The data these tools represent, however, are often old and outdated. New research is costly and does not generate revenue for their investors (Molenbroek and Song, personal communication, 04-09-2017). Data usually comes from research on military populations and not civilians which causes unrealistic dimensions when designing for civilian populations (Robinette, Daanen, & Paquet, 1999).

On top of this, designers often lack the knowledge and experience to interpret ergonomic data correctly (Duffy, 2009). Where bigger companies can hire ergonomic and human factors experts, most design agencies rely on their designers for including ergonomics in the design process. As a result, responsibility lies with a group of engineers of which less than 10% have had as much as a single course on human factors and ergonomics (Chaffin, 2005). When working with advanced tools like DHMs in Computer Aided Design (CAD) programs like SolidWorks, designers have to position the model realistically which is currently a very slow process (Song, personal communication, 17-02-2017).

Concluding, ergonomics are important when designing user products but designers lack the knowledge and experience to correctly apply ergonomics in the design process. Current tools seem to be unable to support designers through correct ergonomic assessment.

1.2 PROJECT GOAL

The goal of this project is to visualize anthropometric data in order to support correct ergonomic assessment of products by designers.

1.3 APPROACH

A literature study will provide background on the design process, ergonomics in design and the current tools used for ergonomic assessment of products by designers [2]. Field research will give insight in how designers deal with ergonomics and anthropometry during design projects [3]. Based on outcomes of the literature study [2] and the field research [3] a list of requirements will be made [4]. A design proposal [5] will be made with the help of creative sessions [3]. The report then splits up in building the prototype [6] and building the interaction design [7]. The final prototype [8] presents the combination of tool and interaction design and will be evaluated on usability, task load and intuitive use [9].

The thesis outline can be seen in figure 1.

2.0 | LITERATURE RESEARCH

2.1 DESIGN PROCESS

The classic design cycle, as described in the Delft Design Guide, consists of five stages (van Boeijen & Daalhuizen, 2010) and can be seen in figure 2.

The first stage, Analyse, includes researching all aspects related to the design goal, the whole context. In the second stage, Synthesize, possible design solutions are generated. In the Simulate stage the ideas are drawn and modelled, either physical or digital, to estimate their expected properties. In the Evaluate stage, the design is evaluated on the criteria and requirements set up during the analyze phase. During the Decide stage, the product is verified based on the requirements and the design goal. In case the product does not fit the requirements the product needs to be revised and taken back to one of the earlier stages in the cycle (van Boeijen & Daalhuizen, 2010).

Currently, new approaches are focusing on shorter concept to market times. These methods promote building prototypes early on and going through numerous cycles of iteration and evaluation as quick as possible. The advantage of early evaluation is solving problems early on, preventing costly setbacks.

Lean is such an approach, developed in the post-war years by the Toyota Motor Company in their Toyota Production System (Eaton, 2013). Lean increases product quality as a result of continuous follow-up on quality, both during and after development (Sehested & Sonnenberg, 2011).

An ergonomic tool that supports the designer in quick ergonomic assessment between iterations assists an iterative approach. The tool should furthermore focus on the earlier design phases as the improvement potential is considerably larger there than later on in the process (figure 3).

2.2 ERGONOMICS IN DESIGN

Each design project asks for a different anthropometric design strategy. In figure 4 an overview of anthropometric design strategies is given. Striving for design for all is noble but hardly ever realistic as dimensions drastically differ from person to person. Design for more types is a popular strategy for clothing, think of size labels, and is a good option when a target group is nonuniform. Design for adjustability can best be recognized in car seats and desk chairs where settings can be changed according to the preferences of the user. With ego-design the designer bases the products dimensions on his/her or any other single person's dimensions. For tailor-made products this is adequate, but when applied to mass production products it will likely not fit the target group. Procrustes was a bandit from Greek mythology who stretched or amputated the limbs of travelers to make them conform the length of his bed. The last strategy was added jokingly as the product dictates the dimensions of the human.

Despite the differences between projects, there can be put up some ground rules for

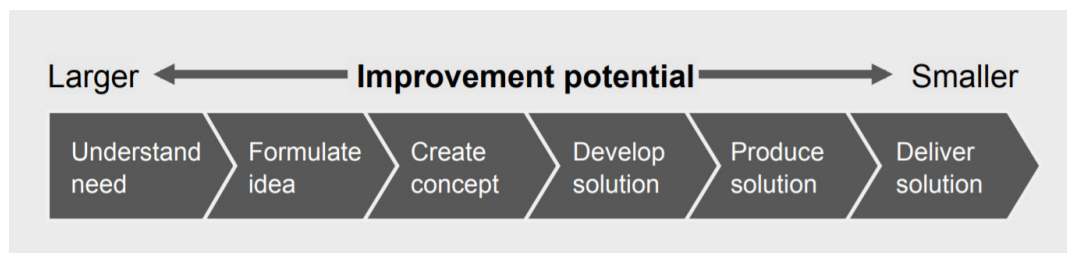


figure 3. The improvement potential in the different design phases (courtesy of Sehested & Sonnenberg, 2011, p6).

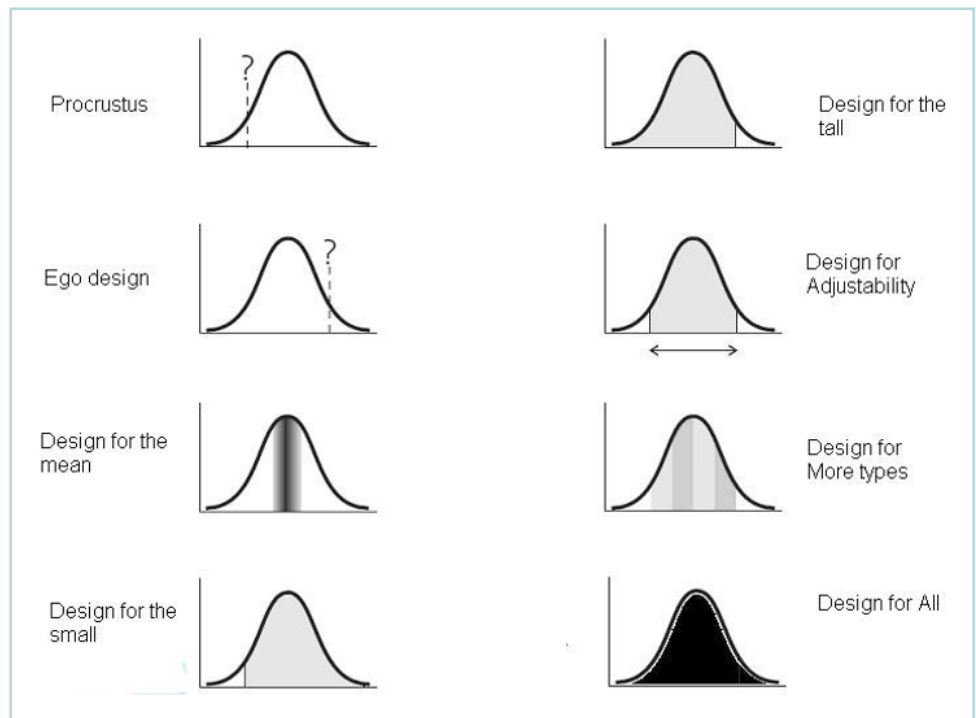


figure 4. Overview of Anthropometric Design Types. Axis description: y= frequency and x= percentile 1 to 100 (courtesy of Molenbroek & de Bruin, 2015, p.2).

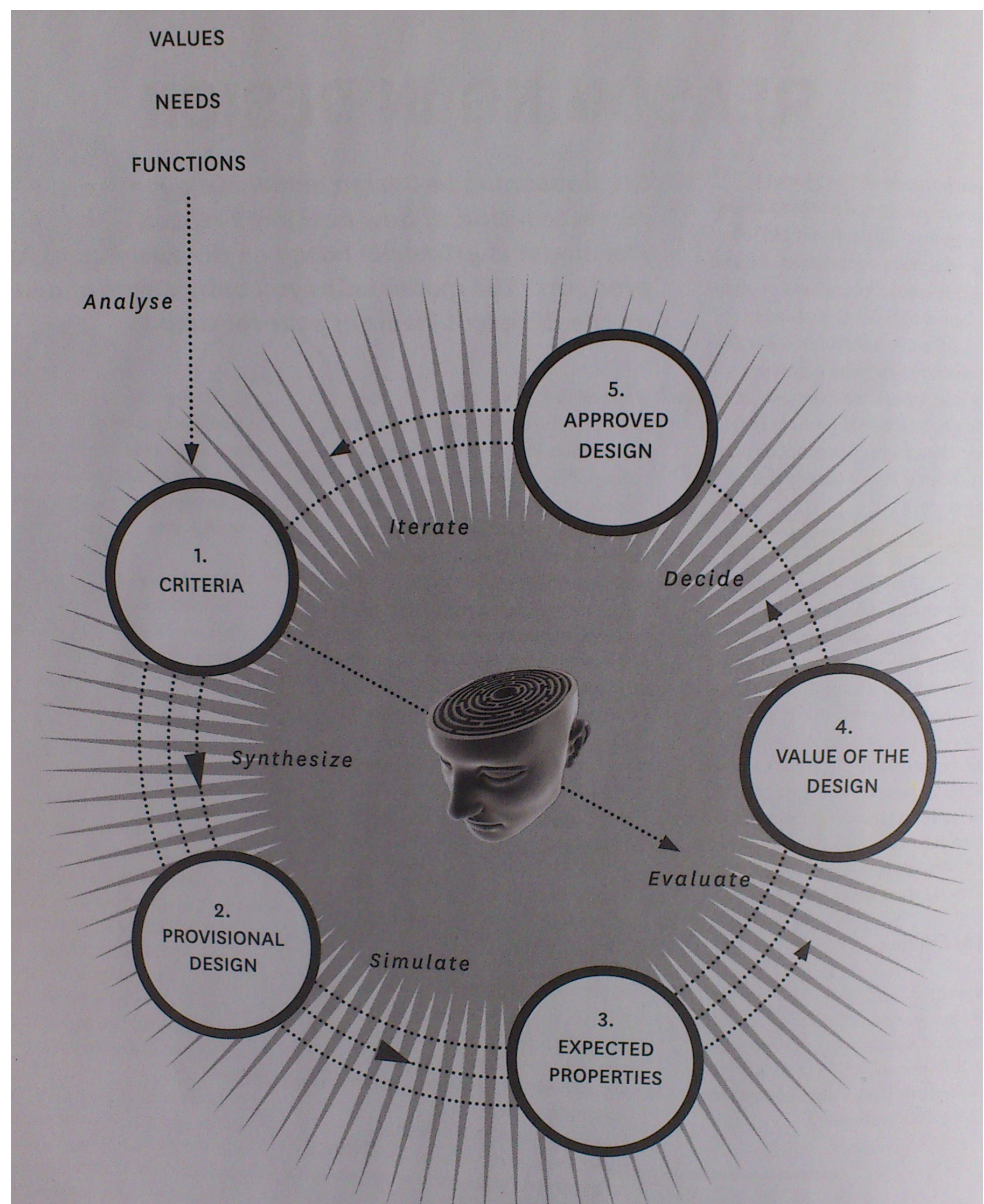


figure 2. The basic design cycle as described in the Delft Design Guide (courtesy of van Boeijen & Daalhuizen, 2010, p.18).

good ergonomic assessment in general (figure 5). In all situations the designer should first try to understand the target group and its characteristics and determine those relevant for the design purpose. When these are found the designer should ideally look up scientific data on these dimensions or research a sample from the target group. In case doing research is not feasible an educated estimation will suffice.

Scientific data is often based on US citizens, which makes using this data for the Asian market problematic due to anthropometric differences between people from different origin. Damascene, Abeysekera and Shahnavaz proved that products designed to fit 90% of the US male population would fit only 10% of the Vietnamese male population (1988). This underwrites the importance of knowing your target group.

An often used approach to deal with differences within the target group is using percentiles. However, using percentiles for more than one dimension will not cover the population indicated by this percentile all thus Robinette and Daanen (2006). Earlier research states that using percentiles to represent people, like the 5th percentile female, does not work as the dimensions do not add up to realistic human models (Robinette & McConville, 1982). Crash dummies that were one percentile on all body parts resulted in large errors (Searle & Haslegrave, 1969). Moreover, when measurements are conflicting or interacting, the use of percentiles will not be sufficient (Robinette & Daanen, 2006) as the ratio between limbs is not automatically 1:1.

According to Robinette and Hudson, seeing if products fit the different body shapes within the target group requires 3D body scans of real people (Robinette &

Good ergonomic practice

1. Understand target group and indicate relevant characteristics
2. Find scientific data on these
3. Understand 3D / 4D situation

figure 5. Good ergonomic practice explained in 3 steps

A representation of the nonuniformity of peoples dimensions was made in an 2011 article by Nicole Patridge called "Who weighs the Aussie average?". The image from this article (figure 6), shows that the bodily dimensions can differ a lot from person to person despite weighing the same.

Hudson, 2006). Similarly, Veitch, Caple and Blewett state that correct digital ergonomic assessment can only be done with 3D data of real people (2009, p.15).

To prevent wrong assumptions, anthropometric data should not be represented as single percentile human models but as real people. Indicating the different percentiles per body part seems interesting for visualizing the spread of the dimensions within the target group.

Ergonomic assessment is often done by designers who are not trained in human factors and ergonomics sufficiently. Designers often build physical prototypes to meet engineering goals instead of human interaction goals (Duffy, 2009). Engineering goals are usually checked in the end when the final concept is known, whereas possible human-product interaction issues should best be found during the initial phases of a new design (Duffy, 2009).

2.3 CURRENT ERGONOMIC TOOLS

There exist many tools for conducting ergonomic product assessment, each with their own advantages. The representativeness and accuracy of ergonomic tools differ as models are an approximation of reality. The notion of how this influences the data should be clear to the designer using them. In a talk with Renate de Bruin, ergonomic expert and advisor, it became clear that this is often not the case (de Bruin, personal communication 14-06-2017).



figure 6. Six Australian women who all weigh 70kg but have different body dimensions (Partridge, 2011)

This chapter lists some of the popular tools and their qualities.

1D DATA

While gaining access might be difficult or costly, 1D data like measurements are interesting because of their ease of use (Veitch et al., 2009). 1D data can help determining size and variation just as checking single parameters. The data, however, is often outdated and gathered on military populations. New research is costly and goes without generating profit making it unlikely for companies to finance. Furthermore, converting 1D data to 2D or even 3D shapes is difficult. In a talk with graduation student Emmylou Hoppe, who is working on shin protection for hockey players based on 3D scans, she indicated that the circumference of an ankle can best be approximated by an ellipse while the circumference of a calf can best be described by a circle (Hoppe, personal communication 15-01-2018) underwriting the limitation of 1D data.

When combining multiple 1D dimensions, all from the fifth percentile, it is hard to recognize unrealistic proportions, whereas proportions in 3D models are immediately apparent. 1D data is relevant when checking single dimensions and comparing these but less so when the 3D and 4D situation has to be evaluated.

2D DATA

To make datasheets easier to interpret Tilley and Dreyfuss combined them with 2D drawings, one of which can be seen in figure 7 (Tilley & Dreyfuss, 1993).

To allow the datasets of different target groups into one visual, Henry Dreyfuss Associates published the *Humanscale* between 1974 and 1981. The *Humanscale Collection* consists of nine 2D sheets of positions with at the side a scroll wheel. The user can change the dataset shown based on their target group (male/female for example) by scrolling the wheel (figure 8). 2D data is more intuitive for its recognizable human shape. It requires no special knowledge on Computer Aided Design (CAD) programs and prevents reading out the wrong value.

The TU Delft's own ergonomics website DINED provides two 2D tools for designing with ergonomic data. Their tool *Ellipse* allows a designer to plot two relevant parameters in a 2D plot to see the spread within the target group, see figure 9. A simple drag and drop allows for making

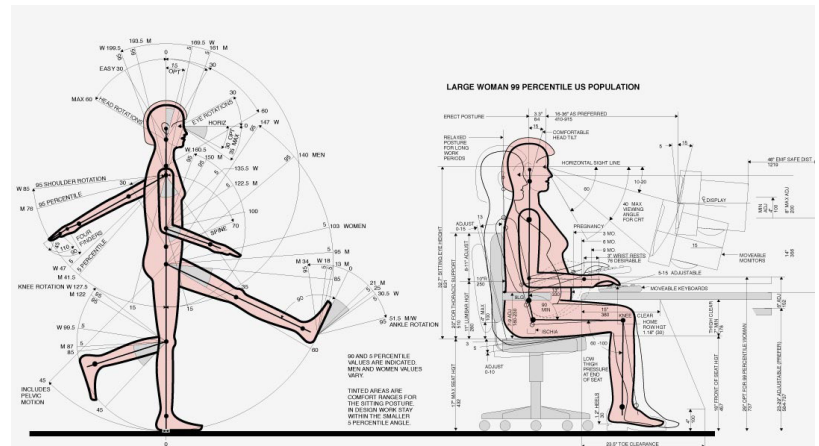


figure 7. 2D datasheet. Image from *The Measure of Man and Woman* (courtesy of Tilley & Dreyfuss, 1993)

quick decisions on size ranges, with the percentage of the target group covered showing immediately. *Ellipse*, with two parameters at a time, does not cover the complexity of designing for the human form, for which 3D models are required.

The other tool from DINED, *Profiler*, was made to compare measurements of a single person to that of a population of people (figure 10). Despite the advantages of understanding diversity (*Profiler*) and being able to quickly determine size ranges (*Ellipse*) these 2D tools, as well as the *Humanscale*, are still based on the outdated data sheets.

The TU Delft's own ergonomics website DINED provides two 2D tools: *Ellipse*, in which a designer can plot two dimensions to see the spread within the target group, and *Profiler*, in which the dimensions of an individual can be compared with the dimensions of the target group.

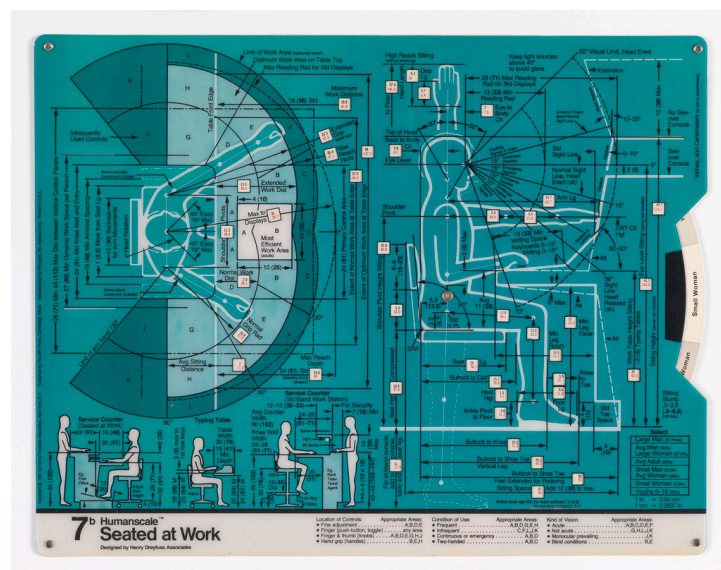


figure 8. *Humanscale* by Henry Dreyfuss retrieved from <https://collection.cooperhewitt.org/objects/51689299/>



figure 9. Ellipse on DINED, the TU Delft ergonomics website showing a plot of reach depth in mm (x-axis) and stature in mm (y-axis) and two size boxes with the percentage of the target group covered.

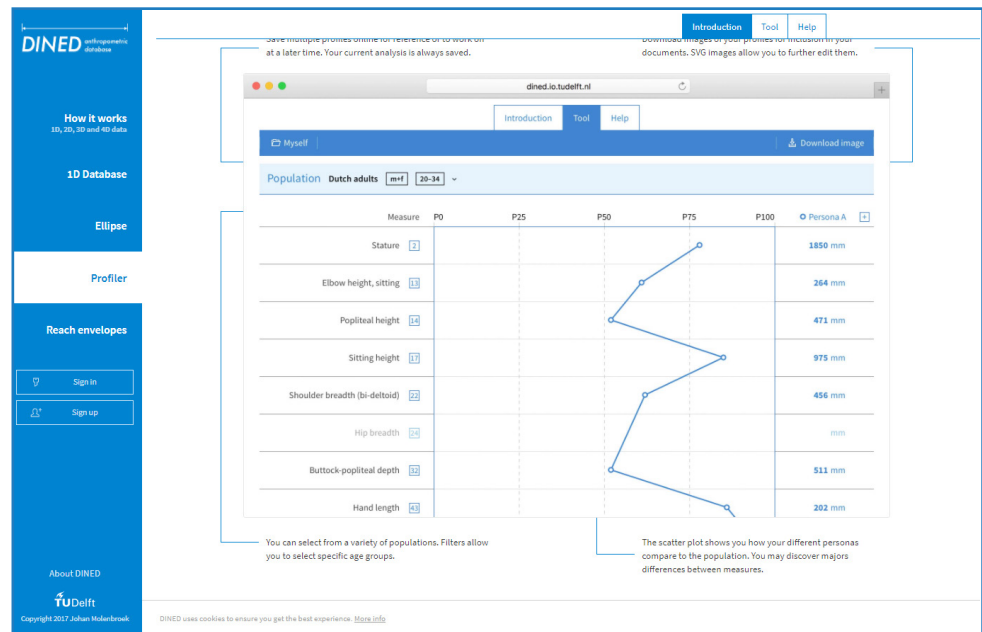


figure 10. DINED's Profiler in which dimensions of a single person are compared with that of a population of people.

3D DATA

Three dimensional models or real test subjects are the most realistic option available at the moment.

User testing with real test subjects requires a sample of representative participants which are difficult to find (Duffy, 2009). From interviews it was found there are design agencies who outsource this search in order to speed up their design process, but especially for smaller design agencies this is not common due to the costs involved. For user testing multiple physical prototypes need to be built as well and the tests need to be conducted, which are both costly and time consuming. User testing with participants is therefore not a good option for quick evaluation of the design.

Digital user testing, making use of DHMs, is gaining importance in human factors engineering and user-centered design (Demirel & Duffy, 2007). Digital user testing is comparatively cheap and quick. DHMs support ergonomics throughout the design process by being available during the whole design process for quick evaluations. Virtually simulating workspaces and human product interactions makes inspecting complex situations possible. DHMs furthermore offer control over designing and analyzing products before they are produced (Demirel & Duffy, 2007) which increases the ability to determine the bottlenecks early on, lowering the time to market (Duffy, 2009). On top of that, DHMs offer a quick way to assess ergonomics and make use of the same skills as required for 3D modelling software (Duffy, 2009). DHMs are, however, also based on percentile information, and therefore give the same problems when designing as stated before [2.2].

On the whole, 3D DHMs seem the most interesting option for visualizing anthropometric data.

3D DIGITAL HUMAN MODELS

One of the first DHMs, SAMMIE, was originally developed by Maurice Bonney and colleagues at Nottingham University (Chaffin et al., 2001). DHMs like SAMMIE but also COMBIMAN and Kilpatrick (see figure 11) show great comparison with the physical tools of Tilly and Dreyfuss (see figure 7 and 8). The first 3D models existed from wireframes indicating the centerline and outlines of the body shape. Later on the 3D shapes got “filled” to be more easily understood and many more DHMs were developed (figure 11).

DHMs can be separated in three main directions: safety assessment (like MADYMO and 3D SSPP), human performance (for example COMBIMAN, DELMIA and Santos) and anthropometry (like Konings 3D Mannequin, MIDEOS and AMIE(E)).

Both Human performance and safety assessment DHMs are very accurate and complete. As a result, these DHMs are also expensive and complex in use. Santos (figure 12) for example, was developed for the army and has a full biomechanical database. It calculates every movement of the body with respect to muscle activity and can even predict behavior. The complexity of the tool requires users to be experienced with the software. The calculating time of such predictions makes it unfit for quick iterative ergonomic assessment. Such tools are therefore less interesting for designers.

Anthropometric models are usually light and work within CAD programs used by designers. The two latest anthropometric DHMs, made by students of the TU Delft, are MIDEOS and AMIE(E). These DHMs were designed solemnly for the use by designers for ergonomic purposes. AMIE(E) works within Solidworks, a popular modelling software for engineers. It has three drawbacks, the first is the absence of an educational aspect, making it only useful for those with perseverance and intrinsic motivation (Blom, 2015). Secondly, research on the tool proved that AMIE(E) is hard to position and requires a manual or tutorial in order to be understood (Blom, 2015). Finally, AMIE(E) was only available with a female appearance.



figure 12. DHM Santos lifting a block.

MIDEOS did not feel intuitive and some test users even got frustrated (Schaefer, 2011). Both models only provided one dataset, yet *MIDEOS* offered the option of feeding it new information.

Expanding the database is interesting for companies that want to create their own database or switch between existing datasets.

Both DHMs showed a human shape but neither of them was based on real humans. Their modelled shapes give a certain unhuman look to the model which made it difficult to detect impossible postures. *MIDEOS* relied on the designer to detect these postures, giving no feedback on the range of motion.

Existing realistic DHMs are usually for art, apparel or the movie and gaming industry. DHMs like *Poser v11* (see figure 13) are highly realistic, yet not based on human dimensions. These DHMs have no scientific significance since their dimensions and movements are not based on anthropometric research. Their only purpose is to look as realistic as possible.

Poser v11 is a so called parametric model, which means that adjustments can be made later on, like the amount of muscles or fat which can be adjusted or the adding of fantasy body structures (horns, wings, bigger eyes etc.). To make these tissues move realistically BodyLabs is working on digitizing soft tissue deformations (Pons-Moll, Romero, Mahmood, & Black, 2015). The model is built from statistical analysis of high-resolution 4D data and can be added to different DHMs. All the while it is controllable and can thus be adjusted to fit fantasy characters.

A scientific approach to bodily deformations is currently being worked on by Charlie Wang, a PhD at the TU Delft faculty of Industrial Design Engineering. Charlie Wang plans on using bijective mapping and volume parametrization to realize this (Wang, PhD Inauguration, 24-02-2017).

Soft tissue deformations are interesting for designers as they indicate contact areas between user and product.

Concluding, 3D DHMs aid quick evaluation and provide 3D/4D information on anthropometry and are therefore the most informative tools available. Unfortunately they are still based on outdated data, expensive and positioning the DHM is complex.



figure 13. *Poser v11* model rendered by Joachim Lopez (2014) retrieved from <https://goo.gl/images/TscdBi>

Realistic DHMs are used in the movie and gaming industry. Despite their realistic appearances they are usually completely computer generated.

These models can therefore not be used for ergonomic product assessment as they are not based on scientific data.

the development in

Digital Human Models

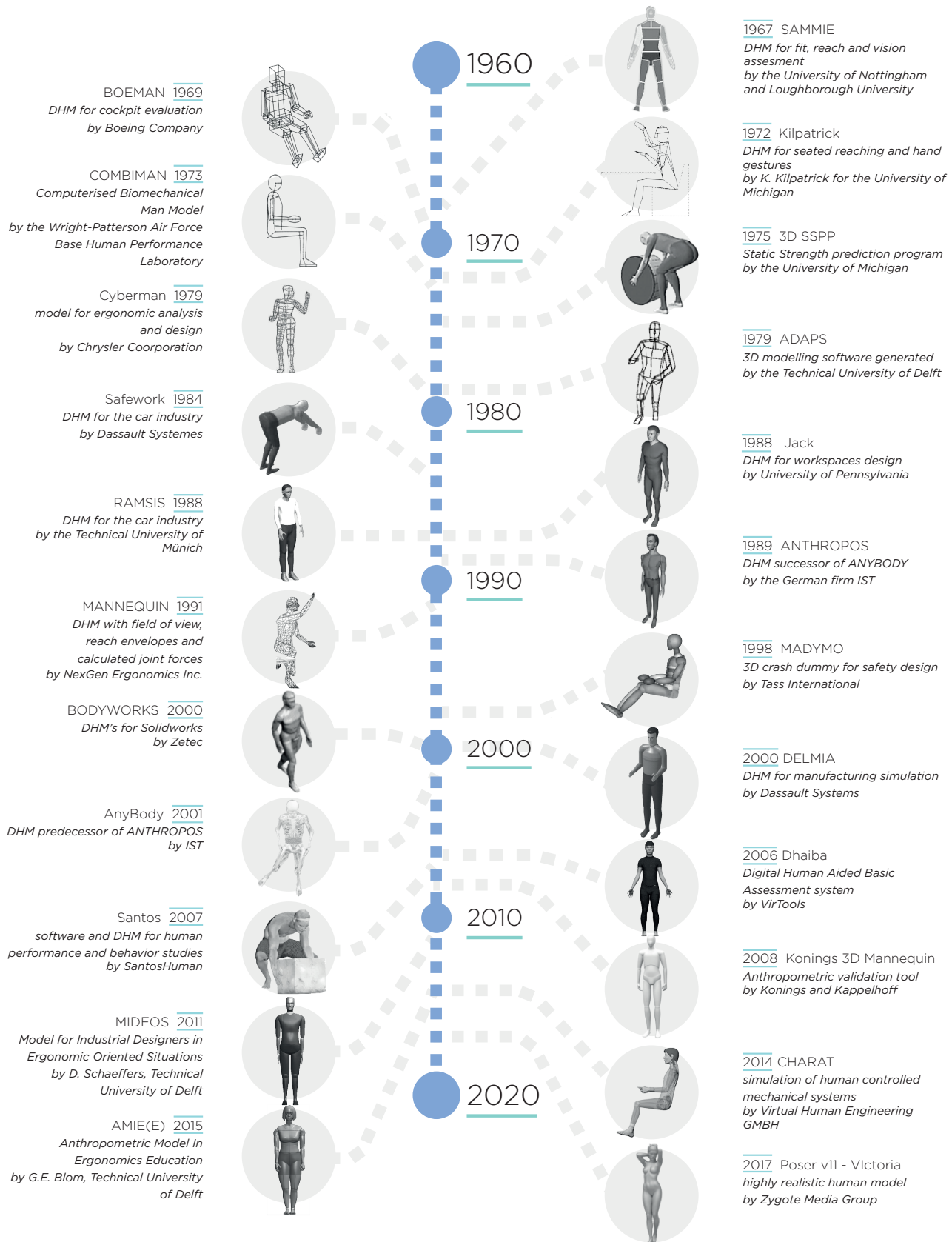


figure 11. Overview of the developments of DHMs from the 1960's till now.



2.4 3D SCANNING

New information on bodily dimensions is being gathered through 3D scanning (Robinette et al., 1999). A 2003 research proved that 3D scans are as good or better in terms of accuracy than anthropometric measurements done by hand (Robinette & Daanen, 2006). 3D scanning can thus be used for gathering anthropometric data and help renew outdated datasets.

3D scanned data still needs to be converted to DHMs for use in CAD programs in order for designers to be able to take advantage of it (Veitch et al., 2009).

To understand the qualities of 3D scanning some background on this technology was gathered.

HISTORY

3D scanning is the act of digitizing a real life object or environment. In the 1960s the first 3D scanning technology was developed using lights, cameras and projectors for scanning. The need to efficiently recreate surfaces of objects and places came from research and design, yet equipment at the time made it difficult and time consuming to accurately scan. In 1985 contact scanning got developed and can still be used for reverse engineering (in which a product is reproduced or a design is made based on the extracted information) (Sokovic & Kopac, 2006). The probe used for contact scanning dents soft and fragile objects and is slow in comparison to methods using light, which is why optical scanners are usually preferred. In the 80s, optical



figure 14. Artec Eva 3D scanner. retrieved from <https://goo.gl/images/m7jXdV>

scanners were still extremely expensive, inaccessible and difficult to deal with. It was not till the come of the 90's REPLICA scanner that it became possible to fast and accurately scan detailed objects. Not much later in 1996 the scanner Model Maker allowed simultaneously capturing the colors of objects and their surface. Advancements since then have made 3D scanning more accessible than ever, with the famous Kinect 3D sensor available for less than €120 in 2010 (D'Apuzzo, 2017a).

3D scanning has been very popular within the entertainment industry for the production of games and movies such as Abyss (1989) and Benjamin Button (2009) (D'Apuzzo, 2017a). In design and engineering the use expanded from reverse engineering, in for example medical design

(Hieu et al., 2005), to also being used for the collection of anthropometric data (figure 14).

When using 3D scans for the collection of anthropometric data, the accuracy can still differ from measurements taken by hand. Some known causes are measuring tape pressing into the soft human tissue, whereas the optical scan does not deform the body (Paquette, 1996), and irregularities while scanning, like breathing.

Despite the current interest of designers into 3D scanning, there has not been a successful tool made for designers to take advantage of this more complete anthropometric data. Current designs based on 3D scans aim at personalized products like Exo-L (figure 15), a company that makes personalized ankle braces based on

your 3D scan and Mesh Lingerie (figure 16), a company 3D printing bra support based on your 3D scan. Exo-L explained in an interview that they use the 3D scan to extract 1D and 2D data.

Projects in which mass market designs were based on 3D scans are fewer and less commercially founded, like the project on designing Airforce masks (Lee, Jung, Park, Kim, & You, 2014), a hip protection for Asian elderly (Ball, 2009) and head forms for US military helmets (Zhuang, Benson, & Viscusi, 2010) which had to rely on their own (experimental) method of interpreting the scan data.

Another use of full body 3D scans by designers is making renders for which models can be found all over the internet, with the simple for free and the more advanced moveable models expensive

With the rapid increase in popularity of 3D scanning, Nicola d'Apuzzo from Hometrica realistically states there is currently a lack of instructions on how to use the scanners and software and a lack of ethical guidelines on usage of scans made (D'Apuzzo, 2017b). On top of that the usage and interpretation of 3D body scan data has not yet been standardized nor has there been any other type of guidance to designers on how to work with them. The new ergonomics tool should therefore create an easy use and interpret way of working with 3D scanned anthropometric data.

HOW IT WORKS

There are different types of 3D scanners available today which range from phone applications and handheld devices to whole static setups. The types of 3D scanners work differently and can be classified based on their physical principles ("3D scanning technologies and the 3D scanning process," 2018) for which it is up to the user to decide which technology works best in the given situation.

