



WETSUIT DESIGN

WITH A FOCUS ON METHODOLOGY

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**SRF
ACE**

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ABSTRACT

On the 15th of October 2018 the kick-off of the project took place. The assignment was to design a science based methodology for the creation of SRFACE wetsuits. The current design process is still almost entirely based on trial and error. A product designer draws seam lines on a 2D body outline, based on his knowledge about fit, insulation and performance. The production company creates and grades the pattern based on this design. A sample is made and adjusted based on the feedback of customers. This report investigates the opportunities of modern day technologies such as 3D body scanning to generate a new methodology.

In the analysis phase the different stakeholders are assessed together with the current methodology. This resulted in a redefinition of the problem. The production company handles the creation and grading of the patterns based on the 2D design of SRFACE. This design is open for interpretation which results in a time and cost consuming optimization phase. Furthermore the anthropometry of the customers is unknown to both SRFACE and the production company. The sizing is therefore based on the sizing of other wetsuit brands. The feedback of the customers is the only input for improving the fit of the different sizes.

The analysis phase resulted in the following main goals for the new methodology. It should incorporate:

- The creation and grading of wetsuit patterns
- Design for fit approach with the use of 3D body scans
- Digital prototyping

Background research is performed on the current branding, market, possible pattern design software and 3D scanning opportunities. This lead to a list of requirements for the creation of a new methodology and software capabilities.

Further research was performed into the anthropometry for the creation of a sizing chart. The 3D body scan database CAESAR has been used as representation of European population. The scans of more than 1800 individuals have been filtered and classified into sizing groups using the height and chest circumference. In this process a new method is proposed for the creation of a new sizing system using the DINED Ellipse tool. This resulted in the creation of digital mannequins that represent average body types for every wetsuit size. These mannequins were then used as basis for the creation and testing of wetsuit patterns.

The current SRFACE wetsuit pattern and materials were digitized and simulated in pattern design software Clo3D. The tightness during static and dynamic fit were assessed and used as reference for future wetsuit design. A new workflow is investigated that uses 3D digital pattern drawing with the 3D mannequins as basis. The resulting pattern was optimized using the stress and strain simulations and graded. A prototype is created of the base pattern to validate the design workflow.

As a result a new methodology is proposed that incorporates a 3D wetsuit design workflow and digital prototyping. This new methodology gives SRFACE more control in optimization and reduces the amount of physical prototyping. Assessment of the prototype has shown that the new methodology is able to produce feasible pattern designs with a good fit. But further optimization is required. Using this methodology over time will increase its accuracy and build on gained knowledge. Multiple prototypes are still required but will decrease over time.



INTRODUCTION

Surfers are very critical about the function, comfort, fit and appeal of their wetsuit. When surfing in extreme conditions with low temperatures, surfers rely on their wetsuits to keep them warm. A wetsuit should have a good balance between a tight fit that still feels comfortable and doesn't restrict their movement. When the fit of a wetsuit is too loose, cold seawater can enter the suit and the level of insulation drops. When the performance and fit of the wetsuits are not up to standard, a customer is less likely to choose SRFACE as their next wetsuit.

There still isn't a scientific approach within the design process behind a wetsuit. In the current methodology the production company handles the pattern creation and

pattern grading based on a two dimensional design by SRFACE. This design is open for interpretation. The result is therefore optimized purely through trial and error. A prototype of a design is used to gain customer feedback. The feedback is used to improve the design which leads to a new and improved prototype. This cycle repeats until the design meets the company's standards. This is a time consuming process. Every prototype lengthens the design process with at least one month. A scientific approach is yet to be investigated and implemented. All the important aspects that build up a good wetsuit, should be taken into account.



SRFACE



Augustus
Schraven



Reinier
Korstanje



Jeroen
Coppers



Christiaan
Brouwer



SRFACE

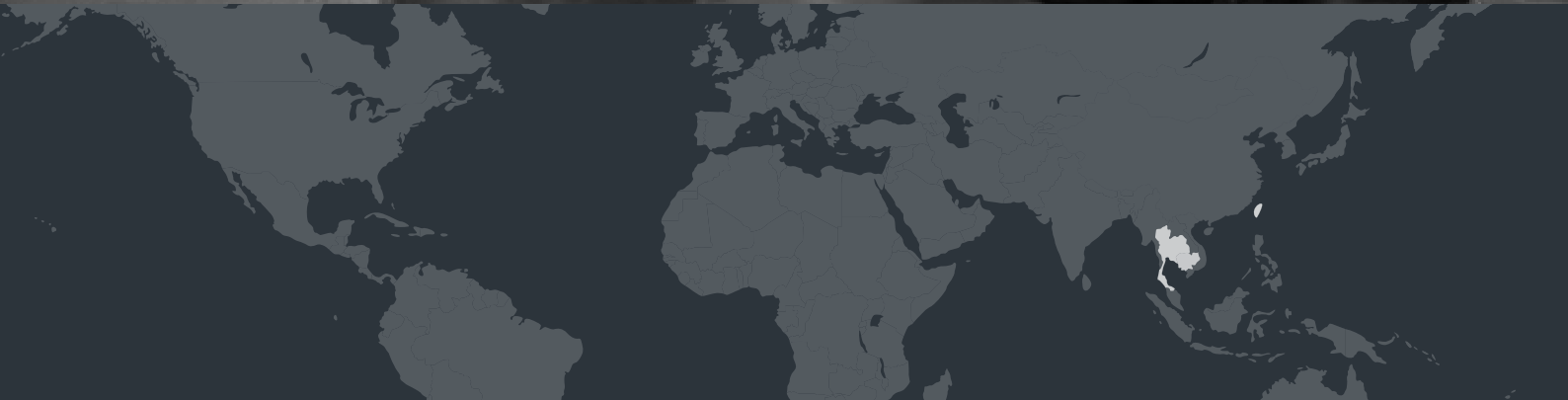
SRFACE

SRFACE is a young Dutch company that has entered the market in mid 2018. It is founded by 4 surfers. Their wetsuits are only sold through their online website. They provide male wetsuits in 3 different thicknesses, 3mm, 4mm and 5mm. A downside is that the customer can't try the fit of their wetsuit before the purchase. This emphasizes the importance of an good fitting system were a perfect fit can be proposed purely based on measurement input of customers. SRFACE now provides 7 different sizes to cover all the different body types. More sizes will be added to ensure a good fit for customers between two current sizes and customers outside of the current size scale. SRFACE initiated this project to gain new insights in optimizing their current design

process. Building up knowledge on pattern creation and pattern grading could reduce the time it takes to design a new wetsuit. SRFACE has a lot of knowledge on the current methodology and all the technical aspects of their current wetsuit. Customers play a huge part in the current design process and their feedback is constantly needed to optimize the fit and comfort of the product. Their main interest is to establish their position in the market as affordable high end wetsuit brand.



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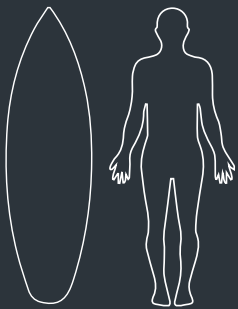


PRODUCTION COMPANY

The current production factory (the name is left out of this report) is specialized in the water sportswear market with a world market share of over 50%. They are building on 40 years of experience in wetsuit production and engineering. Their headquarters and R&D department is located in Taiwan and the production and assembly factories is based all over asia. Providing both engineering and production of wetsuits makes them a valuable partner and minimizing unnecessary costs. They create and grade patterns for SRFACE and many other wetsuit brands. This makes them owner of the resulting patterns. The production company has an unknown formula for determining the prices of the wetsuits. The highest influencing factors are the material price, yield

rate (material waste percentage) and assembly hours. Increasing the amount of panels can result in a better yield rate but it will increase the seam length and therefore increase the production price.

As the market leading wetsuit factory, their knowledge on pattern creation and grading makes them a valuable partner in the wetsuit branch.



Sex: ♂
Age: 20-45

Interests:

Wetsuit with high quality and insulating properties, good fit and affordable prices.



CUSTOMERS

The customers of SURFACE are currently mostly Dutch males between the age of 20-45. Ever since the release of their first wetsuits their customer base has rapidly been extended towards France United Kingdom, Spain, Portugal, Germany and most other western European countries. Their wetsuit is focussed on professional surfers and surfing enthusiasts who want high quality wetsuits that enable them to surf all year long. They want a wetsuit with good fit and insulating properties, to keep them warm all season. Because they can not test the fit of a SURFACE wetsuit in a store, they rely on the online size finder to match them with a good wetsuit size and try them on at home. But it is not uncommon for customers to buy the same size wetsuit as a previous owned wetsuit

due to the absence of measuring tape or laziness. These customers purchase a new wetsuit every 2-3 years to replace an older deteriorated wetsuit. Furthermore the anthropometric characteristics are unknown for a wetsuit brand such as SURFACE. This results in a certain amount of guess work in the scaling of wetsuit patterns. The sales, returns and feedback of the customers is currently the only source for adjusting their wetsuit.

DEFINING WETSUIT DESIGN ASPECTS

There are a couple of aspects that make up the quality of a wetsuit. In a new methodology all these aspects should be taken into account. The following design aspects are elaborated on their meaning and how they relate to one another.



FIT

The fit refers to the how close a wetsuit matches the body type of the user. Currently SRFACE provides male wetsuits in sizes focusing on European anthropometry. A good fit indicates how close a suit acts as a second skin to the user. An improper fit results in air gaps or wrinkles in the panels. This will then lead to cold (sea)water being able to enter the suit and cool down the surfer. To prevent this as much as possible a user has to buy a suit that matches his body type as close as possible. An ideal fit could be gained by providing everybody with a personalized wetsuit fit. This is not viable due to the current production techniques and it would lead to a longer production time and a higher price.



INSULATION

The level of insulation is measured by the sea temperature where a surfer can comfortably perform. The thickness of the different Neoprene panels make up the insulation level of the suit. The insulation is also intertwined with the fit of the wetsuit. When a wetsuit lacks fit, water will compromise the level of insulation.



PERFORMANCE

The performance refers to how closely the wetsuit acts as a second skin during movement. The more it feels like you are wearing no suit at all the better. It could also be described as the dynamic fit. An optimal performance would be a suit that doesn't restrict the surfer in any way while surfing. The stretch and shaping of the panels play a big part in optimizing the dynamic fit.



COMFORT

Comfort is a relatively large concept. It affects the performance of athletes and also their health (Bartels, 2005). Many aspects contribute to a comfortable wetsuit. Next to the fit and features of the wetsuit, the material choice plays a big role. The type and quality of the inner lining makes up the overall feel of the suit. There are a couple of things that can negatively influence the comfort of a wetsuit. One of the biggest factors to take into account during the design of a wetsuit is the seam placement. The panels of a wetsuit rub against the skin of a surfer during surfing. On the inside of the suit the seams will cause more friction with the skin compared to the material itself. When surfing for a long period this can become very uncomfortable. This leads to skin irritation. When the seams are taped they will cause less friction.



DURABILITY

An active surfer owns multiple wetsuits and has to buy new ones every now and then due to deterioration. Intense use of a wetsuit will eventually lead to the tearing of stitches. The stitches that hold the panels together are the weakest points of the wetsuit and don't have the same amount of stretch as the panels itself. At the border of the seams or the seams themselves start to tear when undergoing stress. Placement and reinforcement of the seams can influence the durability. The durability will be defined as the capacity of the suit to withstand long usage without a decrease in comfort, isolation and performance. For instance, when logos will start to deteriorate the performance won't be effected. But when the seams between the panels tear, the isolation is compromised and the suit will do a lesser job in keeping the surfer warm.



STYLING

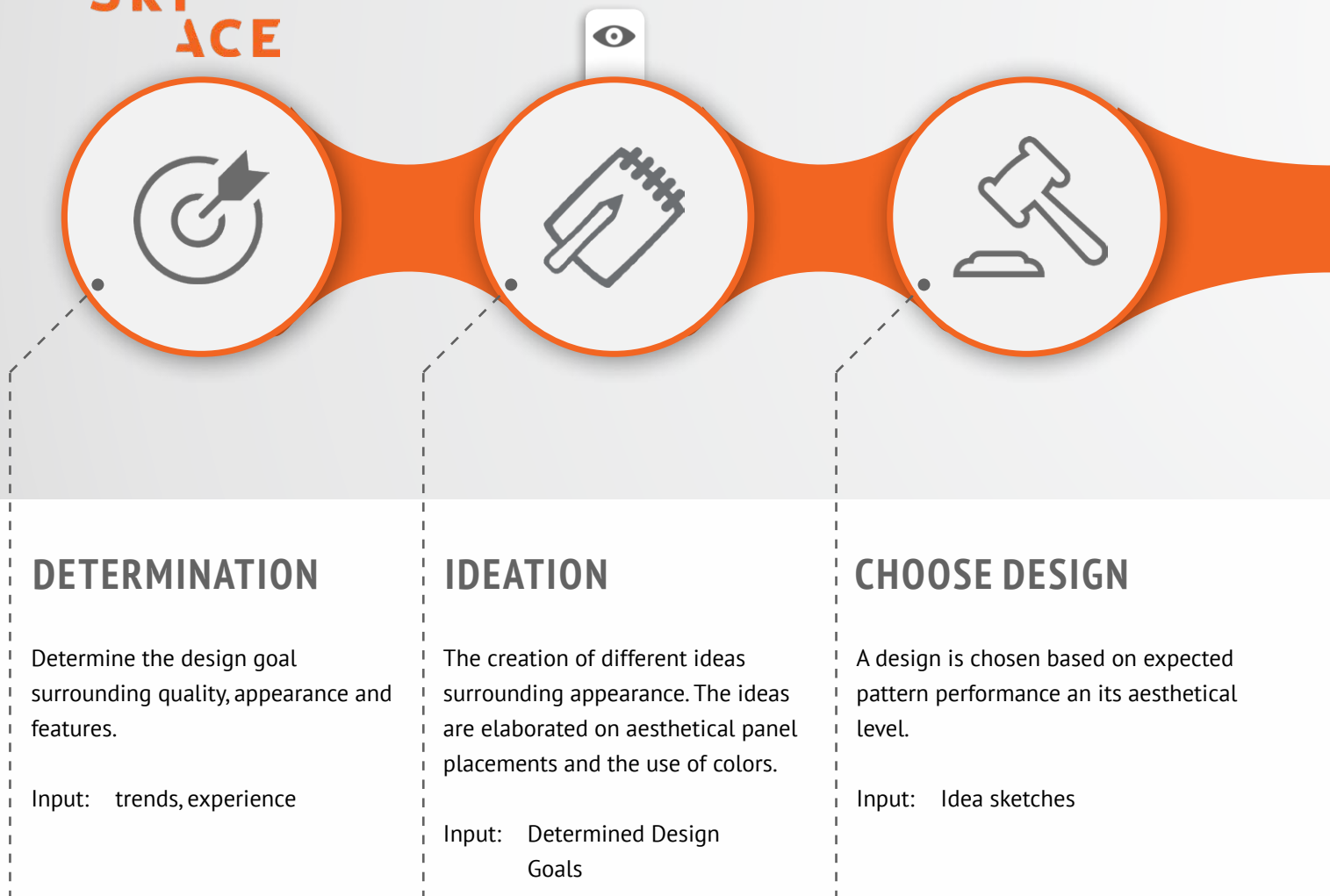
The styling of a wetsuit refers to the overall aesthetics. Although neoprene is available in multiple colors, the current SRFACE wetsuit is made up out of mostly black panels. Therefore the seam placement has a huge impact on the overall styling. These seams are the most visible when looking at the suit. The shape of the panels determine the main aesthetics of the wetsuit. Many details contribute to the styling: logos, zipper placement, inner & outer textures all play an important role in the aesthetics.

CURRENT METHODOLOGY

Before the first steps towards a new methodology can be made, the current methodology is researched. Researching the process behind the current wetsuit of SRFACE will contribute to understanding where it can be improved. The current design process results in an aesthetical wetsuit design with dimensions, placements

of prints and other detailing. The pattern creation and scaling is currently done by the production company based on the design SRFACE provides. The labels in the methodology visualization show in what step the wetsuit parameters are designed. The current methodology consists of the following steps.

SRFACE







DETERMINATION

Before any wetsuit designs were generated SRFACE decided on the overall appearance that they wanted to establish and what features they want their suit to have. Their goal was to sell high quality wetsuits for a low price. The appearance of the design had to be clean and simple. For the features they decided that the wetsuit had to have a neck entry and a key pocket. Furthermore, a chest panel was chosen for comfort.



IDEATION

SRFACE determined the overall goal they wanted to achieve within the design and use this as basis for the ideation. Male outlines are used to draw out the different ideas surrounding the wetsuit pattern. With the chosen features in mind, the designer draws the seam placements on the body outline to show the different panel placements. The designer uses his knowledge and experience to come up with feasible designs. Multiple ideas are generated and colorized to indicate what the final result would look like.



CHOOSE DESIGN

A design will be chosen based on its aesthetical values. SRFACE chose a panel design that looked the most promising and matches their vision. The overall appearance of the panel placements and the expected performance/fitting of the pattern is used in choosing a design.



DETAILING

The detailing consists of elaborating an initial design into a more detailed technical design that The production company can produce. The seam placement is shifted around to optimize the appearance based on feedback from both the team and other experienced surfers. Furthermore, the designs are elaborated on the use of materials and colors. The production company offers a large number of materials and colors where SRFACE could chose from. The type of foam is specified together with the inner and outer lining. The different prints are designed in illustrator and added to the design. The type of stitches, seams and taping is specified. On points that will most likely experience a high amounts of stress, melco dots are added as reinforcement. These points are more likely to tear after long-term usage.

TECHNICAL DOCUMENTATION

The design is documented into a production plan for the production company. In this plan the placement of the panels is visualized together with the stitch-, seam-, taping and print placement. The material type, thickness and color is specified for every panel together with its inner and outer lining. Production specific codes are used to ensure the desired appearance. Comments are added to ensure that production company understands the design. For sizing of the wetsuit pattern SRFACE added dimensions for the chest, waist, hip, leg, neck, wrist cuff, ankle cuff and the overall length for a medium wetsuit size. Further sizing is left to the production company.

PROTOTYPING

To optimize the design SRFACE ordered multiple prototypes. The production company is responsible for creating the pattern and grading towards different body types based on the documentation provided by SRFACE. But the 2D design of SRFACE leaves a lot of room for interpretation when translating it into a pattern. For SRFACE this step is like a black box. The production company has all the knowledge and experience behind the pattern creating and pattern grading. When they transform the design of SRFACE into a cutting pattern the pattern itself becomes their property. SRFACE doesn't own the pattern which makes the optimization a difficult process. The production company is based in Cambodia which results in a long waiting period before a prototype can be analyzed. Every order takes around 30 – 45 days. It is therefore important to find as many flaws as possible within each order for an efficient optimization.



OPTIMIZING FIT & PERFORMANCE

The steps towards optimization uses prototypes produced by the production company as a basis. SRFACE ordered different sizes of the created design in different thicknesses. These prototypes are used to analyze the overall fit of the design and its different sizes. Every desired adjustment is noted down and processed in the technical document or added as note so the production company knows how to adjust their pattern design. The optimization consists mostly out of shifting the seams for a more comfortable pattern, expanding the panels in tight areas and trimming panels to get rid of air gaps/wrinkles. The outer dimensions were also adjusted to comply with the larger Dutch anthropometry. Furthermore, the placement and adjustment of any flat or 3D prints on the suit were also optimized.



This cycle of prototyping and optimization continues until the design meets the standards of SRFACE. The current design needed 3 orders of prototypes to perfect the design and make it market ready. After this final step a bulk order could be placed and the design is made available for the surfing community.