Laser triangulation 3D scanning

technology A laser projects on a surface and measures the deformation of the laser ray.

Structured light 3D scanning technology

Measures the deformation of a light pattern on a surface to 3D scan the object.

Photogrammetry Reconstructs a 3D subject from 2D captures (photographs) with computer vision and computational geometry algorithms.

Contact based 3D scanning Technology

Relies on the sampling of several points on a surface, measured by the deformation of a probe.

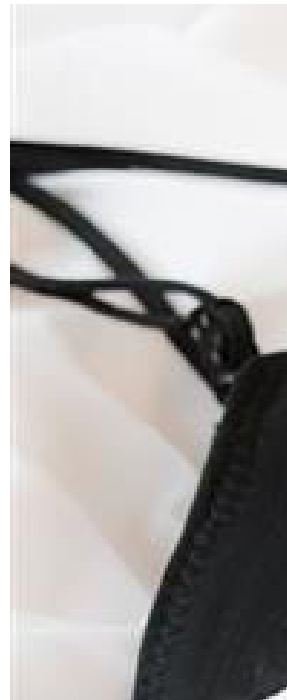
Laser pulse (also called time of flight) The laser beam is projected on a surface and collected on a sensor. The time of travel of the laser between its emission and reception gives the surface's geometrical information.

OPPORTUNITIES

Designing based on 3D scans is becoming more common and with success. As Robinette & Hudson state, 3D scans offer improved accuracy which aids complex design solutions for wearables and apparel (2006). 3D scans are also interesting for gathering anthropometric data as the scans hold all the exact bodily dimensions which can be extracted any time later on.

With scanners becoming more readily available it will also be possible for companies to set up their own data collections, allowing companies like DAF Trucks to build their own specific database of truckdriver DHMs. Keeping the complete scan intact will furthermore prevent wrong interpretation of percentile models. On top of this, a more lifelike model could improve correct interpretation of the data as humans are prone to recognizing impossible postures when presented in 3D.

The new ergonomic tool will therefore make use of 3D scans for making a DHM.





25

figure 15. The Exo-L ankle brace is based on your personal 3D scan and prevents spraining your ankle. retrieved from <https://goo.gl/images/xRozBG>



figure 16. Meshlingerie bra's are produced after the design is adjusted to fit the form of your breasts through the use of 3D scans. retrieved from <https://goo.gl/images/mjxwGB>

2.5 VISUALIZING 3D DHMS

3D visualization of 3D DHMs could solve some of the difficulties of positioning DHMs which would improve usability of the tool. Currently the only two commercially used methods are Virtual Reality (VR) and Augmented reality (AR). VR is a computer interface that strives to immerse the user completely within a computer generated simulation, providing a much more intuitive link between the computer and the user (Mujber et al., 2004). AR covers a range of technologies or devices that provide an overlaid virtual environment to the user (Lanham, 2017). VR is based on the illusion of being in another space and time while in AR you stay in your physical world in which the virtual enters through digital glasses, smartphone, tablet or other means (Papagiannis, 2017). While AR does not require building a virtual world, like VR does, it is more difficult to create regarding good usability and leaves many challenges for proper rendering and user interaction. A medium where the environment is easier to create and control is therefore preferred. With the goal of this thesis in mind, the decision was made to use VR as a 3D visualization method.

2.6 VIRTUAL REALITY

The intuitive link between computer and user is what makes VR interesting when designing a new ergo-nomic tool, as positioning 3D DHMs on a 2D interface is complex. Information was gathered on VR to gain understanding of the technology.

HISTORY

Even though it may sound futuristic, the basic concept of Virtual Reality (VR) originates from 1832. In this year sir Charles Wheatstone created in depth images by presenting both eyes a slightly different image and called his invention the Stereoscope. This same principle is still used in 3D movies today through glasses with either differently polarized lenses or colored lenses (figure 17).

In 1960 a more immersive form of VR was created by Morton Heilig with his Sensorama in which users experienced a pre-recorded 3D movie enriched with stereo sound, motion, wind and aroma's (figure 18). Despite covering many senses, there was no interaction between the machine and user yet.

It took up to 1968 till the widely considered first Head Mounted Display



figure 17. Image of a girl looking at a 3D movie through a red and blue lens, based on the invention of sir Charles Wheatstone in 1832. Retrieved from <https://goo.gl/images/q4yf9e>



figure 18. The Sensorama, a 3D video machine with stereo sounds, motion, wind and aroma. retrieved from <https://goo.gl/images/HZfQLw>

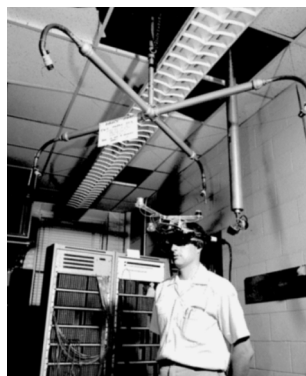


figure 19. The Sword of Damocles, the considered first Head Mounted Display. retrieved from <https://goo.gl/images/9kNyqj>

(HMD) system was created by computer scientist Ivan Sutherland and student Bob Sproull. Depicted were only simple wireframe boxes but the user could already depend the perspective on the position of their gaze with head tracking. In order to track the head a large mechanical arm was connected to the HMD (figure 19) causing the system's name "the sword of Damocles" after Greek mythology. As the cubes were presented like a layer on top of the real world it can best be described as an AR experience.

VR technology as we know it now, with a HMD that takes over your entire field of view, was first brought to the public in the 1990s when it was used in arcade games. It was also in the nineties that the Virtual Boy, one of the first home systems, was brought to market by Nintendo. It never became a big success because of discomfort in use and the lack of games and color (Brown, 2017).

Around 2009 Volkswagen Commercial Vehicles developed a VR prototyping system in which the participant sits in a real driving seat while wearing a HMD and feeling located in a virtual car. The participant could steer through a virtual city which allowed the visual conditions of the instrument panel and environment to be tested (Ma, Gausemeier, Fan, & Grafe, 2009) giving a good example of early VR in design.

Big public interest was only triggered in 2012 with the Kickstarter project of the oculus rift ("Oculus Rift: Step Into the Game," 2012) which managed to create a plug-and-play compatibility accessible for

the average computer user while offering interaction with the virtual environment.

Since the success of the Oculus, companies all over the world began building their own VR headsets, causing huge developments to happen (Brown, 2017). 3D graphics are becoming better and processing power is still increasing at an exponential rate which will further improve the quality of VR.

HOW IT WORKS

The HMD, or phone, tracks the angle of the user's head such that the virtual world follows his, her or its gaze (Craig, Sherman, & Will, 2009). Some VR sets also track movement through space, allowing the user to jump, duck and walk around on top of turning their head. Examples of such systems are the PlayStation VR, Oculus Rift and HTC Vive. Different types of HMDs can be seen in figure 21.

The virtual world you see in VR is pre-built in special software, usually either Unity or Unreal Engine. A photorealistic image from the 3D scenery is being rendered in real time to match the angle of your gaze.

All VR projects focus on the HMD and hands with the rest of the body neglected. Most of the time, the hands interact with the virtual world through physical controllers. These controllers have location trackers and buttons. Another more immersive option is the Leap Motion, an add-on for the HMD that captures hand movements in real time. Other attempts at seamless integration of hand gestures are the thesis project of Tim Bakker, who made a controller that provides haptic feedback (Bakker, 2017) and Adjuvo Motion (figure 20), a company working on a glove for orthopedic rehabilitation by reading out the input you give by moving your hand (like speed and pressure). Both



figure 20. Trying out the MarkV prototype of Adjuvo Motion at YES!Delft.

tools make intuitive grasping and lifting of objects possible.

There are also examples of set-ups that include more body parts, like some sort of bed that makes the user feel like he, she or it is flying or straps with trackers for your legs to be able to kick and play soccer. These set-ups are however not common yet.

So the whole body can be included in VR interaction design. It is also possible to have multiplayer games in which you see a moving avatar instead of the other player, but is still in its infancy.



figure 21. Different types of HMDs under which the google cardboard and oculus rift. retrieved from <https://goo.gl/images/UqFpmq>

OPPORTUNITIES

Compared to Solidworks models and other 3D modelling programs, VR allows a more realistic way to digitally user test products by offering the user of the HMD to look around on eyelevel and walk around objects. Being able to walk around products and product user interactions makes interpretation of anthropometric data easier.

There are also possibilities to go first person perspective and look from the eyes of the DHM which is thought to be helpful when designing car interiors and was also included in earlier DHM ADAPS.

During observations at VR events (appendix 1) it was seen that the learning curve of working with VR is steep, with a low threshold for first time use caused by the intuitive interactions possible in VR. Because of its plug-and-play accessibility VR is easy and quick to set up and works seamlessly with CAD programs often used in design engineering. VR is also becoming increasingly affordable, causing easier access to VR hardware. The VR software is mostly free downloadable.

Anthropometry has not been communicated through VR.

Virtual Reality seems promising as a means to visualize 3D DHMs. Interaction designs made with VR tend to be intuitive and easy to learn.

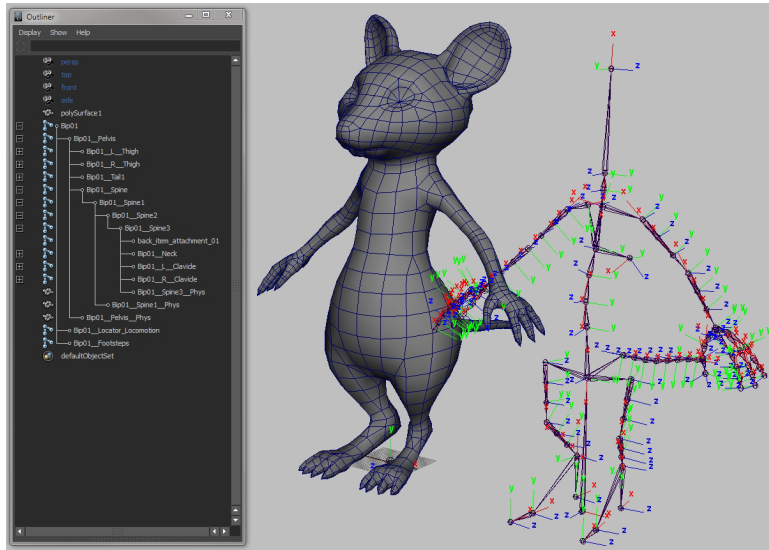


figure 22. A rig built for a mouse character. On the left the bone hierarchy can be seen, on the right the skeleton outside the mesh. retrieved from <https://goo.gl/images/B3SXzV>

2.7 FROM 3D SCAN TO MOVEABLE MODEL: RIGGING

In order to use a 3D scan as DHM, it needs to be moveable. Turning mesh models (digital models of which only the outer surface is known) into mannequins can be done through a method called rigging, which is used a lot in the gaming and movie industry. Rigging is connecting a motion controlling skeleton to a surface or skin (Lunström, Case, & Högberg, 2010). As the website Lifewire explains “A character rig is essentially a digital skeleton bound to the 3D mesh” (Slick, 2017). Just like a normal skeleton, a rig exists of joints and bones which are at the same time handles with which animators, or in this case designers, can bend the character into different poses (figure . Joints should be placed where they would be located in real life with one exception, in the digital world there is a joint hier-archy which has to be taken into account. In order for the rig to function properly, both joints and bones need to follow this hierarchy. It starts with placing the root joint to which all other bones are connected, either directly or indirectly.

There are two ways to calculate joint movement of a fully rigged character. The first is called Forward Kinematics (FK) and causes the bones lower in hierarchy to respond to movements made higher in the hier-archy (Ritchie et al., 2005). This way the designer can pose the character bottom up, starting at the root and moving his way outward to the fingertips for example. The final position of the fingertips is then calculated as a function of the joint angles of every joint above it in the hierarchy.

The other way to calculate joint

movement is called Inverse Kinematics (IK) and is essentially the reverse from FK because the terminating joint is directly placed while the joints above in the hierarchy are interpolated by the software (Ritchie et al., 2005). You could compare this with pulling someone his finger and seeing the effect on the total body because of it. The “chain” of connected bones and joints will follow the pull, resulting in a more lifelike interaction between user and DHM.

The total adult body takes up 206 bones of which many are located in the hands and feet (D. & Bramblett, 1988). For every human this is pretty much the same. The range of motion of the joints however are dependent on genetics, age, ethnic background, gender and physical exercise (if not more) as they depend on bone shape, muscles and tendons. The maximal movement of the joints are important for setting up joint constraints in the case of building an ergonomic model, whereas the “as long as it looks good” usually applies for the game and movie industry.

Once the body is rigged and the skeleton has IK/FK constraints, the mesh will have to be bound to the skeleton in order to follow the movement of the bones. When “binding the skin” the body parts will automatically be weight painted, given an indication of which part of the mesh should move along with the positioning of a bone, but not necessarily move smoothly. Parameters can be adjusted to make the DHM move more realistically.

Rigging is a method often used in the game and movie industry.

A subjective estimation of the bodily deformations is added to the mesh. Charlie Wang is a PhD currently working on a scientifically sound way to imitate bodily deformations.

2.8 CONCLUSION LITERATURE STUDY

3D DHMs offer the best visual representation of the complex 3D/4D situation that is being designed for.

Addressing 3D/4D usability issues on a 2D screen is complex, which is why the decision was made to use the medium VR for building the tool. VR offers 360 degrees viewing angle and allows for walking around the prototype allowing intuitive digital ergonomic assessment.

The import of 3D CAD modelled prototypes will be easy because of the compatibility of VR with popular CAD programs as SolidWorks, MAYA and Rhinoceros.

The DHM will be based on 3D scans as correct digital ergonomic assessment can only be done with 3D data of real people. In order to be able to position the DHM, the static 3D scans will be turned into 4D DHMs through a method called rigging.

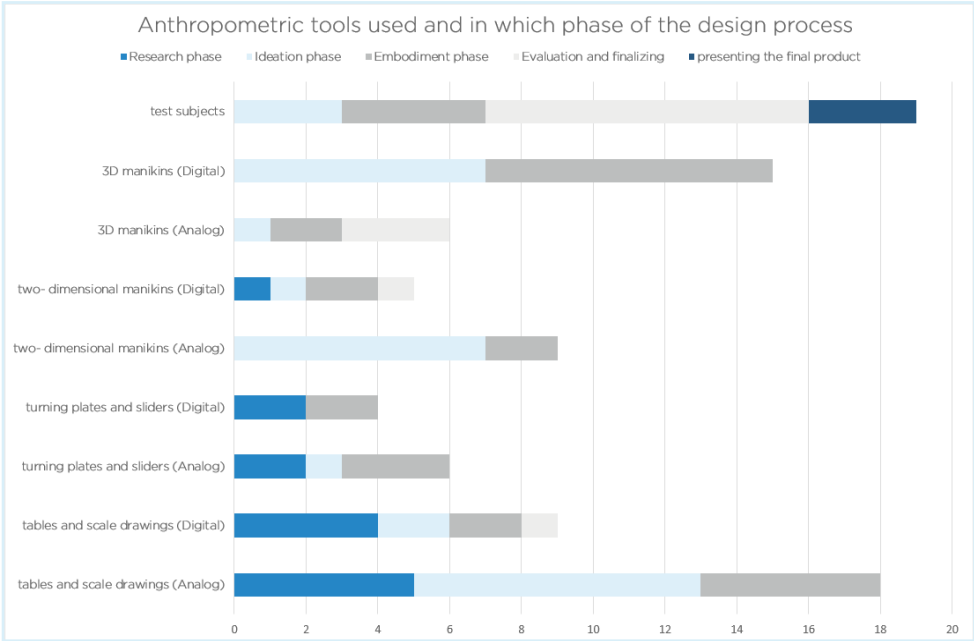


figure 23. Results from the questionnaire showing which anthropometric tools are used in which phase of the design process. (x-axis shows how many times a certain tool was chosen)

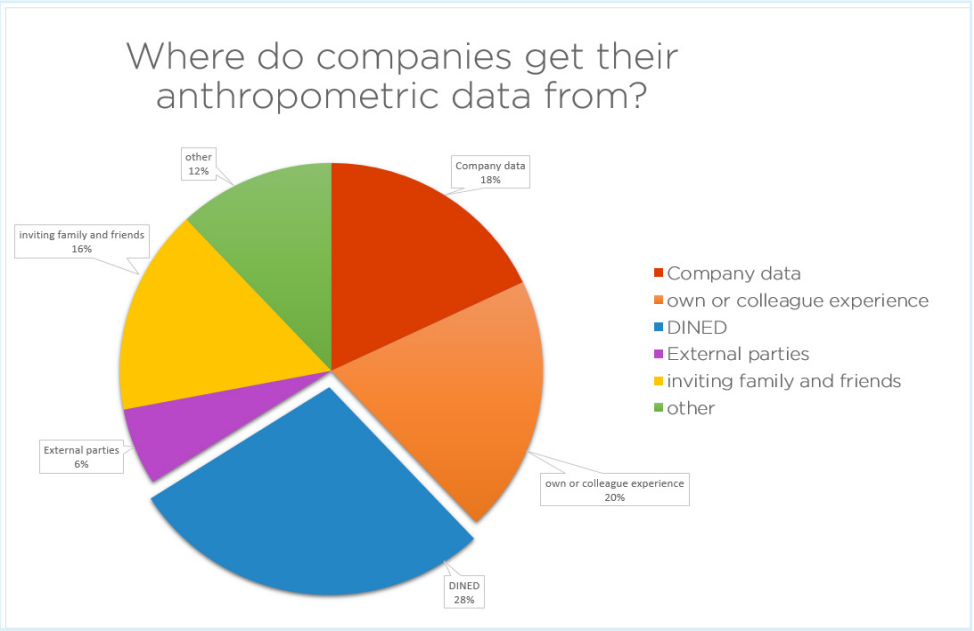


figure 24. Results from the questionnaire showing where companies get their data from.

3.0 | FIELD RESEARCH

3.1 GENERATIVE RESEARCH

The target group for the tool are product designers. A diversity of (design) engineers was approached during the business events Delftse Bedrijven Dagen and the Industrial Design Engineering equivalent IOB (IO Bedrijvenbeurs).

Not only design engineers from design agencies but also from companies like ADSE (who make private airplane interiors) and DAF Trucks were interviewed and asked to fill in a questionnaire. This way a broad image of the design field and how multiple designers might require different functions from the tool could be identified. The main findings from generative research are listed below.

Interesting outcomes generative research:

- // Cross sections are interesting when designing
- // Tool needs to be back- and forth compatible with Solidworks and other popular CAD programs
- // Being able to change the positions of the DHM
- // the DHM needs a graphically generic look
- // Possible to make the model move (follow a path)
- // Make one model visually correct

(colored) for renders

- // Hands and head more detailed
- // Small companies need to work quick and dirty (bigger companies have time and money available for research and Design) and the tool should assist this approach

3.2 QUESTIONNAIRE

The questionnaire was sent to 23 designers with the request to send it forward to colleagues. Eventually 21 respondents filled in the questionnaire. The questionnaire results, figure 23 and 24, showed that test subjects are still most popular, but digital 3D DHMs are used often as well. Interesting to see is that 3D DHMs are used during earlier phases of the design cycle than real test subjects. The results also show that during the research phase 1D and 2D models are more popular.

During the generative research a lot of designers showed interest in using a 3D DHM for presenting the final design, yet the questionnaire results show no signs of DHMs being used for this.

From the questionnaire results we can furthermore conclude lot of information is collected from non-scientific sources as can be seen in figure 24. More about this research can be found in appendix 2.

3.3 INTERVIEWS WITH DESIGN PROFESSIONALS

Seven in depth interviews got held to see what a design process looks like within different companies. Six participants were part of the participants that filled in the questionnaire, one participant was approached through contacting Exo-L for their expertise in designing based on 3D scans.

Interesting conclusions:

// There is a quest for simple 3D DHMs
 // The tool should be easy accessible
 // Compatibility with current CAD programs is important
 // It should be cheap
 // VR is interesting to showcase to clients
 // Adjusting the prototype inside VR would be great
 // 3D scans would be nice for quick evaluation and prototyping but data sheets are better for variation of data
 // Designers have to deal with a lot of regulations when designing as well
 // The force a human can deliver in certain postures is interesting to know
 // Reach and lengths are most important when designing
 // Data needs to be referenceable to convince clients of its worth
 // Checks are done on geometry and comfort
 // The tool should actively support the designer during the design process
 // Field of view is interesting for designers
 // Preset positions of the body makes working easier

3.4 CREATIVE SESSIONS

Co-design is a strategy in which the target group is invited to think along during the design process. It helps form the final product which raises chances of becoming implemented (Sanders & Stappers, 2008). In order to let the user group, designers, in on the problem creative sessions were held. Creative sessions are guided sessions to initiate and stimulate the search for creative solutions to a problem.

Four creative sessions were held simultaneously for which four session leaders were chosen to lead teams of six participants each. The sessions tried to solve one of the following two problems:

- > **Ways to position the model in VR**
- > **How to get dimensions from the model in VR**

The leaders and the participants were TU Delft Industrial Design Engineering Master students. Most of them had not yet experienced VR and many were unaware of current DHMs which, together with their design background made them unique participants for such a research. Their lack of prior knowledge enabled them to explore without being hindered by the boundaries of the technology. Some pictures from the session are shown in figure 25 and 26.

From the sessions, some very interesting results emerged. The main findings are listed below.

Ways to position the model in VR

// Special function for grabbing of the whole hand instead of the phalanges per phalanx
 // When moving one part of the body the rest follows
 // Select what you want to move, then move your hand
 // When moving a *pop-up* with pre-set postures appears
 // Feeling resistance when moving past the degrees of comfort
 // Slower movement towards the limit of the range of motion
 // A circle showing the range of motion in green, the rest in red
 // Face of manikin shows discomfort when moving to the edges of the motion range
 // Controllers vibrate when the posture is impossible
 // A relax button to return to a standing posture
 // One controller to determine what stays the same the other till where it will move
 // Preset positions available
 // A real manikin that can be postured to which the digital model will respond

How to get dimensions from the model in VR

// Measurements appear when your gaze is at it
 // You have a toolbox, select and drop a measuring tool
 // Select two points *pop-up appears* choose circumference or length for example
 // Drag a ruler (for example, but other tools available too) and drop at the area you want to measure
 // Move real life doll which will tell you the degrees



figure 25. Multiple pictures from the creative sessions held. Clockwise, starting at the top left image: positioning each other as if a DHM, "DHM" mirrors the user, ideation, having fun during the sessions and finally discussing and clustering ideas.

3.5 CONCLUSION FIELD RESEARCH

Field research found that the two main necessities when designing are dimensions and reach. Cross sections are being used by Exo-L and provide them insights into the shape of the body when designing.

The creative sessions led to the idea of using both hands to position the model as it was easy to teach and perform when acting out. During the sessions IK constraints got seen as effective and realistic.

For joint limitations a visual type of feedback was come up with, in which green was within the limitations and red beyond.

Measuring the body proved a bit more difficult. Eventually a separate toolbox with tools like a geo triangle that could be dropped at a joint was thought. This solution however did not give room for the designer to measure distances from the mesh, but only from the joints.



figure 26. Two participants of the creative sessions position each other as if a they are working with a DHM.



figure 27. The HMD of the HTC Vive.
retrieved from <https://goo.gl/images/8SVSf5>

4.0 | LIST OF REQUIREMENTS

Findings from both the literature and field research led to the making of a list of requirements. Based on the **MoSCoW** method a prioritization was made. The categories of this method are must have (which are critical for success of the design), should have (important but not necessary), could have (desirable but not necessary) and finally won't have (this time) (least critical, not appropriate at the time).

The final design should at least meet the must have requirements and preferably some of the should have and could have as well.

Must have

- // Gives continuous feedback
- // intuitive interaction between user and DHM
- // Easy to position
- // Easy to interpret
- // Quick in use
- // Estimate dimensions easily
- // Compatible with 3D modelling programs
- // Allows adding own datasets
- // Styled for presenting products to clients
- // Easy understanding of the implications of the method/tool used

Should have

- // Realistic appearance
- // Impossible postures should be easy to detect
- // Somewhat realistic bodily deformations
- // Cheap
- // Shows the percentile per body part
- // Taking pictures in the tool

Could have

- // Able to make cross sections
- // Able to see silhouette only
- // Seeing from first person perspective in the model
- // Tutorial on how to create your own database (for companies)
- // Student (and/or company) guide how to use the tool
- // Adjust product within tool

Won't have

- // Correct bodily deformations
- // Ethics guide on 3D scanning/scans
- // Automated rigging script

5.0 | DESIGN PROPOSAL

The focus of the design proposal lies on the intuitive interaction between user and DHM. The tool makes positioning 3D DHMs easy and anthropometric data insightful, assisting designers throughout the design process. It makes use of 3D scans for more realistic and easy to interpret DHMs.

VR is used as medium to bring together 4D DHM and CAD models of prototypes that need to be tested.

The Wireflow method was used to visualize the interaction design. Wireflows are a combination of wireframes (figure 28) and flowcharts (figure 29) which are popular in the User eXperience (UX) field (Laubheimer, 2016). As the VR interface design has no unique pages but only content based on user interaction, wireframes or flowcharts alone would be suboptimal.

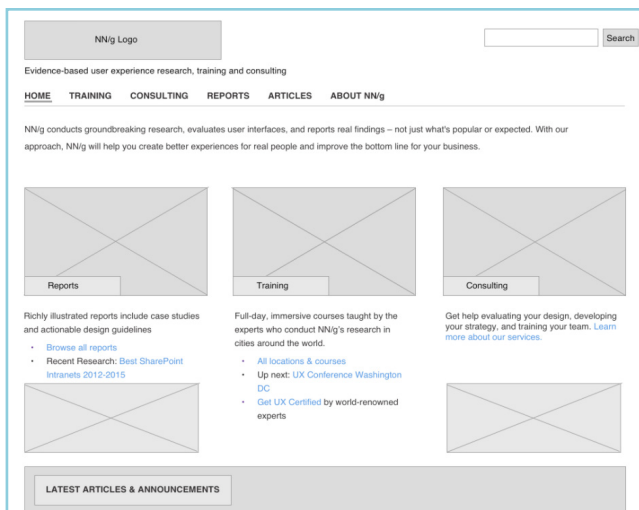


figure 28. A classic wireframe example.
retrieved from nngroup.com

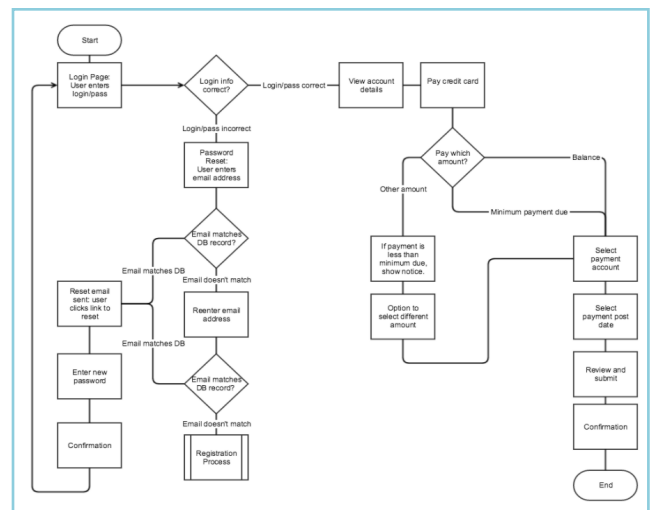


figure 29. A classic flowchart example.
retrieved from nngroup.com

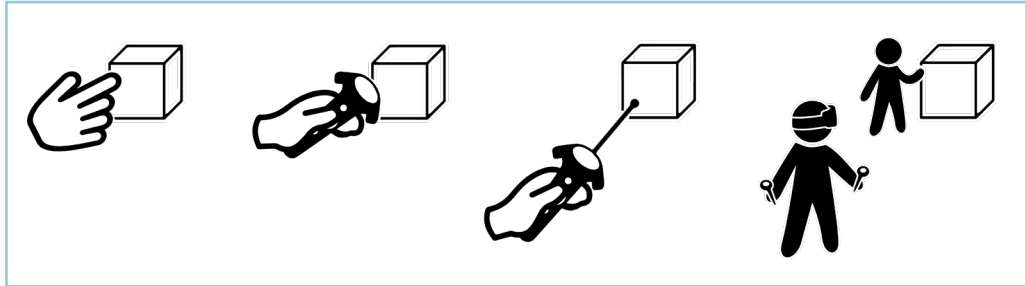


figure 30. The four modes of interaction. From left to right: direct user control, physical control, virtual control and agent control. figure based on an image from the book *Understanding Virtual Reality* (Sherman & Craig, 2013, p.287).

5.1 INTERACTION DESIGN PROPOSAL

Manipulations in VR can be accomplished by using one of the four forms of manipulation, as named in the book *Understanding Virtual Reality* (see figure 30) (Sherman & Craig, 2013). To stay close to reality and make the tool as intuitive as possible [3.4] the ideal form of control would be direct user control in which the user interacts with objects in the virtual world as they would in the real world. The least attractive option would be agent control as it does not require any physical activity from the user, losing the advantages that VR offers. The hands on approach requires a special set up not yet readily available at the TU Delft such as Leap Motion or Manus VR [2.5]. The tool will therefore make use of so called physical control in which physical controllers give the user haptic feedback from pressing buttons and moving the controllers around.

The envisioned experience for the user can be seen in figure 31 and 32.

The scenario for the user is as follows:
figure 31 // Designer is working on a prototype CAD model. Dimensions are difficult to estimate on a 2D screen. The designer saves the prototype in the VR folder and goes to DINED. Here the designer selects one or multiple DHMs that are representative for the target group and saves them to the VR folder. The VR engine is started and the DHM(s) and CAD model loaded.

figure 32 // The designer then puts on the HMD and the following options: positioning the DHM, measuring length, measure angles and walking around the model.

The designer can use these functions to evaluate the product and go back to the CAD program to adjust the CAD model based on these newly found insights.

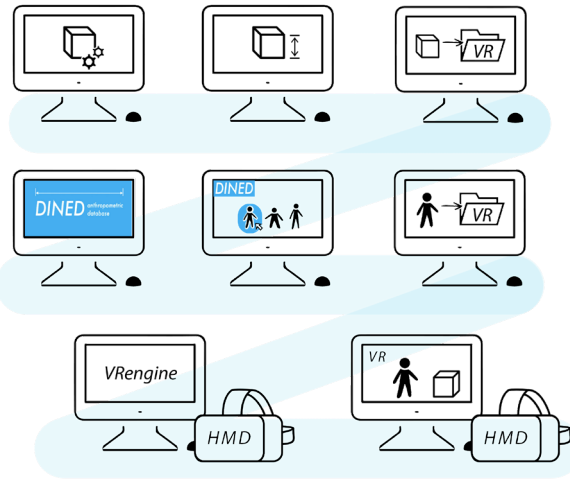


figure 31. Scenario for a designer from CAD model to using the VR tool.

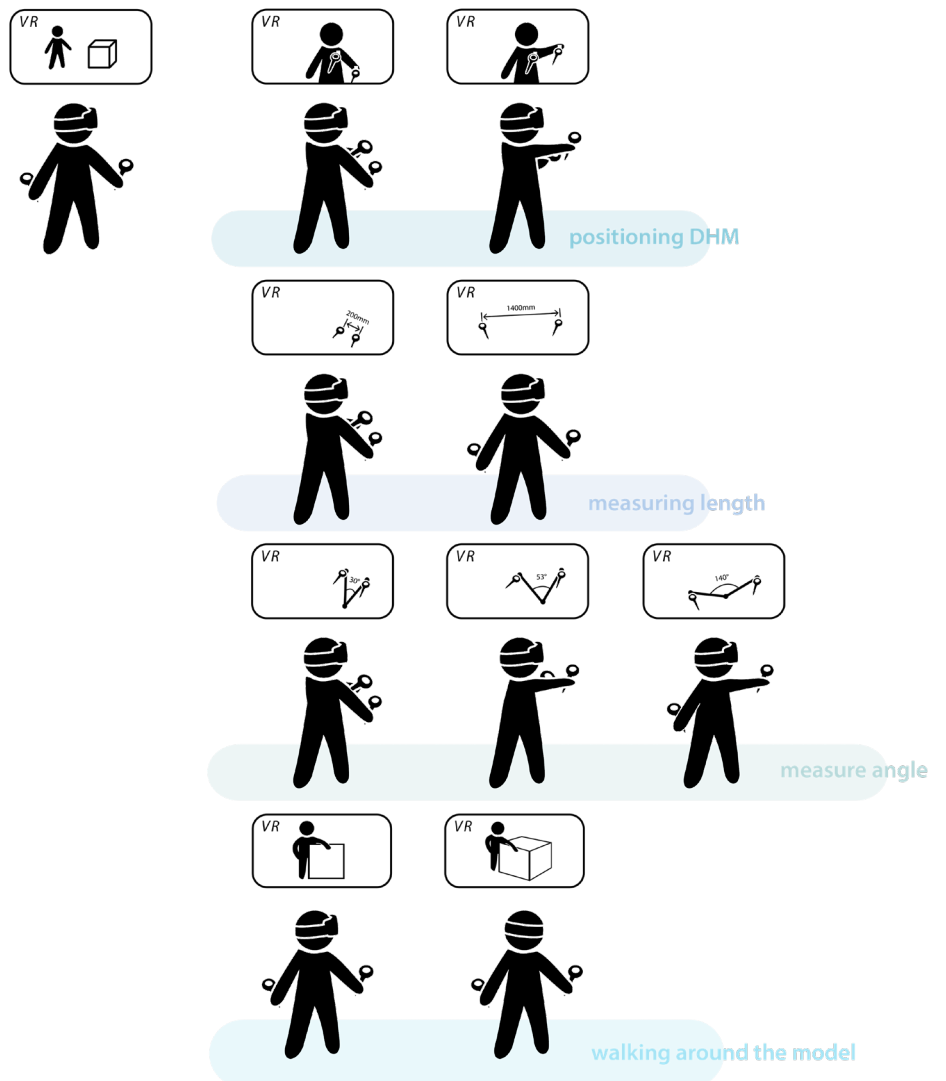


figure 32. The main functionalities for the designer inside VR.