COSTS

A downside to this optimization cycle is the production price. There are a lot of aspects that make up the price that the factory asks for a wetsuit. The cutting efficiency of the pattern plays a big part in the price together with the total seam length. As company you pay for the waste that comes with the cutting pattern. The seam length itself is not measured but makes up the amount of time that is needed to stitch together the wetsuit. The production company doesn't use a formula to calculate the price for a design but chooses a price based on the used materials and amount of time spent on assembly per suit. This price estimate sets a baseline. Every future adjustment will most likely result in an increased price if it adds an extra part or assembly step. It is important to finalize as much as possible in the first design so the additional costs will be minimal.

OPTIMIZING THE METHODOLOGY

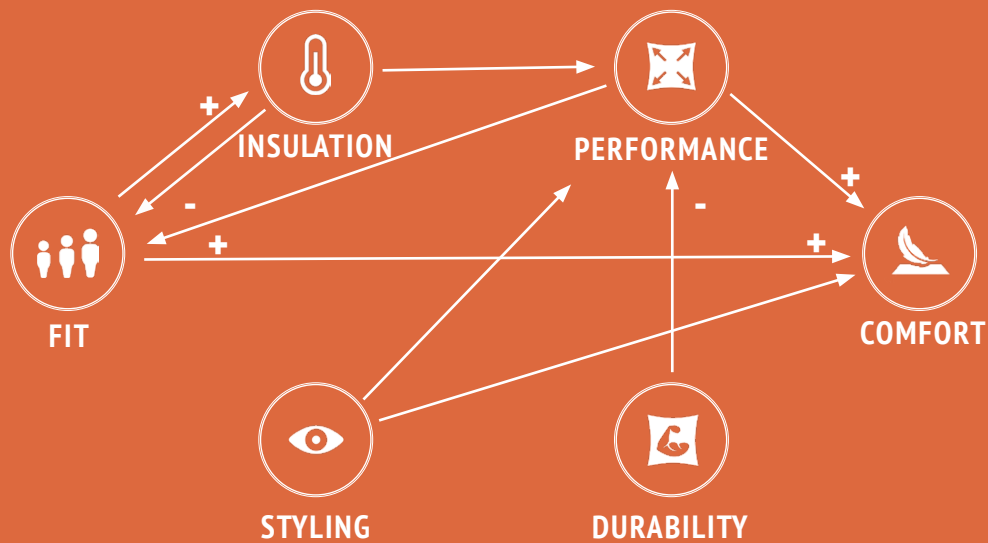
Creating a good fit currently requires a lot of optimization. The reason behind this is that the pattern creation is currently done externally by the production company. They use the 2D design by SRFACE. The translation from this 2D design towards a pattern leaves a lot of room for interpretation. The production company is also responsible for the pattern grading. If SRFACE would do their own pattern creation, the translation step would be eliminated. As a result, SRFACE would have more control on the production output of the production company. For this to happen SRFACE has to gain the knowledge and tools to create their own pattern and do their own grading. The right software will be investigated and the anthropometry of the target group will have to be mapped. Furthermore, if software will be used in the design process it should be validated in its reality accuracy.

In this current methodology a wetsuit is designed purely in its visual appearance. Knowledge and experience is applied to come up with a design that will most likely have a good and comfortable fit. But the real fitting happens during the optimization process. Implementing the fit earlier in the design process will benefit the fit of the resulting pattern and reduce needed amount of optimization. The way to do this is to use 3D human models as a basis in creating a wetsuit pattern. To design for fit, the software should be able to create and scale a pattern and analyze its fit. The same goes for the performance and comfort. If these would be implemented in an earlier stage of the design process it would benefit the resulting design. This means that these aspects will also have to be analyzed through software. The following digital testing methods are proposed: the performance could be tested by subjecting a pattern to a dynamic 3D body (digital applied body movements or even 4D scans). The comfort could be tested by pressure mapping the seams of a pattern and the pattern fitting itself. The only aspect that will be harder to analyze digitally will be the durability of a pattern. Approximatively pattern tests could be performed to analyze the inner stresses of the material around the seams through subjecting them to extreme conditions. The real durability test would come from real life testing a prototype. Wear and tear are hard to simulate digitally.

CONCLUSIONS:

A new methodology will be proposed with the goal of creating a better product and shorter optimization period. To establish this goal, the new methodology should incorporate the following aspects:

- Create and grade own patterns for more control in optimization.
- Use software that is able to use a 3D body scans as a basis for pattern design.
- Use a design for fit approach without discarding the styling.
- Be able to digitaly assess the dynamic fit and the stretch behavior of the pattern.
- Any used software should be validated for its accuracy.



APPROACH

The following illustration shows the main positive and negative influences of the design aspects that make a good wetsuit. It shows that fit and performance are the most critical aspects and have the highest positive impact on the overall design. This project will therefore focus on these aspects for the creation of a new methodology.

The goal will be to centre this methodology around the usage of 3D and 4D digital human models in pattern creation and pattern grading. The methodology should be able to create and optimize a pattern digitally by analysing the stretch of different panels. This will reduce the time and money spent on prototyping. This project will have the goal of generating at least 1 prototype that can validate the workflow.

The following page shows the steps that will be taken for this research. Now that the scope is defined, the next step will be the research phase. In this phase some background research will be performed on the market, sizing and the current SRFACE wetsuit. This will lead to Requirements for both the new methodology and possible pattern design software. During the sizing research surfer body types will be investigated with the goal of creating accurate 3D mannequins. And as final part of the research the pattern and materials of the current SRFACE wetsuit will be investigated. This will be used as reference for future wetsuit design. In the design phase a new pattern design workflow will be investigated using 3D mannequins. This phase includes the creation of a physical prototype to validate the workflow, and a method for pattern grading. The results of these phases will be combined into a new methodology for future wetsuit design.

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Fit and Performance 32
Surfing motions 34
PoR 38
Software 39

SIZING

Body types 40
Mannequins 54
Rigging 58

PRODUCT

Materials 64
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Fit 70

THE WORLD OF WETSUITS

Welcome to the world of surfing. As a dedicated surfer surfing is life and life is surf. Nothing will get in the way between you and riding those perfect waves! Not even the extreme cold weather conditions. This is where wetsuits come in. The current market is filled with lots

of sportswear brands offering you their large range of wetsuits in all kinds of flavours. There are different thicknesses for different weather conditions, different styling to fulfill your visual desires and lots of features. With a higher quality comes a higher price tag.

WETSUIT THICKNESS

Wetsuits come in all shapes and thicknesses to protect you against any kind of weather condition. A thicker suit offers more isolation of cold conditions. A lot of factors should be considered in choosing a suit thickness. The water temperature is used as a reference but the air temperature and wind speed in region where you want to surf should be considered as well. But your personal sensitivity to getting cold, and your activity level while

surfing play a big roll as well. There is no clear guideline for when to use a specific wetsuit thickness but figure 1 shows a rough indication. As seen in figure 1 in water temperatures above 18 degrees a full suit is not necessary and the wetsuits serve more as a protection against the sun instead of keeping you warm. In temperatures below 7 degrees surfers should consider adding gloves, shoes and even a hood to their wetsuit.

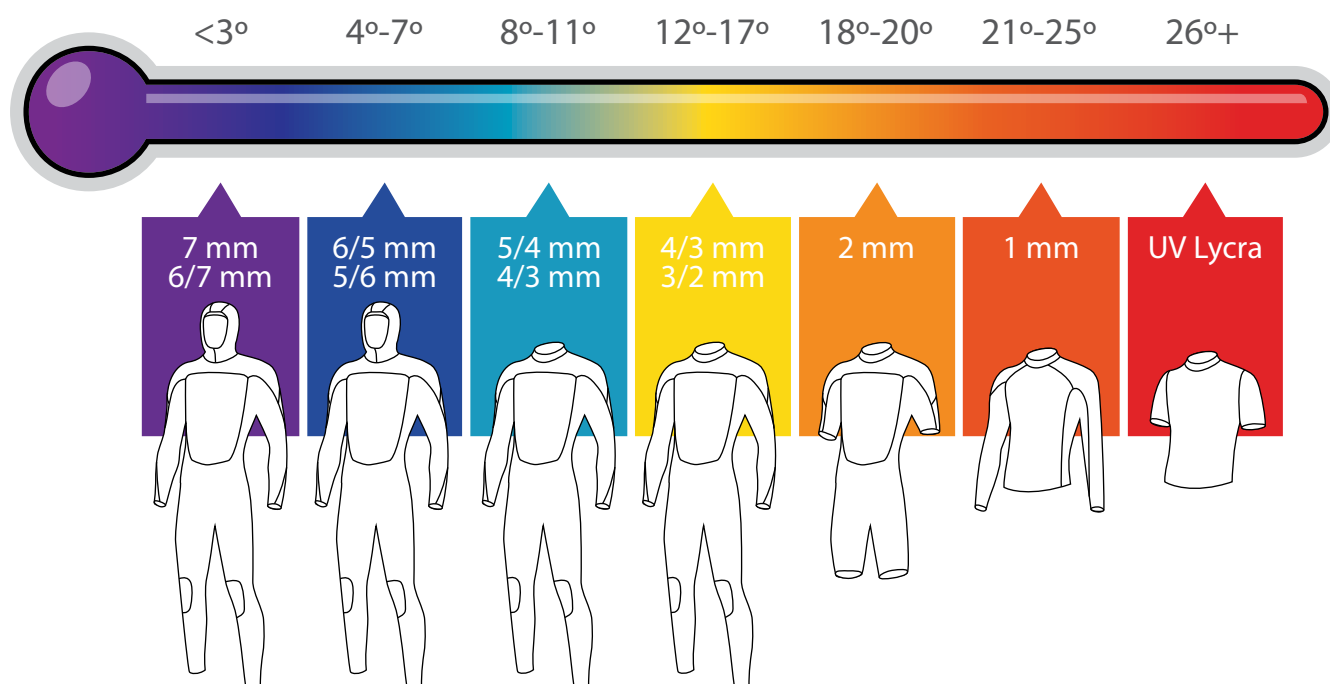


Fig 1: Surfing temperatures of different wetsuit thicknesses

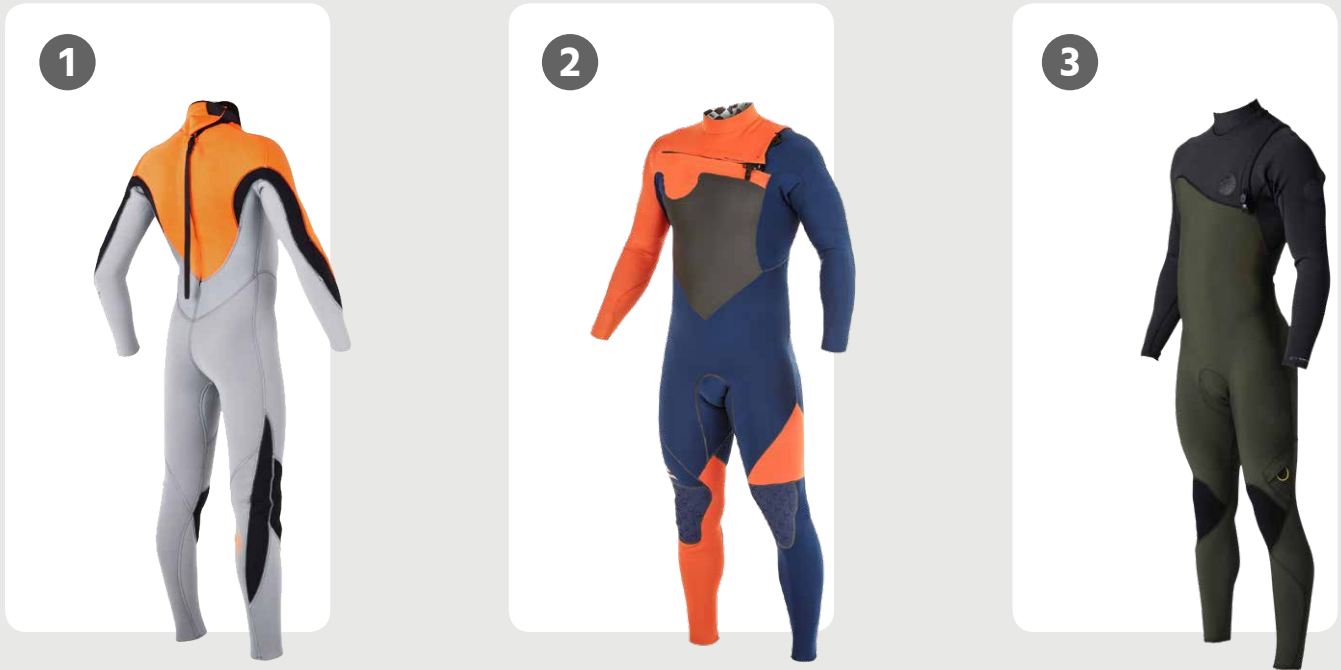


Fig 2: Zipper designs

ZIPPERS

Getting into a wetsuit can be quite a challenge. There are different zipper constructions used in wetsuits which each have different pro's and con's. These constructions can be divided in the following three categories: back zips, chest zips and zipperless.

1. BACK ZIP

The back zip is the most classic solution where the zipper runs down the back of the surfer. A long cord is used so surfers can zip themselves in and out. This zipper construction offers the largest suit entry and is therefore the easiest to enter and exit. On the downside the large zipper and its seams are an easy way for water to enter the suit. In warm temperatures this is no problem but when surfing in cold water this can become really uncomfortable. A lot of companies have tried to reduce this from happening with different techniques which will be elaborated in the features. Furthermore a back zip lacks the ability to stretch. When bending forward the back of the suit will become tense and may restrict movement.

2. CHEST ZIP

Wetsuits with a chest zip are harder to enter and exit. The chest zip offers a cutout around the neck where you can enter the suit. The wetsuit is closed by pulling the neck cut over your head and closing this zipper. This entry is way smaller than the back zip opening but is better at keeping water from entering the suit. The chest zip contributes to a greater level of flexibility in the back compared to the back zip.

3. ZIPPERLESS

There are wetsuits that don't use a zipper entry. This is commonly found in thin wetsuits of 2 or 3mm which offers enough flexibility to enter the suit without widening the opening with a zipper. These suits have mobility as a priority over isolation. The elimination of zippers and stitching results in a highly flexible wetsuit.

MATERIALS

Neoprene (Polychloroprene) lies on the basis of all wetsuits and is a synthetic rubber. Its cellular structure has nitrogen gas bubbles trapped inside which makes it a good heat insulator. There are a lot of things to consider in choosing the right type of Neoprene. The weight, stretch, pressure resistance, price and resistance to UV exposure all play a big role in this choice. Neoprene is available in different amounts of stretch. More stretch equals a higher production cost. The stretch of neoprene depends on the thickness of a panel but can go up to 650%. But within a wetsuit the stretch of a neoprene panel depends strongly on the applied lining and the type and thickness of the foam itself ($\text{Stretch} = \text{Foam} + \text{Lining}$).

A lot of brands have started to use a new type of neoprene based on limestone instead its predecessor based on oil. Limestone neoprene is 95% water impermeable which is a big difference compared to oil based neoprene which is up to 65% water impermeable. Because geoprene absorbs less water it is also lighter during surfing. Limestone neoprene is also recyclable.

LINING

A Lining is an extra layer of material that is applied to the surface of a neoprene panels. This extra layer is applied for multiple reasons. It increases the durability of the panel and reduces friction against the skin of the surfer. Without an inner lining a wetsuit would be nearly impossible to put on. The only downside of lining neoprene is that it reduces the flexibility and adds extra weight to the suit. Most commonly used materials are nylon and polyester which are both available in many colors and with different levels of stretch. Commonly more stretch implies a higher cost. A wetsuit can offer single lined panels or double lined panels.

DOUBLE LINED

Double lined wetsuits panels have a lining on both the in- and outside. These panels are durable and won't tear so easily by nails or other external forces. But the outer lining also results in a lower flexibility and a lower isolative value. The water that this layer holds will vaporize taking away a lot of body heat.

Nylon

Nylon is a very common type of lining with a smooth surface. This makes it perfect to be used as lining. It is available in different amounts of stretch with different grain orientations. Commonly omnidirectional stretch is the most expensive. But one directional stretch or even low stretch nylon can be used as a cheaper option in panels where less stress is needed.



Fig 3: Nylon

Polyester

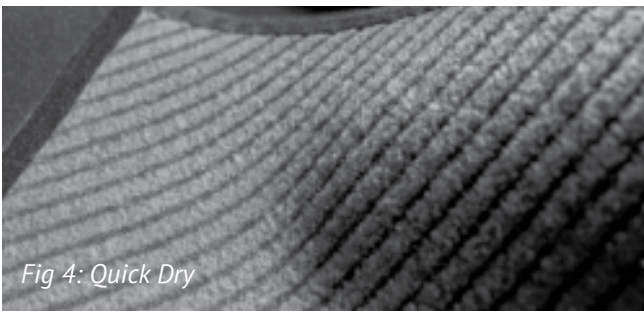
This type of material is used as a cheaper type of lining. It has less stretch than Nylon and has a rougher surface. But Polyester is available in a greater range of colors (especially brighter colors) which can't be found in Nylon lining.



Fig 4: Polyester

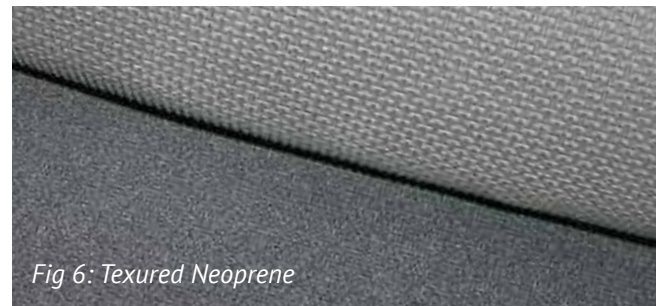
Quick Dry

Wetsuit panels can also be lined with a thicker layer of plush material called Quick Dry. This soft lining provides extra warmth and it is commonly used around the core of the body. When wet, the water can easily run down within the back of the thick layer. This makes the surface feel dry against the skin. Quick Dry lining is available in different colors and patterns.



Textured

A similar finish as smooth skin can be applied where the surface has a texture. A heated plate melts the surface of the neoprene and leaves an imprint of its texture. It is commonly used on chest or back panels to reduce windchill.



SINGLE LINED

Neoprene wetsuits can also have single lined panels. On one side a lining would be applied, and the other side the neoprene itself would be visible. This side feels rubbery and commonly has an applied texture by a heated press or waltz. These types of panels are less durable than double lined panels. But because water doesn't stick to its surface they are more resistant against windchill.

Smooth skin

A smooth skin panel is commonly used to seal the cuffs of a wetsuit. It is a type of single lined neoprene where the surface on one side has been heat pressed with a flat plate which gives it a smooth finish. Glide skin is a version which has an even smoother finish. The resulting surface of such a panel has proven to be a great seal when stretched around human skin.



STICHES

A garment pattern has to be stitched together. There are different techniques used within wetsuits.

Flatlock stitching

A flatlock stitch is one of the most comfortable stitches for wetsuits. The stitches lie flat against your skin and causes little to no skin irritation. But on the downside water can get in through the stitch holes.

Blind stitches

With blind stitching the stitches don't go all the way through the neoprene. This makes the stitches watertight.

Glued

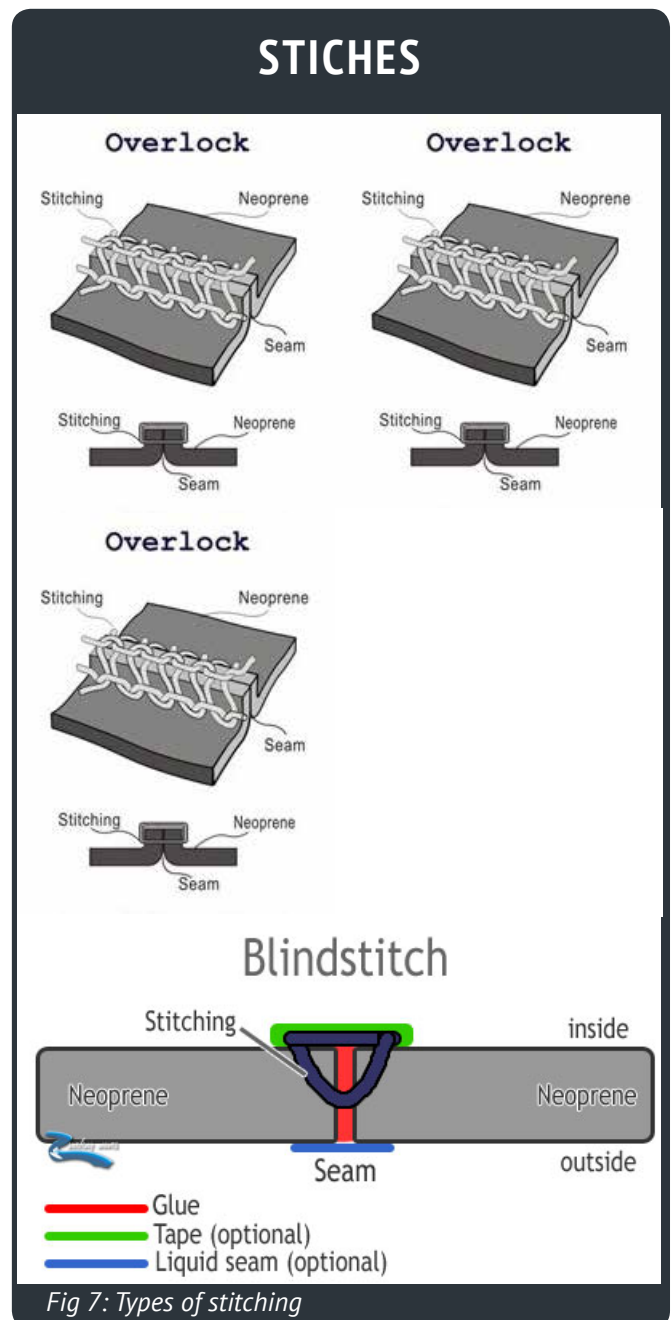
Panels of a wetsuit are always glued together to create a watertight seam. Glueing of the panels is commonly applied together with blind stitching.

Liquid Seal

The seams of a wetsuit can be provided with a molten strip of PU rubber. This provides extra watertightness and durability to the seams. But on the downside they have less stretch than the panels themselves. The difference in stretch can lead to deterioration of the seams. Long exposure to sunlight can also lead to desiccation tears in the seals.

Taping

High end wetsuits commonly offer taped seams. In addition to sealed stitches a thin layer of tape can be applied to the inside of the seams. This tape consists of neoprene which is heat welded on to the suit. It provides extra durability to the seams and provides extra waterproofing.



CONCLUSIONS:

- The availability of materials and production methods should be incorporated in the methodology.
- Different types of lining can be used to reduce the price or create certain stretch behaviours within the panel design of a wetsuit.
- Total seam length makes up most of the production time of a wetsuit and can be reduced to benefit the production cost.
- The seams and the zipper have little to no stretch. A new methodology should be able to incorporate this during stretch analysis.

BRANDING OF SRFACE

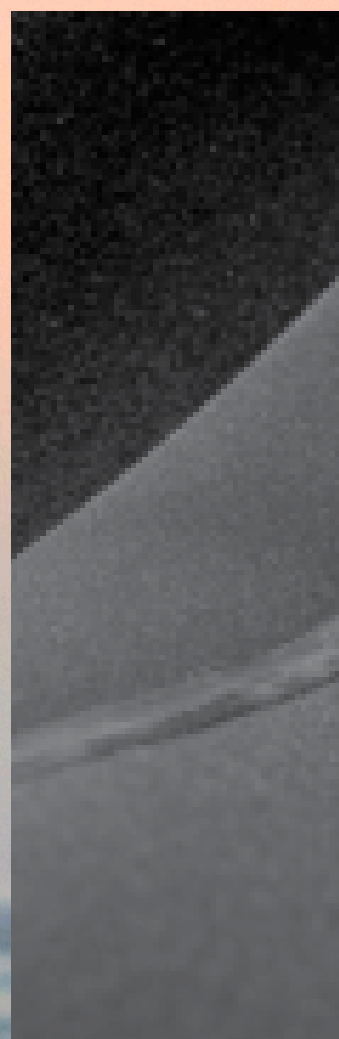
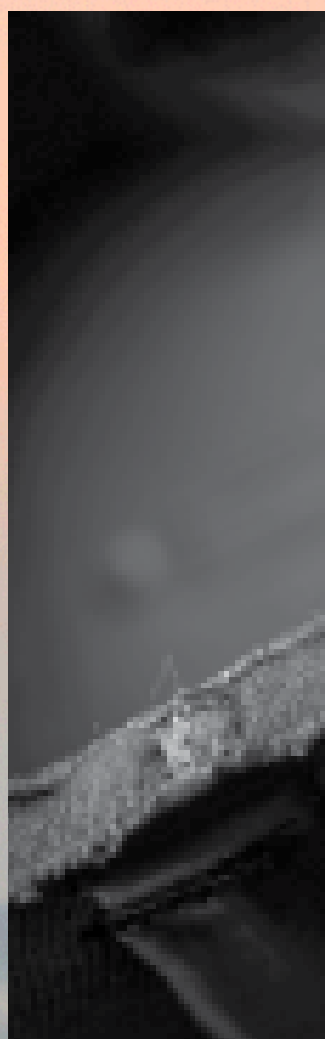
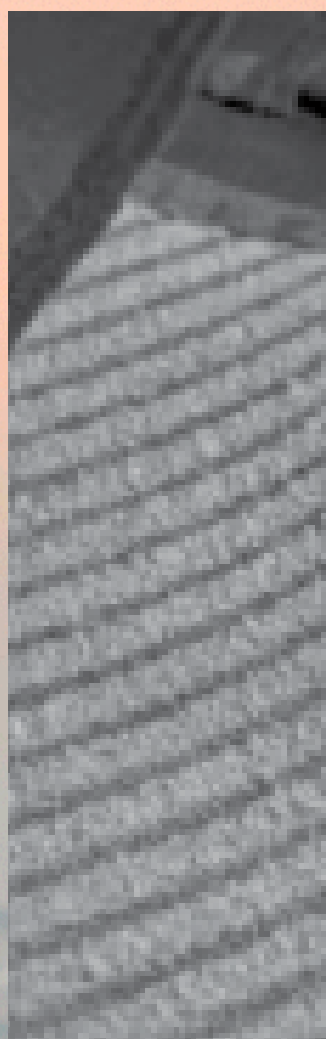
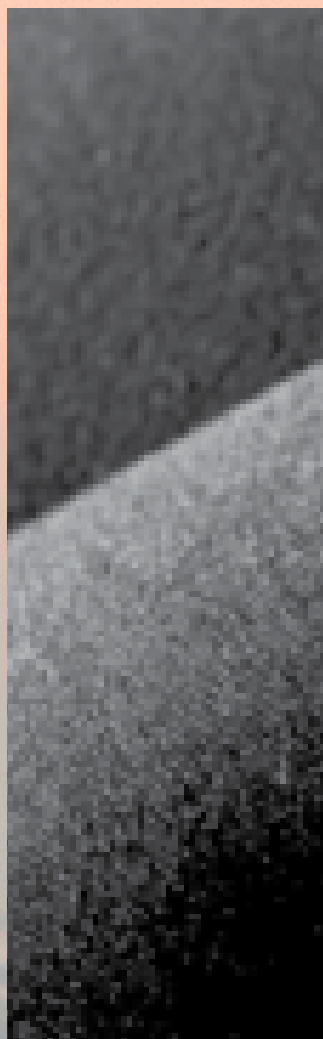
SRFACE has just entered the market with their wetsuit. They have already made an impression with their high quality and affordable design. Their goal was to make an affordable wetsuit with a high quality. This makes it harder for people to try the fit of their wetsuit. But this is counterweighted by the service they provide. Customers can fill in their measurements Online in the size finder to help them choose the right size and try it at home. If the wetsuit doesn't fit as expected, the suit can be returned or changed for a different size for free. Furthermore, the styling of their wetsuit could be defined as a slick and simple design that doesn't have a screaming appearance. This resulted in a full black wetsuit with small orange detailing such as the zipper and logo's. Although their design is new to the market, their reputation and image

is spreading across Europe after MagicSeaweed featured their wetsuit in an article.

For a future design the styling should not deviate too much from their current image. This will increase their brand recognition. The key words that are associated with the styling are:

**HIGH QUALITY
CLEAN SIMPLE**





SRFACE

Currently SRFACE offers one high quality wetsuit design which is available as a 3, 4 or 5mm wetsuit. The overall aesthetics of the suit have a black and dark appearance with a dark gray chest and back panel. The simple design has small orange detailing to represent the SRFACE brand.



SIZING OF CURRENT WETSUIT

The current sizing of the SRFACE wetsuits is based on the sizing of competitors. Through combining the sizing charts of a lot of competitors, SRFACE came up with their own sizing chart adjusted for the larger dutch anthropometry. Currently 7 different wetsuit sizes are available, the S, M, MT, LS, L, LT and XL. After deciding on a thickness the customer can use their size finder to match them with a size that matches their body type as close as possible. In the near future SRFACE will add 5 additional sizes: XS, MS, ST and an XLT. The future size chart can be seen in table 1.

larity of SRFACE and their market expanding to France and Spain, focussing their sizing chart on Europeans would be recommended.

For the scope of this project the target group should be determined to come up with an updated and fine tuned sizing chart for the new methodology. With the rising popu-

Table 1: SIZE FINDER WEBSITE V8

| SIZE | HIGHT (cm) | WEIGHT (kg) | CHEST (cm) | WAIST (cm) |
|------|------------|-------------|------------|------------|
| XS | 164 - 169 | 56 - 63 | 86 - 91 | 70 - 76 |
| S | 168 - 174 | 61 - 69 | 92 - 96 | 73 - 79 |
| ST | 177 - 183 | 67 - 75 | 92 - 96 | 73 - 79 |
| MS | 168 - 174 | 68 - 76 | 96 - 100 | 77 - 83 |
| M | 174 - 180 | 69 - 77 | 96 - 100 | 77 - 83 |
| MT | 184 - 192 | 73 - 81 | 96 - 100 | 77 - 83 |
| LS | 171 - 177 | 74 - 82 | 101 - 105 | 84 - 90 |
| L | 178 - 184 | 78 - 86 | 101 - 105 | 84 - 90 |
| LT | 186 - 194 | 82 - 90 | 101 - 105 | 84 - 90 |
| XL | 181 - 187 | 86 - 94 | 106 - 112 | 91 - 98 |
| XLT | 192 - 200 | 88 - 100 | 106 - 112 | 91 - 98 |

The following graph plots the SRFACE coverage in a parallel dimension plot. The lines are the average wetsuit sizing guidelines. The same coloured areas map the coverage and the overlap between the sizes.

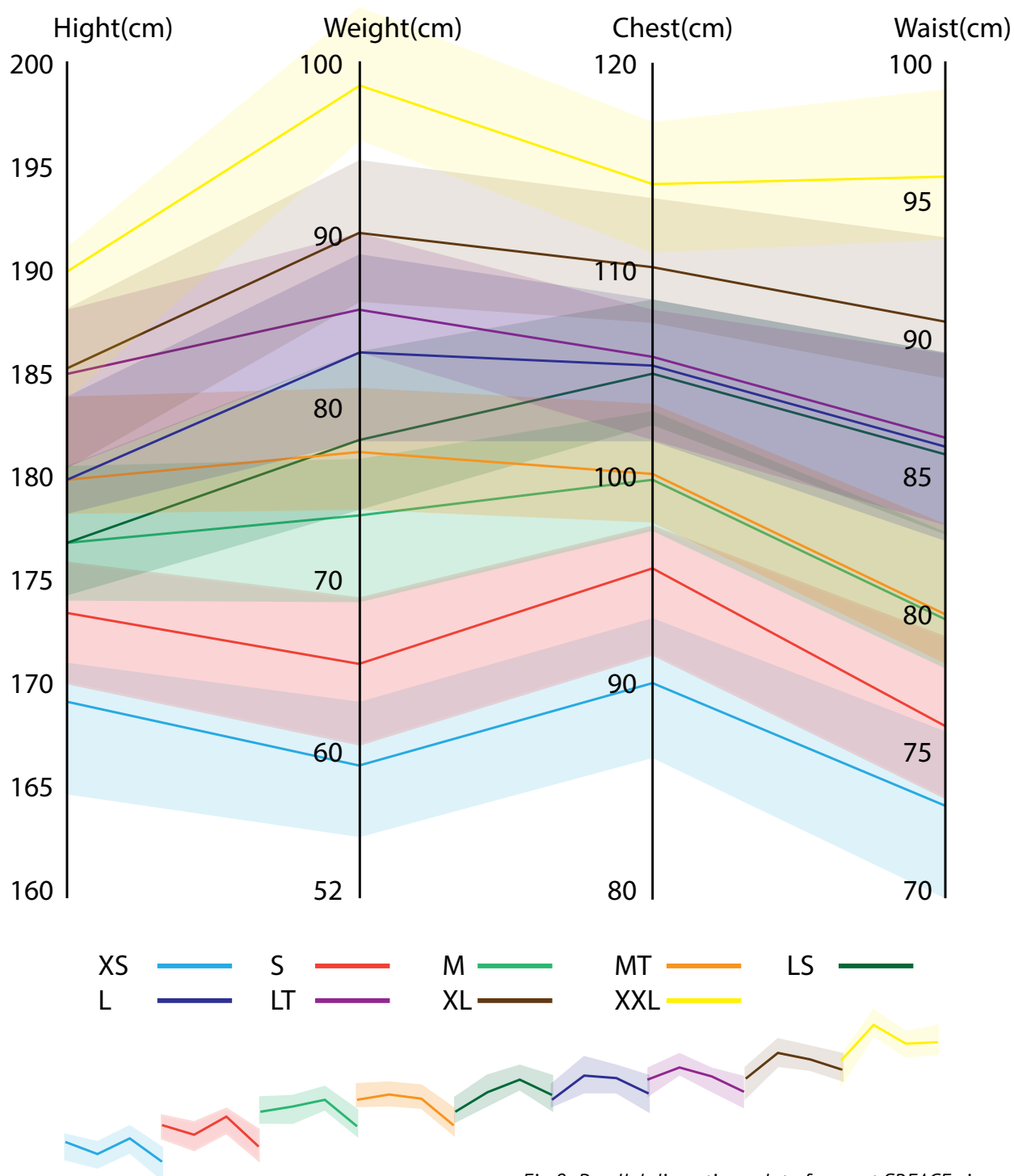


Fig 8: Parallel dimentions plot of current SRFACE sizes

This plot uses the DINED database with the body measurements of a male population with an age range of 20-50 years. The Current Wetsuit sizes of SRFACE are mapped on their coverage based on height and weight.

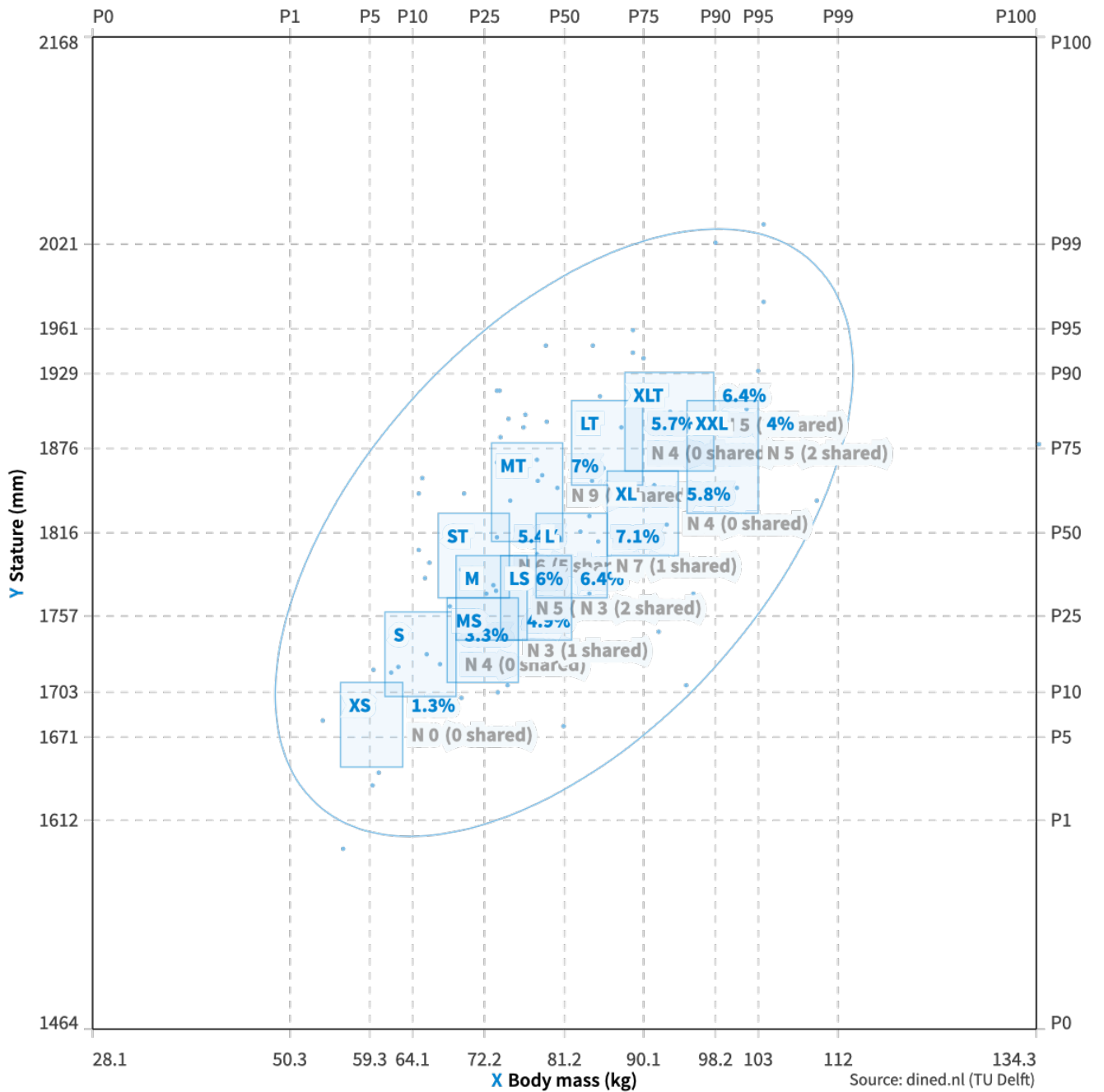


Fig 9: Dined Ellipse plot of current SRFACE sizes

FIT AND PERFORMANCE

STATIC

A good fit is crucial for the effectiveness of a wetsuit. The fit is measured by the customer by wearing the wetsuit and checking the overall tightness. The following dimensions serve as a good indicator for checking the fitting: the length of the sleeves and the length of the legs and the fitting on the inseam between the legs. Figure X shows the correct fitting around the extremities. When wearing a wetsuit gaps and wrinkles show that the fit is not optimal.

DYNAMIC

A good fit can be gained from a tight fitting wetsuit. This traps a thin layer of water between the skin of the surfer and the wetsuit. The insulation provided by the panel thickness together with this layer of water contributes to keeping the surfer warm while surfing in cold water. But if a wetsuit is too tight the suit may restrict the movement of the surfer which limits them in performing surfing movements. Therefore, a good fit is having a balancing amount of tightness. While surfing, cold water can enter the suit and fill these areas compromising the effectiveness of the wetsuit. Critical points where these gaps occur are on the inseam between the legs and under the armpits. The chest is also a critical point. While sitting on a surfboard in a crouched position a gap starts to occur where from the excess material around the chest/waist.