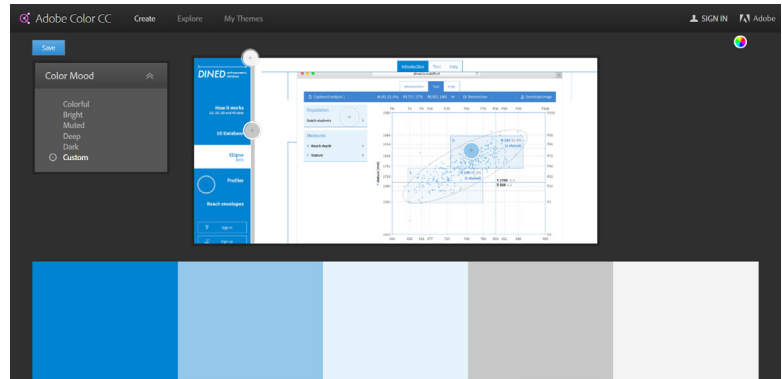


figure 33. Adobe Kulor was used to select the colors of the DINED homepage.

5.2 EXTRA FUNCTIONALITIES

Besides making the DHM easy and intuitive to position, there are some other functionalities that are interesting for designers[4]. Making renders of the user – product interaction will be made easy by building in a snapshot function, saving designers a lot of time when photoshopping renders (Flex, appendix 3).

Saving postures will help speed up ergonomic assessment between iterations and in cases where designers work with similar products a lot (DAF, appendix 3).

An indication of the degrees of freedom of the joints should prevent unrealistic postures without solemnly relying on the designers experience or knowledge on the matter [3.4]. These are not necessary for the tool but would increase usability for designers.

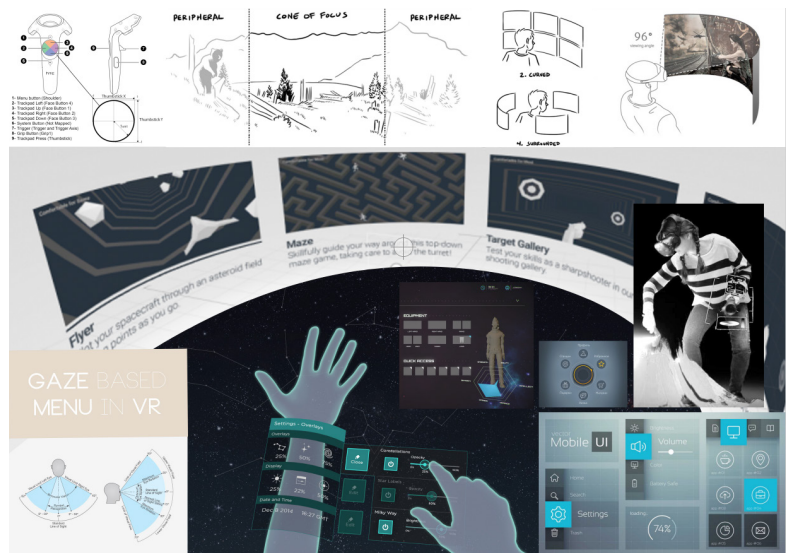


figure 34. A collage made to show the opportunities in interaction design.

5.3 STYLE

The tool is aimed at design agencies, so it needs to look professional and trustworthy. A color panel was made based on the colors of DINED in order to make the tool fit in (figure 33). In order to make use of the unique qualities of VR, a collage was made with inspiring interface designs and things to consider when designing such as the field of view and futuristic interface designs (figure 34).

An industrial appearance was chosen for the virtual world that needed to be created in order to give the tool a context to exist in. An industrial hall looks professional, clean and prevents being too market specific as the target group is aimed at designers in all sorts of fields. Figure 35 shows such a clean industrial looking hall.

An artists impression of the tool can be seen in figure 36.



figure 35. Image of an empty and clean industrial hall that was used as inspiration for building the virtual world. retrieved from <https://goo.gl/images/6V8Esb>

female 24y 55

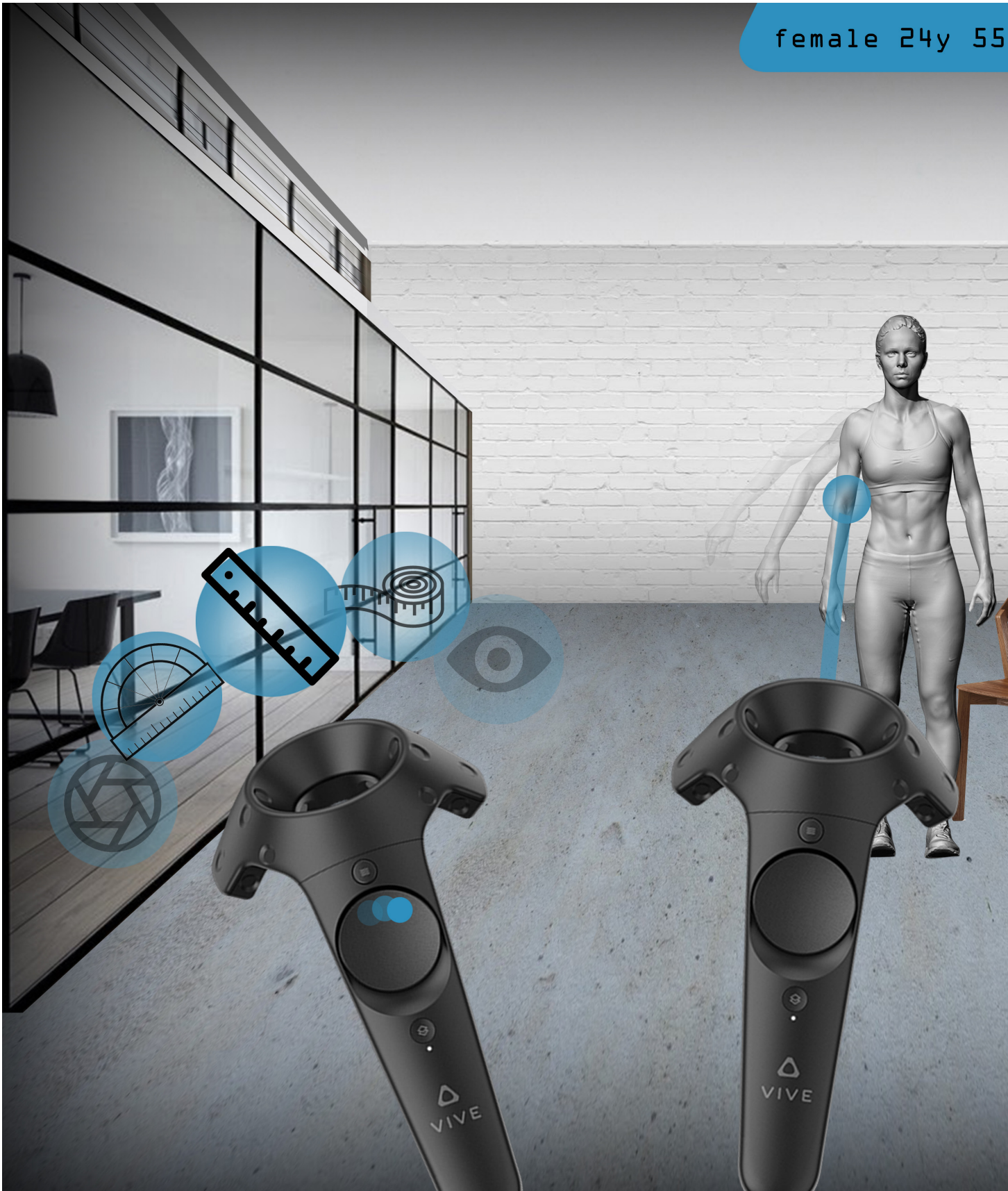




figure 36. Imagined look and feel of the tool as seen through the HMD.

6.0 | 4D DIGITAL HUMAN MODEL

44

The most essential to the tool would be turning full body 3D scans into movable DHMs. To prove that rigging [2.6] could make this possible, a 3D scan provided by B. Naagen on March 16, 2017 was rigged making use of the free software Blender.

The scan provided was a .stl file of a random subject of which the face was blurred for privacy reasons.

Blender was used as it is free downloadable and popular, meaning tutorials could be found online. During use, it became clear that the scan provided gave certain issues. The armpits and pelvis area resulted in unrealistic deformations when positioning the model (figure 37). Rigging itself however was proven to be successful (<https://www.youtube.com/watch?v=9Wm951a6Jxs>).

After the proof of concept, scans with the preferred output quality were made [6.2] and different rigging and later also VR software were experimented with and were listed with their advantages and downside [6.4.4].

This chapter will present the full process of creating a functional DHM from 3D scans.

6.1 THE 3DMD SCANNER

This thesis makes use of the 3DMD full body scanner (figure 38), chosen for its availability at the faculty of Industrial Design Engineering in Delft.

The 3DMD full body scanner makes use of stationary cameras to scan a stationary object. It digitizes the real world using flashes of light (following the Laser Pulse principle [2.4]). The distance from the flash to the object can be calculated because the speed of light and the position of the flashlight are known. By calculating the time between the flash and the reflection of light returning to the camera (and under which angle), an exact measurement of the points in space can be determined.

The best quality output come from surfaces with an uniform color and reflectivity (Kucklick, 2005), which is why clothing that is white, from natural fiber and tight fitting are used when scanning people. The position of the camera can help improve the output

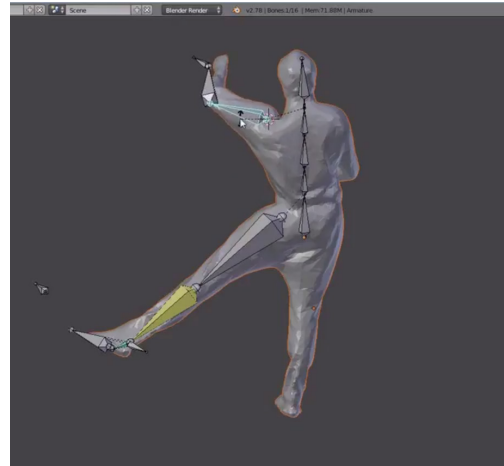


figure 37. Unrealistic deformations after moving the rigged 3D scan in Blender.

quality as well because the cameras only capture information from visible surfaces within their field of sight. In the case of using a full body 3D scanner like the 3DMD full body scanner, these are calibrated before use.

The 3DMD software creates a map, matching overlapping images into one big point cloud after taking the scan. To turn the scan into a workable surface the software automatically generates a STereo Lithography (STL) file of the scanned object. A STL file approximates a models' shape with flat triangles ("What Is An STL File?" 2017). If there were surfaces visually blocked, these will remain open like holes in the model (figure 39).

Post processing programs like Geomagic (3D systems) and Artec (Artec 3D) are then used to fill holes, trim excess material (like the ground plate), smoothen the surface and determine the density of triangles (thus file size and quality). Usually both Artec and Geomagic are used for creating the final workable scan, as Artec comes with the scanner and offers some basic tools and Geomagic offers more advanced options.

At the TU Delft faculty of Industrial Design Engineering there are several computers that offer these programs. Unfortunately they are licensed and the costs of these have to be considered when companies want to make their own database.



figure 38. The 3DMD full body scanner. retrieved from <https://goo.gl/images/EW7K8Q>



figure 39. The raw 3D scan opened in Microsoft 3D builder shows the areas that were outside the vision of the 3D scanners as holes.

6.2 CREATING A 3D SCAN

To improve scan quality when scanning the outfit consisted of a tight fitting, natural fiber (cotton), white long sleeved shirt and idem legging with a wig stocking covering the hair. The choice in outfit as well as the final scan could bring up an ethical debate on privacy, which is why I stood model myself (figure 40).

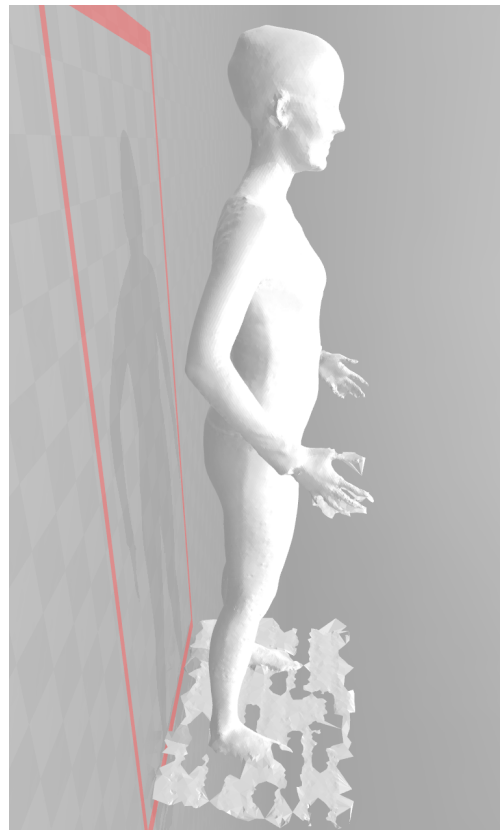
Scanning takes at least two people, the model and the operator which is why I would like to thank Bert Naagen for making the scan.

During the scans extra care was put into the position while scanning such that the clearest distinction between limbs and torso were captured.

Tips for 3D scanning:

- // check with ethical committee
- // Take a position with arms and legs spread
- // white, natural fiber, tightfitting clothes

The scan was taken in a series of postures, just to be sure. Eventually the scan with the best output quality was used and can be seen in figure 41.



When 3D scanning the surface of the object or environment to be scanned should be taken into consideration. Shiny surfaces can best be covered with a non-reflective powder to improve scan quality. Areas outside the field of view of the scanner will result in holes, which needs to be minimized.

figure 41. Raw scanning data as it comes out of the 3DMD scanner opened in Microsoft's 3D builder.



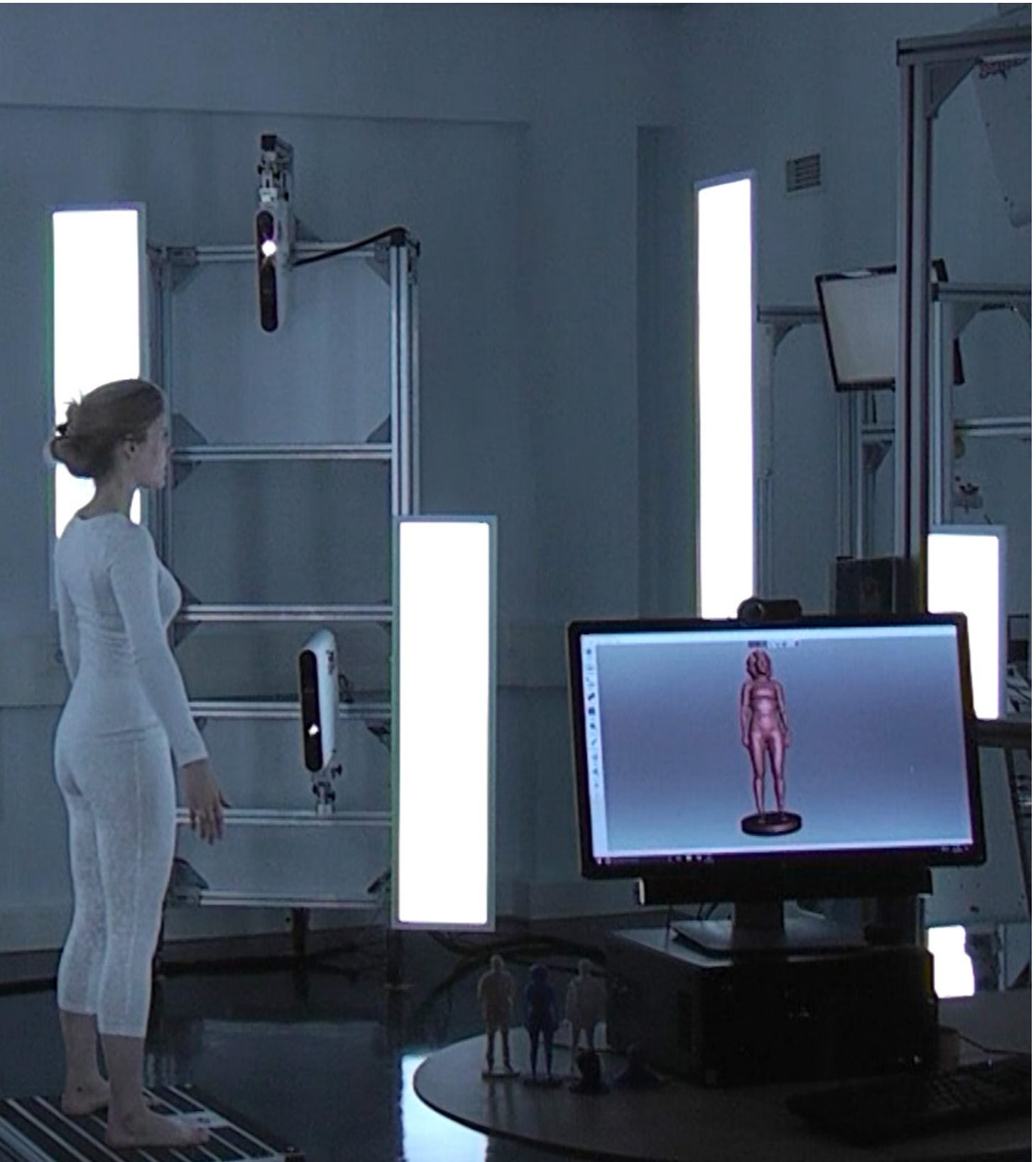


figure 40. Taking a 3D scan making use of the 3DMD full body scanner available at the TU Delft faculty of Industrial Design Engineering.



figure 41.a

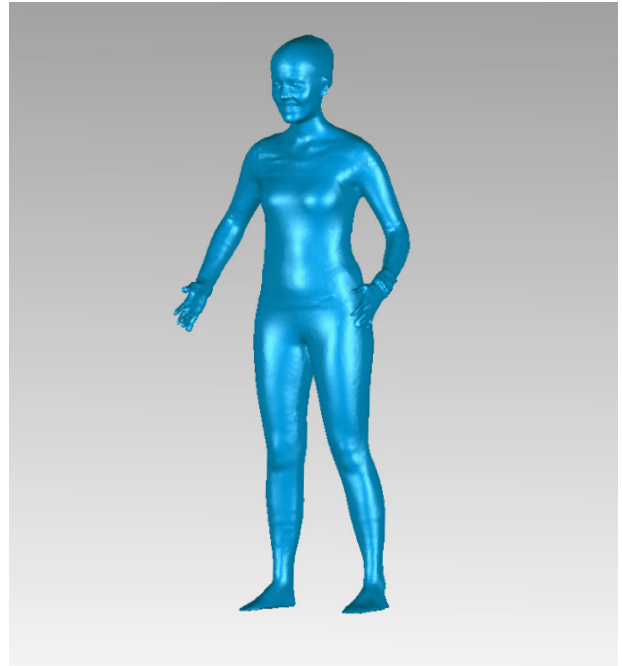


figure 41.b



figure 41.d

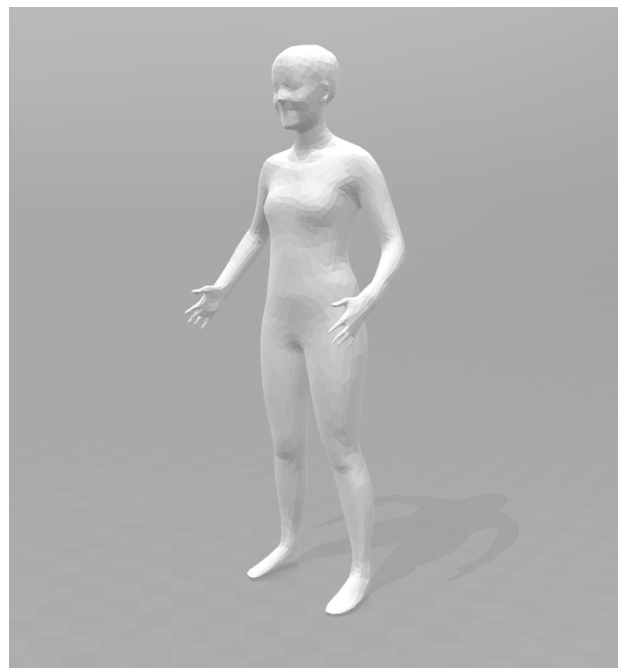


figure 41.c

6.3 POST PROCESSING THE SCAN

For trimming excess material and filling holes in the surface output of the 3DMD scanner, the programs Artec (Artec 3D) and Geomagic (3D systems) were used. They can be seen in figure 41a and 41b respectively. They were also used for lowering the amount of polygons of the mesh (figure 41c) and smoothening the surface (figure 41d). After doing so, the polygons are not divided equally which has to be done too in order to make weight painting easier in a later stage.

figure 41.

- a. The 3D scan in Artec.
- b. The 3D scan in Geomagic.
- c. 3D scan after post processing and with the mesh made larger, opened in Microsoft's 3D builder.
- d. Post processed 3D scan after smoothening, opened in Microsoft's 3D builder.

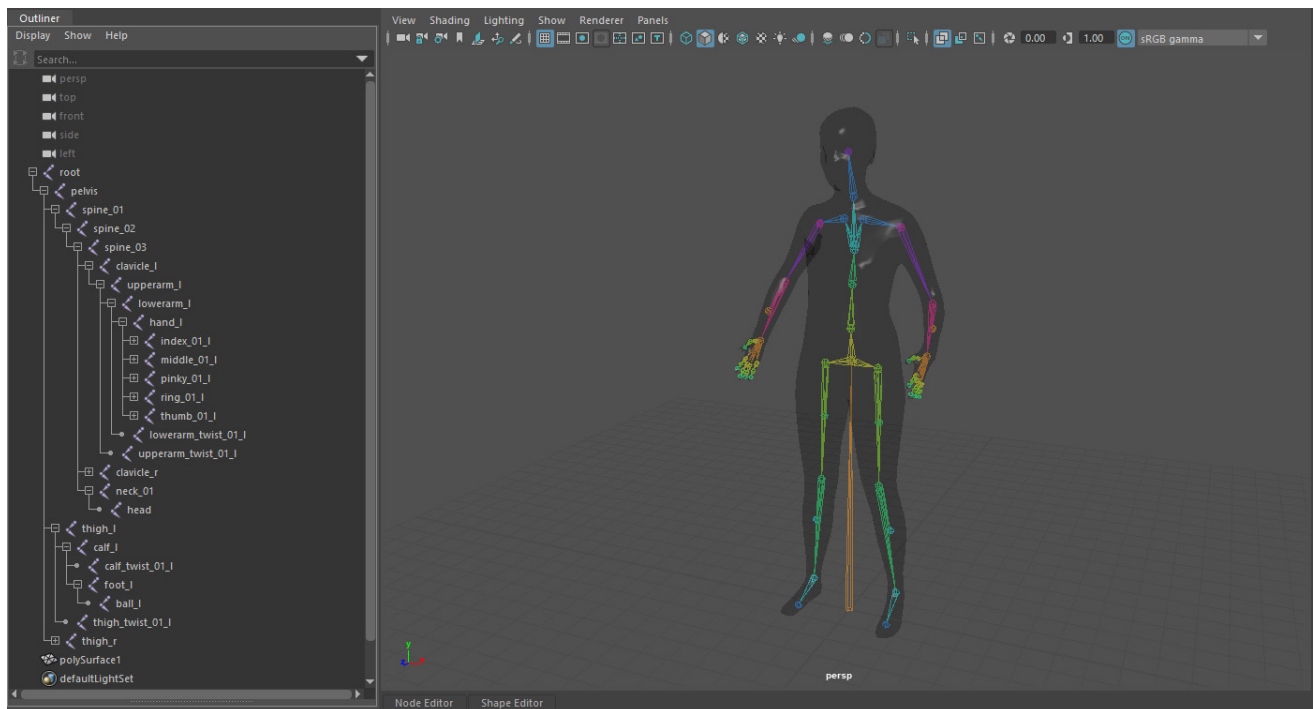


figure 42. The bone structure as built in MAYA, the hierarchy can be seen on the left.

6.4 BUILDING THE RIG

The 3D scans can be used for building the rig after post processing. This chapter describes the creation of a rigged 3D scan.

6.4.1 BONES

The amount of bones for a realistic human rig are pretty much standardized nowadays. The head and neck will both get one joint, the spine 3-5, the arms will have the clavicle, shoulder, elbow and wrist and the hands will have 3 bones per finger. The amount of spine joints was based on the book *The Art of Rigging* which states that 3-5 spine joints is enough to pose the spine into any position (Ritchie et al., 2005). From the root bone the legs will have the hips, knees and ankle and the feet which usually have one joint each. When animating, an extra joint will be added to the feet for animating the rolling of the feet when walking, jumping, etcetera. The toes can be rigged separately as well but is only done when these have special functions like the claws of a bird or when designing for the feet. For this model the feet were not rigged into detail.

In a rig, the bones have to follow a certain hierarchy which can be seen on the left in figure 42. They are all linked from the root bone (pelvis) outwards.

The bones were built inside the 3D scan to better estimate the position of the joints. In figure 42 you can therefore see the rig inside the model as x-ray mode was put on. As of right now the positioning of the joints is done by hand and based on estimations, preferably this would be automated in the future.

After twisting and turning around the model for positioning the joints and building the rig, the 3D scan mesh can be connected to the bones. By doing so the mesh will move along with the bones. The results of this are still unrealistic because the weight paint was automatically made after binding the skin (as connecting the mesh to the bones is called). To adjust this, the model needs to be weight painted by hand.

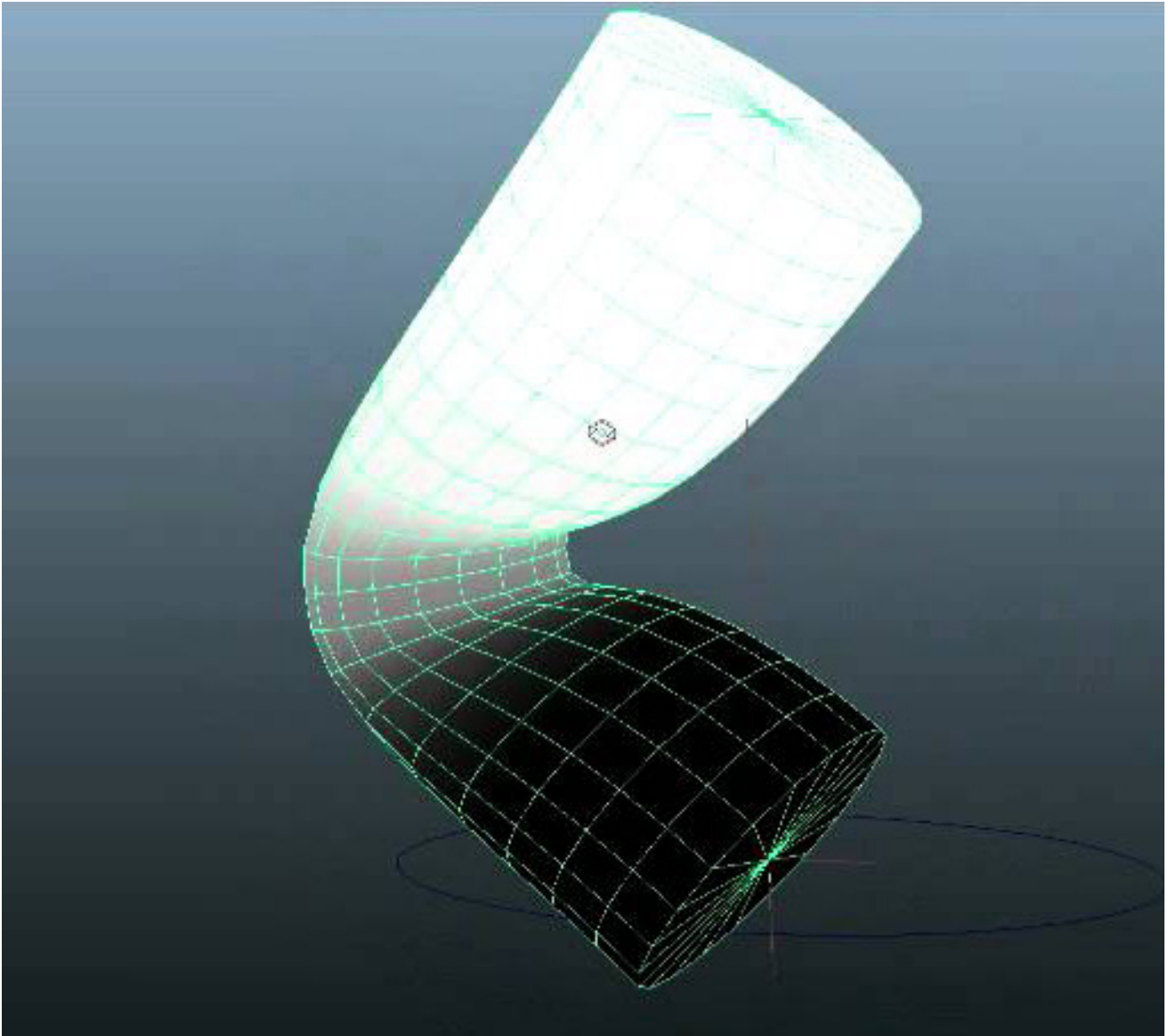


figure 43. An weight painted tube to show the effects of weight painting.
retrieved from <https://goo.gl/images/U8AEP7>

6.4.2 WEIGHT PAINTING

Weight painting or skin weighting is an animation techniques which addresses the unrealistic deformations that can occur when rotating the joints of an 3D model (Choi, 2004). It is an subjective method that relies on interactive tools that allow a range of color, which is applied through a kind of digital spray paint, to indicate which specific regions are

anchored to the joints in which amount. Standard white and red indicate the strongest connection and black and blue no or little connection between the skin and the bone (see figure 43 and 44) The colors can also be adjusted or switched to a gray level scale in which the greater the effect a given bone has on a region the higher the gray level value (Yang, 2008).

The process of weight painting asks for a lot of back

and forth positioning of the model in different positions. Each position the weight paint needs to be adjusted to realize the most aesthetic (seeming realistic) deformation of the model. To create a scientifically proven deformation is even more difficult. Currently the Dyna project is working on doing so by making use of 4D recordings and mathematical calculations to create even more realistic computer generated deformations (Pons-

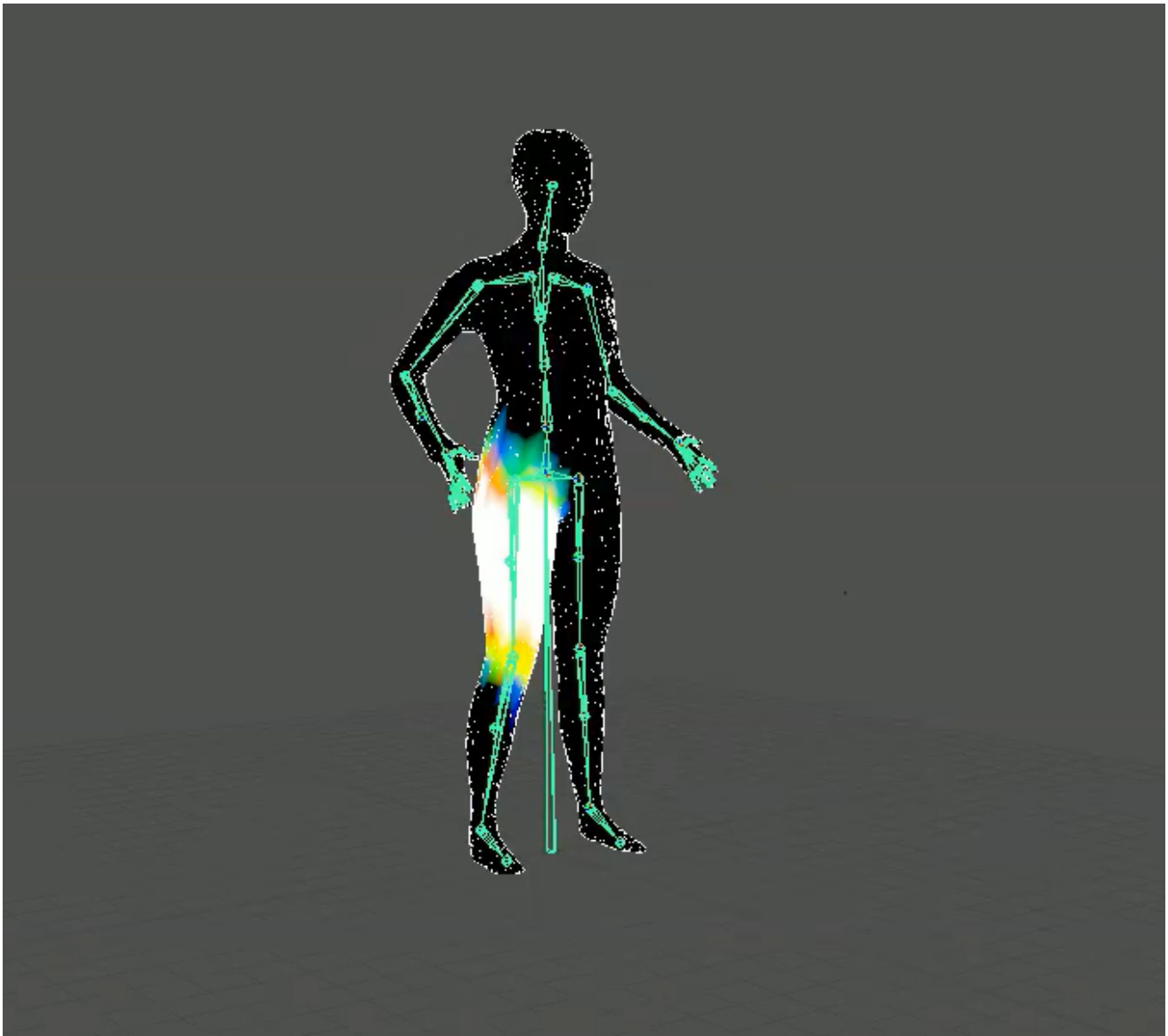


figure 44. The weight paint of the upper leg as applied in Maya.

Moll et al., 2015).

Inside Maya there are options to weight paint your model after binding the mesh to the bones. In figure 44 you can see the adjusted weight paint of the upper leg bone. White indicates the areas that will move along the most and blue the least with black meaning it will not change when this particular bone is brought to a new position. To make joint areas look realistic a transition between white and black needs

to be made. Obviously the transition areas are the most difficult to get right which is why at some point the decision was made to stop weight painting. Weight painting was stopped when the model was moving realistically enough to not be disturbing during user tests.

An automated and preferably scientifically sound script for rigging the model would definitely improve the tool's potential.

6.4.4 RIGGING SOFTWARE

The initial software used for rigging was *Blender* for its free availability and broad fanbase. As was experienced straight away, *Blender* is quite unforgiving. It took a lot of time to rig the mesh correctly which made it interesting to look for other rigging software as well.

In discussions with Arno Vreeke, from the VR Lab at the faculty of Architecture at the TU Delft, the new plug-in for Maya *ART v1* was opted (Vreeke, personal communication, 20-10-2017). *ART v1* is offered by UE self and promises to work quick and easy. The software can be found for free in the *Unreal marketplace* which opens up automatically when you have installed and open UE.

ART v1 works within Maya as a plug-in and takes the user through a step by step procedure to half automated rigging of your model. For the parts that were unclear an online tutorial found on YouTube was consulted on the side.

Creating a rig was indeed shockingly quicker with the time from scan to rig at an hour (after practice) where in *Blender* it would have taken up to a week to finish.

The issue with *ART v1* was the fact it does not allow adjusting the weight paint after finishing the rig. Weight painting a model is tricky and especially when working in VR the model can unexpectedly behave differently in VR than it did in Maya, which means adjusting the weight paint. A lack of tutorials and online documentation on *ARTv1* and how to change the weight paint afterwards made it impossible to continue with this tool.

Eventually the decision was made to use the rigging tool that is standardly available in Maya which, just as *ART v1*, requires a Maya license and is thus less attractive for companies. Since a Maya license is available at all TU Delft computers and can be

downloaded by students from the TU Delft website, this was still preferred over *Blender* for its clear working method and broad online support.

As stated in the book *The Art of Rigging* “Maya’s architecture is one of the best in the industry. It is extremely extensible and open to adaptation. This is why it has become the 3D animation package of choice for the demanding film and television industries.” (Ritchie et al., 2005). It delivered, Maya’s rigging tool proved both quick when rigging and comparatively easy in adjusting the weight paint.

After having tried out these programs I would like to provide an overview of my experiences below.

Blender

- + free
- + documentation and tutorials available
- takes a lot of time
- difficult to pick up (slow learning curve)

ARTv1

- + free from Unreal Marketplace
- + quick rigging
- + IK/FK handles placed automatically
- Little documentation and tutorials available

Maya

- + professional (used in game building and movies)
- + TU Delft has a license, other students can apply for a free one through Autodesk.com
- + has an own rigging tool
- + lots of documentation and tutorials available
- + Architecture VR Lab has some experience
- requires a license (companies)

7.0 | VR INTERACTION DESIGN

Creating the envisioned interaction design VR hardware and software had to be chosen. Walking around the CAD model and DHM to estimate dimensions is essential to the design proposal [5] which is why a VR set that allows movement through space was chosen. For this thesis the *HTC Vive* was used, as a setup is available for use at the TU Delft faculty of Industrial Design Engineering (Applied Labs) and at the TU Delft faculty of Architecture (VR Lab).

The free VR software *Unity* and *Unreal Engine* (UE) were both experimented with and elaborated on [7.2].

This chapter explains the creation of the virtual world and interaction design for the 4D DHM in VR.

7.1 HTC VIVE

The *HTC Vive* basic set-up consists of a headset with audio jack (for plugging in headphones), two base stations and two handheld controllers (see figure 45).

The tracking system used for the *Vive* is called *Lighthouse technology*. Its name stems from the two base stations that emit invisible light, sweeping the room sixty times each second, guiding the HMD and controllers to navigate on their own (Buckley, 2015). The HMD and controllers receive the infrared light like a time stamp after which an x-plane laser sweeps the room and the location of the HMD in this plane is found, where after another pulse and an y-plane sweep allow determination of the angle between sensor and base station (“SteamVR HTC Vive In-depth - Lighthouse Tracking System Dissected and Explored,” 2016).

This system requires line-of-sight to function which means sensor occlusion is a problem. Other people in the room should not block the line of sight of the base stations. When at least five sensors have a direct line-of-sight to the Lighthouse, the position and orientation of the HMD relative to the base station can be calculated



figure 45. The *HTC Vive* basic hardware: HMD, 2 lighthouse technology blocks and two handheld controllers. retrieved from <http://cdn.gamer-network.net/2016/usgamer/HTC-Vive-Shot-01.jpg>

as the sensors distance relative to each other on the HMD are known. The lighthouse tracking system is accurate at 1,5mm and 1m9mm respectively ("SteamVR HTC Vive In-depth - Lighthouse Tracking System Dissected and Explored," 2016).

The set-up can be seen in figure 46.

7.2 VR SOFTWARE

At the start of the project the VR software used was Unity. Unity is a famous, free software which allows for a lot of design freedom. Unity requires knowledge on C# and programming to build functions. For this reason the switch was made later on to work in Unreal Engine (UE) which is a gaming engine just like Unity but then relies on a more graphical form of programming comparable with the plug-in grasshopper for the CAD program Rhinoceros (see figure 47).

Unity

- + used by companies
- + professional
- C# coding knowledge necessary
- more difficult to write iterations
- no knowhow at the TU Delft

Unreal

- + professional
- + graphical interface (no hardcore coding in C# but works more like grasshopper)
- + relatively quick iterations possible
- + great graphics
- + feedback possible at Architecture VR Lab
- not always used in companies

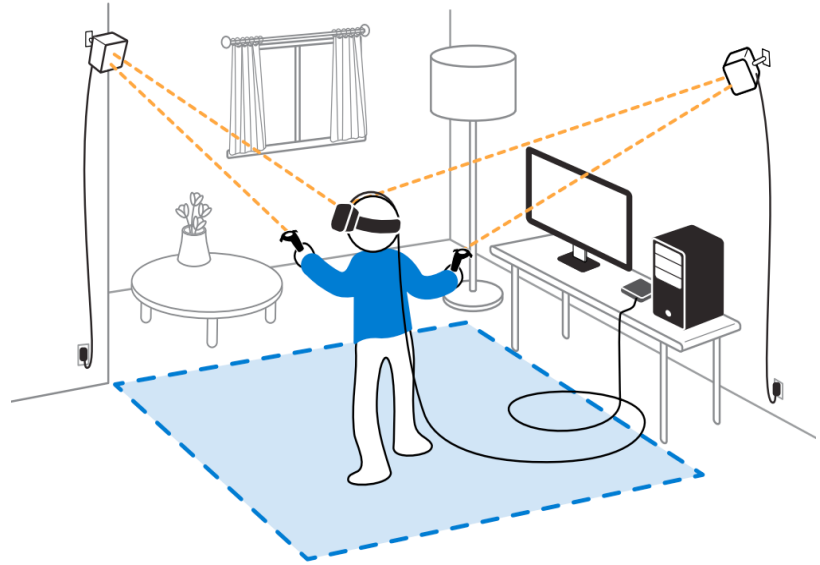


figure 46. The HTC Vive set-up. The base stations look down on the player area, which is indicated at the start. retrieved from <https://goo.gl/images/kWy6PA>

The room got built using Maya and Unreal Engine.

In Maya the basic shapes were built which were given texture and depth in UE.

Both sunlight and point lights (added inside lamps) made the room come alive.

The furnishing is all based on existing designs.

7.3 BUILDING THE CONTEXT

7.3.1 MAYA ROOM CREATION

For building the context in which the testing would take place, a fresh and clean looking warehouse was built. The looks were chosen to give both the sense of an industrial workplace for the users and a professional image to their customers [4]. During testing it should be understood by the clients of design agencies that the model to be tested is not the final product yet. The industrial look should assist this feeling of testing a prototype. Complementary, its clean look will help come across more professional when making renders for customers or when testing with participants.

In the room there are added certain extra's like two separate rooms, one empty for own interiors and one with a table and chairs for products that need to stand on a table or should be interacted with from a seated position. The room is ambiguous and facilitates a presentation ground for a wide range of product designs, as intended for the user group.

The dimensions were chosen so that it could fit the assumed largest product type (a truck) and all products smaller than this. The largest EU truck that should fit in the hall has a height of 4m, width of 2,6 m and length of 18,75m (evofenedex, 2017). The dimensions set upon for the room are therefore a 25m long hall with a height of 6m, with on both sides a lower roof with a height of 4m. The left side got a width of

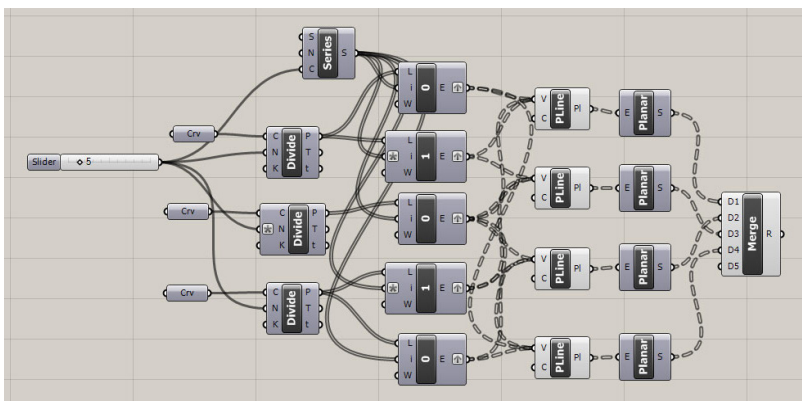


figure 47. Grasshopper plugin for Rhinoceros 3D modelling software. retrieved from <https://goo.gl/images/cTgkAF>

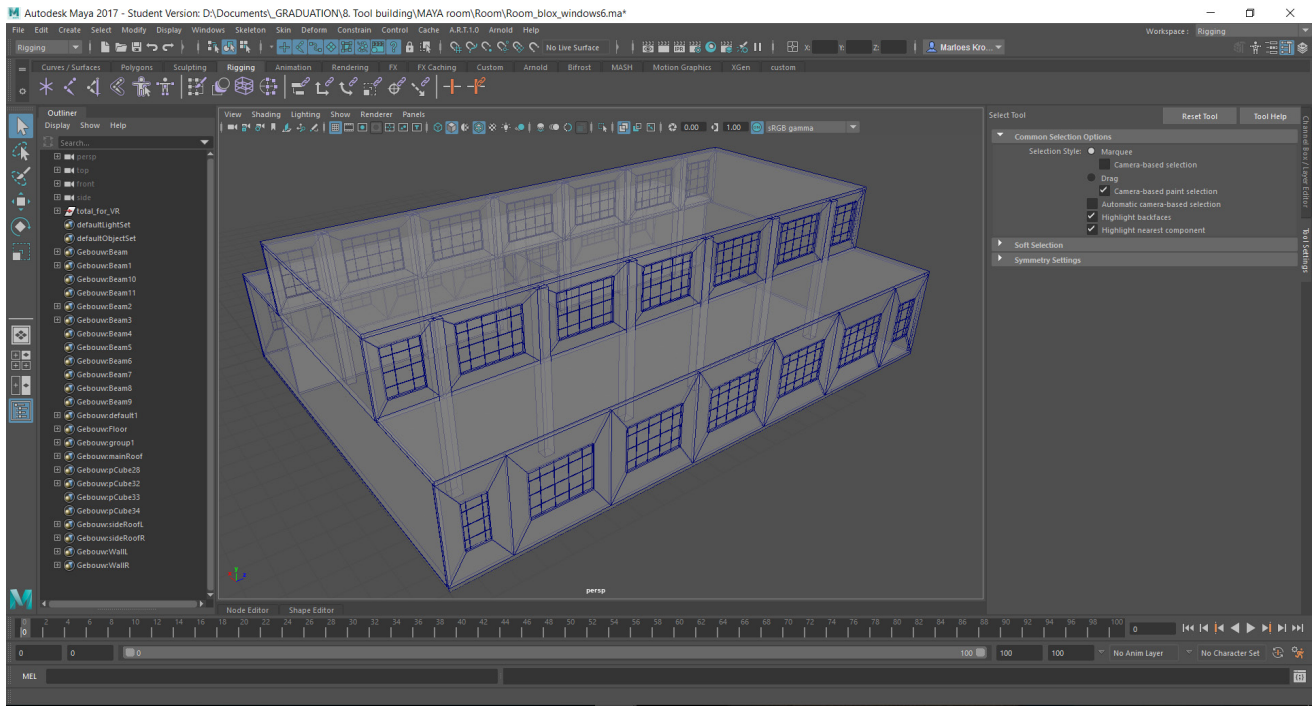


figure 48. The room built in Maya.

4m, a single wall and a closed office kind of room where smaller products could be tested. The right side is open and offers sunlight to come in from that side too.

The walls, pillars, floor, roof and barred windows were built in Maya (figure 48). The walls containing windows had to be faceted to be understood by UE. UE and any other gaming engine, works with tris, triangle shapes, to build models. Maya uses quads, square shapes, which makes the adding of these lines important for UE to read out the shape. When this is not done, as was tried out before, the windows would get filled by Unreal.

After finishing the basic shape of the industrial hall, the model was imported into UE as a .fbx file. A check of the width and height in VR was done, using the HTC Vive, and based on this the position of the windows was slightly adjusted in Maya before continuing in UE.

7.3.2 UNREAL ATMOSPHERE AND MATERIALS

In UE the textures and materials could be added to give the grey block a realistic appearance. Important for creating a realistic appearance are not only the materials applied and their size (think of brick size) but also their depth. When applying a simple white brick material the walls still look fake. By adding Bump Offset mapping an illusion of depth was created for the brick walls and the concrete tiles on the floor. Another trick that was used

to make the room look more realistic is Ambient Occlusion.

Ambient Occlusion is an option that makes the shadows more harsh creating a more in depth kind of feel. In Unreal it was used for the feel of depth of the room, but it can also help in making characters look more realistic as can be seen in figure 49.

To create a reflection off the material, so called Reflection Spheres were added inside the room. Sunlight and light within lightbulbs were created through making the material light emitting and adding a point light inside the lamp. The sunlight and most of the other lighting got baked which means it is fixed and doesn't change while in VR.

A light bake requires a lot of preparation but makes playing and loading a lot faster which means less lagging. Dynamic lighting is however needed to create shadows from objects that can be moved or were added to the world later on. This type of lighting takes up a lot of calculating time from the computer.

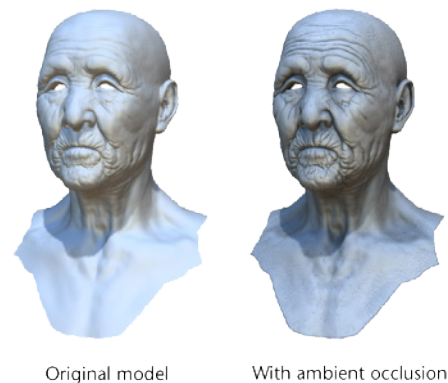


figure 49. Ambient Occlusion applied to a character. retrieved from <https://goo.gl/images/TjHLMd>



figure 50.a



figure 50.b



figure 50.c



figure 50.d

The room got decorated with existing design products to look more realistic.

The products used are:

- Rivage Easy Chair by Ritzwell
- Merano Chair by Ton
- Bluetooth Gramophone by Gramovox
- Mesa Table by Poltrona Frau
- E27 pendant lamp by Muuto
- Be easy table by Kristalia
- Flow chair by MDF Italia
- Hollywood Floor Lamp by It's About Romi

The products used were downloaded for free, opened in Maya to group which facets had to be the same material (figure 51).

This way the CAD model could later on get

assigned different materials in UE.

All the separate materials had to be made in order for the products to respond to the lighting and to look realistic. The materials are therefore handmade and differ from the original products appearances which can be seen in figure 50.

The center of the room was chosen as the center which means all imported products will appear in the middle of the room, making it easy to position it in VR. The finished room in Unity can be seen in figure 52.



figure 50.e



figure 50.f



figure 50.g



figure 50.h

- figure 50.
- a. Rivage Easy Chair by Ritzwell
 - b. Merano Chair by Ton
 - c. Bluetooth Gramophone by Gramovox
 - d. Mesa Table by Poltrona Frau
 - e. E27 pendant lamp by Muuto
 - f. Be easy table by Kristalia
 - g. Flow chair by MDF Italia
 - h. Hollywood Floor Lamp by It's About Romi

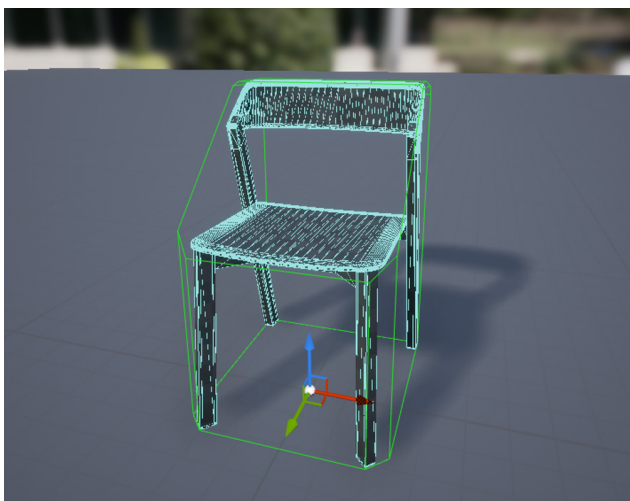


figure 51. Facetted Merano Chair in UE.

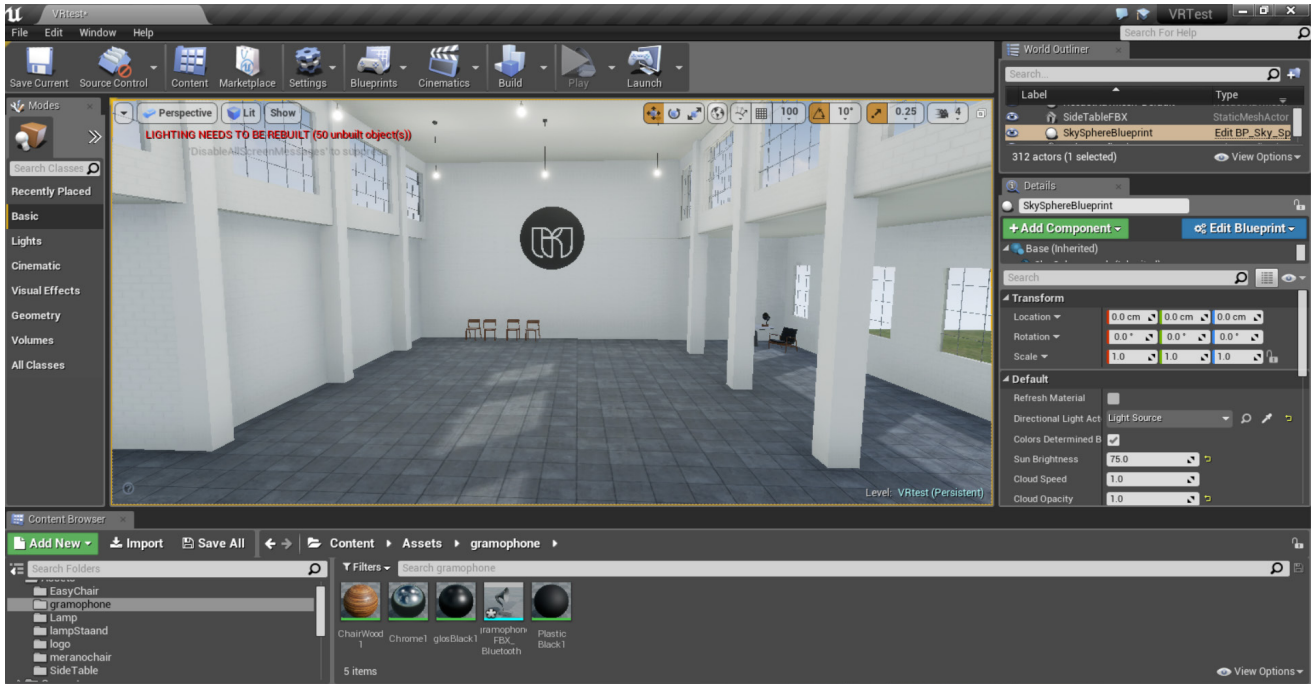


figure 52. The built room in Unreal Engine, flight perspective, with materials and textures. For decoration only existing design products were used.

7.4 BUILDING THE GRAPHICAL USER INTERFACE (GUI)

7.4.1 NAVIGATION

For the User to walk around in the room, a navigation mesh that binds the volume got placed over the area. A collision map was added to make sure the user does not do the “impossible” like standing inside a table or walking through a lamp. To make the map visible in Unreal you can simply type P. What you will see is a bright green representation of where the user can walk (figure 53).

Walking around can be done by physically walking around, covering larger distances can be done by teleporting yourself to a point further away in space. This option was added to provide a solution to the limited tracking volume the HTC Vive but also Oculus Rift and PSVR offer (“7 ways to move users around VR without making sick,” 2016). Teleportation is used a lot within VR games and navigation and can be recognized by a parabolic beam that you can aim with one of the controllers when pushing a button. At release the user will teleport to the position where the beam hit the floor which is indicated by a highlighted circle (can be seen in figure 54).

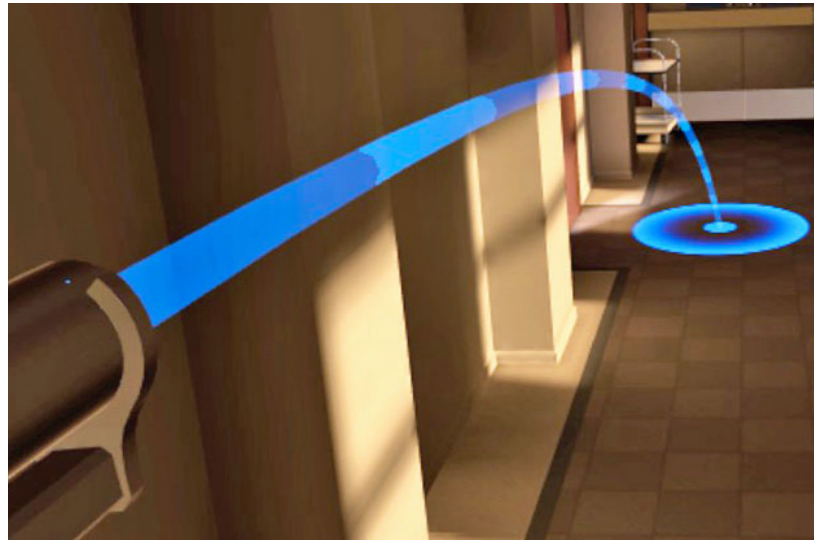


figure 54. The teleportation function used in a VR game. The blue ring indicates to where the user will be teleported. The beam is for aiming. retrieved from <https://goo.gl/images/YqTWfX>

7.4.2 POSITION THE MODEL

Unreal works with so called Blueprints (BP), a visual scripting language, in which interactions can be built. An overview of the BP that was built for positioning the model can be seen in figure 55.

To be able to grab and position the model, interactive objects (grips) were placed at the joints (figure 56). These grips are linked to the bone structure and can be grabbed by the user through the controller.

Whenever the grips are used to position the DHM they are deleted and a new grip is placed at the location where the previous grip was left to take the last position as the new starting point.

Translucent balls were chosen to indicate the handles of the DHM for they show the model no matter their size. A round ball shape was chosen for its multidirectional appearance, triggering the user to not just move in planes but move the handles in any direction as well as rotate them.

The bones were connected with an IK constraint to be able to pull the hand and let the arm follow. The shoulder could not be included as this would result in unrealistic postures, which is why several IKs were made (one for each arm, one for each leg and one for the head). One main grip was placed in the center of the model so the model can be picked up entirely and be placed anywhere in the room.

Several tests had to be done and even the weight paint had to be adjusted several times while making the grips and the reaction of the DHM on the grips run smoothly and make bending the limbs look natural. With a reset button on the controller the model can easily be reset to its default pose.

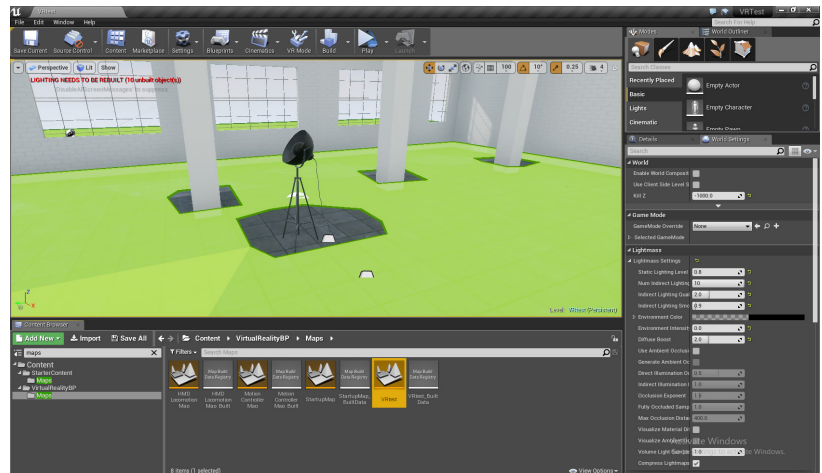


figure 53. The built environment in Unreal Engine, with the collision map visual. Green indicates where the user will be able to walk.

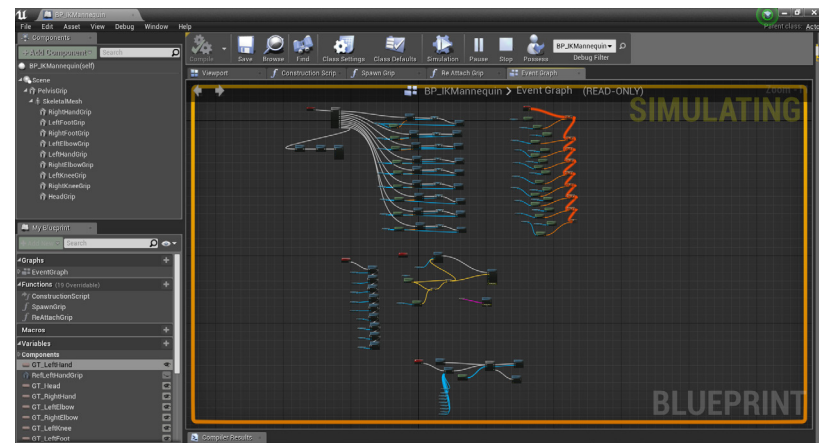


figure 55. Overview of the Event Graph in UE, showing the blueprint of steps that will happen either at an event tick (highlighted in red) or when interacted with.

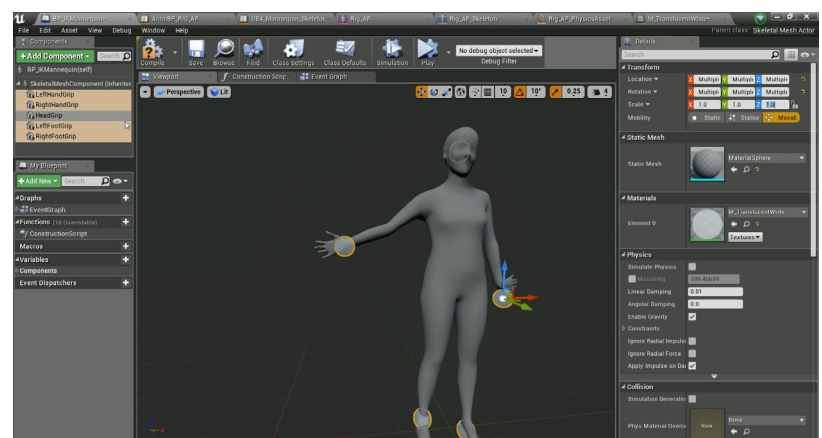


figure 56. Translucent balls indicate the grips for the IK constraint in UE.

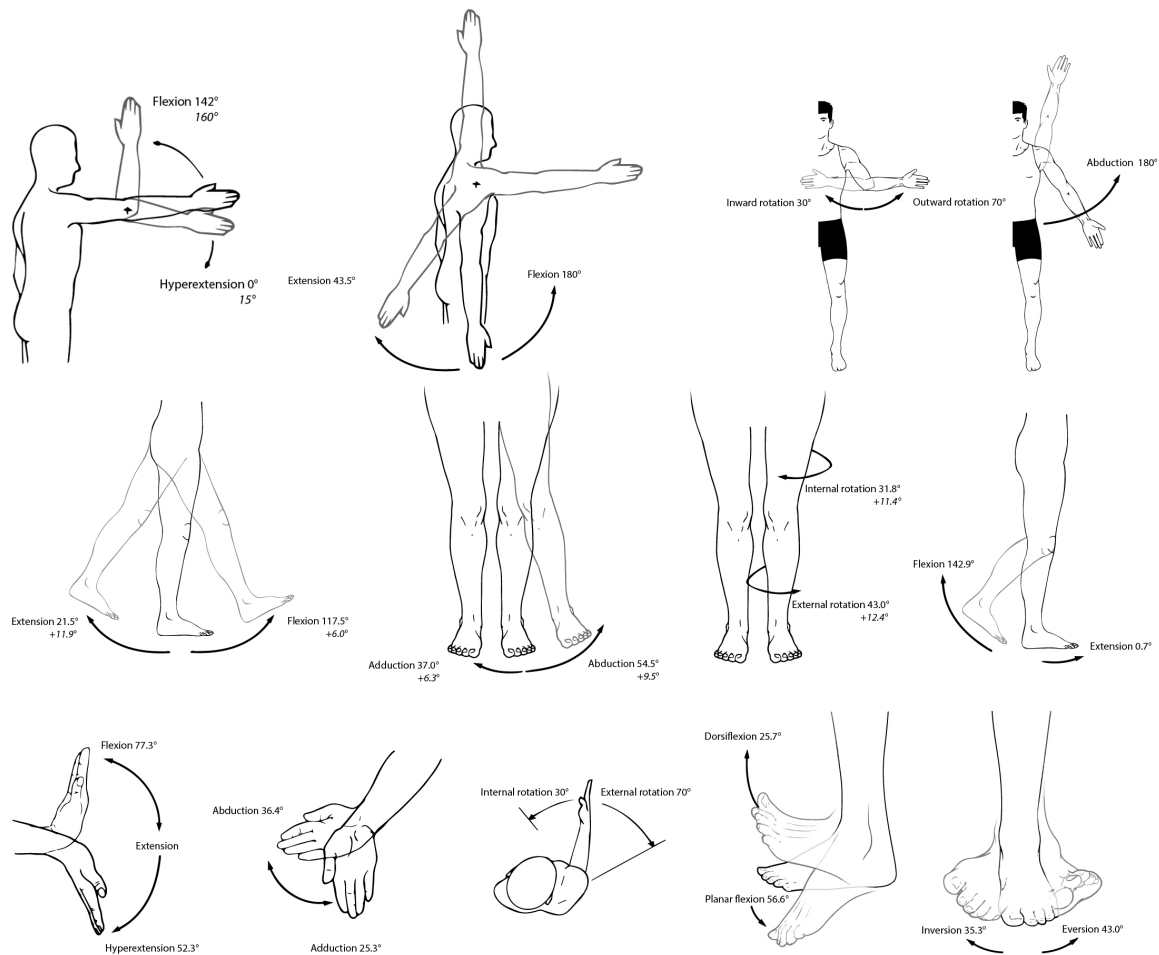


figure 57. The reach of movement of different body parts. Values taken from the book *Clinics in Rheumatic Diseases* (Wright, 1982).

7.4.3 RANGE OF MOTION

The movement of joints is important for setting up joint constraints of the DHM as one of the requirements asks for feedback on unrealistic postures.

Range of motion of the human joints are dependent on genetics, age, ethnic background, gender and physical exercise as they depend on bone shape, muscles and tendons. Abnormal motion like hypermobility, also called hyperflexion or hyperextension, means larger than normal ranges of motion which can be caused by accidents, falls or other types of trauma but can also be part of one's DNA.

Through exercising, acrobatics or yoga for example, one can enlarge their range of motion by stretching ligaments, tendons and muscles. The moment of recording and the amount of measurements taken (warming up the muscles) has an influence on the results. Having others present can influence the range of motion as well (Molenbroek, personal communication, 6-7-2017).

3D scans unfortunately do not hold such information and researching all the different joints and their movement for all the possible combinations of age, sports and so on, is outside the scope of this thesis. Instead, the values used for setting up joint constraints in MAYA/ Unreal were taken from the book *Clinics in Rheumatic Diseases* (Wright, 1982). The book contains research results subdivided in several age groups and gender, of which the values of a 20-30 year old female were chosen for the scan of a 24 year old female. It is acknowledged that this might not be accurate but will be good enough for testing the interaction with the tool and its main functions. The second value, which can be seen in some of the postures of figure 57, show the most extreme value encountered.

Unfortunately there was no way found to include the constraints in the model as it was set-up now, meaning the positions of the limbs would be for further research [13].