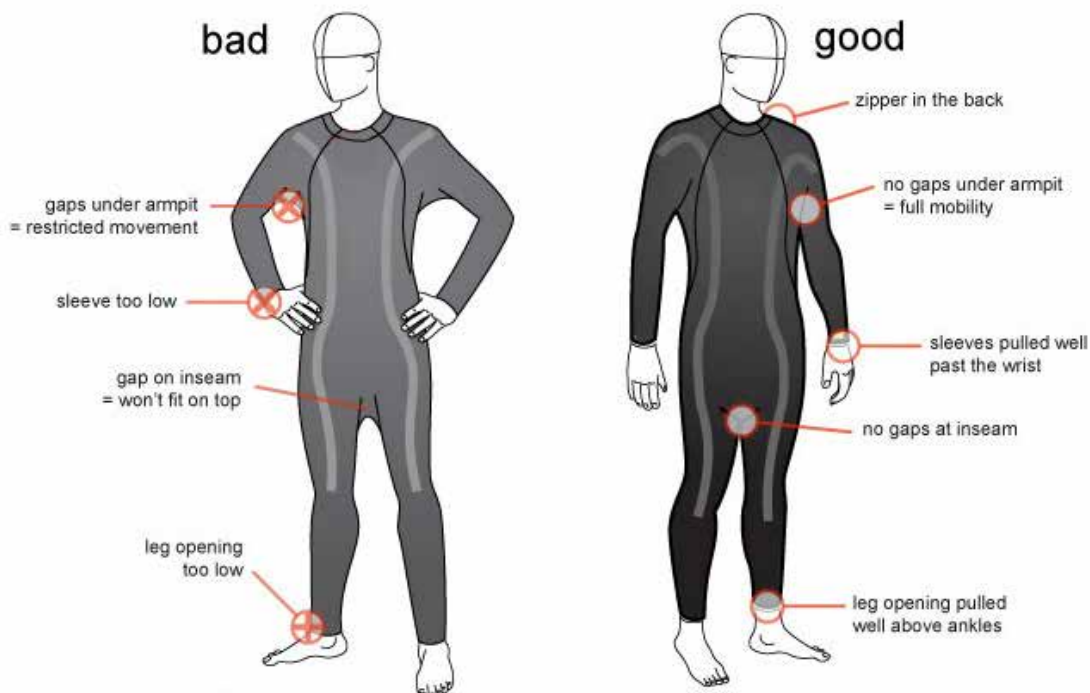


Fig 10: Fit characteristics. source: onetri.com

SRFACE Fitting Optimization

The SRFACE team visits the factory to assess the first prototypes. Together with designers from the production company they walk through the whole design to check if everything is up to standards. Every part of the initial design is checked together with the fit. As last step the wetsuits will be tested in real conditions. By surfing with the wetsuits the team assesses its overall comfort and durability. The total analysis can be divided in the following steps:

| | | |
|----|-----------------------|--|
| 1. | Aesthetics | <i>Materials</i> <i>Colors</i> <i>Prints</i> <i>Features</i> |
| 2. | Static Fit | <i>Eaze of entry system</i> <i>Sleeve length</i> <i>Ankle length</i> <i>Tight or loose areas</i> <ul style="list-style-type: none"> - Neck - Shoulder - Chest - Waist |
| 3. | Dynamic Fit | <i>Arm movement</i> <i>Waist</i> |
| 4. | Comfort Durability | & <i>Seamplacement</i> <i>Durability</i> <ul style="list-style-type: none"> - Seams - Prints - Seals - Features |

Table 2: Analysis steps

SURF MOTIONS

The following movements are the most occurring movements during surfing. A good fitting pattern is able to sustain an unrestricting fitting during these movements. The occurrence of air gaps compromises the insulative function of the suit and should be minimized as much as possible by the pattern. During the current design

optimization the wetsuit is tested within real conditions. During the use of a prototype these movements show the behaviour of the pattern. These movements should also be incorporated in the new design methodology for performance analysis.

SURF MOVEMENTS

Each of these surfing movements result in requirements for the wetsuit pattern.

Sitting on a surfboard to rest or to spot a good wave is an important position to take in account. In such a situation the surfer can cool down a lot quicker than during surfing itself. A critical point in the wetsuit is the chest and back. These parts have the biggest surface that can cool down by wind. Lots of suits use single lined neoprene to reduce the windchill. Plush insulation can also be used for extra warmth in these areas. Concerning the behaviour of the pattern, during a sitting position the excess material on the chest/waist will wrinkle and cause air gaps. These gaps can then be filled with cold seawater which is compromised the insulative level of the suit.

Paddling requires a lot of stretch around the shoulder. When extending your arm, the panel under your armpit should follow the elongation of the skin. This is a critical part in pattern making. An optimum has to be designed where the occurrence of an air gap is minimized without restricting the movement of the arms.

Popping up on a surfboard is also a critical action during surfing, especially for beginners. Gliding and scrubbing over the top of the surfboard can test the durability of a wetsuit. A common mistake with inexperienced surfers is to scrape their knees over the board during this action. Durable padding of the knee panels is needed in these areas.

For the stance and turning during surfing the wetsuit should act like a second skin. This means that the suit itself should not feel restrictive in any way during these movements. The more it feels like you're not even wearing a wetsuit at all, the better. A couple of motions are applicable in this situation. Torso rotation, crouching and full rotation of the arms (flexion, extension, abduction & adduction).

When paddling against the waves duck diving is an effective way to prevent the wave from pushing you back. During such an action water can enter the suit through the neck if the neck seal is not tight enough.

SITTING

Source: adventureinyou.com

PADDLING

Source: adventureinyou.com

POP UP

Source: thesurfingsumo.com

STANCE

Source: surfeducators

DUCK DIVE

Source: tickettoridegroup.com

CONCLUSIONS:

- The current branding should be incorporated in the new methodology to increase future brand recognition.
- The sizing should be focussed on the European anthropometry as the current market is expanding outside of the Netherlands
- The new methodology should analyse the performance by subjecting the pattern to the mentioned motions. The performance analysis should minimize the occurrence of air gaps in a pattern focussing on the armpits, the inseam between the legs and the waist/stomach.
- The same dimensions are used for the different wetsuit thicknesses. A wetsuit with a different thickness should have other pattern dimensions to compensate for the difference in stretch.

PROGRAM OF REQUIREMENTS

METHODOLOGY

Combining the information gathered in the previous research, the following requirements can be listed. A distinction can be made in software requirements and requirements for the final methodology.

A new methodology should:

- Incorporate the creation and grading of own patterns for more control in optimization.
- Use software that is able to use a 3D human body as a basis for the pattern design.
- Use a design for fit approach without discarding the styling.
- Incorporate digital analysis of the dynamic fit where the stretch and pressure behaviour of a pattern are mapped.
- Use validated software packages.
- The current branding should be incorporated in the new methodology to increase future brand recognition.
- The sizing should be focussed on the European anthropometry as the current market is expanding outside of the Netherlands.
- Incorporate sizing towards different body types.
- be able to analyse the performance/dynamic fit of a pattern digitally with surfing motions.
- Design with the available materials from the production factory.
- Be able to use different types of neoprene and lining combinations to influence the stretching behaviour of a pattern
- Minimize the total seam length for it makes up most of the production time of a wetsuit.

SOFTWARE

The new design methodology will incorporate the use of a digital pattern creation and grading tool. Therefore most of the previous listed requirements have an implication on the abilities of the software. Therefore the following requirements are focussed on the software itself.

The software should:

- Easy to learn and use.
- Be able to create patterns ready for production (acceptable to the standards of the production factory)
- Include accurate flattening tools
- Have easy to use pattern scaling
- Have a 3D workflow and approach to designing garments
- Have adjustable mannequins or be able to import them
- Be able to analyse pattern compression
- Be able to adjust or animate the mannequins
- Be able to analyse the stress and tension in the pattern
- Be able to virtually simulate the draping of garments
- Be able to adjust material properties or have an extensive library including Neoprene, Nylon and polyester.

SOFTWARE ANALYSIS

For SRFACE to be able to do their own pattern creation and pattern grading the right software package should be chosen. The software should meet the desired requirements for the creation of tight fitting garments. One of the most important aspects is that it incorporates a 3D workflow where the wetsuit patterns can be designed using 3D mannequins as basis. This will improve the overall (static) fit of the designs. In designing for an optimal dynamic fit there are a couple of things that the software should be able to analyse. The 3D workflow should not only assess the visual appearance of a pattern but also have an accurate draping simulation that is able to show the overall compression and stress of the pattern based on the properties of Neoprene. The designer should be able to manually adjust the stance of the mannequins or apply the pattern designs on mannequins with different stances based on surfing movements. Mapping these aspects will give a good indication where the pattern should be adjusted. Furthermore the software should incorporate easy to use scaling tools to create different wetsuit patterns based on a base size.

The following list contains software that could contribute in a new methodology. Appendix 1 contains the full software analysis.

- Optitex
- Tuka3D
- Clo3D
- Accumark
- Lectra Modaris 3D
- Assyst Human-Solutions
- Rhino

LIST OF SOFTWARE:

There are a lot of different companies on the market with specialized software packages for the creation and scaling of garments. Most of these packages currently incorporate a 3D workflow to communicate the visual appeal of a pattern. Most of these packages also offer a digital simulation of the overall fit. Yet little can be found on the accuracy of the different packages which all claim to be the most realistic. Although the 3D workflow is integrated in most of the available software not every package has a 3D approach in the design of the patterns. The following software has been chosen to because they can use a body model as basis to draw pattern lines on:

- Optitex
- Accumark
- Clo3D

Determining the right software package for the creation of wetsuits should be done by comparing workflows. But due to the limited response of Optitex and Accumark, only Clo3D is investigated in this project. Further focus of this project will be to assess the ability of Clo3D to use 3D mannequins as basis and creation of accurate wetsuit patterns.

SIZING

RELEVANT MEASUREMENTS

In addressing the sizing of future wetsuits there are a lot of body measurements that are useful in plotting the variety within different body types. Before looking into this variety the relevant measurements should be addressed together with how they can be measured. The following body measurements are relevant in the design of wetsuit patterns.

Looking into the variety of every one of these dimensions for every wetsuit sizes would take a lot of time. Digital mannequins will be created based on height, chest and waist. These dimensions are currently used in the SRFACE sizing chart. The resulting mannequins will serve as an average representation of the intended user body type. These mannequins can be imported into the pattern design software or can be used to extract the relevant measurements to adjust the mannequin provided by the software itself.

On the following pages the wetsuit sizes of SRFACE and an other wetsuit brand are plotted in an ellipse plot. The distinction between Tall, Standard and Short wetsuit sizes can be seen in the difference in weight. The standard wetsuit sizes are located on the average weight of the population. Tall sizes focus on the lighter body types and the short sizes focus on the heavier weighing body types. Using the CAESAR database the sizing will be assessed and different approaches will be tested in determining the right distribution of the wetsuit sizes for a maximum coverage of the intended user population.

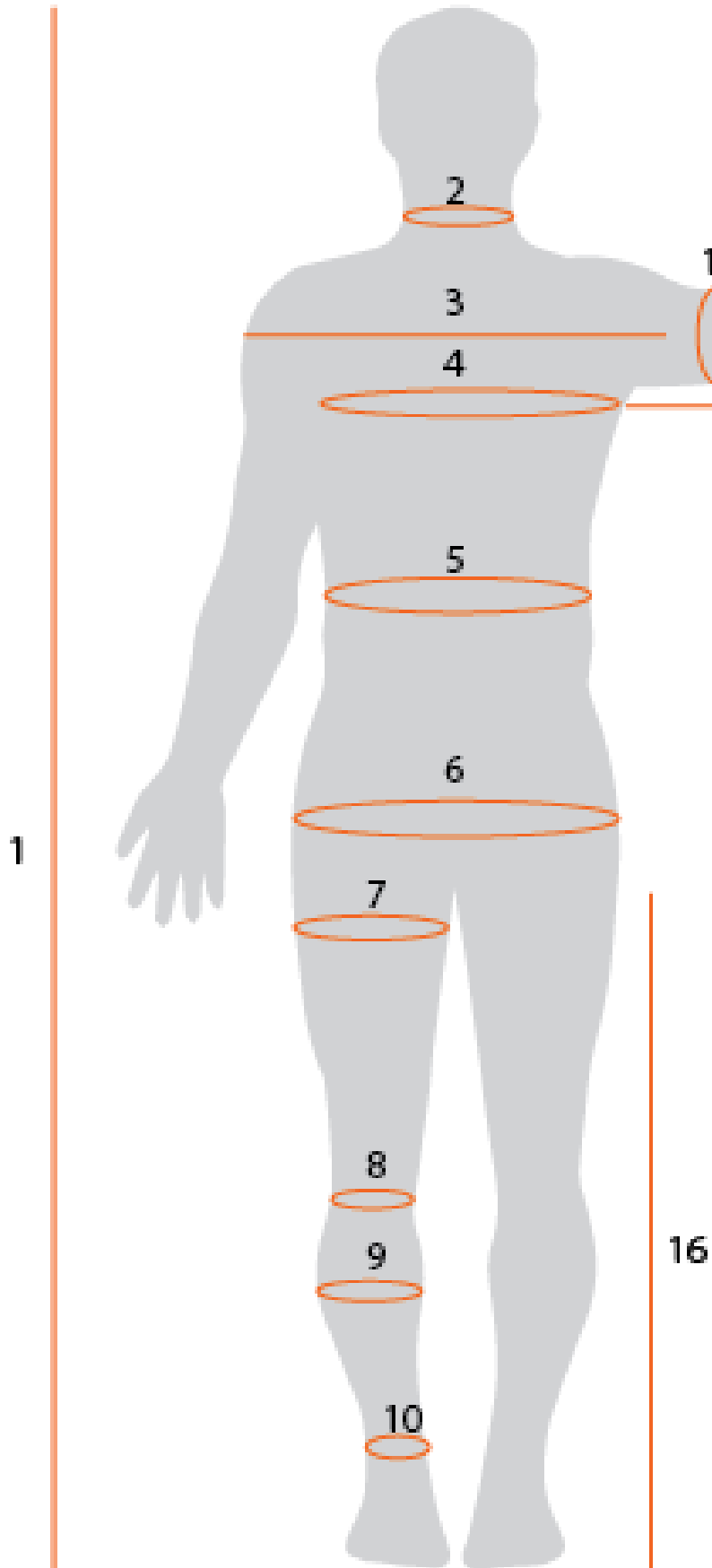
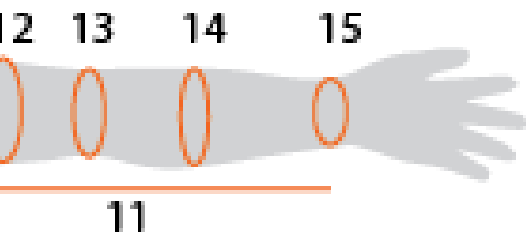


Fig 11: Relevant measurements for sizing



1. The height is measured as the vertical distance from the standing surface to the vertex (highest point of the head).
2. The neck circumference is measured just under the Adam's apple
3. The shoulder breadth is gained by measuring the distance of between the widest points of the bi-deltoid muscle.
4. The circumference of the chest is measured just above the nipple height and under the armpits.
5. The waist circumference is measured between the iliac crest and the lower rib.
6. The hip circumference is measured around the widest part of the hip on the height of the femur bone.
7. The Thigh circumference is measured around the highest part of the upper leg right under the groin.
8. The circumference of the knee is measured around the miniscus.
9. The calf circumference is measured around the widest part of the gastrocnemius.
10. The ankle circumference should be measured around the ankle just above the malleolus medial which is the most highest and distal protrusion of the ankle.
11. The length of the arm is measured from the junction between the pectoralis and the bicep to the styloid of the wrist.
12. The biceps should be measured around the upper arm just below the deltoid muscle.
13. The circumference of the elbow is measured around the elbow joint with slight concentric flexion in the under arm.
14. The underarm circumference is measured around the widest part of the under arm.
15. The wrist circumference is measured around the styloid of the wrist
16. The crotch height is measured as the vertical distance from the standing surface to the highest point of the crotch.

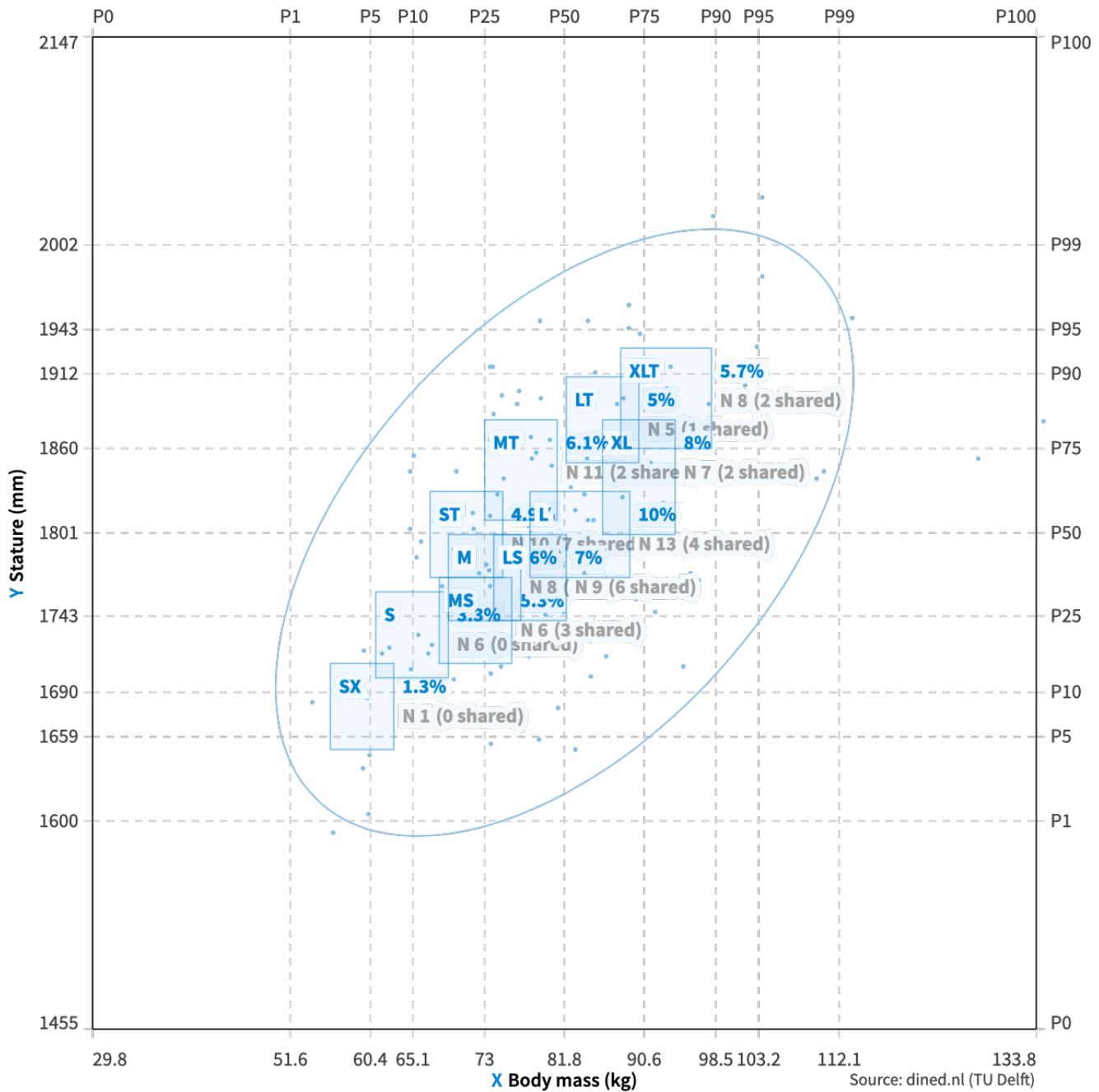


Fig 12: SRFACE coverage of height and weight

The following ellipse plot contains the coverage of the current wetsuit sizing based on the height and weight of the intended population. The plot is based on the DINED measurements of 2004 of the male population between the ages 20 and 50.