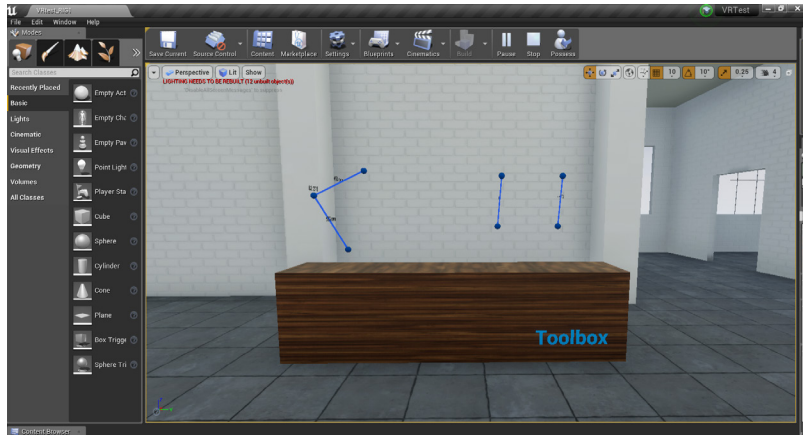


figure 58. Translucent balls indicate the grips for the IK constraint in UE.

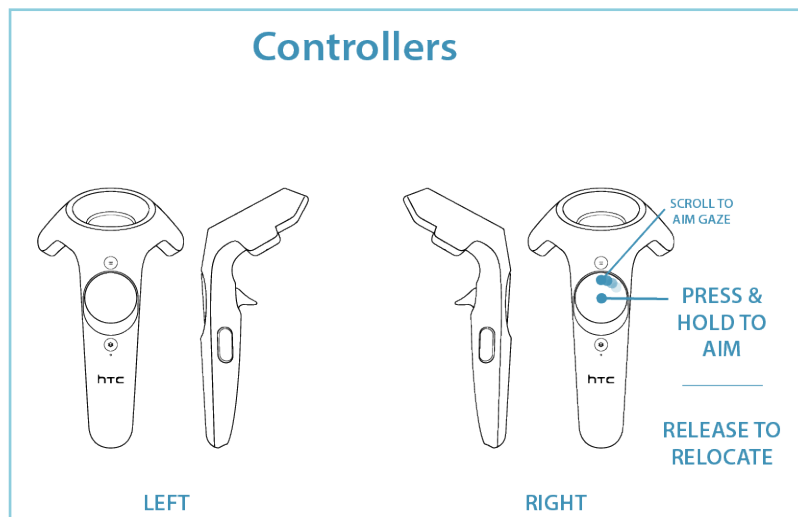


figure 59. One of the menu screens present at the start. The exit button and ok button (to continue to the next screen) miss because these needed to be built in UE.

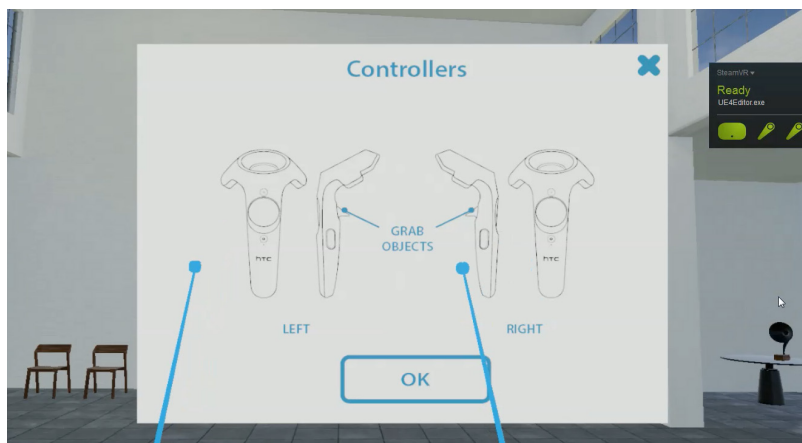


figure 60. The menu as seen in VR. The pointers come from the controllers to be able to interact with the buttons on the screen.

7.4.4 MENU STRUCTURE

The focus of the design was on the usability of positioning and measuring the 3D DHM in VR. Due to time constraints the decision was made to build only the main functionalities of positioning the model and measuring it.

The menu structure as imagined [5.6] around the left controller was not realized as creating such a menu is quite difficult especially for the expertise at the time.

The main functionalities were the ones built and should be accessible which is why the classic menu structure was not needed. The decision was therefore made to place the measurement tools in the environment (figure 58) and locate the relax posture and snapshot function under buttons on the controllers.

For initial use a menu was put in place to explain the buttons of the HTC Vive controllers. Lines were kept simple and the colors are black white and blue according to the color scheme [5.3], one of such screens can be seen in figure 59.

The menu was bound to the controllers viewport which means it was always in front of the user until exited. The flipping through the explanations of only 4 screens could be done by clicking the OK button with the controllers which, as long as the menu was open, had pointers making use of the virtual control method (fig 60).

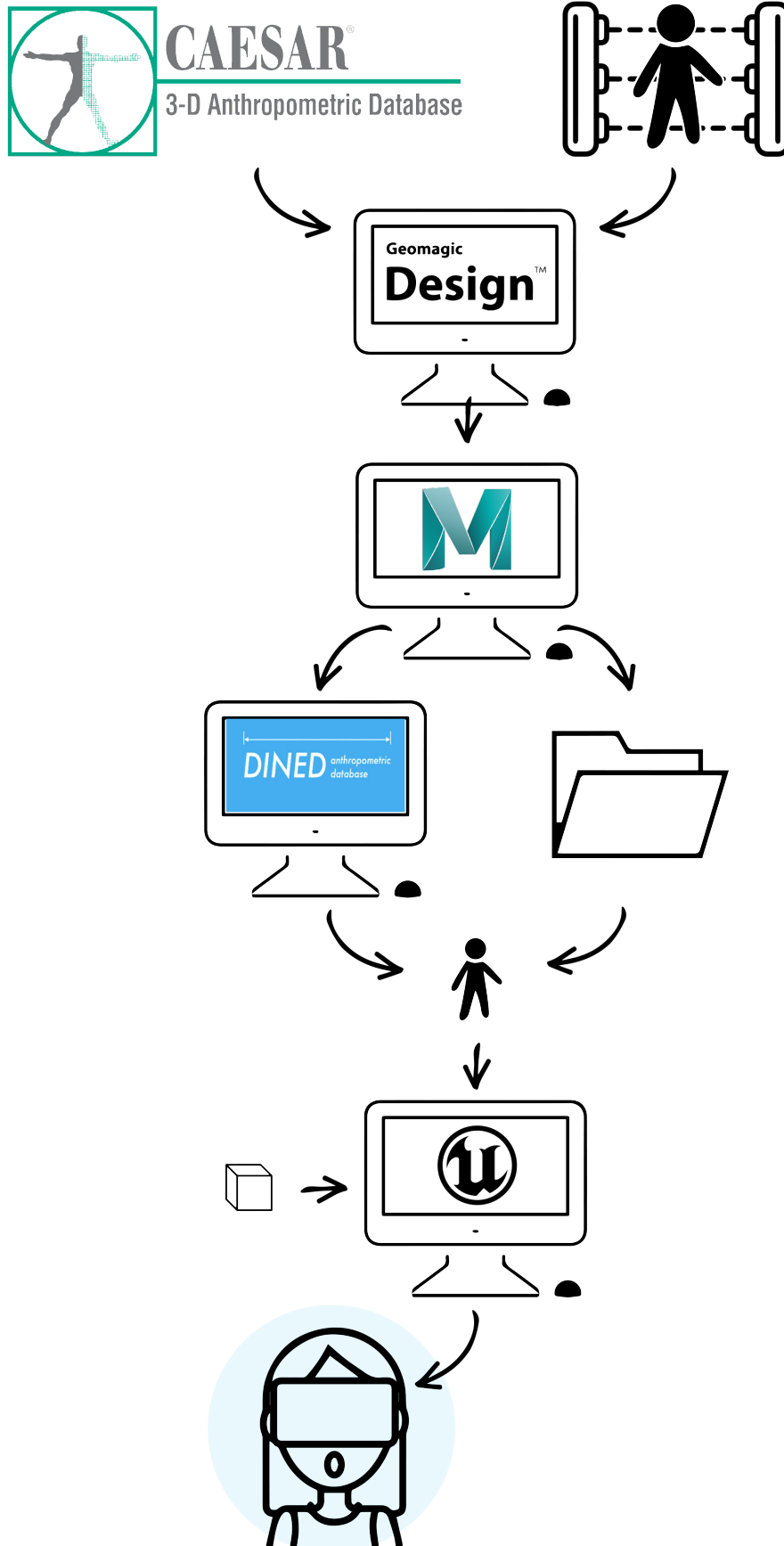


figure 61. Overview of the steps from 3D scanning to entering the virtual world through the HMD.

8.0 | PROTOTYPE: INTERFACE AND USE

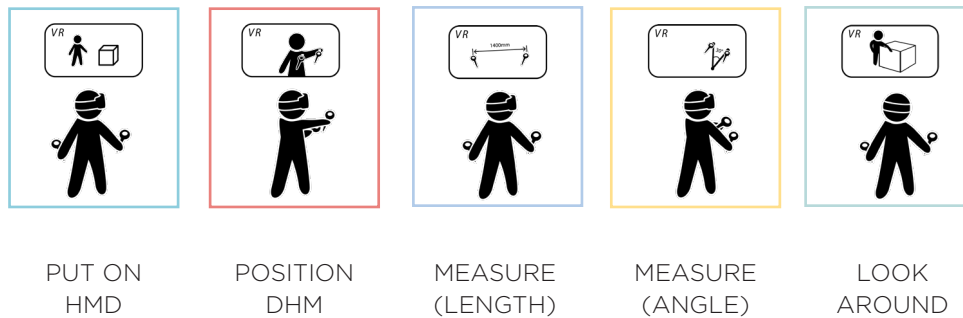


figure 62. Overview of the hands-on functionalities of the tool.

Preparation for the tool, as seen in figure 61, requires a 3D scan which can be taken from the CAESAR database or self made. The scan is then post processed with the use of Geomagic and put in Maya to be connected with the rig (which can be available at DINED), weight painting has to be done by hand. This rigged scan is then saved as a .fbx file in the company folder or can be available at DINED in that form. The designer brings the 4D DHM and CAD model of the product together in Unreal Engine. The HMD can be put on and the rest of the design takes place inside VR.

The situation in VR is visualized as the real life position of the user and a screen showing what is seen through the HMD (figure 62).

When starting up the VR experience, a menu appears that explains the different actions the controllers can perform (figure 63). The menu flies over the virtual world and is fixed to the camera, forcing the user to read those before continuing in VR. For repeated use there is an option to click away this menu immediately. Figure 64 shows the DHM in its default position.

To make use of the unique qualities of VR, it was thought best to have as little menu structures as possible and let the tool

speak for itself. The controllers are the same in VR as in the real world, minimizing the feeling that the VR world is virtual (figure 65). Transporting through the area can be seen in figure 66. Interaction with the DHM was turned into an almost physical, real life interaction. By grasping handles located at the limbs the model can be pushed, pulled and rotated into the right position (figure 67). Pulling on the wrist would automatically let the elbow and shoulder joint move accordingly by the built IK constraint [7.3.2]. This would give a feeling of pulling the arm of a real person.

The DHM is a fixed object which allows the designer to drag it up in the air to position from a convenient posture.

A physical toolbox within the room stands out to grasp the attention and direct users towards itself. The way the measuring tools work was based on the real world interaction with measuring tape and the reading of a geo triangle. For length two ends can be pulled and an automatically generated number, the distance between the two points, changes according to its position (figure 68). The angle tool will measure the angle between two points compared to a center point.

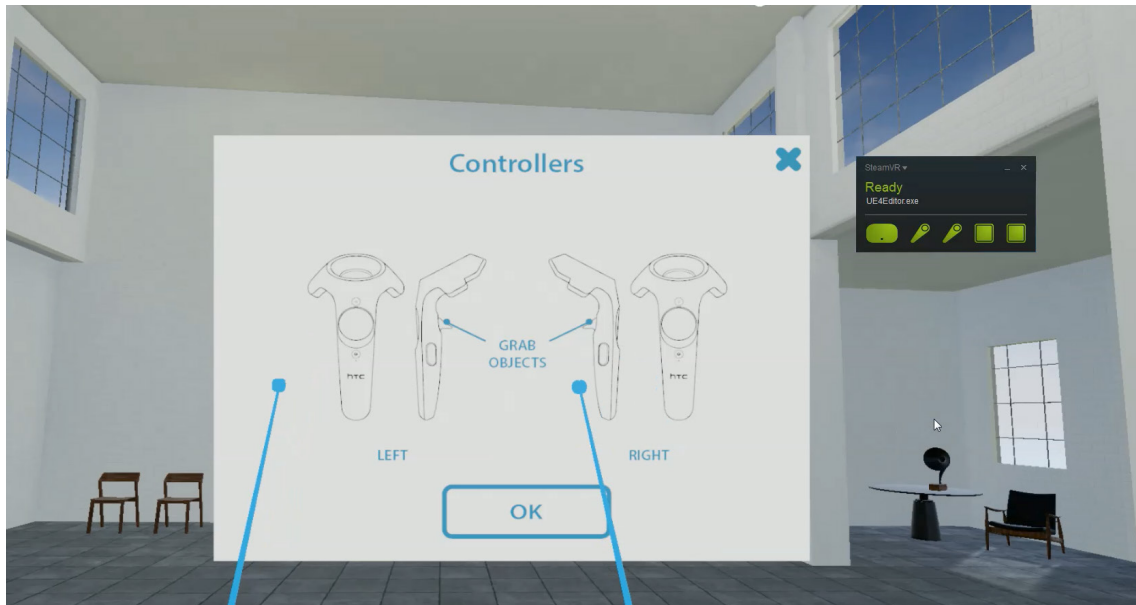


figure 63. The opening menu as seen through the HMD.



figure 64. The DHM in its default position in VR.

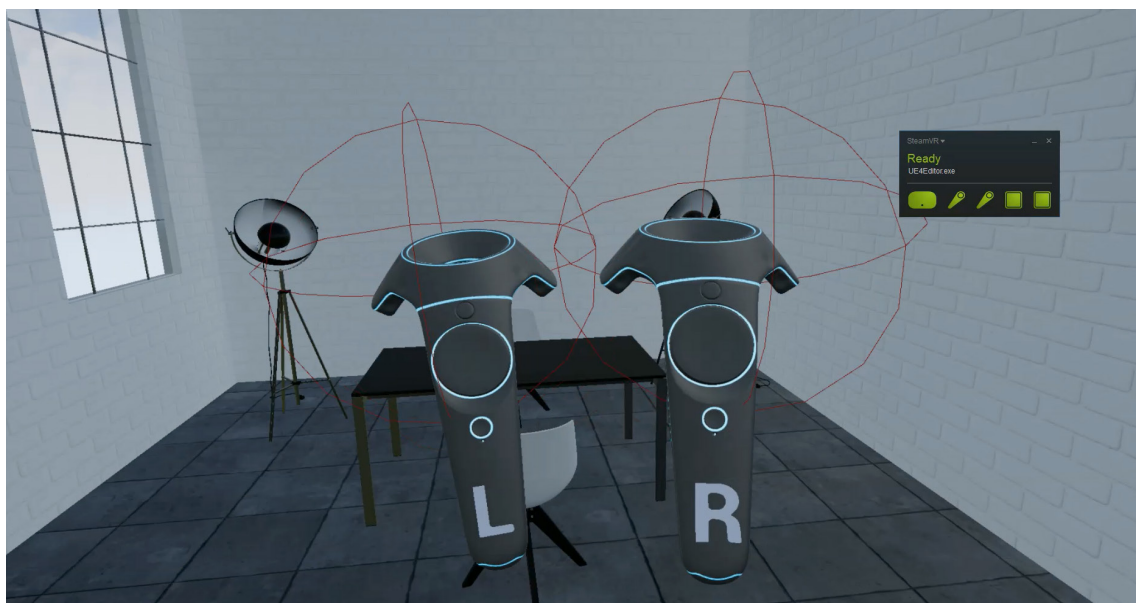


figure 65. The controllers as seen through the HMD in VR.



figure 66. Transporting through the room can be done through aiming the beam with the controller.



figure 67. User positioning the model with two hands at the same time.

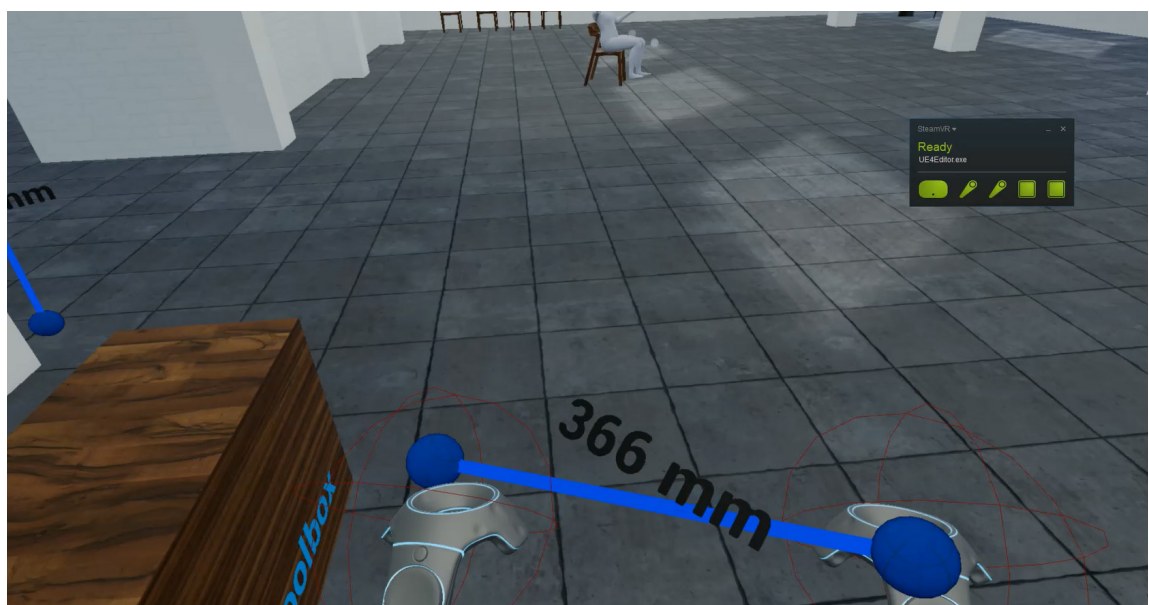


figure 68. User holding the measuring length tool with both hands.

9.0 | USABILITY RESEARCH

To check if the functionalities of the tool are intuitive to use and easy to understand, a usability research was held. Intuitive use can be described as the subconscious use of prior knowledge in interacting with technology (Hurtienne & Naumann, 2010). To check this the *Questionnaire for Measuring the Subjective Consequences of Intuitive Use* (QUESI) was used between tasks. The questionnaire consists of 14 items grouped into five subscales: (1) Subjective mental workload, (2) Perceived achievement of goals, (3) Perceived effort of learning, (4) Familiarity, and (5) Perceived error rate (Hurtienne & Naumann, 2010). To check the task load of using the tool the NASA TLX questionnaire was used after each task as well.

VR requires imagination to accept the virtual world as a reality. The immersive tendencies of the participants was therefore checked by the use of the *Immersive Tendencies Questionnaire* (ITQ) at the start of the research.

To find the specific usability issues for improvement of the tool, *Product Usability Evaluation* was used to validate the usability of the tool in use (van Boeijen & Daalhuizen, 2010, p.133).

9.1 METHOD

Initially the *Rapid Iterative Testing and Evaluating* (RITE) method was chosen for evaluating and adjusting the prototype. The RITE method is very similar to typical usability testing methods as participants are asked to think-aloud and complete a list of tasks. The major difference is that discovered issues are dissolved immediately meaning iterations are made more quickly

The Rapid Iterative Testing and Evaluating (RITE) method seemed very promising for this type of project. Unfortunately, due to a lack of time and knowledge in VR combined, this could not be performed. Eventually, a combination of Product Usability Evaluation, Immersive Tendencies Questionnaire, NASA Task Load index questionnaire and the Questionnaire for Measuring the Subjective Consequences of Intuitive Use were used to evaluate the prototype.

and often (Shirey, Charng, & Nguyen, 2013). The RITE method has proven to be highly effective in terms of finding and fixing problems and generating positive user feedback (Medlock, Dennis, Terrano, Romero, & Fulton, 2002). Martin and Hanington agree this method is effective and reliable (2012, p.142).

Unfortunately, performing such research would take up a lot more time than classic research due to the lack of knowledge and experience in Unreal. Estimating the time needed to solve issues would be impossible, making this type of research unfit for the situation.

The decision was thus made to go for a more classic approach. This meant testing the same tool with all participants and gathering the usability issues found, ordering them on occurrence, in order to write an improvement plan. This plan would explain the main issues that need to be solved in order to improve the design.

9.2 PROCEDURE

The participants got a booklet at the start of the research with a short introduction, consent form and the questionnaires. After the signing the consent form and filling the ITQ they were asked to perform the first task of the list.

tasks

1. Position the human model onto the chair
2. Measure the upper leg length of the human model
3. Measure the angle between upper and lower leg of the human model
4. Take a snapshot of the human model

During the tasks in VR the participants were asked to speak out loud. This method helps capture the participants perceptions on the usability (Barnum, 2011a). Retrospective recall, a method in which the participant has to comment on a task performed earlier on, was used between each task by having the participant fill in the QUESTI and NASA TLX questionnaires. Recalling situations or feelings improves the natural feeling of using the tool during testing due to less communication while performing the tasks (Barnum, 2011b). In this research the method of speaking out loud and retrospective recall were combined to prevent recall bias but be able to perform the tasks relatively unhindered while still giving the questionnaires briefly after performing the task.

The research was recorded by making use of a video camera on a tripod capturing the participants movements in real life and by screen capturing what the participant could see (figure 69). These two were then brought together to be able to better analyze the situations and problems the participants had when performing the tasks. Based on the found list of usability issues a redesign proposal will be made.

9.3 PARTICIPANTS

The amount of participants was 7 which would stand for finding about 90% of the usability issues and was already recommended for a small project based on a 1993 research (Nielsen & Landauer, 1993). According to the Nielsen Norman Group, five should be the magic number for the amount of participants, being both quick and efficient with about 80% of the usability issues found (figure 70) (Nielsen, 2000). Van Boeijen & Daalhuizen state a simple qualitative evaluation requires four to ten participants (2010, p.133). Flexibility regarding sample size is advised as projects differ a lot, and the most nuanced explanation comes from Albert & Tullis who state five to ten participants should be enough if its ok to miss some of the major usability issues, if there is only one distinct user group, and if the scope of the design is limited (2013).

As this research was held to identify the usability issues of the prototype consisting of a limited set of functionalities (posing, measuring and snapshot) and the product is aimed at a distinct user group (that of Design Engineers) the amount of participants was pinned down to seven. For testing eight master students from

the TU Delft faculty of Industrial Design Engineering were chosen to participate. One participant served as pilot. Two of the participants were female and six were male. The amount of experience in VR differed from zero to having tried it once or twice.

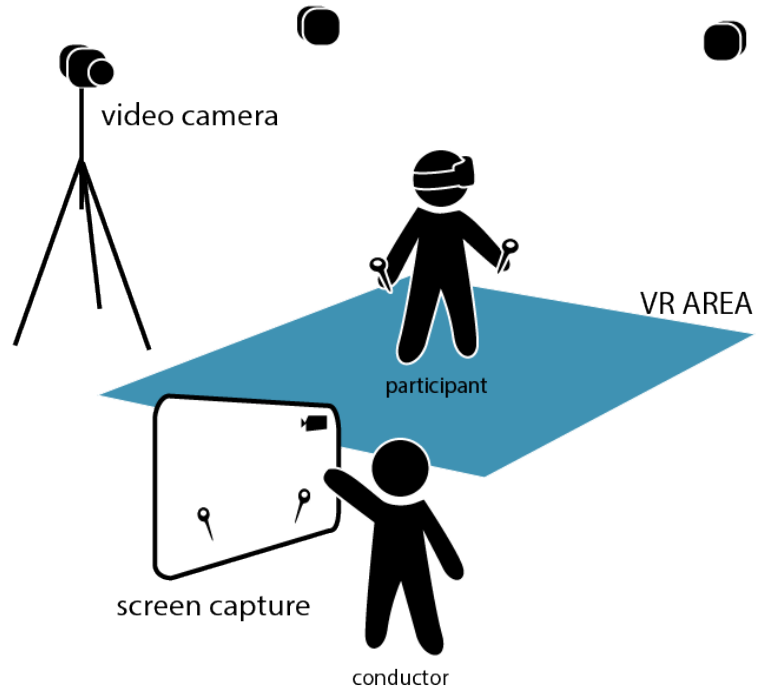


figure 69. The research set-up.

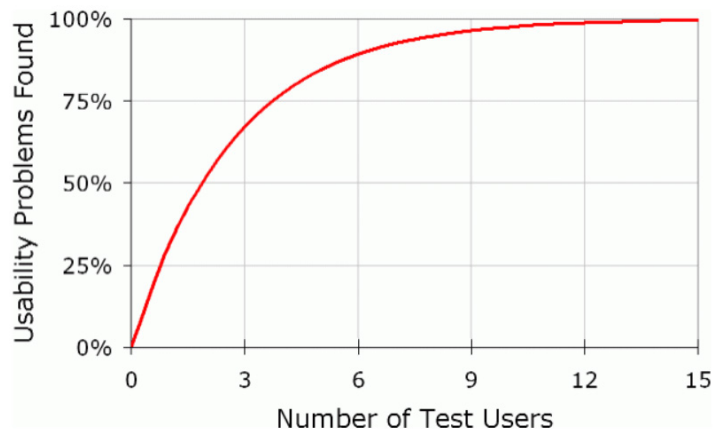
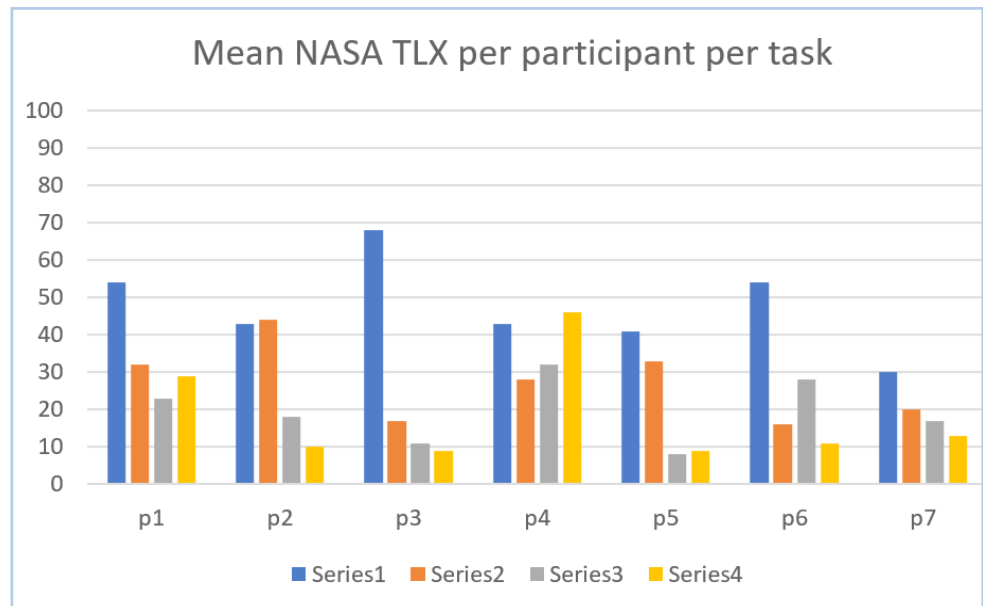


figure 70. Percentage of usability problems found compared to the amount of participants (courtesy of Nielsen, 2000).



9.4 RESULTS

First off, all the users were able to position the model after their liking within 10 minutes (figure 71). Despite this the NASA TLX results show the most difficulty was encountered during this task (positioning the model) as the mean is 48% compared to 27%, 20% and 18% for tasks 2,3,4 respectively (figure 72). As there are no comparable designs, a comparison is difficult to make. Combined with the comments of the participant on how smooth it went, we can conclude this score is good.

According to participants the tool was easy to use and they were indeed quick. The QUESI results show low values (appendix 8) indicating the tool is indeed intuitive to use.

The Product Usability Evaluation resulted in a list of usability issues (figure 73) which were numbered and ordered on occurrence. The most interesting one to name, which was not expected, was the issue some people had towards the level of intimacy they felt when positioning the model. This could be culture dependent but is definitely worth looking into.

Furthermore nausea made three of the eight participants stand still for a little bit before continuing. It was not more than a slight nausea but the participants were only in VR for a maximum of 15 minutes at the time.

Having a menu which allows you to move around the room already proved to be is distracting and makes people find ways to work around the menu (not exiting it). The results of the ITQ questionnaire (figure 74) could not immediately be found back in the problems that were encountered.

figure 72. The NASA TLX results, per task (series) and per participant (p1-p7). Vertically is the taskload percentage from 0% to 100%.

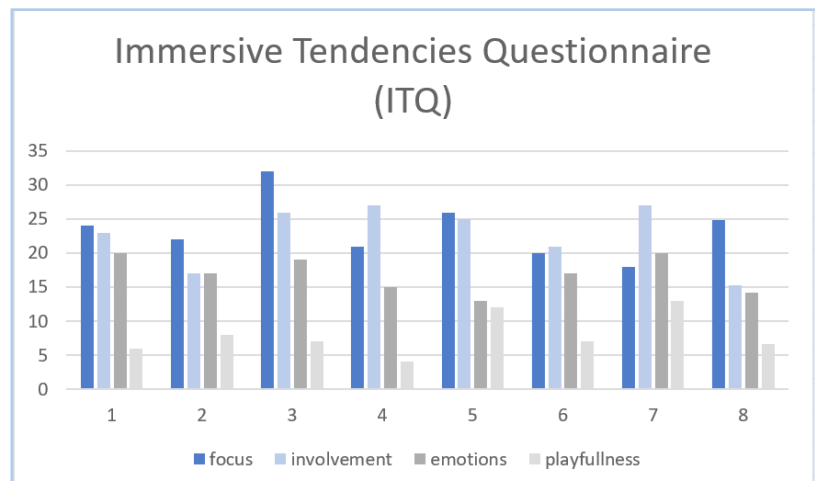


figure 74. Outcomes of the Immersive Tendencies Questionnaire (ITQ) per participant indicating their ability to get involved, focus, experience emotions and how playful they are. Number 8 shows the mean value.

“It felt very smoothly.”

“Oh this is really cool!”

“Now I’m really bummed I don’t have three hands..“

“This feels like the materix!”

“This is interesting!”

“Did you built it all yourself?!”

“The HMD feels like I have a very long ponytail.“

“I think you get used to this real quick.“

Nr.	occurrence	Problem description
1	16	Position of the grips unclear
2	13	Snapshot function makes unreal crash
3	11	Unwanted interaction between controller and chair
4	10	Unclear which button is for grabbing
5	9	Grabbing measuring tool unclear
6	7	Measuring tool disappears in DHM
7	7	Intimacy issues
8	6	Cords annoy
9	6	Unwanted interaction between DHM and chair
10	6	Grips missing in the upper body
11	6	Position of the grips unclear
12	6	Grabbing the handles from a distance
13	5	Lack of feedback from a snapshot
14	4	Reset posture glitches
15	4	Not being able to take all grips of the angle tool at once
16	4	No feedback of the distance between objects/DHM and the floor
17	3	Nausea
18	3	Cannot find snapshot button
19	3	Joints can go to unrealistic postures
20	3	Unclear how to get the DHM seated
21	3	No gravity on DHM
22	3	How to click inside the menu unclear
23	3	Not reading the menu
24	2	Cannot grab measuring tool in the center
25	2	DHM falls back when lifted
26	2	Interaction between chair and DHM missing
27	2	Grips go out of sight
28	2	Grab model instead of grips
29	2	Transportation cannot be canceled
30	2	Menu text unreadable
31	1	No reset room option
32	1	Reset posture button unclear
33	1	Accidentally adds second character
34	1	Angle value does not turn with your gaze
35	1	Unclear how to transport
36	1	Meaning of the OK button unclear

figure 73. List of usability issues encountered listed on occurrence.

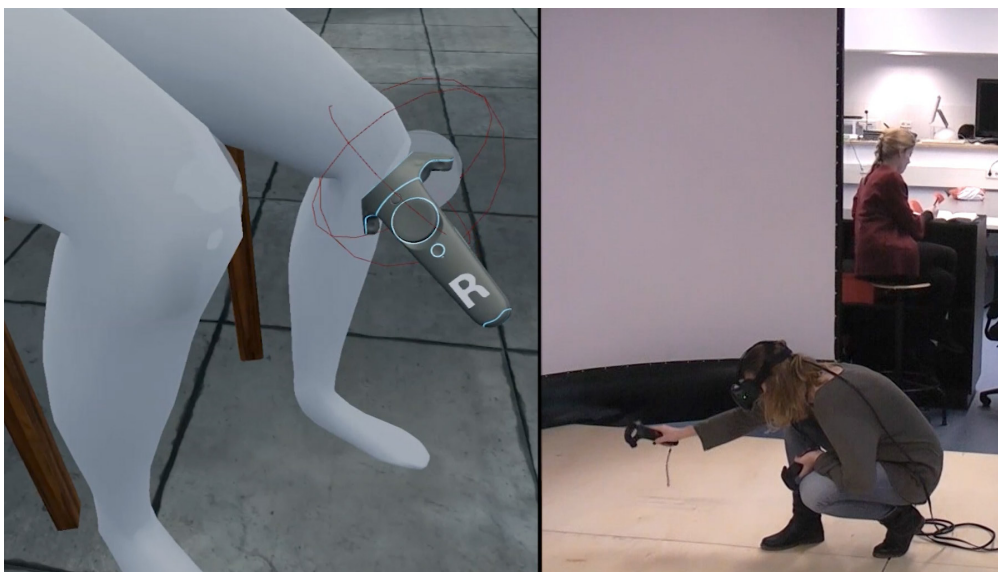


figure 71. A participant positioning the knee of the DHM in VR. On the left the view in VR, on the right the real life situation.

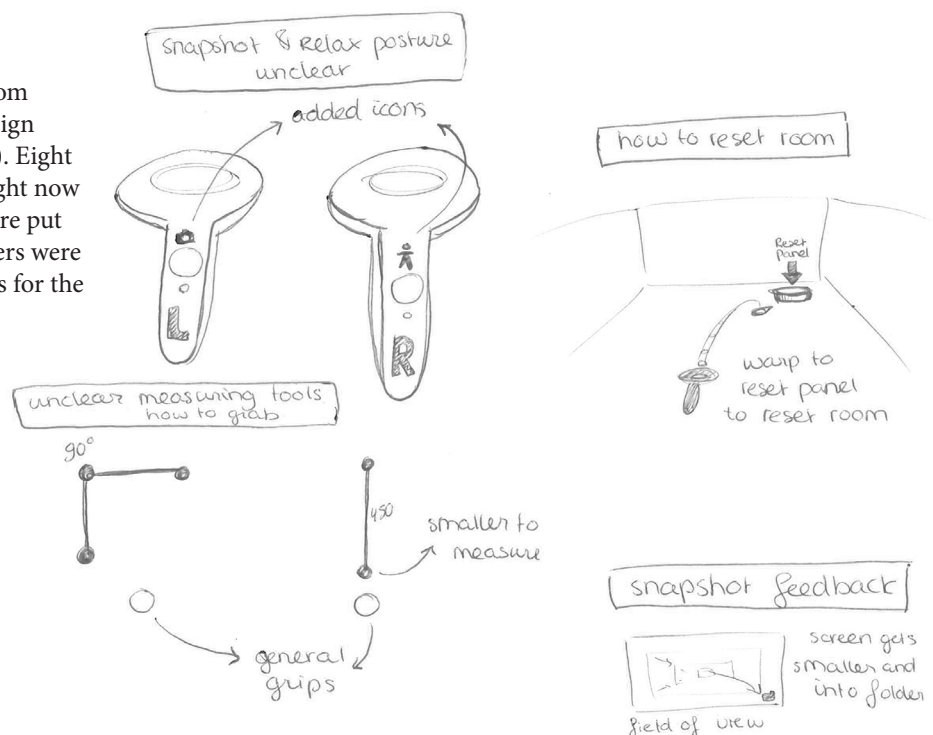
Problems	Solution
2	Update UE to version 4.19
1, 6, 7, 11	Model will turn transparent when user is very near
3	Hitboxes around the controllers smaller
4, 12, 18, 20, 22, 23, 24, 28, 30, 32, 35, 36	Build an exploration area in the empty room, with posters on the wall explaining the different functionalities and where to find them. Also add a grip to show that it lights up if it can be grabbed and let people experience the interactions here first, in a guided situation. Takes off the curiosity in a fun way.
5, 15, 24	General grip for lifting the measuring tools
7 *	Tests should be done on the preferred distance to the model to prevent intimacy issues.
8 *	Wireless HMDs
9	Delete collision between handle and chair
10	Adding handles in the: upper, lower and middle back, the shoulders, hips and the neck
13 *	Snapshot shrinks the screen and shows it moving to a folder
14, 33	Make the glitch invisible
16, 26	Adding shadows
17 *	Have a nausea disclaimer asking participants to move slowly to prevent nausea.
18	Camera icon on button
19 *	Adding the limitations of the joints
21 *	Gravity would mean a ragdoll effect so this is simply not possible with the grips as they are now, a different way of building the grips could maybe thought of.
25	Hold position after handle is let go of
26 *	Vibrations when the DHM touches the object
27	Grips snapping back to their position on the DHM after being let go of
29 *	Build an own transportation tool in which cancellation is an option
31	Add a reset room option
32	Add human icon on controller
34 *	Make the angle number turn with the users gaze

figure 75. List of solutions to the usability issues found.

9.5 REDESIGN PLAN

To deal with the issues found from the usability research [9.4] a redesign plan was put up (figure 75 and 76). Eight problems were unsolvable as of right now (the ones with the asterix), but were put in the recommendations. The others were considered possible improvements for the near future.

13, 21 and 29 are problems that occur with now pre made functions of UE. Addressing these would require serious programming skills.



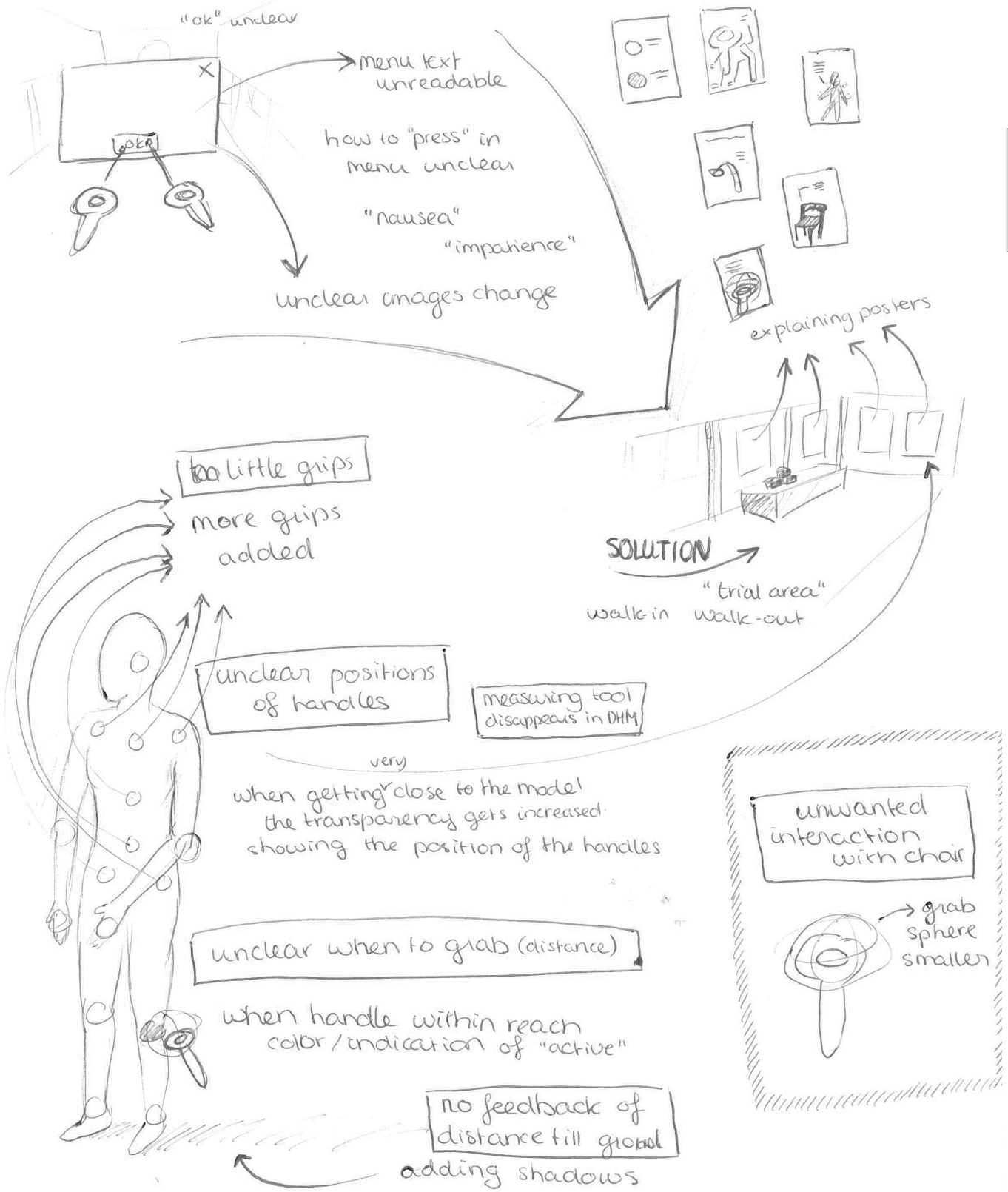


figure 76. Quick sketches visualizing the redesign concepts.

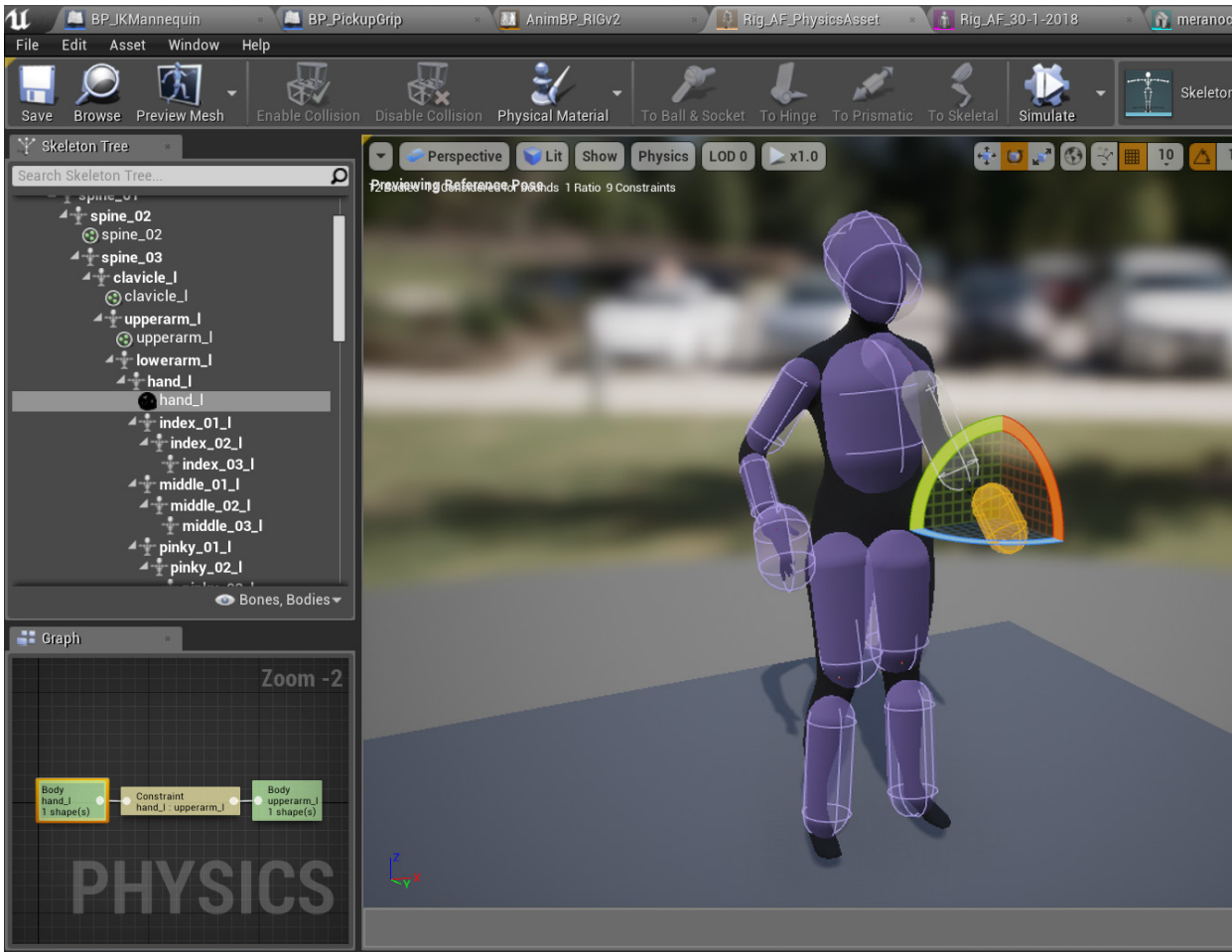


figure 77. Adjusting the capsules to be a little more accurate in forming the capsule shadows in UE.

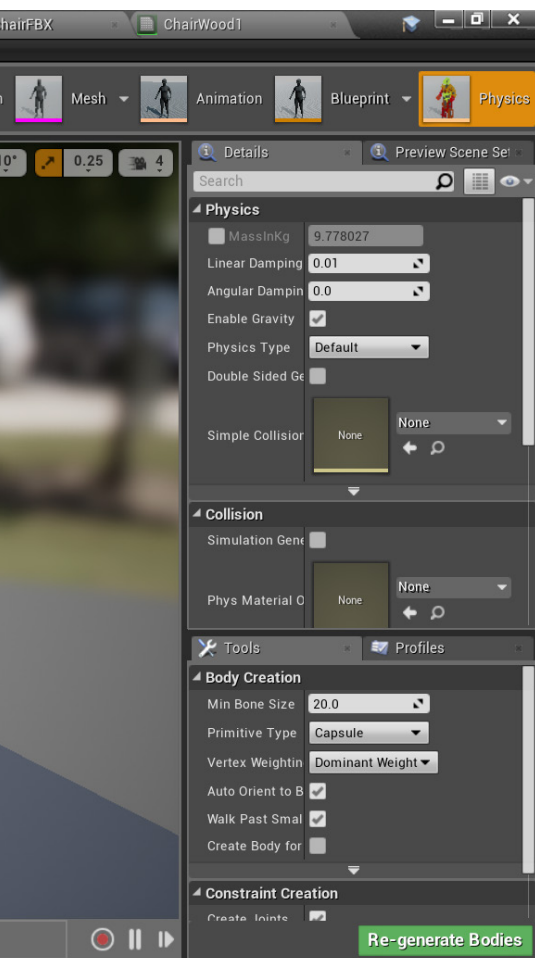
10.0 | REDESIGN

The time for redesigning the prototype was limited, but a lot of iterations were made during developing. This was done based on own experiences and that of friends and trespassers. The most important problems from the usability research, that could easily be solved were built in, resulting in the redesign, and listed below.

Capsule shadows were added to the DHM, which is an efficient way to create shadows by mimicking the models shape with capsules (figure 77). To also have shadows of the movable objects and products imported later on, one dynamic light source was added (more would be heavier to calculate) generating a soft shadow on the floor. The intensity of both had to be checked in UE and in VR to be set to a reasonable value.

Icons for both the relax posture button and the snapshot function were added to the controllers. The grab spheres were made smaller and there were grips added. The tool was updated to UE 4.19, the glitch made invisible and the DHM does not fall back when regrabbing the entire DHM grip anymore.

The redesigned prototype will be up and running after the graduation presentation on the 14th of March 2018 at the Joost van der Grintenzaal at the TU Delft faculty of Industrial Design Engineering. The program will furthermore be given to the the TU Delft.



11.0 | DISCUSSION

11.1 CONSIDERATIONS OF USING 3D SCANNING

When post processing the 3D scans, the dimensions change with tools like smoothening. When scan quality improves this won't be an issue anymore.

Measurements by hand might differ from those subtracted from 3D scans due to real life measuring tools like measuring tape that dent soft tissue when measuring for example the waist (Paquette, 1996).

Ethics of 3D scans and the lack of guidelines on this, as described by d'Apuzzo (D'Apuzzo, 2017b), makes it difficult know when boundaries are overstepped when scanning people. This can also cause trouble when companies try to set up their own databases.

It is difficult to indicate landmarks to be automatically read by a computer, which is why in recent research this was done by hand for each scan, despite the fact that it is very time consuming (Lee et al., 2017). The scans therefore need to be rigged by hand per scan, meaning the positioning of the bones will not be the same but will depend on the person rigging, who will need skill and understanding of the human anatomy and the programs being used.

Creating an own dataset for companies would be difficult without a 3D scanner of sorts but as the quality is getting better and prices are getting lower this could improve. Lending scanners like the one available at the TU Delft would be an option too.

11.2 CONSIDERATIONS OF USING VR

VR is an interactive medium interesting for design since walking around the product and DHM is a big advantage over current tools. Conversely, objects

can appear smaller in VR than in real life, undermining the improved situation for estimating dimensions. As both the DHM and the product suffer this effect they can still be judged together.

Hardware is increasingly affordable with the full HTC Vive for €488, making it interesting for smaller companies who are more inclined to use the tool as it is now because of their quick and dirty approach.

11.3 CONSIDERATIONS OF THE 4D DIGITAL HUMAN MODEL

By using full body 3D scans for the DHM data collection becomes easy and allows companies to build their own databases which can be a big advantage for companies. Post processing the scans before they can be used as a DHM in the tool requires the programs Geomagic and MAYA, which are licensed programs. Licenses are expensive for companies which cost will obstruct the creation of own datasets.

The details like fingers and toes are not realistic because of scan quality and post processing. A solution for post processing without adjusting the measurements of the 3D scan should be found as scan quality will improve over the years.

Post processing the scan will take a lot of time and requires basic knowledge on the human anatomy and on Geomagic, Maya and UE.

11.4 RESEARCH LIMITATIONS

The participants of the usability research [9] were master students industrial design engineering with no or little work experience. They are also young compared to professionals in the field, which might

influence the tests.

The NASA TLX questionnaire got filled in between the ticks instead of on the ticks which meant, following the NASA TLX guidelines (NASA, 2017), that the values had to be rounded off upwards. All the NASA TLX values are therefore 2,5% to 5% higher than the participants intended.

The results of the third and sixth participant were both at the end of the day meaning this could have influenced their results as well.

As there were no comparable cases found, the NASA TLX could not be compared, meaning the values do not say much about the actual task load of the tool. Results of the NASA TLX can however be used in the future to compare this version to newer versions.

12.0 | CONCLUSION

The project proved the viability of an anthropometric tool based on 3D scanning and operational in VR. Through building a functional prototype, making use of the software Artec, Geomagic, Maya, and Unreal and the hardware HTC Vive, 3DMD scanner and a personal computer, a usability test could be done to determine the task load and intuitive use. Both generated good scores despite the fact that comparison at this point is difficult.

In the future, the tool will probably be used by design students, aiding human factor engineering lessons. It will help students gain understanding of the complexity of user centered design situations, see the merit of using 3D scans as well as make students experience the unique advantages of working in VR.

Chances of the tool becoming embraced

by design agencies are at this stage low. The tool is not yet scientifically sound and will therefore have a hard time convincing clients. The tool is furthermore time inefficient and costly to work with since there is no database of 4D DHMs available. The licenses and knowledge required make it difficult for smaller design agencies to start building their own databases.

Nevertheless the tool can be seen as a proof of concept, hopefully inspiring designers and developers to better understand the advantages of VR and 3Dscanning techniques for applications outside the entertainment scope.

13.0 | RECOMMENDATIONS

During the project it became clear that solving all the blemishes of current DHMs and implementing all the interesting possibilities found, would be impossible.

Future work therefore lists the research that is needed for further development.

Current design improvements are the smaller improvements that were not solved for the redesign, but can in the near future be solved.

Future improvements are vague ideas for the future. Hopefully they can inspire other designers and researchers to look into.

Future work

// Determine the effect of post processing 3D scans on the dimensions

// Movement predictions, humans move along the path of least resistance and tools

// Determine the correct way to weight paint in order to create realistic soft tissue deformations of the DHM

// Save positioned model for use in CAD programs

// Tests should be done on the preferred distance to the model to prevent intimacy issues.

// Find a way to add the joint limitations to the model

// Find ways to post process, rig and weight paint 3D scans automatically

// Build a platform for DINED where designers can easily select the DHM(s)

Current design improvements

- // Model will turn transparent when user is near
- // Build an exploration area in the empty room, with posters on the wall explaining the different functionalities and where to find them and add a grip to show that it lights up if it can be grabbed and let people experience the interactions here first, in a guided situation. Takes off the curiosity in a fun way.
- // General grip for lifting the measuring tools
- // Wireless HMDs
- // Delete collision between handle and chair
- // Snapshot shrinks the screen and shows it moving to a folder
- // Have a nausea disclaimer asking participants to move slowly to prevent nausea.
- // Adding the limitations of the joints
- // Feedback when the DHM touches the object
- // Build an own transportation tool in which cancellation is an option
- // Add a reset room option

Future improvements

- // Use AR for building mock-ups
- // Using AR for giving feedback on physical mock-ups (like degrees/height and such values projected alongside it)
- // Visualize comfort
- // Heatmap to show pressure of the product/DHM surface
- // Pre-scripted animations like walking, sitting down, getting up, lying down etc.
- // Day/night switch
- // VR lighting adjusts automatically to the lighting in Real Life
- // Isolate one particular body part to work on
- // Interesting finding from the creative session was to make the face turn sad when the pose is uncomfortable
- // It would be interesting to create a model that can show the min. and max. within a target group or size box (of ellipse) to be able to see the biggest differences and design for this

14.0 | REFERENCES

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15.0 | APPENDICES





figure 78. The final posture one of the participants put the 4D DHM in during the usability research.



Sport & Cultuur

Agenda Sport Cultuur Horeca Ruimteverhuur

15/02 Kick-off: Drawing in 3D

15 februari 2017 | 20:00 - 22:00
 plaats: at Culture
 door: Communication



Experience a world in another perspective with drawing in virtual reality (VR).

During the Free Try-Outs at Culture you can grab the opportunity to experiment with a 3D pen and drawing in VR with the Tilt Brush. Even when these techniques are new to you, with the help of an expert on side, you will easily be able to create something and much quicker than you can imagine! There are many ways in which you can use a 3D pen. From Jewellery and pendants to personalizing your laptop and phone case.

Tilt Brush lets you paint in a 3D space. Whatever your location, once you put on the glasses, your surroundings turn into an endless canvas. You can simply draw or paint anything from your imagination.

Enjoyed the experience? Or you already know how awesome these tools are? On 15 February you can subscribe to a VR Designing Project that will be held on 8 March at Culture.

Wednesday | 20:00 - 22:00 | at Culture | €0,-



figure 79. Clockwise from the top left: the Sports and Culture invitation to the VR demonstration, the VR area with the HTC Vive setup, a participant trying out Tilt Brush and finally the menu and view as seen through the HMD (presented on a computerscreen).

APPENDIX 1

VR EVENTS

event | 4TU | February 15th 2017

The Culture Centre in Delft held an universal try-out event with diverse activities. One of these activities involved the HTC Vive, a Virtual Reality (VR) set (see figure 79) with the *Tilt Brush* software. The set makes the wearer see a 3 dimensional area and lets you draw in 3D.

The limitations of the virtual world were marked by a grid on the walls (seen through the HMD). You cannot see the real room you are in, neither yourself. You can move around your drawings to check all sides with the goggles aiming where you look and the software following your gaze.

To draw in 3D you have two kinds of joysticks which are identical. One of them is your so called 'palette' and the other is meant for aiming and drawing. By ticking the bottoms against each other the functionality switches as to make it fit both left- and right-handed people.

It was not possible to move your drawings. To adjust your drawings there was a return arrow to go one step back at a time. Saving could be done both in 3D and by taking a picture of your sketch in 2D.

The participants of this event were loosely questioned about their experience and also the presenters were asked for their experiences. Unanimous, everybody agreed that as soon as you put the goggles on and put the controllers in your hands you knew instinctively what to do, how to operate it. This sense of control was liked a lot by the crowd. They called the experience "intuitive", "familiar" and "fun", which are great responses to working with a new product. The learning curve was evidently very steep.

Unfortunately the tool was not very precise and thus made it hard to connect lines in 3D. A thick wire went from the goggles to the computer which made it dangerous for trying on your own, a simple solution to this would be a wireless headset which are available already.

Overall it was great to have had this experience early on and see how quickly people picked up the controls.

DELFTSE BEDRIJVEN DAGEN & IOB FAIR

DDB | TU Delft | February 21 & 22 2017
IOB | TU Delft | March 17 & 18 2017

Business events attended to get in touch
with designers from different disciplines.



figure 80. The banner of the Delftse Bedrijven Dagen 2017 event at the TU Delft.
retrieved from <https://goo.gl/images/Vhb1fX>



figure 81. The IOB fair entrance at the TU Delft faculty of Industrial Design Engineering.
retrieved from <https://goo.gl/images/MStBmc>

BRUNOTTI

Company visit | Brunotti | 23 Februari 2017

91



HANS KRUYSSSE
Size and fitting specialist BRUNOTTI

JOFFREY DELFGAAUW
Head of Design BRUNOTTI

BRUNOTTI is a boardsport and lifestyle brand from the Netherlands. Originally started in 1979 by the 23 year old Italian Claudio Brunotti, who had moved to Scheveningen. By now the brand has become widely known for its gear and clothing.

Wetsuits are surfer garment, usually made from a neoprene, and worn to keep its wearer warm when in cold waters. A wetsuit should therefore fit like a second skin. With every body unique, providing each customer a fitting wetsuit is quite the challenge. For the purpose of creating a digital mannequin it thus seemed like a good idea to pay them a visit.

At the Spacelab in Amersfoort, the Netherlands, where the design office is seated, I met with both the head of design Joffrey Delfgaauw and size and fitting specialist Hans Kruijsse.



figure 82. BRUNOTTI poster. retrieved from <https://goo.gl/images/utoHww>

INAUGURATION CHARLIE WANG

inauguration | TU Delft | February 24, 2017

Inauguration of the PhD'er Charlie Wang
who will work on a scientific approach to
deformable human models.

VR INTEREST GROUP MEETINGS

VR discussions | Sports and Culture | March 15, 29 and April 5 and 12, 2017

A group of interested students that decided
to meet and work on VR projects. During
these sessions the making of a 4D Digital
Human Model were also discussed.

ADJUVO MOTION

company visit | Adjuvo Motion | April 21, 2017

A company visit to Adjuvo Motion was
planned to check out their prototype.
They are working on a glove for VR that
accurately reads out the position and force
the hand gives and is aimed at revalidation
of hand trauma. The tested prototype can be
seen in figure 83, in 84 the latest version.



figure 83. Trying out the Adjuvo Motion MARK.V prototype at YES!Delft.

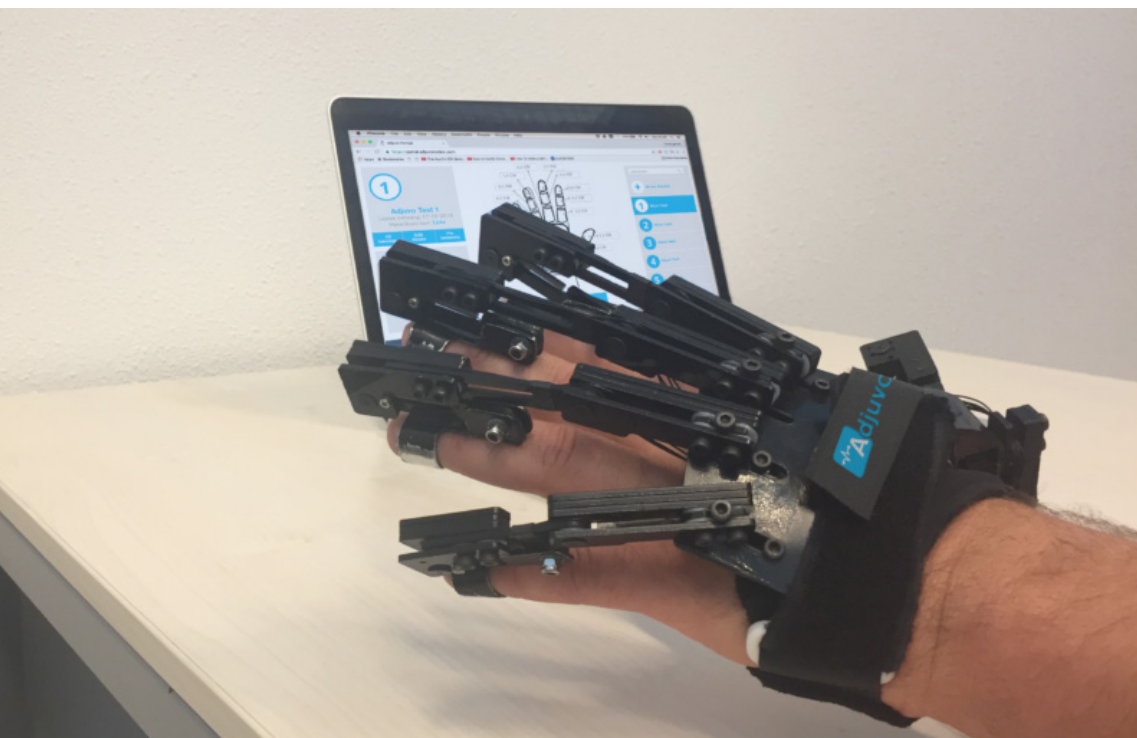


figure 84. The latest Adjuvo Motion prototype.
retrieved from <https://goo.gl/images/N5QQhJ>

LECTURE NICOLA D'APUZZO ON 3D SCANNING

Lecture | TU Delft | May 22, 2017

Lecture given by Nicola D'apuzzo from Hometrica Consulting on the history and future of 3D scanning.

RESEARCH EXHIBITION

exhibition | TU Delft | June 6, 2017

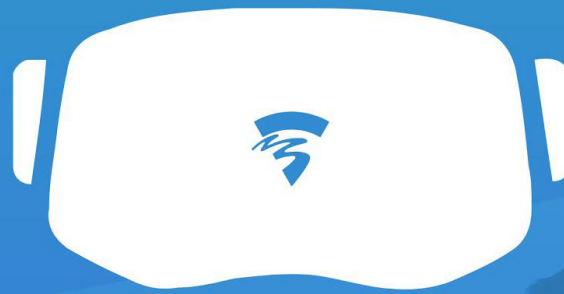
At the research exhibition held at the TU Delft Library a VR escaperoom was presented. Tried this out and discussed with the makers the possibilities in VR.

WEAREREASONABLE PEOPLE

company visit | Wearereasonablepeople | June 27, 2017

Contact was sought with the company Wearereasonable people to talk with them about the best approach to an software problem. Eventually Invision and quick testing methods were discussed. The best approach for this particular problem seemed to be building a high fidelity prototype and user test this.

HVA MINOR EXPO VIRTUAL REALITY



Gratis toegang
4e verdieping van
Theo Thijssenhuis (TTH)

28 juni 2017
15:00 - 19:30

BEKIJK EN ERVAAR
VIJF PROTOTYPES I.S.M.



alchemist



iNDiViDUALS

figure 85. Invitation to the minor exhibition at the HvA 28-6-2017.



figure 86. The Oculus Rift HMD for VR.
retrieved from <https://goo.gl/images/MPnHf2>



figure 87. The HTC Vive HMD for VR with LeapMotion attached.
retrieved from
<https://goo.gl/images/hdrchM>



figure 88. The Microsoft HoloLens HMD for AR.
retrieved from <https://goo.gl/images/GxPxhP>



figure 89. The HTC Vive HMD and controllers for VR.
retrieved from <https://goo.gl/images/PY7ESx>

VR PRESENTATIONS

exhibition | University of Applied Sciences of Amsterdam | 28 June 2017

At the University of Applied Sciences in Amsterdam, a showcase event for their new interdisciplinary Minor was held on the 28th of June 2017. During this day students, teachers and family got invited to see what the five teams, each of around six students, had accomplished for their “client” in half a year. The companies that were involved were: Unicef, KLM, Vlisco, iNDiViDUALS and Alchemist. Each of the teams worked with a different VR/AR software and hardware combination.

The Unicef Team

This team made use of an Oculus Rift with LeapMotion sensor attached to it (figure 87). By clever use of sound, visuals and intuitive hand gestures they were able to create a very holistic experience. It starts off in a town by the beach which gets bombed. They made use of the 360 degrees view by letting you follow three villagers that run out of the streets and burning buildings, making you turn around to see where they are heading. From this scene it is a harsh transition to a refugee campsite where you are in charge of filling a help package by choosing

between three items at the time. Here the LeapMotion comes to play an important role. The LeapMotion sensor basically allows you to see your own hands in 3D and even though it is not perfect, your hands tend to rotate a lot, it allows you to grab one item and drop it into the cardboard box next to you. This way you fill the box. Thereafter a little game of Simon (an original 80's memory game) starts. The goal of this project was to make people aware of the difficulties of what to offer refugees and to raise money by letting people play the game while getting sponsored. Graphically not very strong but the interactions and storyline were amazing.

KLM

The team that worked for KLM built two things, a VR simulation of an airplane in which you have to manage three flight attendants when a fire breaks out. It felt a bit like the Sims but definitely worked its magic for the purpose, namely, learning flight attendants the different roles in such scenario.

The hardware they used were the HTC Vive and its controllers (figure 89) to hop from one place in the (virtual) plane to another (figure 90). Graphically very detailed, something you would expect KLM to use in practice mere weeks from now.

Even more stunningly, however, was the AR experience of another team, which was made for the same purpose. This time you are acting out as one of the roles. By wearing the Microsoft Hololens (figure 88) the plane context had to be mimicked by chairs but the (fake) laptop definitely made this experience more exciting as it suddenly bursts into flames which you can see like a digital layer over the (fake) laptop. Their AR experience has undoubtedly merit over VR in general for its tactile feedback of having to grab the laptop and walk it to a bucket (digitally) filled with water. As KLM might have to choose one option to continue on I would definitely suggest AR for it allows muscle memory to be formed.

Vlisco

The project done for Vlisco, a Dutch company that produces high quality fabric with African prints, comes closest to the tool I am working on for my thesis. The team made use of the HTC Vive (figure 89) and managed to create an adorable yet fashionable and spacious changing room (figure 91). Here you see the, possibly disturbingly realistic, body of an African woman of which you can change the sizes according to your own sizes. This scaling would help prevent the local African tailors from cutting the costly fabric into something that does not look like what the client had in mind after all, because this tool allows their clients to see how the clothing will eventually look on their bodies instead of on a model.

The interaction of adjusting the sizes was very easy but not very accurate. The extra scenes which they made to show off how the clothing would look either on a red carpet, in a wedding setting or in a business setting was a very nice touch and probably much appreciated by the end users.

Clothing company Alchemist

This project made use of Google Cardboard (figure 92) and an AR app that can be downloaded on your mobile phone. Through Google Cardboard you could see a digital catwalk in a nice nature environment. With the AR app you could see models pop up on the brand's catalogue to give a better view on the garment. Very feasible on short terms and readily available since it works with only a smart phone.



figure 90. The virtual world built in a way to represent the airplane interior for KLM crew safety training.