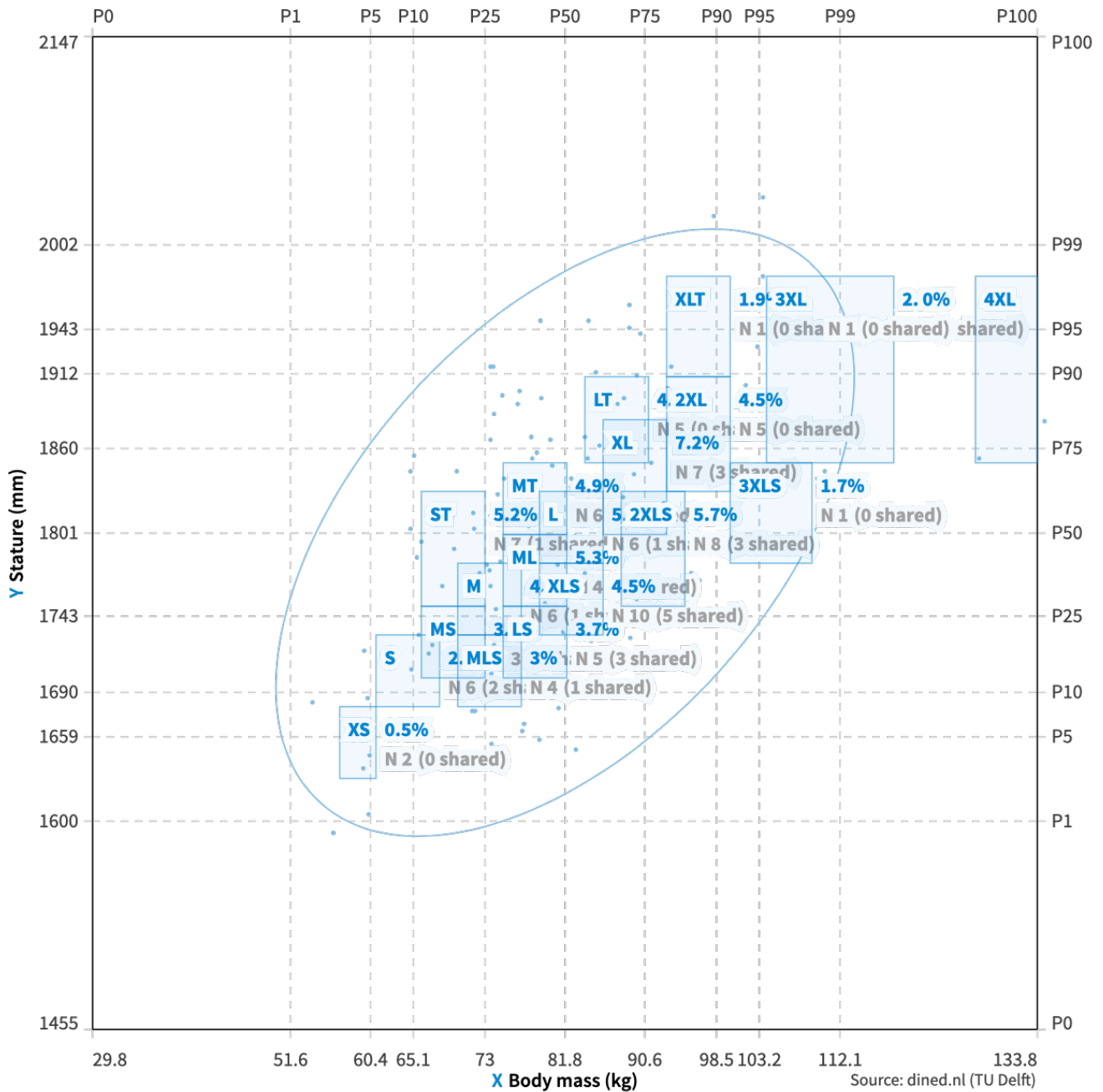


Fig 13: Coverage of height and weight

This second plot shows the coverage of the sizes of an large competitor brand in the same population ellipse. This company offers the largest sizing in wetsuit design and can be used to compare the coverage and the overlap between sizes.

HUMAN TAXONOMY

In 1940 William Herbert Sheldon introduced a classification system for the human physique called Somatotypes. The Somatotypes can be divided in three categories named: Endoderm, Mesoderm and Ectoderm. Sheldon's work attempted to associate the Somatotype classification with human temperament types but was deemed to be too subjective and was therefore discredited. But his classification of the human physique still stands and is widely used in anthropometric studies.

Ectomorph:

People in this category are defined as being tall, slender and thin. They are lightly muscled and therefore have a flat chest and abdomen, thin arms and a low body fat percentage. They have narrow shoulders and hips.

Mesomorph:

A mesomorphic individual has an athletic build with muscled arms and legs. Their body could be defined as wedge-shaped with narrow hips and broad shoulders. They have a minimum amount of body fat.

Endomorph:

A pure endomorphic individual typically has a higher percent of body fat. Their body has wide hips and wide shoulders.

In: "Anthropometrika: A Textbook of Body Measurement for Sports and Health Courses" a formulaic approach as been used as a qualifier for body type. As Mentioned by R. Rempler in "A Modified Somatotype Assessment Methodology" it is the best single qualifier of total body shape. The following equations in figure 15 asses several body measurements on a seven-point scale. Hereby 0 indicates no correlation with the Somatotype and 7 a very strong correlation.

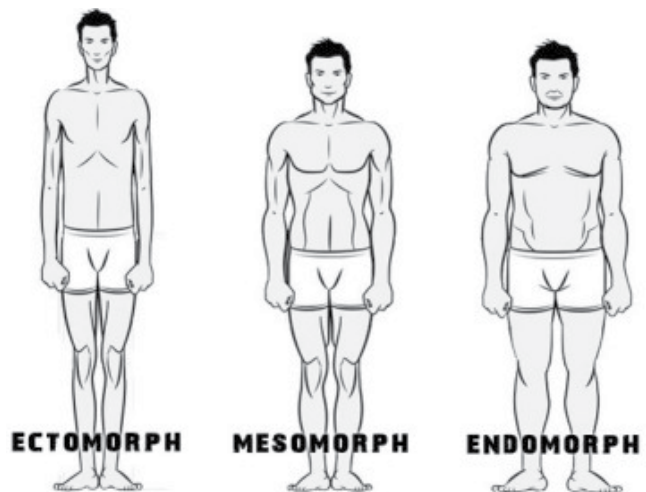


Fig 14: Somatotypes

A pure endomorph would score 7 for endomorphy and 1 for both mesomorphy and ectomorphy. This would be noted as 7-1-1. A pure Mesomorph would be 1-7-1 and a pure ectomorph 1-1-7. There aren't a lot of people who can be classified as one of these pure body types but would be somewhere in between these extremes.

$$\text{Endomorphy} = -0.7182 + (0.145 * X) - (0.00068 * X^2) + (0.0000014 * X^3)$$

$$\bullet \text{ where: } X = (\text{tricepSkinfoldMM} + \text{subscapularSkinfoldMM} + \text{supraspinalSkinfoldMM}) * \left(\frac{170.18}{\text{heightCM}}\right)$$

Mesomorphy: =

$$(0.858 * \text{HumerusBreadthCM}) + (0.601 * \text{FemurBreadthCM}) + (0.188 * \text{upperArmGirthCM}) + (0.161 * \text{maxCalfGirthCM}) - (0.131 * \text{heightCM}) + 4.5$$

$$\text{Ectomorphy: Calculate the subjects Ponderal Index: } PI = \frac{\text{height[cm]}}{(\text{mass[kg]})^{1/3}}$$

- If $PI > 40.74$, $\text{Ectomorphy} = (0.732 * PI) - 28.58$
- If $39.65 < PI < 40.74$, $\text{Ectomorphy} = (0.463 * PI) - 17.615$
- If $PI < 39.65$, $\text{Ectomorphy} = 0.5$

Fig 15: Equations for determining correlation with somatotypes

SURFER BODY TYPES

M. J. Barlow et al. researched the anthropometric profiles of male surfers in junior, intermediate and professional levels. With a total of 80 subjects the following plot was made positioning each of the subjects on a somatotype plot (figure 16). The BMI score means were also calculated for the three different surfer categories together with the standard deviation in table 3.

As seen in the plot in figure X surfers could be categorized as having a higher correlation with a mesomorphic body type.

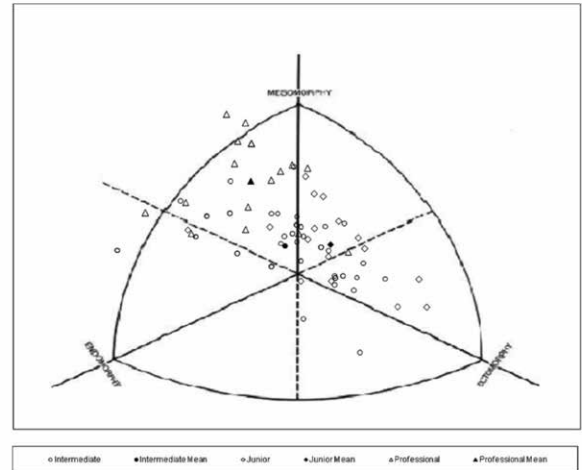


Fig 16: Somatotypes distribution of Surfers

Table 3: Skill and anthropometric variables of professional, junior and intermediate level surfers

| Measure | Professional (n = 17) | Junior (n = 16) | Intermediate (n = 47) |
|----------------------------|-----------------------|-----------------|-----------------------|
| Body mass (kg) | 78.57 ± 7.17** | 63.27 ± 7.17†† | 77.83 ± 9.43 |
| Stature (cm) | 177.28 ± 6.29 | 173.86 ± 5.72 | 179.90 ± 5.41** |
| Triceps skinfold (mm) | 8.69 ± 4.25 | 7.72 ± 2.38 | 8.93 ± 2.91 |
| Subscapular skinfold (mm) | 10.88 ± 4.46 | 8.13 ± 2.63 | 10.59 ± 4.44 |
| Biceps skinfold (mm) | 3.84 ± 1.18 | 4.69 ± 0.77 | 5.10 ± 2.54 |
| Iliac crest skinfold (mm) | 14.41 ± 6.75 | 8.78 ± 3.95 | 13.64 ± 5.55 |
| Supraspinale skinfold (mm) | 7.03 ± 3.53 | 6.78 ± 2.22 | 10.05 ± 4.57† |
| Abdominal skinfold (mm) | 14.71 ± 5.20* | 10.48 ± 4.42 | 14.56 ± 6.39** |
| Front thigh skinfold (mm) | 13.27 ± 7.74 | 11.03 ± 2.90 | 11.88 ± 3.50 |
| Medial calf skinfold (mm) | 9.71 ± 5.67 | 8.24 ± 2.15 | 8.38 ± 2.26 |
| Relaxed arm girth (cm) | 33.36 ± 2.23** | 27.71 ± 4.24† | 31.89 ± 2.41** |
| Flexed arm girth (cm) | 34.02 ± 2.36 | 30.46 ± 2.45 | 34.53 ± 2.51 |
| Waist girth (cm) | 83.11 ± 3.91 | 73.01 ± 3.26 | 81.23 ± 5.69 |
| Gluteal girth (cm) | 101.04 ± 4.63 | 85.03 ± 9.57 | 98.59 ± 5.42 |
| Calf girth (cm) | 37.05 ± 1.27** | 34.13 ± 2.59†† | 36.82 ± 2.64** |
| Humerus breadth (cm) | 6.87 ± 0.37 | 6.70 ± 0.48 | 6.40 ± 0.53†† |
| Femur breadth (cm) | 9.58 ± 0.44 | 9.19 ± 0.43 | 8.96 ± 0.72†† |
| Endomorphy | 2.48 ± 1.12 | 2.18 ± 0.71 | 2.79 ± 1.03 |
| Mesomorphy | 5.00 ± 1.02 | 3.72 ± 0.88†† | 3.57 ± 0.90†† |
| Ectomorphy | 1.03 ± 1.06 | 3.24 ± 1.37 | 2.42 ± 1.08†† |
| Body mass index (BMI) | 24.99 ± 1.61** | 20.91 ± 1.93†† | 23.90 ± 2.49** |
| Sum of six skinfolds (mm) | 64.29 ± 28.14 | 50.74 ± 14.33 | 64.36 ± 20.22 |
| Body fat percentage | 11.28 ± 4.20* | 8.41 ± 2.37† | 10.87 ± 21.49* |

*Significantly different to junior surfers $P < 0.05$.

**Significantly different to junior surfers $P < 0.01$.

† Significantly different to professional surfers $P < 0.05$.

†† Significantly different to professional surfers $P < 0.01$.

VARIETY ANALYSIS

THE GOAL

The goal of this analysis is to create digital mannequins that can be used for the creation of wetsuit patterns. These mannequins will give insight in the anthropometric differences of the intended user population between the different wetsuit sizes. These models might also be used within future pattern creation software to design for an optimal fit.

The CAESAR database will be used as a representation of the user population. The body scans within this database will be used for the creation of mannequins. The focus will be on the chest and waist variation for it is currently used in the SRFACE sizing chart and serve as a good indicator for body type. Multiple wetsuit sizes are used for people within a given height range and therefore the waist and chest coverage will be determined for every individual size.

Mannequins will be created having body dimensions which represent the average body type for each wetsuit size. This mannequin can then be used as a basis for pattern creation. Furthermore, 2 extreme body types will be made where one represents the largest body type that should fit in the same pattern size, and the other represents the smallest. This results in 3 different mannequins for every wetsuit size. An average mannequin for the creation of a wetsuit pattern, and two extreme mannequins for testing the fit of the design.

The height from the current wetsuit sizes will be used as the primary measurement for determining the body type variations. Looking at the ellipse plot from both the current SRFACE and the other brand wetsuit sizes the standard sizes (S, M, L etc.) are set on the average weight within a given height range, whereas the Tall sizes are classified having a lower weight and the Short sizes a higher weight.

The following approach will be used: the intended user population will be chosen based on availability of anthropometric data. Multiple criteria will be set up with the focus of excluding non surfer body types. Different approaches will be investigated in classifying the body types for individual wetsuit sizes using a primary and a secondary measurement. The result will serve as a selection method for the creation of mannequins and a sizing chart.

CHOOSING INTENDED POPULATION

The CAESAR database currently contains measurements and scans of 3 different populations. A Dutch population with $n=1267$, an Italian population with $n=802$ and an American population of $n=2387$. Currently SRFACE wetsuits are sold mainly in the Netherlands, Spain and France. Because no anthropometric data is available of Spain and France the Italian and Dutch population will be used as a representation of the intended user population. As seen in figure 17 the Italian population is generally smaller compared to the Dutch population. By using both data collections a more general population distribution is acquired. The higher amount of used data will also increase the accuracy of the calculations. Table 4 contains the percentile values of the sizes compared to the different CAESAR populations of men between the age of 20-45. Figure 17 shows the percentiles in a violin plot for every CAESAR population.

Combining Both the Italian and the Dutch CAESAR population gives the following ranking seen in table 5. The percentile ranking has a better distribution over the height of the population ranging from around P10 - P88. This population will be used for further analysis.

| Height | Sizes | NL | IT | USA |
|--------|-------|-------|-------|-------|
| 1890 | XLT | P79,9 | P91,7 | P91,7 |
| 1840 | XL | P58,1 | P93,3 | P78,9 |
| 1810 | L | P46,1 | P86,3 | P66,3 |
| 1770 | M | P25,8 | P68,7 | P45 |
| 130 | S | P12,9 | P48,2 | P25,9 |
| 1680 | XS | P3,4 | P19,4 | P8,5 |

Table 4: Percentile ranks of SURFACE standard sizes compared to the different CAESAR populations (men, age 20-45)

| Height | Sizes | NL+IT |
|--------|-------|-------|
| 1890 | XLT | P88,1 |
| 1840 | XL | P73,6 |
| 1810 | L | P63,9 |
| 1770 | M | P44,9 |
| 130 | S | P28,5 |
| 1680 | XS | P10,6 |

Table 5: Percentile ranks of SRFACE standard sizes in the combined population.

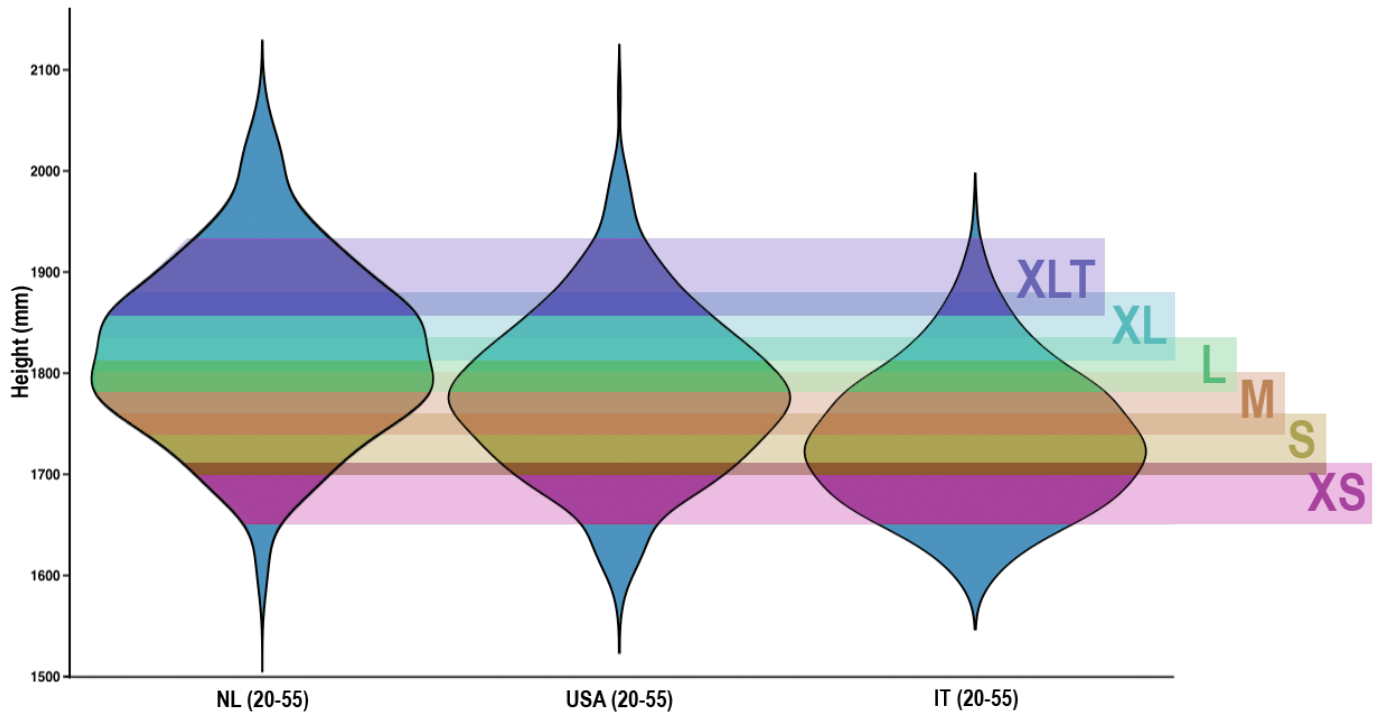


Fig 17: Violin plot of the percentile values for the current wetsuit sizes.