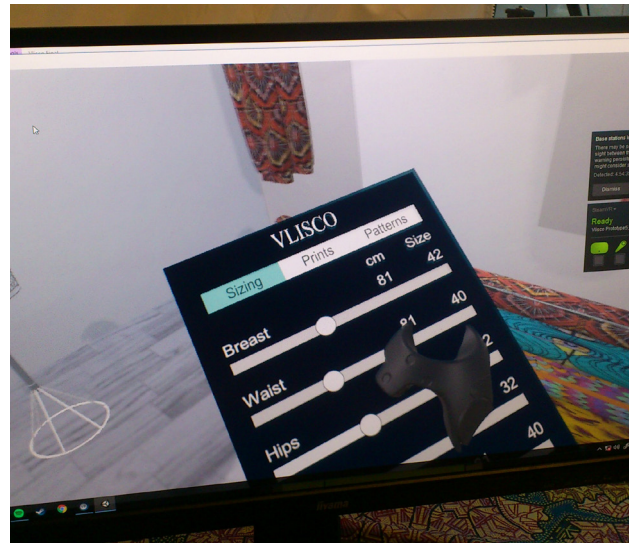


figure 91. The changing room and menu made for Vlisco as presented at the HvA.



figure 92. Google cardboard. retrieved from <https://goo.gl/images/Ma7bBi>

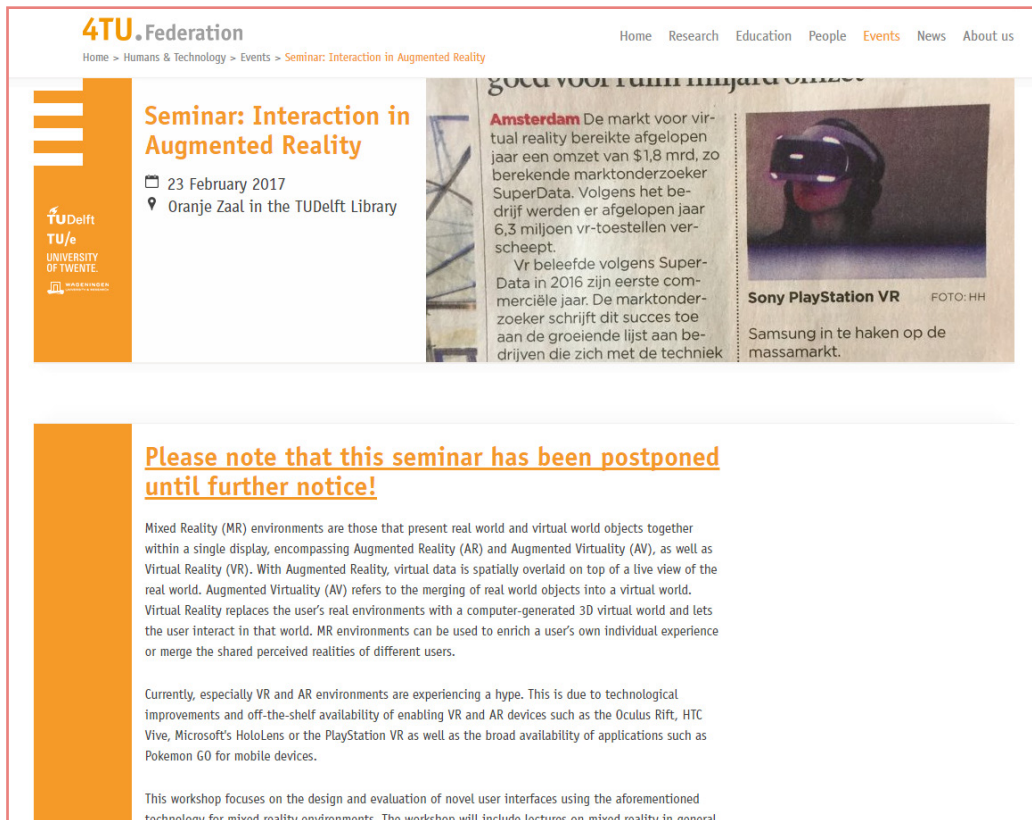


figure 93. 4TU website showing the first notice given on the event.

VR EVENT BY 4TU

VR event | 4TU | October 5, 2017

4TU is a collaboration between four Technical Universities in the Netherlands. These are: TU Delft, TU Twente, TU Eindhoven and TU Wageningen. The event was put up to inspire the use of VR for educational purposes.

APPENDIX 2

QUESTIONNAIRE

SUMMARY

In order to gain insight in the use of anthropometric data in the design process of design professionals, different (design) companies were approached at two business events, Delftse Bedrijven Dagen and IOB fair. From this reach out 21 Designers filled in the online survey, 15 chose the Dutch and 6 the English version. From the group of designers participating, 28% uses DINED whereas 36% of their anthropometric data comes from experience and inviting friends and family to model. Company data, from experience or research, accounts for 18% of the anthropometric data. Only a small 6% is outsourced to companies specialized in looking up the data.

The graphs give proof that anthropometric data is important throughout the design process, yet most important for the embodiment phase. Nowadays companies make use of test subjects, analog tables and 3D manikins mainly. 3D Manikins are not yet used for the research phase, evaluation and finalizing nor presenting the final product. At DINED the 1D data is most popular.

GOAL

The goal of this research was to gain insight in how companies deal with ergonomics. The questions were aimed at finding out which tools are being used and where in the design process.

METHOD

In order to get the answers to the questions an online questionnaire was sent out. Following up this questionnaire a generative research was held by holding interviews and asking how a design process looks like at their company, what tools they use and why. Interestingly as well most interviews resulted

in a similar sketch of what kind of functionality the tool should have. [see User Research 2]

QUESTIONS

The questionnaire contained 7 questions.

Q1. In which phases of the design process do you make use of anthropometric data (human dimensions)?

To answer this question four options were given and multiple answers were possible. The options divided the design process in four, as taught at the faculty Industrial Design Engineering of the TU Delft and commonly used in the profession. Consequently these were also the four used in the research of Lombaers et al. in 1986 but then translated in English. These options were “research phase”, “Ideation phase”, “Embodiment phase” and “evaluation and finalizing”.

Q2. To you, how important is anthropometric data in each phase?

To answer this question the same four options were available, only this time they had to choose between “very unimportant”, “unimportant”, “neutral”, “important” and “very important”. To analyze this they got weighted scales of consecutively -2, -1, 0, +1 and +2. This way the importance could get determined of anthropometrics in each phase.

Q3. Which anthropometric tools do you use when designing?

For this question the types of tools available for using anthropometric data came from the book “Anthropometrische modellen” by Lombaers et al. (1986). The different categories were: “tables and scale drawings, Analog”, “tables and scale drawings, Digital”, “turning plates and sliders, Analog”, “turning plates and sliders, Digital”, “two dimensional manikins, Analog”, “two dimensional manikins, Digital”, “3D

manikins, Analog”, “3D manikins, Digital”, “test subjects”. Again, the participants could add in which phase they use this kind of tool. Multiple answers were possible.

Q4. From where do you retrieve your anthropometric data?

Knowing where companies get their data from is interesting for it shows the likeliness of finding the tool on DINED and defines whether special advertisement will be needed to make the tool a success eventually. The options given were formed by talking to several companies during the Delftse Bedrijven Dagen, the visit to BRUNOTTI and the IOB fair where a lot of insight was gathered already. The options therefore were “Company data”, “Own or colleague experience”, “DINED”, “External parties (companies that look up this data for you)”, “inviting family and friends to try it out” and lastly “other, namely: ...” where participants could add other sources unknown at the time of writing the research plan.

Q5. Which function, if any, from DINED do you use?

This question was included to see what functions of DINED are currently used the most. The options were the options the DINED website offered at the time (July, 2017). These options were “1D data”, “ellipse”, “profiler”, “ADAPS”, “Konings and Kappelhof 3D manikins” and lastly “we do not use DINED”.

Q6. What is your job description?

With the use of an online survey through links the questionnaire could have ended up with anyone which made this question useful in order to see who filled it in, proving its validity for the design profession.

Q7. Would you be so kind to leave your e-mail here so I can contact you for further questions or remarks?

Interviews could be set up with the participants that were willing to help out some more.

PARTICIPANTS

Participants got found through networking at the IOB fair and the Delftse Bedrijven Dagen

which are events where a lot of different companies come together to connect with students from Delft.

Through explaining the goal of this study and asking for designers to the members of the company present at those events (which are not all designers themselves) a diverse group of designers working on different product categories got found (figure 94).

RESULTS

The questionnaire received 21 responses of which 15 Dutch and 6 English. These results were manually put together in Excel to give out graphical representations of the results.

Q1 - From this graph, figure 95, it can be seen that anthropometric data gets used in all phases of the design process but not equally much. The ideation phase is marked as the phase in which anthropometric data is used the most and the evaluation and finalizing phase the least.

	Name	Company	Job description
1	W.Put	Spark Design	Project manager / industrial designer
2	K. van der Wiel	MMID	Senior Functional Designer
3	C. Weel	MMID	Senior Designer Look & Feel
4	M. Loth	TU Delft	PhD candidate
5	R. Mastenbroek	NS	Senior Engineer Interior
6	E. Vroege	ADSE	Specialist Industrial Improvement / productontwikkelaar
7	H. Kruijsse	BRUNOTTI	Sizing & Production Coordinator
8	R. Verhaagen	Van Berlo	Senior Designer
9	M. van Zwet	Flex	Design Engineer
10	M. van Gelderen	NUNA	Design Manager
11	F. Verstraelen	ADSE	Design Engineer – Aircraft Interiors
12	A. Roijackers	DAF Trucks	Voertuigeigenschappenbeheerder Ergonomie
13	W. Lee	TU Delft	PhD candidate
14	-	-	Fashion Designer
15	-	-	Researcher
16	-	-	Industrial Designer
17	-	-	Product Design Engineer
18	-	-	Designer
19	-	-	Research & Design
20	-	-	Senior Product Designer
21	-	-	Industrial Designer

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figure 94. List of participants of the questionnaire.

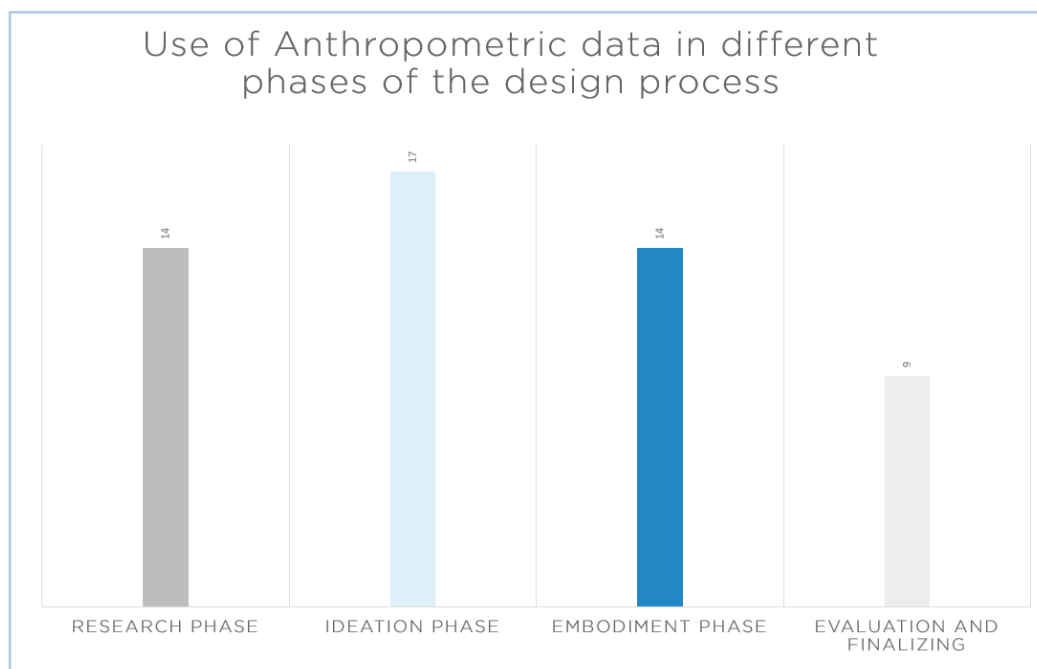


figure 95. The use of anthropometric data per phase of the design process.

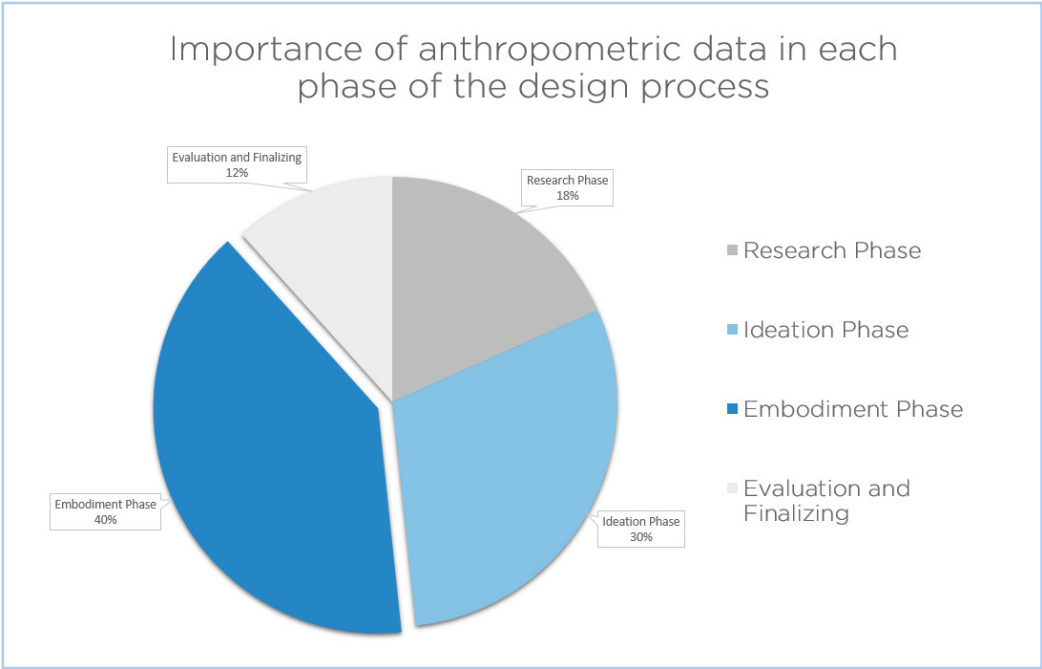


figure 96. The importance of anthropometric data in each phase of the design process according to the respondents.

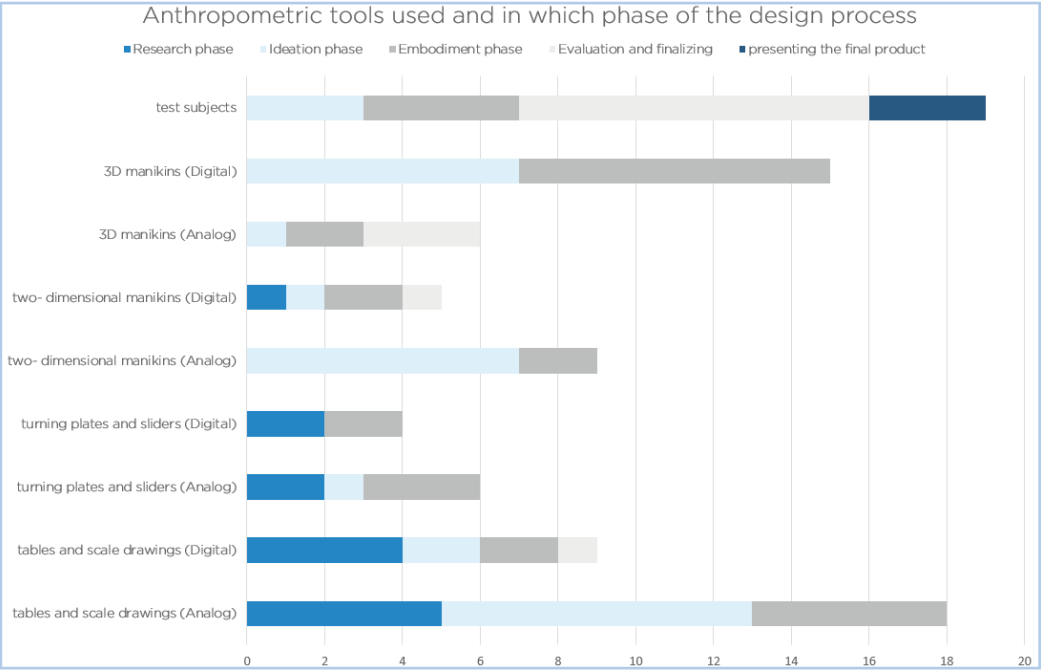


figure 97. Which tools are used in which phase of the design process. The x-axis shows the amount of respondents choosing that option.

Q2 - Interestingly enough, the embodiment phase was picked as the most important phase to have anthropometric data at hand (figure 96).

Q3 - Most used are test subjects although tables and scale drawings and 3D manikins get used a lot as well (figure 97). Analog and digital tools both get used a lot but in different phases.

Q4 - In this graph, figure 98, we can see clearly that analog tools are still used more often, but digital tools are used a lot already with exception from the evaluation and finalizing and presenting the final product. This is interesting to take along to the interviews as companies at the DBD and IOB fair were especially interested in this.

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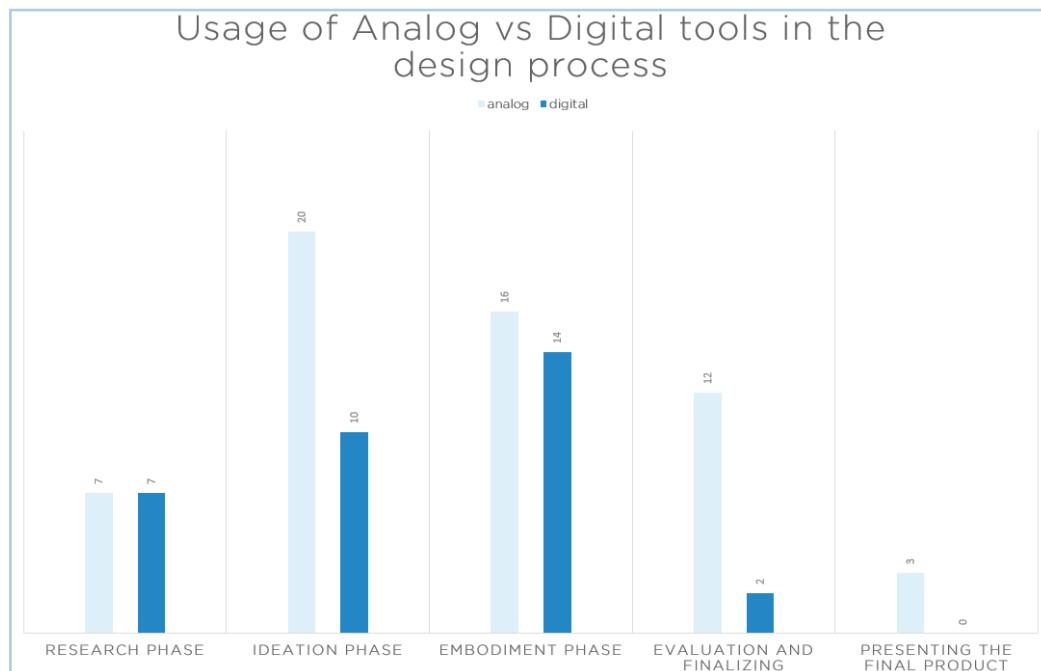


figure 98. The usage of digital versus analog ergonomic tools during the design process.

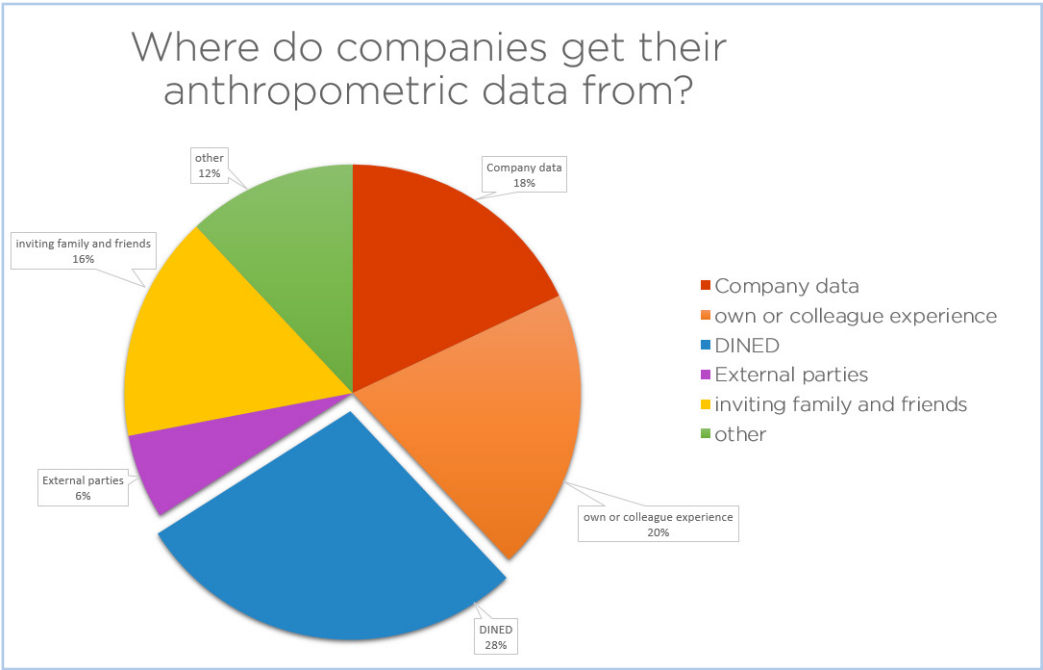


figure 99. Piechart showing where companies get their anthropometric data right now.

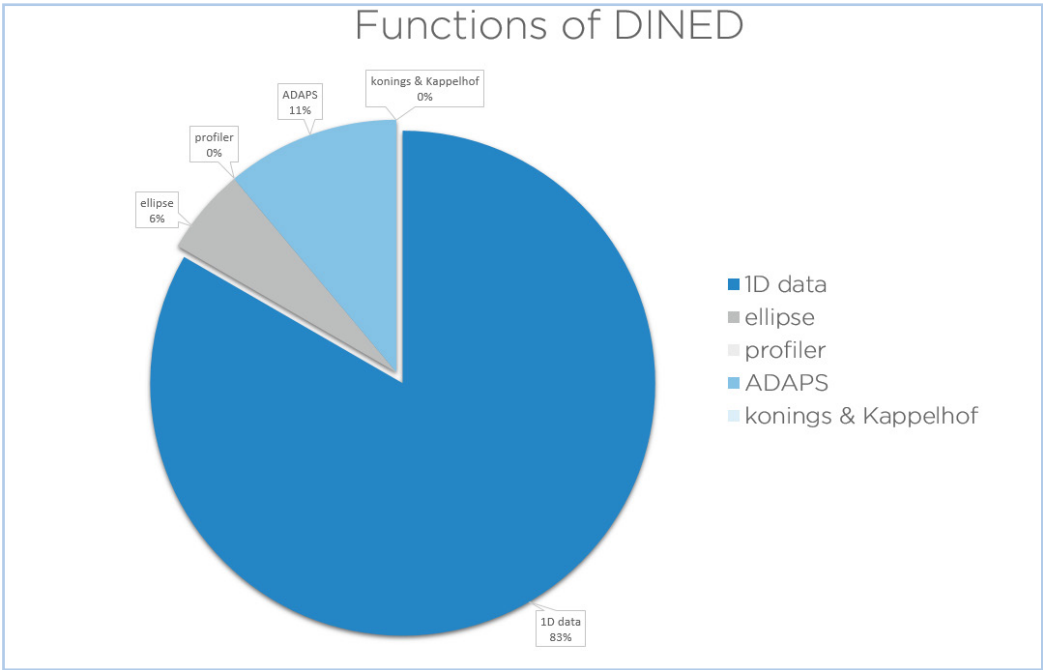


figure 100. Piechart indicating which functions of DINED are currently used the most.

Q5 - DINED currently only covers 28% of the anthropometric data (figure 99). Asking friends and family to model and experience takes up a cumulative 36%. External parties stood for 6% of the data and company data both from experience and from research was good for 18%. The 12% other were: the University of Michigan published database, test subjects (x2), laws, handbooks, norms, google images and 3D models like from 3D content central or Grab CAD and CAD models.

Q6 - The DINED tool most used is 1D data (figure 100). This is in line with the experiences of Lyè Goto (from a talk before writing the research plan). ADAPS was fairly popular as well.

DISCUSSION

In preparation to this research a meeting with Lyè goto was put up. Lyè is a PhD candidate at the TU Delft faculty of Industrial Design Engineering working on designing based on 3D scans. In particular she's designing oxygen masks for infants based on 3D scans of their heads. From experience she could tell that having experience and little funds available makes most companies to only look for anthropometric data late in the design process. Furthermore she could tell that when using 3D models for designing, companies usually extract 1D or 2D measurements. Her experiences have influenced the questionnaire to some extent because it was important to find out if these claims were true.

Furthermore the people that were reached at the business events did not yet include companies explicitly working with 3D data. In order to get in contact with these companies e-mails and phone calls were sent out.

Companies like Exo-L (making ankle braces based on 3D scans) and Mesh Lingerie (bra's made based on 3D scans) were found this way. Despite both products are focused on individual designs, their input might be key to finding a way to translate their way of working to industrial production and convection sizing. Thus, this inspired the second user research: the interviews.

APPENDIX 3

INTERVIEWS

The interviews were held with:

Jiaji Zhao from MMID
 Arno Roijackers from DAF Trucks
 Edward van Grol from Flex
 Rombout Mastenbroek from NS
 Erik Vroege from ADSE
 Floris Verstraelen from ADSE

Floris Verstraelen – ADSE

Works as engineer for private airplane interiors. As example project in which he used ergonomics he told about an interior job for a Chinese man (no details given). For creating the interior safety rules like the aisle width but also comfort constraints needed to be taken into consideration. It was a case of balancing 20 different parameters, building models in Cathia. Within Cathia no DHMs were used. To do so mr dummy (a free parametric DHM, figure 101) was used in SolidWorks. Its sizes were put to Chinese dimensions but, as he admittedly said, were probably not correct. A table for 8 persons was built and with mr Dummy checked on whether the knees would hit the table edge or the feet would meet in the center of the table. There was a physical mock-up built and tested with people from the company as well because, arguments Floris, comfort is difficult to estimate in 3D. When asked about a VR experience he was interested but did say that now mr Dummy and SolidWorks are easy so in order for the tool to work it should be easy too. Costs of such a tool would be a factor as well. VR would be very interesting to show the atmosphere which is now hard for them to test and show to their client. It would also be interesting if within the program product parts can still be moved. As Floris has a background in the caravan industry he recommended the use of such a tool for the development of caravans.

Daan Janssen – Exo-L

At Exo-L they make ankle braces that prevent

spraining with the use of 3D scans. Daan Janssen, industrial design engineer for the company, talked me through their process and explained the benefit of using 3D scans to their company. The quick evaluation and prototyping benefits from 3D scans whereas for variation of values the numbers (data sheets) are better. From the scan they take the shape of the ankle by making cross sections and indicating the positions of the bone. Right now they do not take into account soft tissue deformations in the model, if such model exists they would gladly use it as some tendons are important. Now they avoid any pressure on the Achilles heel for comfort but it is no exact science yet. For every Exo-L they make new scans to design the customized product. They are building their own database every scan at the time. Automatic readout of the points they are interesting works in many cases yet when someone is more corpulent the bone structure is harder to interpret for the

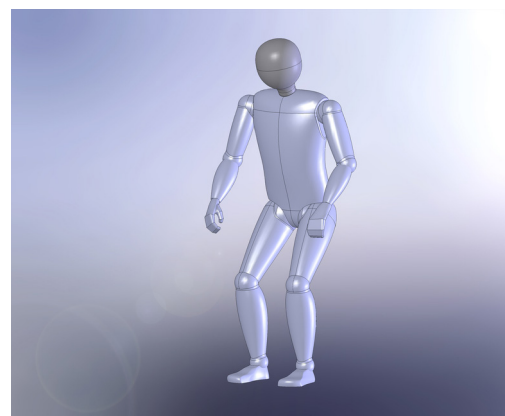


figure 101. Mr. Dummy a free downloadable parametric DHM. retrieved from <https://goo.gl/images/dAg79f>

algorithm, causing every automatic readout to be checked by a designer. Making choices based on the 3D scan cannot be done by a computer and is thus done by hand. From the point cloud they use the surface and product with offset. Interpreting scans requires a lot of turning around the product and looking at cross sections. When a heatmap overlay was suggested to show pressure sensitivity on the body Daan got very excited. That would be very interesting for the Exo-L. Now they make prototypes and test them 1 or 2 times per user to get it right. They once did a test with 100 people to validate the general concept. To secure the position of the ankle every scan is made with their own built scanner that “forces” the ankle in a fixed position and angle. According to Daan this is no unnecessary luxury as every ankle differs a lot from the next.

Erik Vroege – ADSE

Erik Vroege works at ADSE as airplane interior designer. For doors he explains that if the P95 (95th percentile of length in this case) can walk through, the door is good. Thinking on it more is irrelevant. Right now they use “less relevant data” with which he means research from the 80s, men or women. He would like some more specific data to convince clients but much detail on ergonomics usually does not grab their attention much. The EASA puts up restrictions as well and thus it is mainly important to have quantifiable values to validate choices. For the door example they use simple profiles to check dimensions in 2D. They did check the armlength and leg length to DINED data. He did suggest it would be great to have the DINED data more concrete. Another example he gave was when he was making sure people can check the server cooling system and operate it. To check this the team used a 3D

model from 3D content central which was merely a metric doll. Deformations were not really relevant for this particular use and the model was scaled in total not per body part. To check the interaction they needed to find how much force a human can deliver, the bodily dimensions and reach of an arm. When asked if he would like to have such functions available in VR he said it would be nice for verification and tests but mainly interesting if it would add something for the end user. Working on interior design for private airplanes ethnicity is import to take into consideration. Verification is done to see if designs are technically sound, as to which ergonomics is applied. For Validation of a design, to see if the users are content, VR could add something but Erik still prefers having test persons experiencing the design. He would like to have the power a human can deliver under certain poses more insightful but finds reach of limbs and bodily dimensions the most important when designing. Furthermore he argues that sound scientific foundation of such tool will be important. Aerospace rules are global like “without tools people should be able to see a screen”. To check this now they put a line on the floor a screen printed out on paper and tested it with colleagues. For airplane chairs there is not much choice available due to the few companies making those. Sizes like the aisle width are important but fixed by the EASA to be 24 inches measured on the floor. Proving dimensions based on 3D models is too unknown now. They use CAESAR data which is fine for them, just as the outdatedness is approved. Erik argues that 10 up to date scans are less worth than 4000 outdated ones. Now they reference DINED as proved source or books but those have older data, yet a title to reference to. Rombout Mastenbroek – NedTrain R&D Working as an R&D engineer for NedTrain

he knows a lot about ergonomics needed for such projects. He describes their process as a 6 phase process. When for example the NS (Dutch Railways) asks for a proposition they first check if they can provide, then how much that would be (chairs for example). They then propose a price which is the first go/no go moment if it is a go they will enter the preliminary concept phase. Here the concept is being checked with the requirements and the design is checked with DINED data on ergonomics. They work together with suppliers to determine the sizes. They then send the preliminary design concept to the suppliers who will take the concept model into production. The close contact with the suppliers is important to adjust production molds if necessary. They then review the requirements and use a 3D DHM for comfort. If it is a go after this a critical design review will take place and production necessities will be made. At this moment it is past the point of no return. They have three big checks, one for the requirements in the preliminary design review and one for the 3D design before the critical design review. The last check is the final design review when the first tool is already made to check quality. They use dummies to review the design for The National Institute for Occupational Safety and Health (NIOSH), ARBO (Dutch safety requirements for working environments) and TNS NIPO (Dutch institute for the public opinion and market research). In agreement with Peter Vink ergonomic constraints are put up and a builders estimate is made. They check designs on 3D geometry and on comfort. The 3D models they use are the best available in NL. It is the last info that science has but as the population changes they might not be super accurate. Which population they use is a choice made by the NS in this case, as problemowner. The supplier looks at the tables and adjust the 3D DHMs parametrically based on the DINED data. Muscles and such are just how the model was made. This dummy, MIRA type III, is mainly used for crash tests and is expensive, housing heavy software for movements. In general they come pretty far with the use of 3D data for, for example, arm reach. Rombout was enthusiast about the concept of 3D scans in combination with

positioning this model to do geometric checks. Now they can buy models and adjust them. It then becomes a solid. Per target group such a solid has to be made and it takes them up to 2 days to do so. A questionnaire for the experience of the chair and having a pressure point map is good enough. The main goal of this is to take away the production risk and to speed up the process. Rombout believes that dummies are mainly interesting to recognize risks in an early stage and to generate nice images.

Edward van Grol – Flex Delft

The first project that came to the mind of Edward van Grol, design engineer at Flex Delft, was that of a herb rack for the Albert Heijn (Dutch supermarket concern). They made pre-concepts which were broad and gave a nice appearance. Testing these concepts was done by hanging cardboard boxes on the wall and changing the angle and height. The test subjects were colleagues and the client. Edward called it quick and dirty but also very insightful. Building things really helps you see the first person perspective and dimension of things. When using DINED data they check the smallest and biggest of the values but does not say anything about the ease of use. In 2D they use the reach to determine sizes. Flex has an in-house built 3D model from which in illustrator 2D sketches can be made. Eventually ergonomics is valued less highly than the opinion of the client. 2D is often chosen for speed, needed because of budget. Visualizing concepts to the client now costs a lot of time because days can be spent on finding the right human posture in a picture to go with a render. The picture takes a lot of time because it needs to be copyright free, the right perspective, the right colors (or adjusted in photoshop) and cut out in photoshop. When a VR solution with moveable and scalable boxes was discussed he was enthusiastic. This way building cardboard prototypes would not be needed. He also thought it would be amazing to be able to make renders from those screens for the DHM would have the right perspective, posture and colors as the prototype. He was eager to stay in touch to see more of this tool.