FITNESS CRITERIA

Body types of people that would most likely not be surfers should be excluded. This will increase the accuracy of the resulting mannequins. 3 different approaches were applied for excluding body types based on the paper Anthropometric variables and their relationship to performance and ability in male surfers by M. J. Barlow. M.J. Barlow made a distinction between 3 different surfer categories; professional, intermediate and junior surfers. The junior population, with the age of 15.61 ± 1.06 , will not be taken into account. The CAESAR project doesn't have enough data to use the somatotype classification as a criteria for excluding non-surfer body types. Therefore the Quetelet index (BMI) will be used for it has a high correlation with body fat percentage (Dennis A. Revicki) and can be calculated with the measurements in CAESAR. The CAESAR project also contains the subscapular skinfold and the triceps skinfold as a measurement of fat percentage. The results of M. J. Barlow for both skinfolds and BMI will be used as criteria.

Table 6 shows the results of M. J. Barlow for both the professional and intermediate population. The criteria will be set on excluding the top 2.5% of the surfing population. Combining the results of both populations the highest criteria will be used. This results in the criteria $BMI < 28.88$ ($23.90 \pm 2sd$). The subscapular skinfold was measured having a mean of 10.88 ± 4.46 which leads to the criteria set on 19.80. The Triceps skinfold was measured having a mean of 8.69 ± 4.25 which leads to a criteria of 17.19. The same is done for excluding the bottom 2.5%.

As a fourth criteria the waist-to-hip ratio (WHR) could be used. A male average for waist-hip ratio (WHR) is 0.90–0.95 (see table 7). People with a higher score are classified as obese and most likely won't be surfers. The CAESAR database currently includes only the preferred waist circumference. The WHR uses the Waist circumference right under the 10th rib. Because this circumference is not yet included in the database the WHR will not be used as a criteria.

| | Professional (n=17) | Intermediate (n=47) |
|-------------------------|------------------------|------------------------|
| BMI | 24.99 ± 1.61 | 23.90 ± 2.49 |
| Subscapular Skinfold | 10.88 ± 4.46 | 10.59 ± 4.44 |
| Triceps Skinfold | 8.69 ± 4.25 | 8.93 ± 2.91 |

Table 6: Test results of M.J. Barlow

| Waist-to-Hip Ratio (WHR) Norms | | | | |
|--------------------------------|-----------|-----------|-----------|---------|
| Gender | Excellent | Good | Average | At Risk |
| Males | <0.85 | 0.85–0.89 | 0.90–0.95 | >0.95 |
| Females | <0.75 | 0.75–0.79 | 0.80–0.86 | >0.86 |

Table 7: Waist to Hip Ratio Norms

Source: American Council on Exercise, April 2014

This results in the following criteria for excluding body types of non-surfers.

$19 < BMI < 29$

$0 < \text{Subscapular Skinfold} < 20$

$3 < \text{Triceps Skinfold} < 17$

CLASSIFICATION

Height is mainly used as primary dimension in the clothing industry. But for the creation of mannequins a distinction should be made between people who should fit in a standard size (S, M, L etc.) and people who should fit in a tall (ST, MT etc.) size or short (MS, LS, etc.) size. Next to the height a secondary dimension should be used as a classification method between these sizes. Wetsuit sizing charts commonly include the chest, waist and weight to make this distinction. Within these measurements the chest is used as the most important measurement. The chest area in the wetsuit will experience more stretch during surfing motions compared to the waist. Therefore the chest plays the highest role in dynamic fit and comfort. The chest will be used as the secondary dimension for assessing the different wetsuit sizes.

DINED

The Dined Elipse tool will be used to plot the CAESAR data and evaluate different sizing approaches. Figure 18 shows the height plotted against the chest circumference of both Dutch and Italian populations. In this same figure the possible surfer body types have been plotted according to the criteria determined in the previous chapter. The overall difference in height distribution between the two

populations is clearly visible in the size of the ellipses. The same is seen for the chest circumference. Both populations are combined into one ellipse plot in Figure 19. This plot serves as a representation of the European surfer population and can be used to determine and map out the wetsuit sizes.

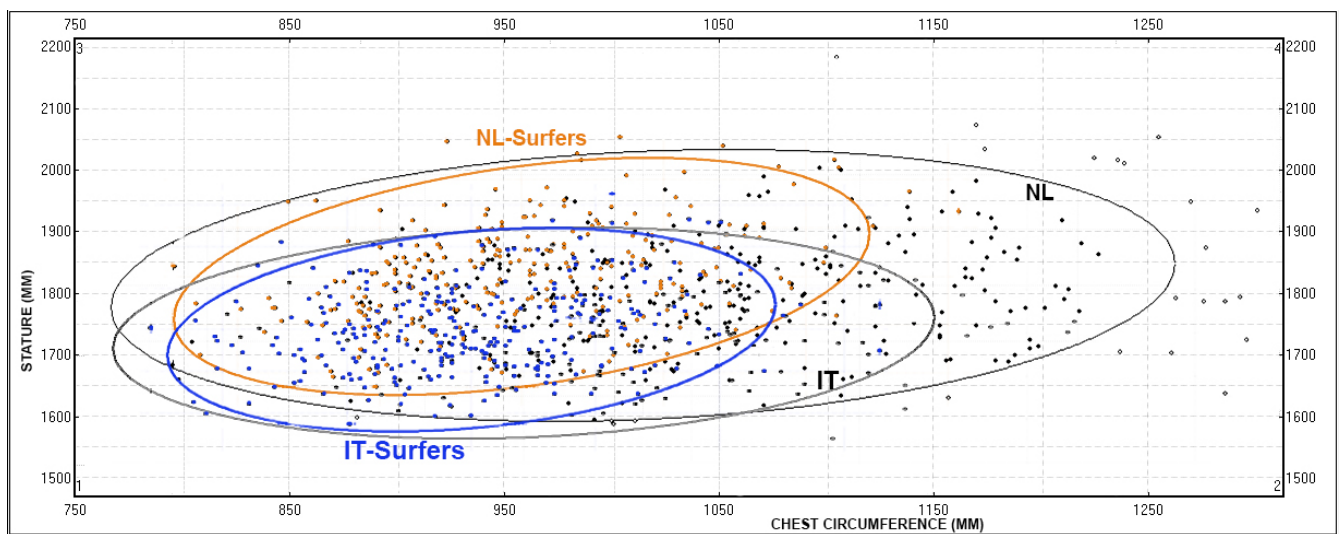


Fig 18: Overlapping Ellipse plots of the Dutch and Italian population with highlighted surfer body types.

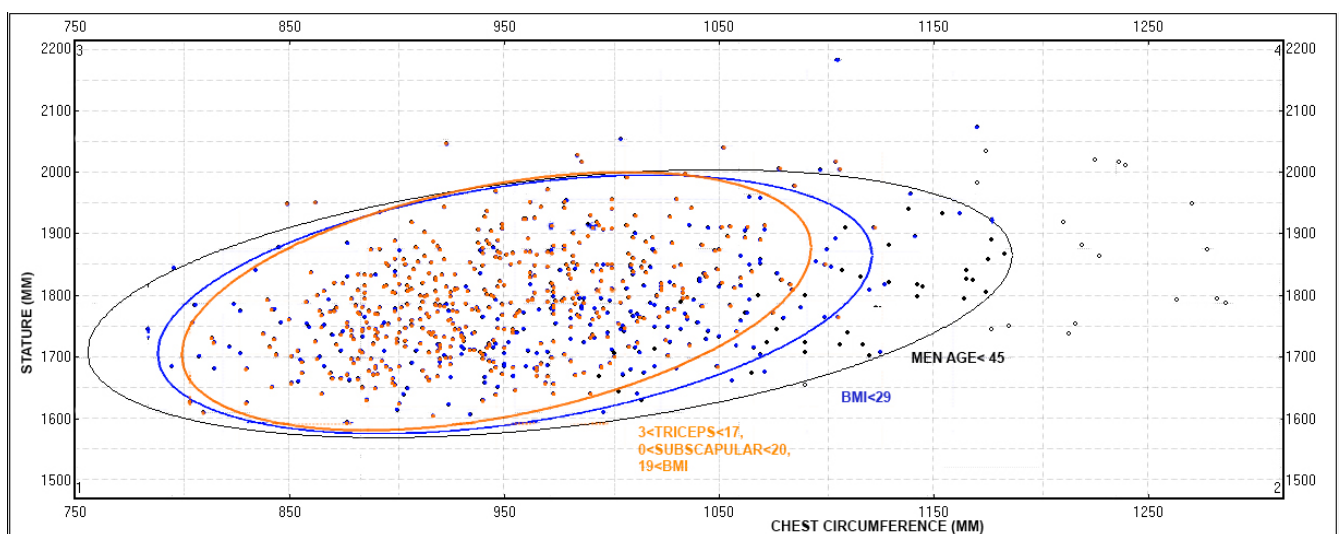


Fig 19: The combined Dutch and Italian population using the determined criteria

SIZING METHODS

There are different classification methods for the creation of a sizing chart. The different methods are mapped on the Ellipse plot of the intended user population. The distribution of sizes in the primary dimension (stature) is kept the same in every method. This distribution currently

used by SRFACE and is based on sizing charts of other wetsuit brands. Deviating too much from this distribution could result in uncertainty for the customers and might cause more miss purchases. The intervals of the different sizes is also kept the same for it is widely used in the current market.

CURRENT SRFACE SIZE

The first plot in figure 20 shows the sizing distribution of the most recent SRFACE sizing chart. These wetsuit sizes are based on the sizing of competitor wetsuit brands. The biggest benefit of this sizing is that it matches the sizes of other brands. Customers who will buy a SRFACE wetsuit based on other or previously owned wetsuits, will acquire a similar fitting wetsuit. Another benefit is the wide distribution of sizes. The wetsuit sizes have little to no overlapping surfaces which creates a high coverage. On the downside the largest sizes (XL & XLT) are located on the edge of the ellipse of the surfer body types. This indicates a low coverage. Furthermore a big portion of the population is located having a smaller chest circumference than the coverage of the different sizes.

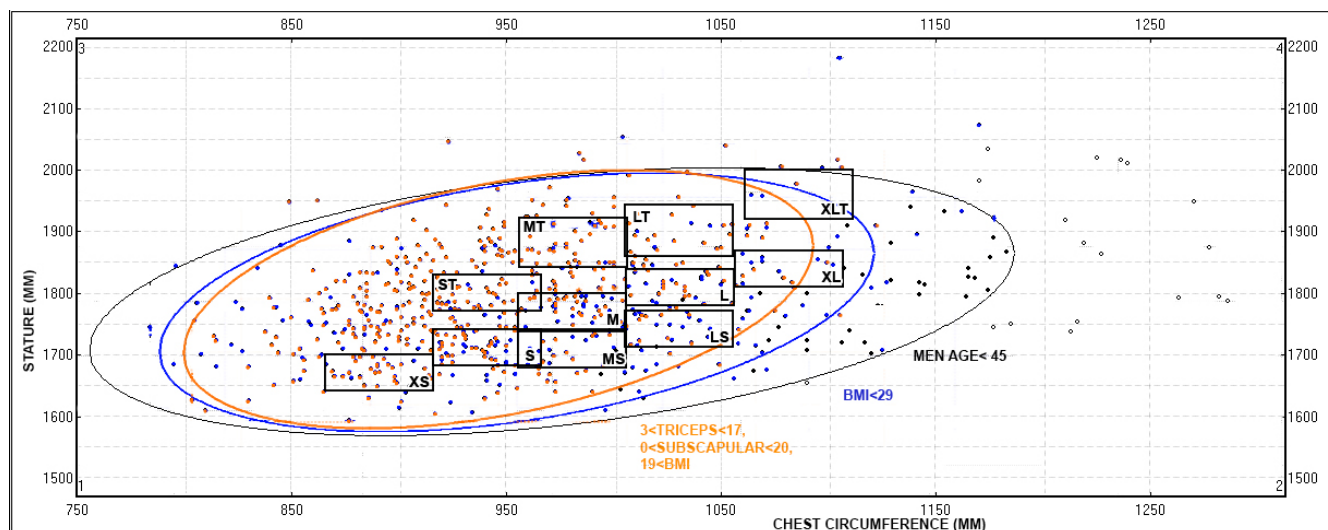
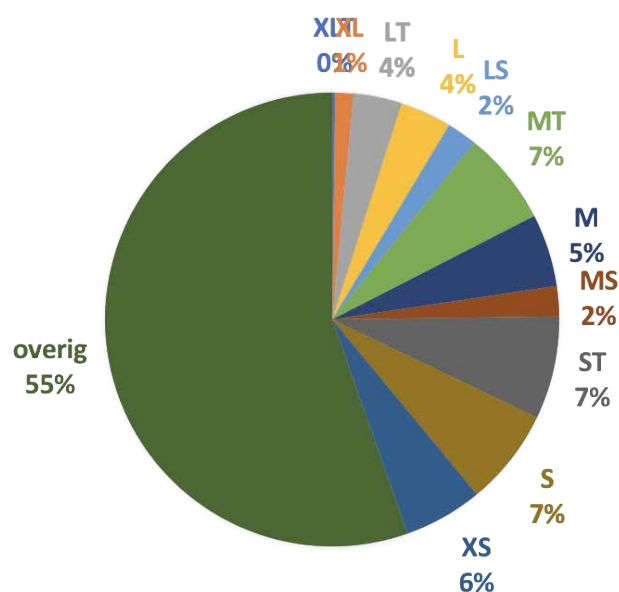


Fig 20: Current SRFACE sizing distribution mapped on the CAESAR population ellipse.

MARKET CONSISTENT

The second plot in figure 21 shows another distribution of sizes. The interval and distribution on the primary dimension is kept the same as the the current sizing chart. The sizes are repositioned to gain the highest percentage of coverage without overlapping each other. The overall positioning of the sizes has also been kept similar with the Tall sizes position above the standard sizes and the Short sizes directly underneath. The Extra Small, Small and both of the Short sizes have been shifted towards a slightly bigger chest size to gain a higher percentage in coverage. The benefit of this sizing chart is the high coverage percentage.

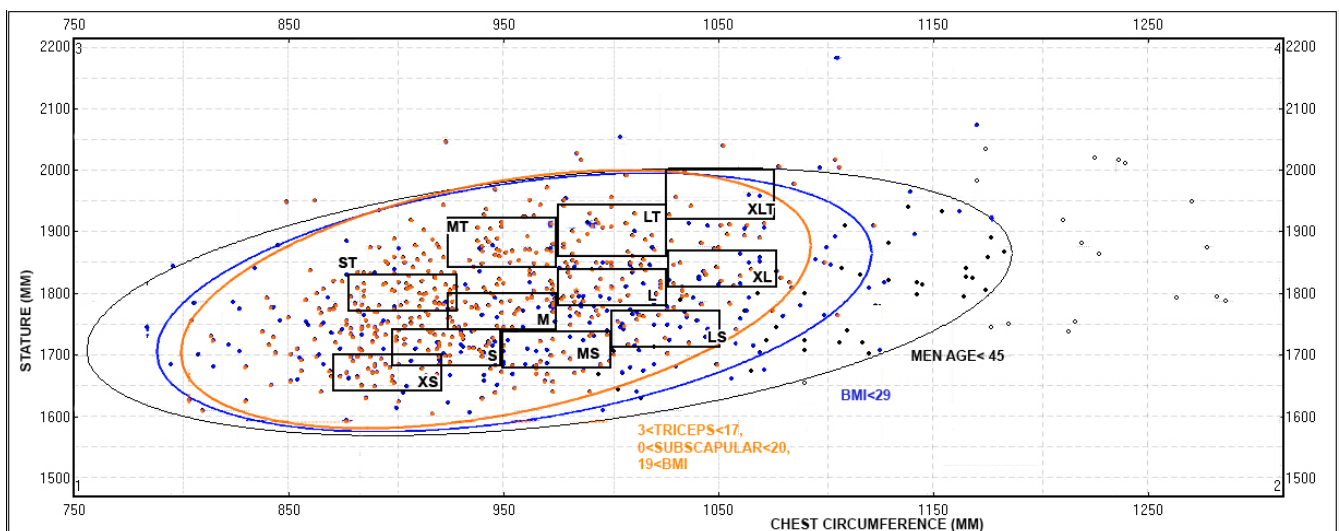
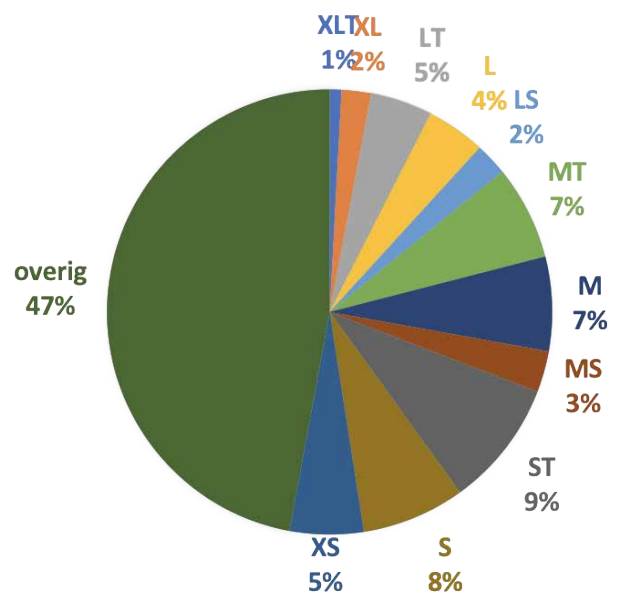


Fig 21: Market consistent sizing distribution mapped on the CAESAR population ellipse.

AVERAGE BASED

The third classification method is shown in Figure X. This method discards the non overlapping method used in the previous plots in Figure X, Y. Instead each wetsuit size is positioned using the normal distribution in the secondary dimension. The Standard sizes are positioned on the average chest size as shown in Figure X. The Tall sizes are located left of the standard size interval and therefore focus on a smaller chest size. The same goes for the Short sizes focussing on the bigger chest sizes. This sizing method results in an overlap of 6.89%. This enables the customer to have more sizes to choose from but it also limits the reach of the wetsuit sizes. The chest coverage ranges from 860-1040 mm.

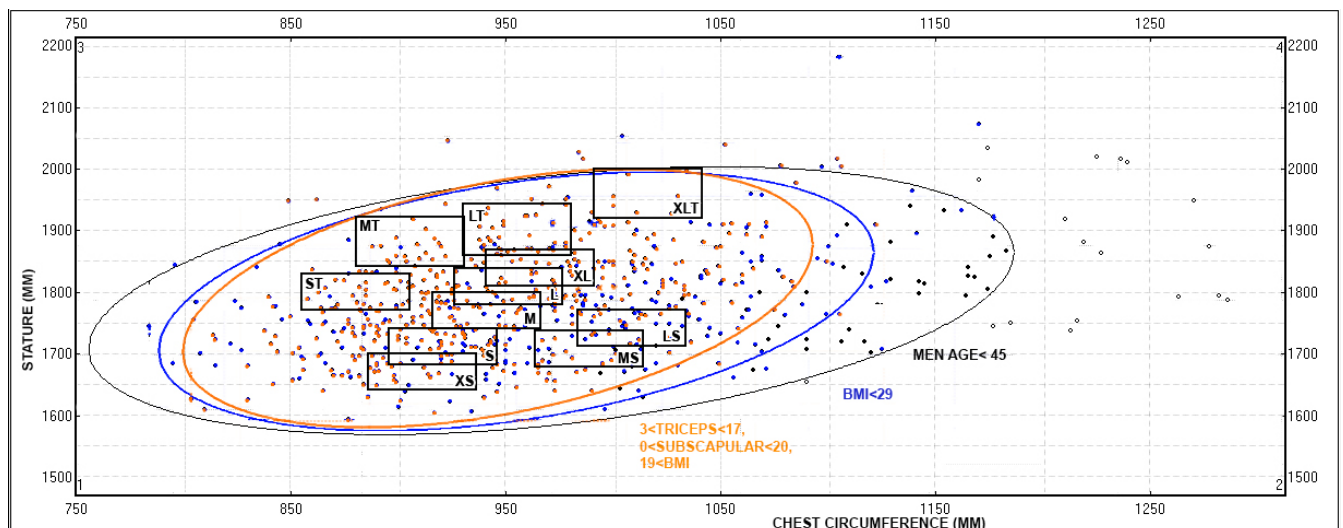
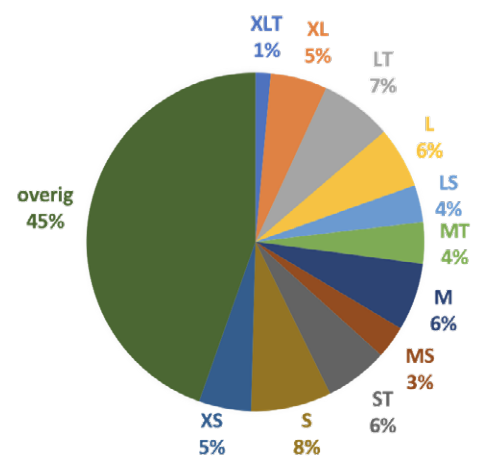


Fig 22: Average based sizing distribution mapped on the CAESAR population ellipse.