Jiaji Zhao – MMID

Jiaji Zhao is a usability designer at MMID working on user interfaces. As an example project he spoke about a smart mirror in which it was interesting to see where would be the comfortable position for information. In reality, he said, it is hard to look up research because it takes up a lot of time. Usually a quick google search is applied instead. For positioning building mock-ups and testing with colleagues is the most common. When using datasheets the P95 and P5 are checked. Sometimes a 3D DHM was used to position it and see if it looks comfortable. This model is mainly used in the concept and research phase. For relevant data they do not check a 3D DHM because it is not there yet, so if it is not special they google else they do a “safe guess” to determine dimensions. Jiaji would be interested in a database that explains if positions hurt. However, the amount of time for such info is limited. If measurements are possibly a risk they take a high risk margin. Models to them are in the first place to control the risk, risk management and secondly for idea generation. He argues the tool would be most interesting if the tool would not just be to check risks but actively supports designers in designing. For the mirror a 3D DHM would be interesting to show the angle and where the primary and secondary information would have to go. The field of view would also be great to see.

Arno Roijackers – DAF Trucks

As Design Engineer at DAF Trucks, Arno Roijackers has to deal a lot with ergonomics. As he explained, a chauffeur of their trucks has to live in it, drives in it and sleeps there. They have to continuously check the ergonomics of a human in the cabin when designing. One of the biggest trouble in doing so is to find 3D models of corpulent humans as truck drivers tend to be overweight. They build 3D models of the cabin and look up 3D models of humans to check with, in which the topic decides which model (small, medium or large). They have to make JACK or RAMSIS more fat, but then proportions are not realistic anymore. Arno argues he would rather have one generic model than 10 body scans however. Usually their approach is that when it fits the biggest person the smallest will fit too. For

reach they look at the smallest reach too. A lot of research is also done on the behavior in cabins. They then also take into account the reach width a lot. They use the biggest sizes of DINED, CAESAR and their own research in determining dimensions. However enthusiastic about the DINED data for being up to date and indicating the development of bodily dimensions over time, the biggest downside for DAF is the fact that there is no working population division. Especially for DAF, having such information would make ergonomic assessment a lot more realistic as the general truckdriver is a lot more corpulent than the average civilian. The idea of sending nice renders to customers did not appeal to Arno as much. The idea of having a preset library of positions however did. He named the following of being of interest when designing a truckdriver cabin: seated position for behind the steering wheel, standing (undressing/getting dressed), lying down on a bed/sleeping postures and sitting on the bed. Animations would also be nice. Now they use Unigraphics but it is not compatible with Jack, who is a stand-alone DHM. Arno is convinced the tool would have to work within the program in which the design is being built as switching programs is annoying and time consuming. For accuracy he speaks of a 3-5 mm accuracy. For determining the steer they do tests with test subjects in a mock-up cabin environment. Right now the P5 and P95 are often used with the proportions from CAESAR.

APPENDIX 4

ASSIGNMENT CREATIVE SESSIONS



Topic: Interaction Design in VR (Virtual Reality)

Short Introduction:

Virtual reality offers a lot of new ways to interact with a computer, but it also comes at a cost. 3D objects are easier to understand by walking around them but to interact with them in a 3D space can feel rather complex.

For my thesis I am working on an ergonomics tool for Designers in VR to help them assess their products in an intuitive and visual way. This should help speed up the process and give more realistic information than the tools used nowadays.

Problem description:

Therefore my problem right now is: How to make an 3D human model easy to position in Virtual Reality?

Goal/Objectives:

It needs to be quick, intuitive and very visual. First time use should be very easy to understand.

Elaborating Picture: *3D model in seated position, this is a very low poly however, my scans are better :3*



Contact Information:

Marloes Kroonen - marloeskroonen@gmail.com

0648863046

APPENDIX 5

IMAGES CREATIVE SESSIONS



figure 102. A collection of the images made during the creative sessions.

APPENDIX 6

USABILITY RESEARCH MANUAL

Page 3 and 7 were left out as they only stated “part 1” and “part 2”. The pages 8 and 9 were repeated per task but were only put in the appendices once to save paper.

4D Digital Human Model for Designers

USER TEST

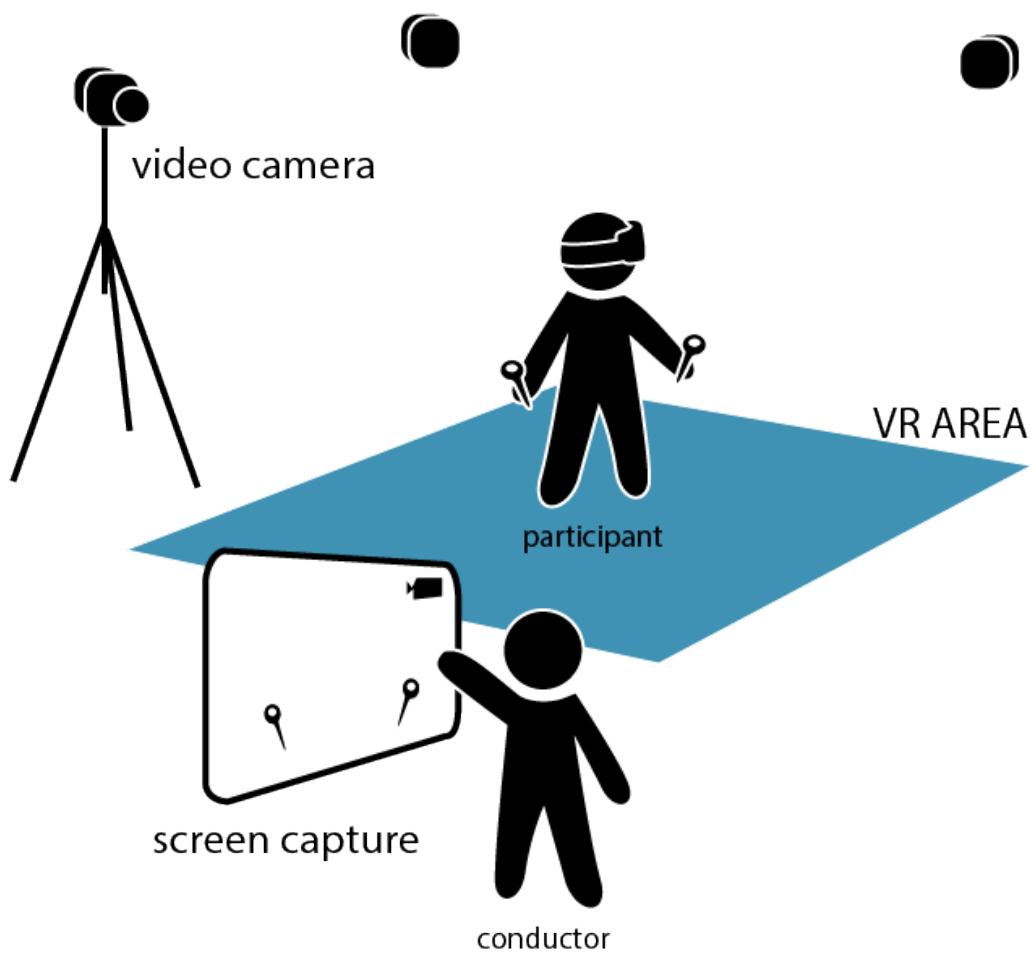


Figure 1 test set-up that is used for this research

Please read this carefully and fill in only the first part of the questionnaire before continuing in VR.

Welcome

Thank you for participating in this user test.

The test consists of two parts. During part two of the test we will make use of the HTC Vive, Virtual Reality hardware. The test, however, focusses on the software. Therefore you are asked to focus on the software during the test. After part one is concluded you will get the opportunity to read part two, do not read part two already.

Part 1

- Consent form
- Participant Information
- Immersion Tendency Questionnaire (ITQ)
- Read assignment in VR
- Think out loud while performing task 1(VR)

Part 2

- QUESI (per task)
- NASA TLX (per task)
- Comments and recommendations

The software

You will be testing a software made for designers to perform regular ergonomic assessment of products in between iterations. This research is to find any usability issues.

Consent Form

I declare that I am properly informed about the nature, method and goal for the research. I know that the data and results of this research might be used for the graduation presentation of Marloes Kroonen, and that I will be unrecognizable due to the head mounted display of the HTC Vive. I understand and consent to the use of the recordings (unrecognizable due to the head mounted display) for public display.

I understand that data and information I share today will be handled confidentially and anonymously. I will not be identified by name or by showing my face.

I participate voluntarily with this research and have the right to stop with my participation at any time without explanation.

I understand that the research will take no more than 60 minutes.

I acknowledge that I received a copy of this statement.

Please sign below to indicate that you have read and you understand the information on this form and that any questions you might have about the user test have been answered.

Date: _____

Name participant: _____

Autograph participant: _____

Thank you!

I appreciate your participation.
For questions use contact information below:

Marloes Kroonen
marloeskroonen@gmail.com
0648863046

Participant Information

Age: _____

Gender: M / F / 0

Native language : _____

Understanding of the English language: basic – adequate – good – native

Educational background: _____

Current occupation: _____

Experience with VR: Y / N

Participant: Pilot – 1 – 2 – 3 – 4 – 5 – 6

VR Assignment

When wearing a head mounted display, you will not be able to see the real world. There are cords attached to the head mounted display so be careful not to trip on these. Furthermore, be weary you cannot see real life objects anymore. Within the game there is a light blue grid visible which shows you the limits of the area you can move around in, in the real world. Be aware of this when walking around in virtual reality.

Now, before you will put the headset on, here are the steps I want you to follow. After each task you will get a short questionnaire before continuing to the next task.

- 1. Position the human model onto the chair**
- 2. Measure the upper leg length of the human model**
- 3. Measure the angle between the upper and lower leg of the human model**
- 4. Take a snapshot of the human model**
- 5. Position the human model as you wish**

!! Remember to speak out loud while performing the tasks !!

Please put on the Head Mounted Display (HMD) now. The controllers will be handed to you once the HMD is in place.

Position the human model onto the chair

QUESI - Questionnaire for Intuitive Use

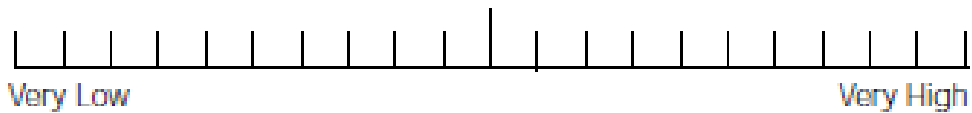
Note: In evaluating the system, try to refer only to the use of the system (and not for example to the difficulty of the task itself). There are no right or wrong answers. Please answer spontaneously and don't leave any questions out.

		Fully disagree	Mainly disagree	Neutral	Mainly agree	Fully agree
1	I could use the system without thinking about it.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2	I achieved what I wanted to achieve with the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3	The way the system worked was immediately clear to me.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4	I could interact with the system in a way that seemed familiar to me.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5	No problems occurred when I used the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6	The system was not complicated to use.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7	I was able to achieve my goals in the way I had imagined to.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8	The system was easy to use from the start.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9	It was always clear to me what I had to do to use the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10	The process of using the system went smoothly.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
11	I barely had to concentrate on using the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
12	The system helped me to completely achieve my goals.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
13	How the system is used was clear to me straight away.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
14	I automatically did the right thing to achieve my goals.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

NASA TLX

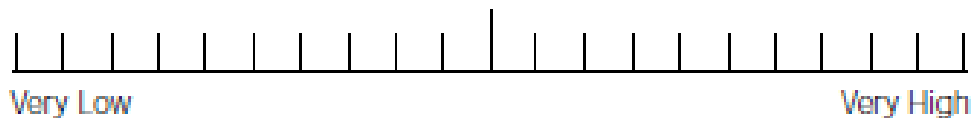
Mental Demand

How mentally demanding was the task?



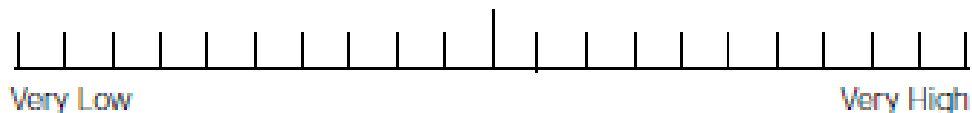
Physical Demand

How physically demanding was the task?



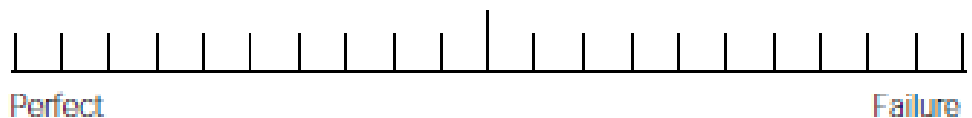
Temporal Demand

How hurried or rushed was the pace of the task?



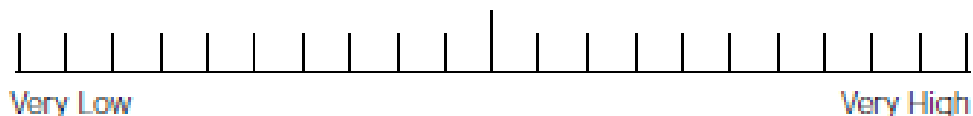
Performance

How successful were you in accomplishing what you were asked to do?



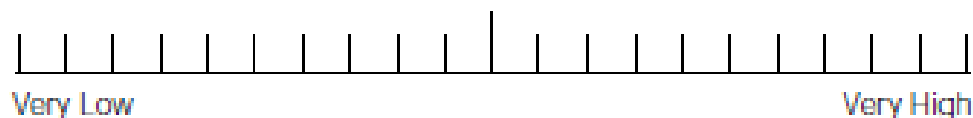
Effort

How hard did you have to work to accomplish your level of performance?



Frustration

How insecure, discouraged, irritated, stressed, and annoyed were you?



This image shows a single sheet of white paper with horizontal blue or grey ruling lines. The lines are evenly spaced and run across the width of the page, typical of notebook paper. There are no margins, text, or other markings on the page.

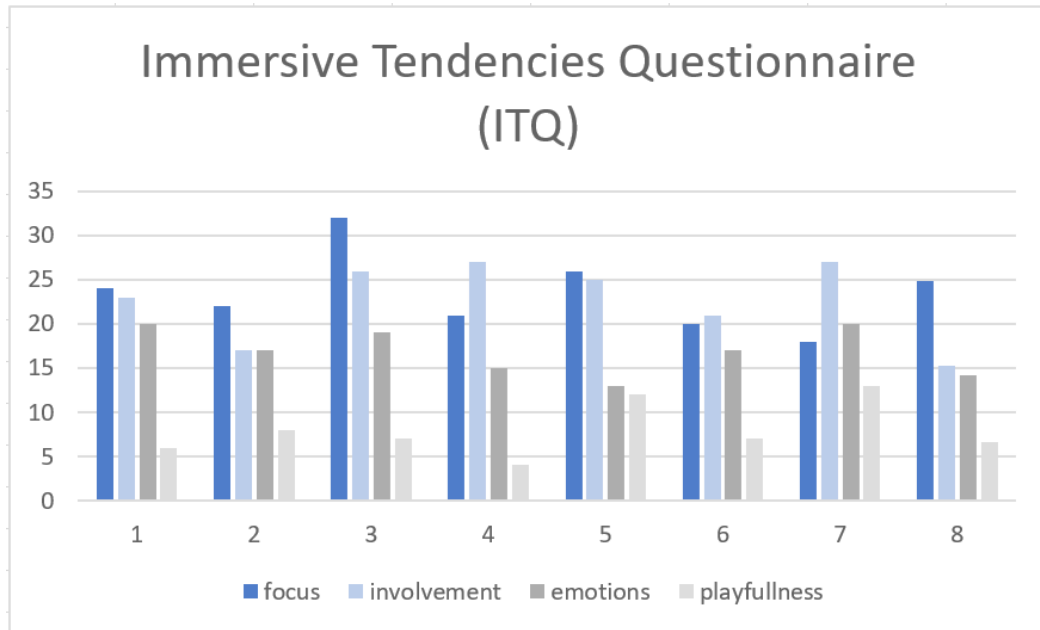
16

APPENDIX 7

USABILITY RESEARCH RESULTS

Results of ITQ, QUEST and NASA TLX.

121



	p1	p2	p3	p4	p5	p6	p7	norm
1	6	3	7	5	6	2	2	
2	4	4	6	5	5	3	3	
3	4	4	6	4	6	6	4	
4	5	2	5	2	4	1	3	
5	5	2	7	5	7	5	5	
6	2	2	4	2	2	1	5	
7	3	5	7	3	6	5	4	
8	4	5	6	2	4	3	5	
9	3	2	2	1	6	4	5	
10	6	1	6	6	2	3	6	
11	3	5	7	2	3	5	5	
12	2	7	2	7	7	6	7	
13	6	6	7	5	5	6	4	
14	1	4	1	1	1	1	3	
15	5	4	6	5	3	6	5	
16	6	5	5	6	4	3	6	
17	6	3	1	2	3	3	4	
18	5	5	6	7	5	6	6	
total	76.0	69.0	91.0	70.0	79.0	69.0	82.0	64.11
mean	3.9	3.7	4.7	3.6	4.1	3.7	4.4	3.56
focus	24	22	32	21	26	20	18	24.81
involvement	23	17	26	27	25	21	27	15.33
emotions	20	17	19	15	13	17	20	14.25
playfulness	6	8	7	4	12	7	13	6.56

P1
1234

QUESI - Questionnaire for Intuitive Use

Note: In evaluating the system, try to refer only to the use of the system (and not for example to the difficulty of the task itself). There are no right or wrong answers. Please answer spontaneously and don't leave any questions out.

	Fully disagree	Mainly disagree	Neutral	Mainly agree	Fully agree
1 I could use the system without thinking about it.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
2 I achieved what I wanted to achieve with the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
3 The way the system worked was immediately clear to me.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
4 I could interact with the system in a way that seemed familiar to me.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
5 No problems occurred when I used the system.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
6 The system was not complicated to use.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
7 I was able to achieve my goals in the way I had imagined to.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
8 The system was easy to use from the start.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
9 It was always clear to me what I had to do to use the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
10 The process of using the system went smoothly.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
11 I barely had to concentrate on using the system.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
12 The system helped me to completely achieve my goals.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
13 How the system is used was clear to me straight away.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
14 I automatically did the right thing to achieve my goals.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>

P2

QUESI - Questionnaire for Intuitive Use

Note: In evaluating the system, try to refer only to the use of the system (and not for example to the difficulty of the task itself). There are no right or wrong answers. Please answer spontaneously and don't leave any questions out.

	Fully disagree	Mainly disagree	Neutral	Mainly agree	Fully agree
1 I could use the system without thinking about it.	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
2 I achieved what I wanted to achieve with the system.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
3 The way the system worked was immediately clear to me.	<input checked="" type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
4 I could interact with the system in a way that seemed familiar to me.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
5 No problems occurred when I used the system.	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
6 The system was not complicated to use.	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
7 I was able to achieve my goals in the way I had imagined to.	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
8 The system was easy to use from the start.	<input checked="" type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
9 It was always clear to me what I had to do to use the system.	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
10 The process of using the system went smoothly.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
11 I barely had to concentrate on using the system.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
12 The system helped me to completely achieve my goals.	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
13 How the system is used was clear to me straight away.	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
14 I automatically did the right thing to achieve my goals.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>

P5

QUESI - Questionnaire for Intuitive Use

Note: In evaluating the system, try to refer only to the use of the system (and not for example to the difficulty of the task itself). There are no right or wrong answers. Please answer spontaneously and don't leave any questions out.

	Fully disagree	Mainly disagree	Neutral	Mainly agree	Fully agree
1 I could use the system without thinking about it.	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
2 I achieved what I wanted to achieve with the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
3 The way the system worked was immediately clear to me.	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
4 I could interact with the system in a way that seemed familiar to me.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
5 No problems occurred when I used the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
6 The system was not complicated to use.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
7 I was able to achieve my goals in the way I had imagined to.	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
8 The system was easy to use from the start.	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
9 It was always clear to me what I had to do to use the system.	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
10 The process of using the system went smoothly.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
11 I barely had to concentrate on using the system.	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
12 The system helped me to completely achieve my goals.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
13 How the system is used was clear to me straight away.	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
14 I automatically did the right thing to achieve my goals.	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>

P6

QUESI - Questionnaire for Intuitive Use

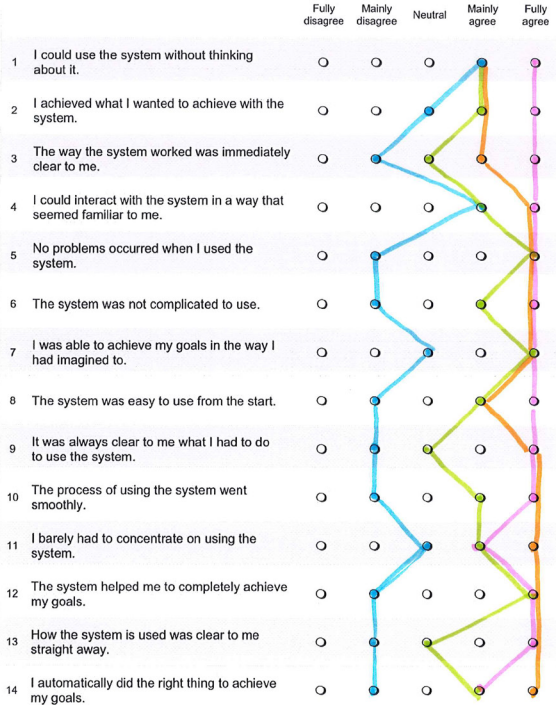
Note: In evaluating the system, try to refer only to the use of the system (and not for example to the difficulty of the task itself). There are no right or wrong answers. Please answer spontaneously and don't leave any questions out.

	Fully disagree	Mainly disagree	Neutral	Mainly agree	Fully agree
1 I could use the system without thinking about it.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
2 I achieved what I wanted to achieve with the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
3 The way the system worked was immediately clear to me.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
4 I could interact with the system in a way that seemed familiar to me.	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
5 No problems occurred when I used the system.	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
6 The system was not complicated to use.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
7 I was able to achieve my goals in the way I had imagined to.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
8 The system was easy to use from the start.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
9 It was always clear to me what I had to do to use the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
10 The process of using the system went smoothly.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
11 I barely had to concentrate on using the system.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
12 The system helped me to completely achieve my goals.	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
13 How the system is used was clear to me straight away.	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
14 I automatically did the right thing to achieve my goals.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>

P3
1234

QUESI - Questionnaire for Intuitive Use

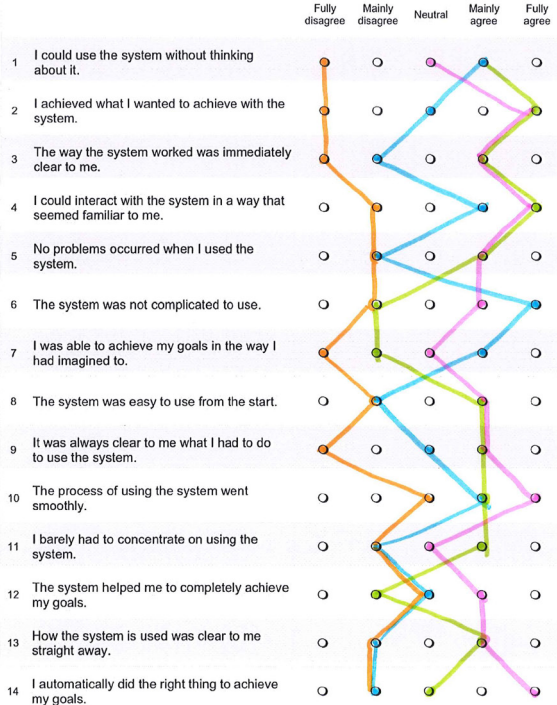
Note: In evaluating the system, try to refer only to the use of the system (and not for example to the difficulty of the task itself). There are no right or wrong answers. Please answer spontaneously and don't leave any questions out.



P4

QUESI - Questionnaire for Intuitive Use

Note: In evaluating the system, try to refer only to the use of the system (and not for example to the difficulty of the task itself). There are no right or wrong answers. Please answer spontaneously and don't leave any questions out.

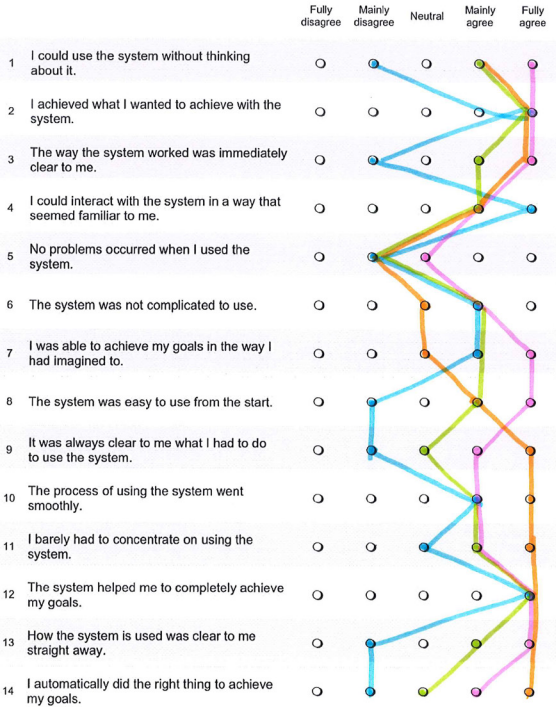


123

P7

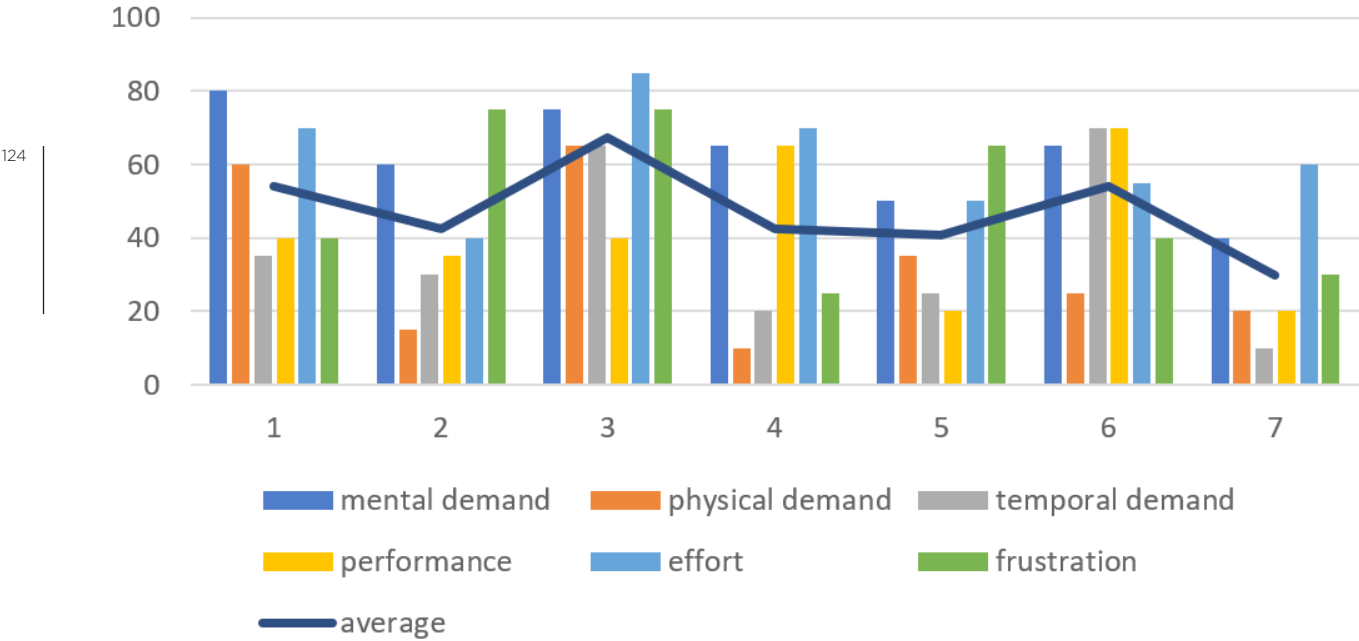
QUESI - Questionnaire for Intuitive Use

Note: In evaluating the system, try to refer only to the use of the system (and not for example to the difficulty of the task itself). There are no right or wrong answers. Please answer spontaneously and don't leave any questions out.

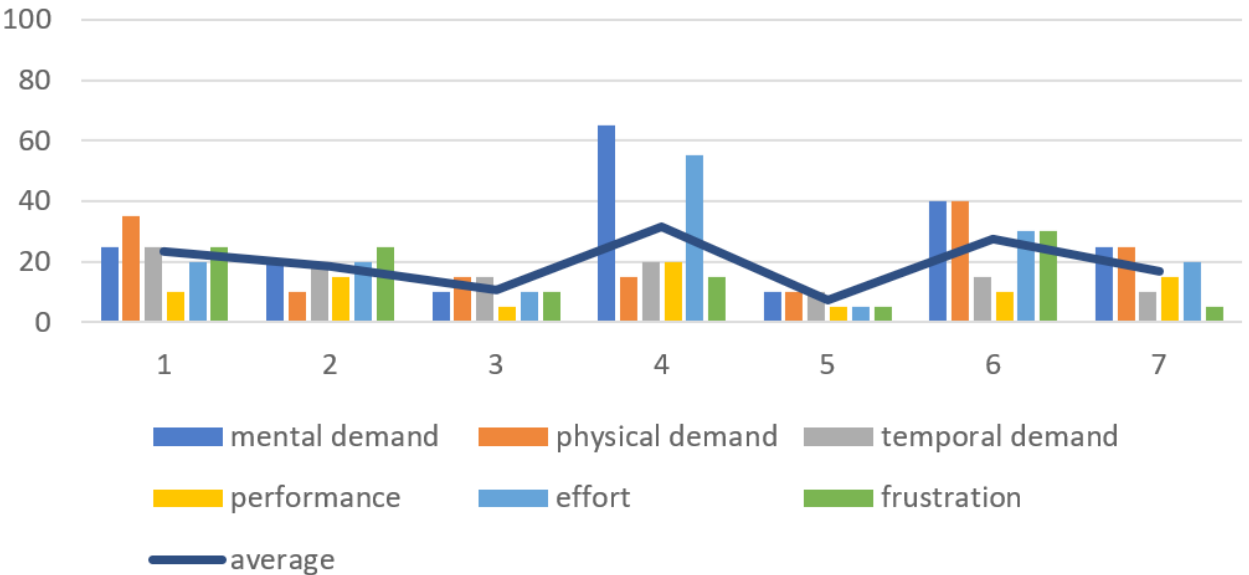


The QUESI results per participant, with colors indicating the tasks.
Blue is task 1, green is task 2, pink task 3 and orange task 4.

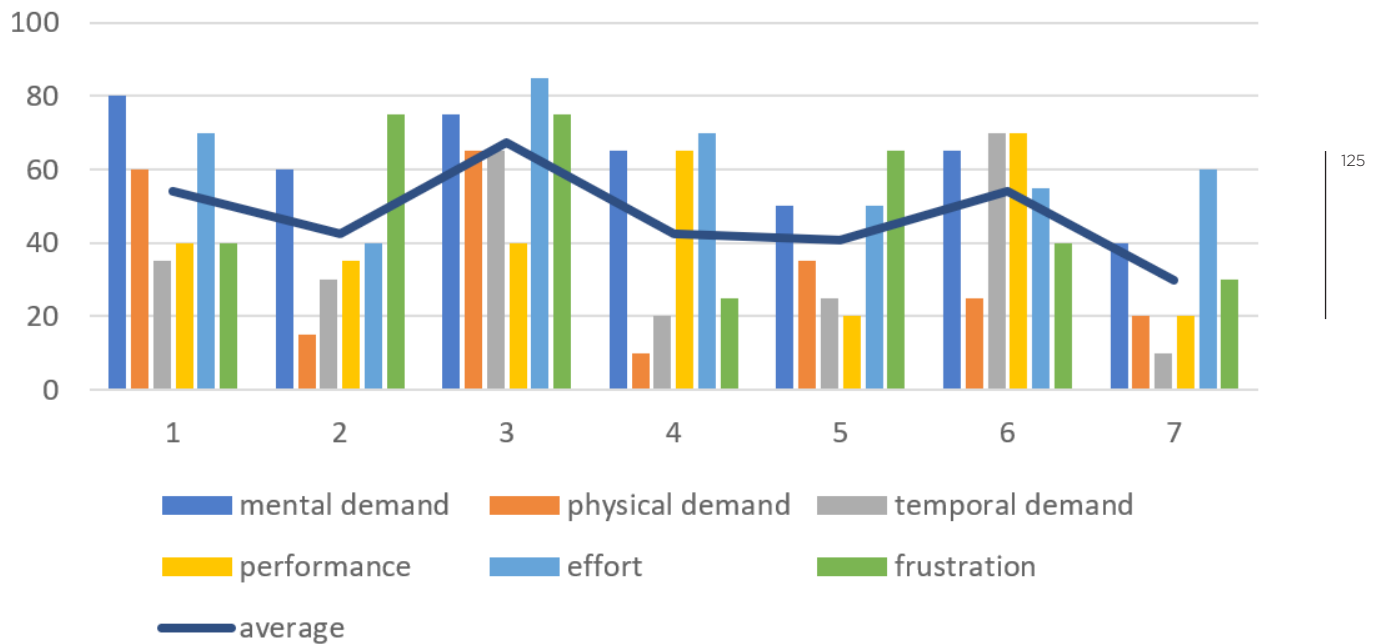
NASA TLX positioning the DHM



NASA TLX measure angle between upper and lower leg



NASA TLX positioning the DHM



NASA TLX take a snapshot of the scene