COMMENTS

The market consistent method and the average based method both result in smaller chest sizes than the original SRFACE sizing. A reason for this could be vanity sizing. This concept is commonly seen in womens clothing. Ennis (2006) uses the following explanation “It is the phenomenon of dropping clothing size without losing a single pound”. Through the years the clothing sizes have dropped compared to the EU standard. The smaller sizes promote a positive self-image. The same could be applicable for the chest circumference in mens clothing. Having a slightly bigger chest will be appealing for male customers. The expansion in chest circumference ranges up to 100 mm between exhaling and inhaling shown by Owlsen, et al. (2011) in their paper on measuring chest expansion. Without specific measuring guidelines the customer decides where in their inhaling spectrum they will measure their chest.

Yet some of the feedback gained from the customers includes the chest being to tight. A reason could be comfort preference. But it could also indicate that the wetsuit patterns themselves could be too tight around the chest area. The exact pattern dimensions of the current wetsuits are unknown.

The size of the used intervals is not researched in the scope of this project. The intervals used by other brands have been researched by SRFACE and applied in their own sizing chart. These intervals are used within the mentioned methods. Increasing these intervals would increase the total coverage with the same amount of wetsuit sizes. But this is not desirable for it will have a negative impact on the fit.

CONCLUSION

More sizing distributions can be mapped in the Ellipse plots. It is up to the SRFACE to determine their main sizing goal before mapping the sizes. The following aspects could be considered:

- Coverage percentage
- Coverage range
- Market consistency

The Ellipse plots can also be used for choosing extra wetsuit sizes. The empty areas in the plot indicates a part of the population that doesn't fit in any of the sizes.

The average based classification method is used as illustration for further pattern creation and pattern grading. With the current sizing distribution, the average based method has the highest coverage percentage. But the coverage range is very limited compared to the other methods. For future sizing the market consistent sizing method would be the most promising. It has a large coverage range and percentage and is relatively similar to the sizing of other wetsuit brands. This will cause less confusion for customers who expect sizing consistency between brands.

A sizing chart can be set up based on the the classified population groups. By looking at the average weight and waist of the sizing groups, the intervals can be determined for every wetsuit size. The weight and waist will serve as a size indicative measurements. The following table shows the resulting sizing chart from the average based sizing method.

Table 8: Average Based Sizing Chart

| | Height | Weight | Chest | Waist |
|------------|-----------|---------|-----------|---------|
| XS | 164 - 169 | 59 - 67 | 89 - 93 | 74 - 80 |
| S | 168 - 174 | 65 - 73 | 91 - 95 | 78 - 84 |
| ST | 177 - 183 | 62 - 70 | 86 - 90 | 76 - 82 |
| MS | 168 - 174 | 71 - 79 | 98 - 102 | 83 - 89 |
| M | 174 - 180 | 70 - 78 | 93 - 97 | 81 - 87 |
| MT | 184 - 192 | 69 - 77 | 89 - 93 | 78 - 84 |
| LS | 171 - 177 | 75 - 83 | 99 - 103 | 85 - 91 |
| L | 178 - 184 | 71 - 79 | 94 - 98 | 81 - 87 |
| LT | 186 - 194 | 75 - 83 | 94 - 98 | 83 - 89 |
| XL | 181 - 187 | 74 - 82 | 95 - 99 | 82 - 88 |
| XLT | 192 - 200 | 87 - 95 | 100 - 104 | 91 - 97 |

SIZING OF THE FUTURE WETSUITS

The sizing methods proposed in the previous chapter used the current SRFACE sizing chart as basis. The height distribution was kept constant in every method. But what if SRFACE would like to add more sizes in the future. There are different sources that can serve as basis for the expansion of their sizing chart.

- Dined Mapping
- EU standard
- Market

MARKET

The current sizing chart of SRFACE is based on the sizing of other wetsuit brands. Using the market as basis for determining wetsuit sizes creates consistency between brands. When SRFACE would want to create more wetsuit sizes they can use this same method. The ellipse shown on page 43 shows all the sizes of a large wetsuits brand. Plotting the sizes of competitor brands can serve as a good indication for the distribution of height in future sizes.

DINED MAPPING

The previous chapter elaborates on a sizing method using Dined plots of the CAESAR population. These same plots can be used to investigate what additional sizes would benefit the overall sizing coverage. The populated areas that are not covered by a specific sizes indicate an opportunity for an additional wetsuit size.

EU STANDARD

The European clothing sizing standard EN 13402 (2004) shown in table 9, can be used as a basis. This standard determines the dedicated population for every standard size for the Germanic population. This population includes Austria, Germany, The Netherlands, Denmark, Finland and Sweden. This standard incorporates the body type variations within the given population by adding sub scales for people who fall outside the standard sizing (Tall, Short and Portly). This same classification is used in wetsuit sizing by adding a letter to the standard sizes. For instance ST is a small tall, or MS is a medium short. This standard can be used as baseline for the new wetsuit sizing system. Of course not all sizes will be used and a selection has to be made of the most popular sizes. The amount chosen sizes will have its limits and not every body type would be able to match with a specific size. The coverage of the chosen sizes can then be shifted around to cover a desired range using the methods from the previous chapter.

TABLE 9: EN 13402 STANDARD (AT/DE/NL/DK/SE/FI)

| | | | | | | | | |
|----------------|-----------------|---------|---------|---------|---------|---------|---------|---------|
| International | XXS | XS | S | M | L | XL | XXL | 3XL |
| | Chest (cm) | 86-89 | 90-93 | 94-97 | 98-101 | 102-105 | 106-109 | 110-113 |
| | Waist size (cm) | 74-77 | 78-81 | 82-85 | 86-89 | 90-94 | 95-99 | 100-104 |
| | Hip circ (cm) | 90-93 | 94-97 | 98-101 | 102-105 | 106-109 | 110-113 | 114-117 |
| | Height (cm) | 166-170 | 168-173 | 171-176 | 174-179 | 177-182 | 180-184 | 182-186 |
| Short / Stocky | XXS | XS | S | M | L | XL | XXL | 3XL |
| | Chest (cm) | 89-92 | 93-96 | 97-100 | 101-104 | 105-108 | 109-112 | 113-116 |
| | Waist size (cm) | 81-84 | 85-88 | 89-92 | 93-96 | 97-100 | 101-106 | 107-110 |
| | Hip circ (cm) | 97-100 | 101-104 | 105-108 | 109-112 | 113-116 | 117-120 | 121-124 |
| | Height (cm) | 163-167 | 166-170 | 169-173 | 172-176 | 175-178 | 177-180 | 179-182 |
| Tall size | XXS | XS | S | M | L | XL | XXL | 3XL |
| | Chest (cm) | 88-91 | 92-95 | 96-99 | 100-103 | 104-107 | 108-111 | 111-114 |
| | Waist size (cm) | 74-77 | 78-81 | 82-85 | 86-89 | 90-93 | 94-98 | 100-104 |
| | Hip circ (cm) | 92-95 | 96-99 | 100-103 | 104-107 | 108-111 | 112-115 | 116-119 |
| | Height (cm) | 175-179 | 178-182 | 181-185 | 184-188 | 186-190 | 188-192 | 193-197 |

MANNEQUIN CREATION

The creation of digital mannequins will be based on body scans out of the CAESAR database. The first step is to filter the CAESAR population using the predetermined criteria to exclude non surfer body types. The next step is to divided the resulting population into size groups using the classification method described in the previous chapter. The 3D scans in these groups will be used to create the digital mannequins.

There are 3 types of mannequins that are relevant for the design of a specific wetsuit size.

- Average mannequin

This mannequin is created by combining all the body scans that are classified for a specific size. The resulting mannequin will incorporate all the average anthropometric dimensions of the wetsuit size. This mannequin can be used for the creation of a wetsuit pattern.

- Two extreme mannequins

These two mannequins represent extreme body types who should still fit within the wetsuit. These mannequins can be used to test the fit of the pattern. They are created using 3 body scans with the highest or lowest BMI scores within a given size population. The highest BMI indicates the tallest bodies with the largest body volume, and the lowest BMI indicates the smallest bodies with the lowest body volume.

The mannequin creation process consists of the following steps. T. Huysmans has created new 3D models of the entire CAESAR database using Wrap3. In Wrap3 a template body mesh is wrapped on a 3D scan to create a digital model without holes (see figure 23). The resulting models will consist out of a similar amount of faces. This opens up the possibility to combine multiple 3D meshes into an average body mesh.

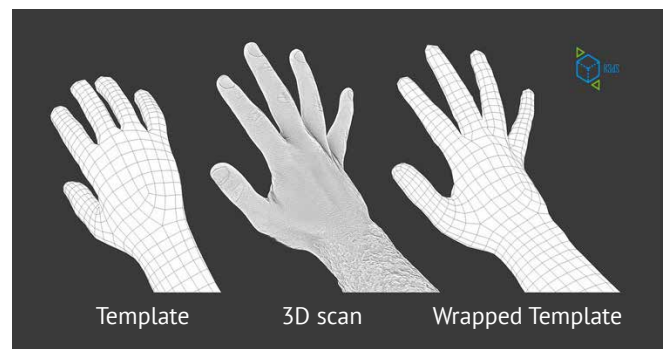


Fig 23: Wrap3 Workflow

The creation of the final mannequins is done using the 3D meshes of T. Huysmans. A selection of these models is put into Paraview. In Paraview a VTK filter (provided by T. Huysmans) is applied that combines the mesh selection into an average 3D mesh. The resulting mesh is rotated to face the Z direction and positioned above coordinate (0,0,0). The resulting mesh is exported as an object file and can now be used as mannequin in further wetsuit design. The mannequins resulting from the chosen population, criteria and sizing method are shown on the next page.

ST



MT



LT



XLT



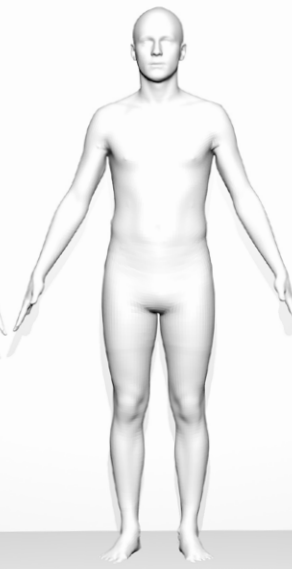
XS



S



M



L



XL



INCORPORATING MOTION

The mannequins that have been created for wetsuit design are static digital models. They can be used to gain insight in the body types and anthropometric dimensions of the users. These models are perfect to test the static fit of a digital wetsuit. But the new methodology should

also take the dynamic fit into account. Therefore different methods will be investigated concerning the important surfing motions. This chapter will look into 4D scanning, rigging and motion tracking.

4D SCANNING

The 4D scanning process is comparable to shooting a film of a 3D model. Instead of making one 3D scan, the scanner makes multiple scans with a frame rate of about 10 fps. The frame rate enables the possibility to scan a movement. Figure 24 shows the result of a 4D scanning test of the surf motions established in the chapter Surfing Motions. The results of a 4D scan give a good insight of the occurring skin deformation during motion. But on the downside the scan is only relatable to the scanned individual and can't be projected onto a mannequin. Furthermore the 4D scanner creates static 3D models just as a normal 3D scanner. To create usable models, the scans have to be optimized by filling in all the gaps and non scanned surfaces.

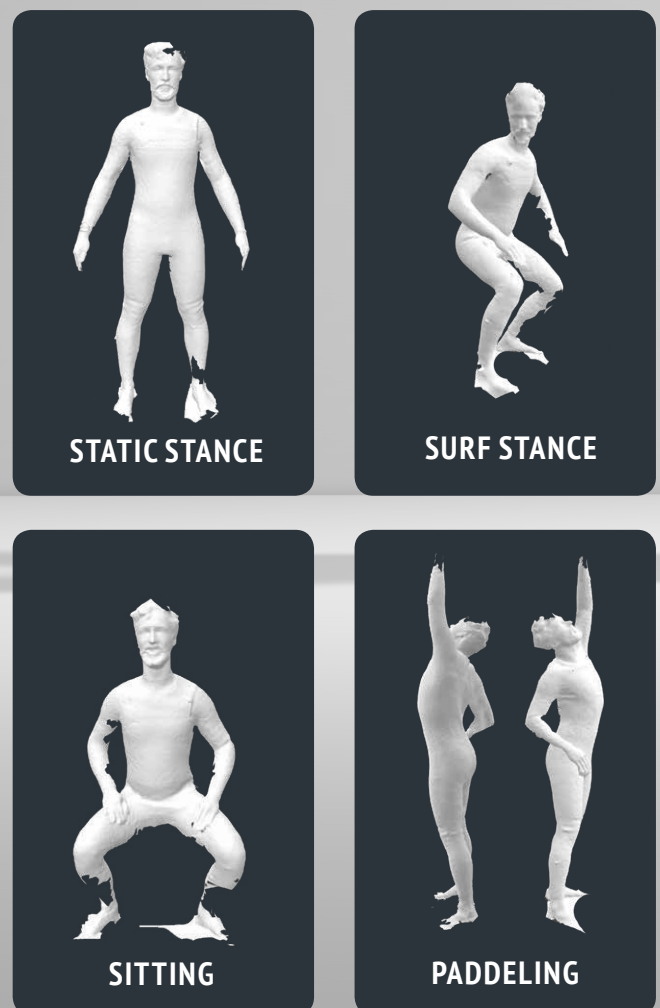


Fig 24: 4D scan results

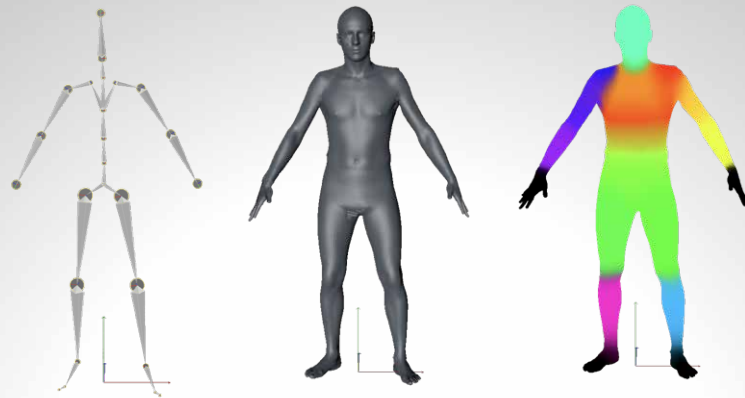


Fig 25: Rigging method



RIGGING

An other method that has been tested is the rigging of the existing mannequins. Rigging is the process of creating a bone structure for a 3D model. This structure can then be used to manipulate a 3D model and create animations. For the design of a wetsuit it will enable the designer to manipulate the positioning of the limbs to test the performance of the panels inside the garment. Figure X,Y show the rigging of the mannequin. After a bone structure is created, the model is weight painted. The different colors connect the skin of the model to

the different bones. It is a delicate process to create a good weight distribution on the surface of the model that results in a realistic deformation of the skin. The rigging itself can be done in 3D computer graphics & animation software such as Maxon Cinema 4D and Autodesk Maya. An easier method is to use Adobe Mixamo. This is an online tool for rigging of 3D human models. Which is also able to apply animations onto the rig from their animation database.

MOTION TRACKING

A motion track experiment has been performed with the purpose of digitizing the surfmotions. This experiment has been performed with the MoCap motion track suit seen in figure 26. This suit is able to capture motions as a digital animated rig. The resulting rig animation can be applied to any human model regardless of the size. This makes it perfect to incorporate into a mannequin based design method. The test is performed with the professional surfer and founder of SRFACE; Augustus Schraven. Figure 27-29 show the different surfing motions that have been captured.

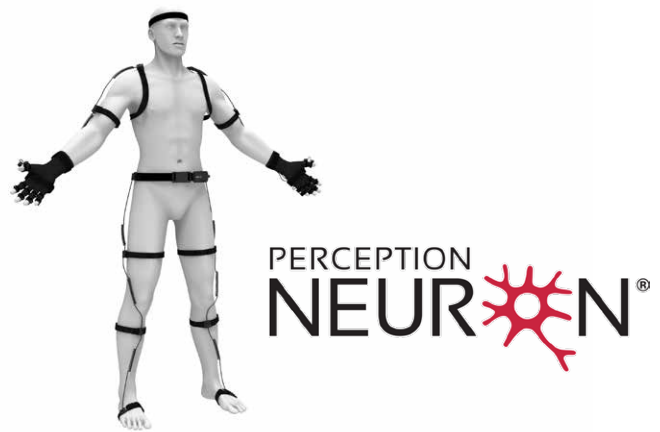


Fig 26: perception Neuron Suit

NEURON SUIT



Fig 27: The surfing motions are captured by the Neuron Perception suit.

ANIMATION

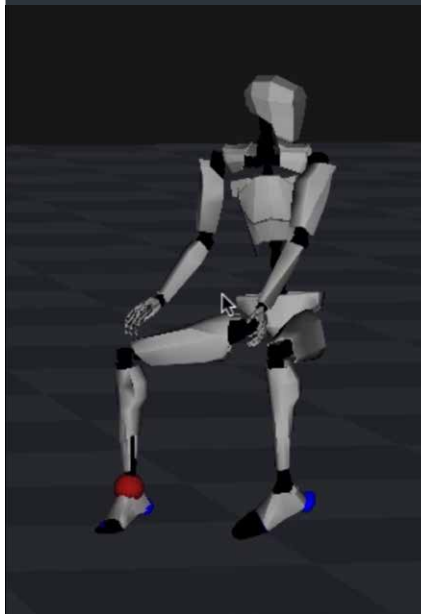


Fig 28: The resulting skeleton animation is optimized and attached to a rigged mannequin in Maya.

MANNEQUIN



Fig 29: The mannequin is imported in Clo3D and the animations can be used to test the fit of digital garments.

RESULT

The 4D scanning method has the most accurate representation of skin deformation during motion. These scans need a high amount of optimization and only incorporate anthropometric information on the scanned individual. Therefore the use of mannequin rigging is chosen as the best method for incorporating motion in the design methodology. The biggest benefit of the

rigging process is that movement and full animations can be applied to any digital mannequin and is also supported in Clo3D.

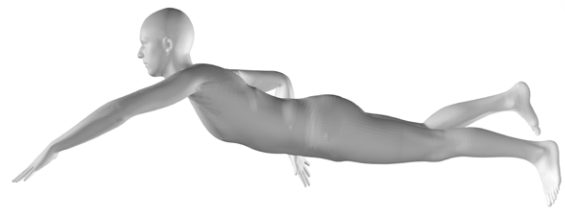
This results in a fully rigged medium mannequin equipped with all the surfing motions needed to test the dynamic fit of a garment.

SITTING

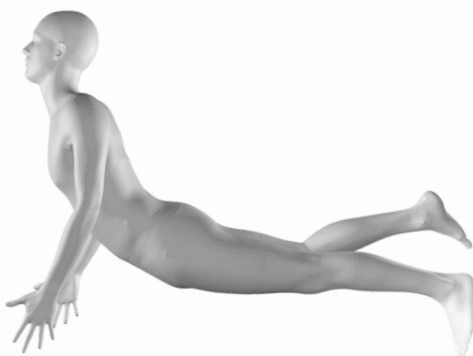


Fig 30: Animation results

PADDELING



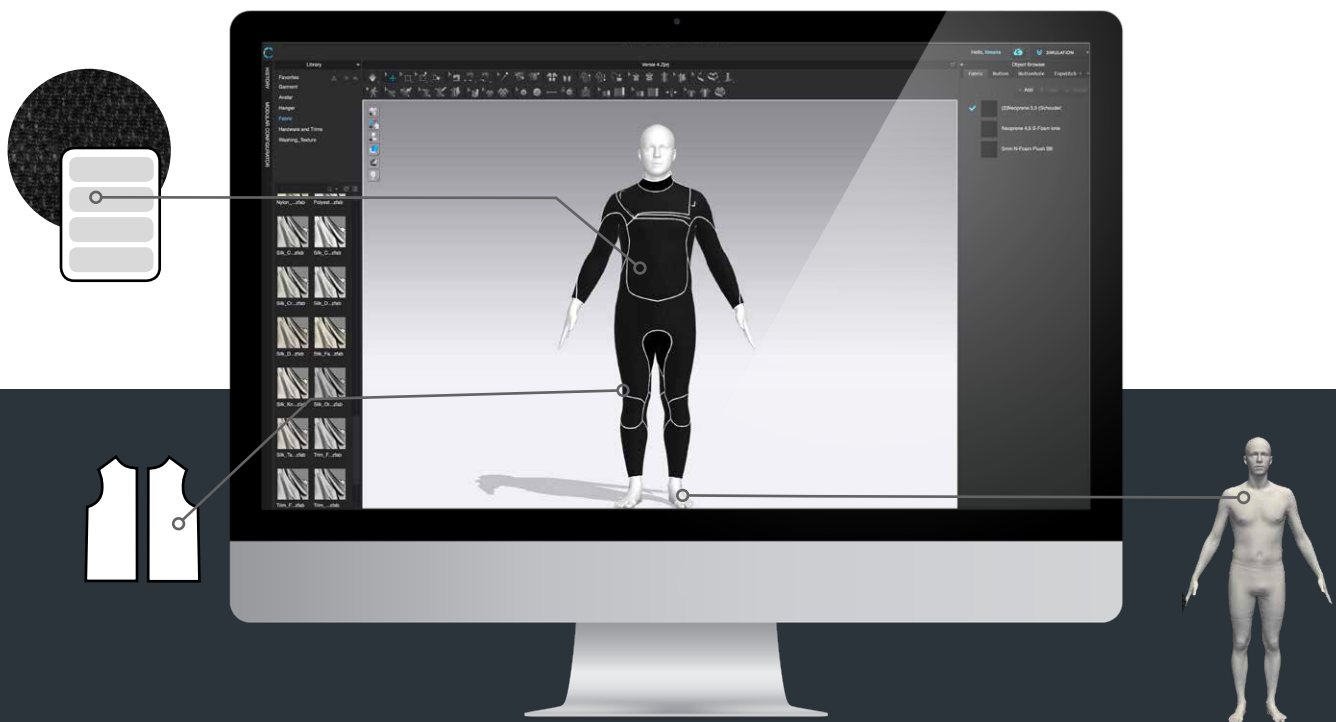
DUCK DIVE



STANCE



PATTERN DIGITALIZATION



METHOD

Currently the production company owns the pattern of the SRFACE wetsuit. This pattern has been optimized a lot since the first prototype. This wetsuit can and should be used as a reference in any future SRFACE design process. Unfortunately the pattern itself is not of SRFACE. Therefore in this chapter their current wetsuit will be digitized. The digital pattern can then be tested on its performance and fit. Three steps needed to be made to analyse the current wetsuit.

- Recreating the original SRFACE wetsuit
- Determining the material properties of the panels
- Creating a medium sized mannequin

The pattern is gained from cutting out the panels of a medium SRFACE wetsuit and tracing the panels. A stretch and bending test was performed to gain the material properties for the simulation. A mannequin is created that represents the intended medium sized body. The panels will be stitched together in Clo3D and assigned with the right properties. The created medium mannequin will be dressed

MEDIUM SRFACE MANNEQUIN

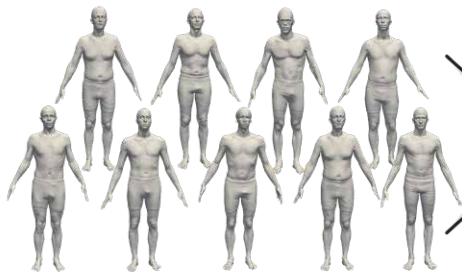
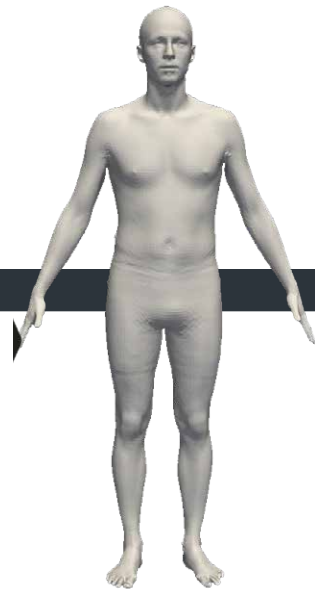


Fig 31: Mannequin creation



The pattern should be tested on a mannequin with the same body dimensions as the intended user population. Therefore a mannequin is created using the original SRFACE sizing chart. A selection was made of CAESAR body scans that fit within the boundaries of the sizing

chart. These scans were combined into an average body using ParaView and a programmable vtk filter provided by Toon Huysmans. Figure 31 shows the selected body scans and the resulting average.

MATERIAL TEST

INTRODUCTION

Creating a prototype of a garment pattern is currently the best way to address the fit and draping. But nowadays some garment designing softwares incorporate simulation features where these aspects can be addressed digitally. To create a realistic simulation the software needs physical properties of the used fabric. Software packages commonly offer a library with an extensive amount of fabrics. When this library doesn't offer the necessary material you can manually input the properties of your fabric.

Clo3D also offers such a library and the ability to create your own digital fabrics. In the current Clo3D version Neoprene is not available in the library. And even if it would be, the wide variety of neoprenes and the application of inner and outer lining limits the use of such a library. In this chapter the neoprene material will be tested on its physical properties to generate parametric input for the design software.

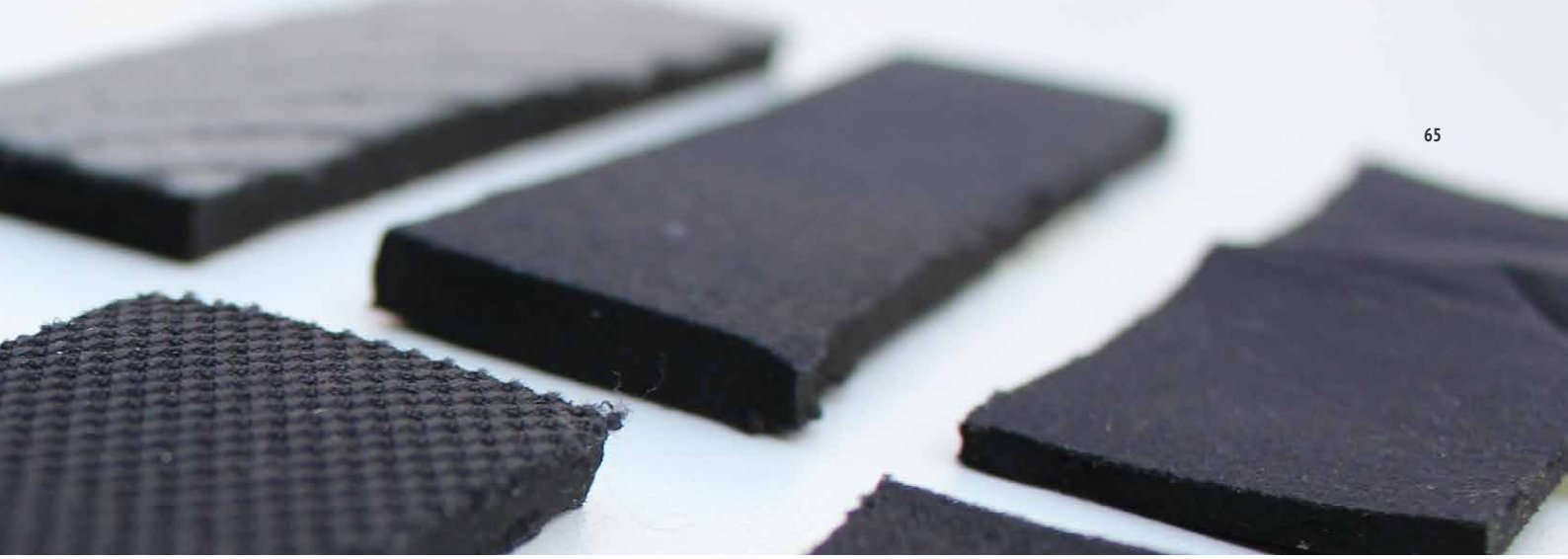
METHOD

The material test consists of determining the weight, thickness, bending behaviour and stretch behaviour of Neoprene. Different combinations of lining and neoprene thicknesses will be tested to investigate the effect it has on the properties of a wetsuit panel. Neoprene itself is marketed as having the same stretching behaviour in every direction. But most fabrics have a grain direction which results in different stretching properties in different directions. When applying a lining to the neoprene the combined material will gain different directional stretching behaviours. To assess the different directional stretch properties the tests will be done with 3 different swatches of 120*30mm for every panel. One

that follows the grain (warp), one that is perpendicular (weft) to the grain and one angled at 45 degrees from the grain (bias).

All materials will be tested on a stretch of 180% of their own length. The tested stretch length is 100mm and the amount of force needed to stretch the material to 180mm will be measured.





The following materials will be tested gained from the current 5mm SRFACE wetsuit design:

Table 10: Materials from original SRFACE wetsuit

| Panel location | Foam type | Thickness | Outside | Inside | Swatch weight |
|----------------|-----------|-----------|--------------------|-----------|---------------|
| Upper Leg | X-FOAM | 5 MM | Nylon | Plush | 4,50 g |
| Chest/Back | Y-FOAM | 5 MM | Texured | Plush | 4,98 g |
| Knee | Y-FOAM | 4,5 MM | Abrasion resistant | BTN | 3,97 g |
| Schoulder | X-FOAM | 3,5 MM | Nylon | Nylon | 3,34 g |
| Calf | X-FOAM | 4 MM | Nylon | Nylon | 4,13 g |
| Shone | X-FOAM | 5 MM | Nylon | Nylon | 4,10 g |
| Neck | X-FOAM | 2,5 MM | Nylon | Glideskin | 2,89 g |

BENDING TEST

Furthermore a bending test has been performed with all of the test strips. This test determined at what length the strip would touch the floor, starting from a height of 35 mm. Both the contact distance and the length of the extended strip were measured. This test was performed with only the warp and weft directions.

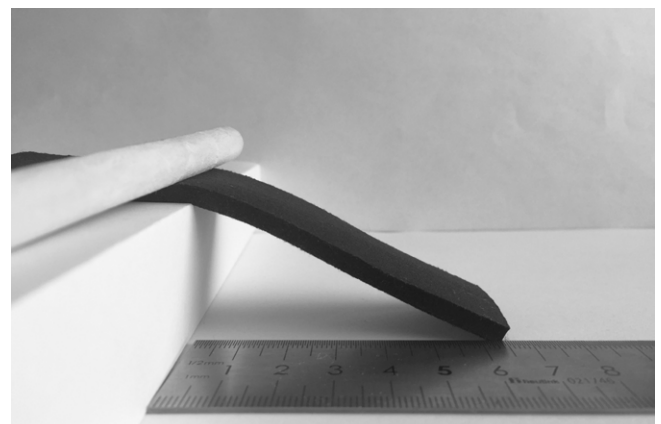


Fig 32: Bending Test

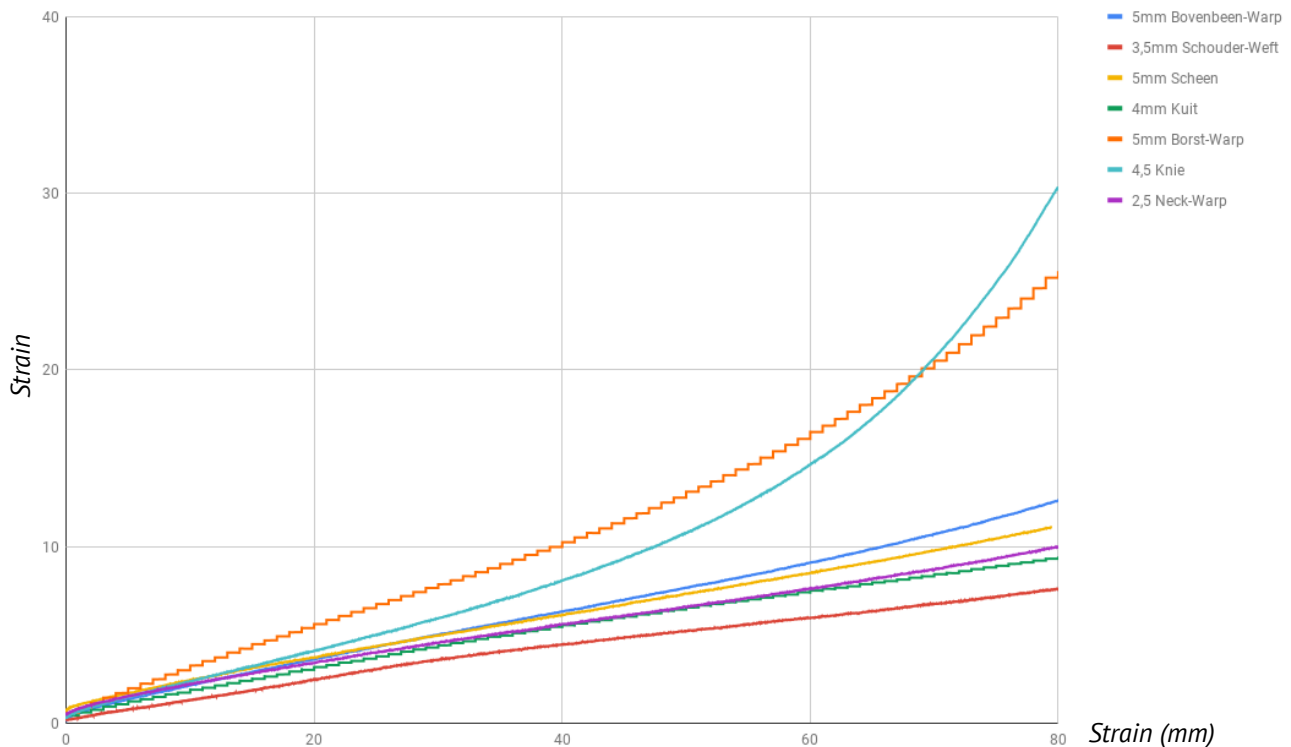


Fig 33: Stress & Strain plot of the wetsuit materials

COMMENTS

As can be seen in the graphs in figure 33, not all materials have been tested on warp, weft and bias. This is due to the limited availability of material. The first thing to notice is that both the panels made from Y-Foam show less stretch than the panels with an X-Foam. Furthermore the decrease in flexibility is visible in the increase of the Neoprene thickness.

The results of the stretch and bend test can be found in Appendix 2. Table 11-12 shows the results of the panel located on the upper legs. These results are used to create a custom material in Clo3D. The material is applied with the textures shown on the next page.

| Bovenbeen (mm) | Warp (kgf) | Weft (kgf) | Bias (kgf) |
|----------------|-------------|-------------|-------------|
| 5 | 0,137558589 | 0,131444874 | 0,135520684 |
| | 8 | 7 | 7 |
| 20 | 0,36784 | 0,37905 | 0,361728 |
| 40 | 0,66333 | 0,66130 | 0,643977 |
| 60 | 0,92826 | 0,94151 | 0,951701 |
| 80 | 1,28082 | 1,26859 | 1,33278 |

DIGITAL SIMULATION

The results from the stretch test were put in to the software Clo3D as a custom fabric. Figure 34 -35 shows pictures of two panels with different thicknesses and lining, draped on top of a sphere. The sphere has a diameter of 100 mm and the panels are 200 * 200 mm. Under these pictures a digital simulation is shown of the resulting materials inside of Clo3D. The similarity indicates an accurate simulation of the materials.

| Bovenbeen (mm) | Warp (mm) | Weft (mm) |
|------------------|-----------|-----------|
| Contact Distance | 79 | 83 |
| Length | 78 | 82 |

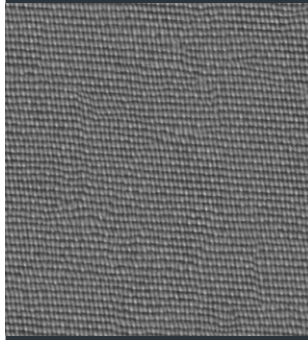
Tables 11 & 12: Stretch test (left) & Bend test (right) results 5mm X-Foam with plush lining

DIGITAL MATERIALS

**ABRASION
RESISTANT**



TEXTURED



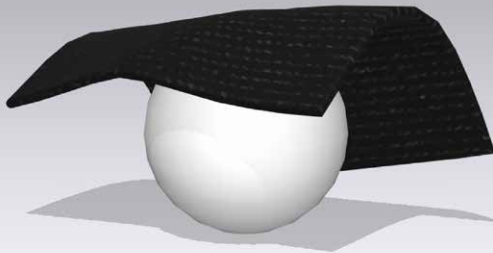
NYLON



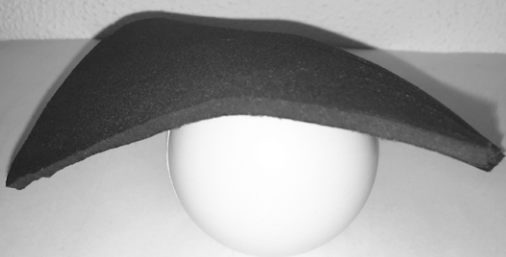
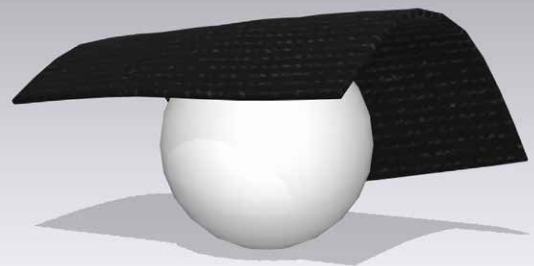
GLIDESKIN



**FIG 34: 3,5 MM X-FOAM
NYLON - NYLON**



**FIG 35: 5 MM X-FOAM
NYLON - PLUSH**



SRFACE WETSUIT RECREATION

INTRODUCTION

Currently the production company owns the wetsuit pattern of SRFACE. This pattern has been optimized a lot since the first prototype. This wetsuit can and should be used as a reference in any future SRFACE design process. Unfortunately the pattern itself is not of SRFACE. Therefore in this chapter their current wetsuit will be digitized. The digital pattern can then be tested on its performance and fit

METHOD

To gain the original panels of the SRFACE wetsuit design a 50M 5mm Wetsuit will be cut out. The panels are separated by accurately cutting over the seams. These panels were then photographed on raster paper (see figure 36). The raster paper serves as guide in eliminating the lens distortion and determining the dimensions. To eliminate any tracing flaws the outlines were adjusted using the symmetry of the pattern itself. The finalized pattern is then simulated on a mannequin in Clo3D to simulate the fit.

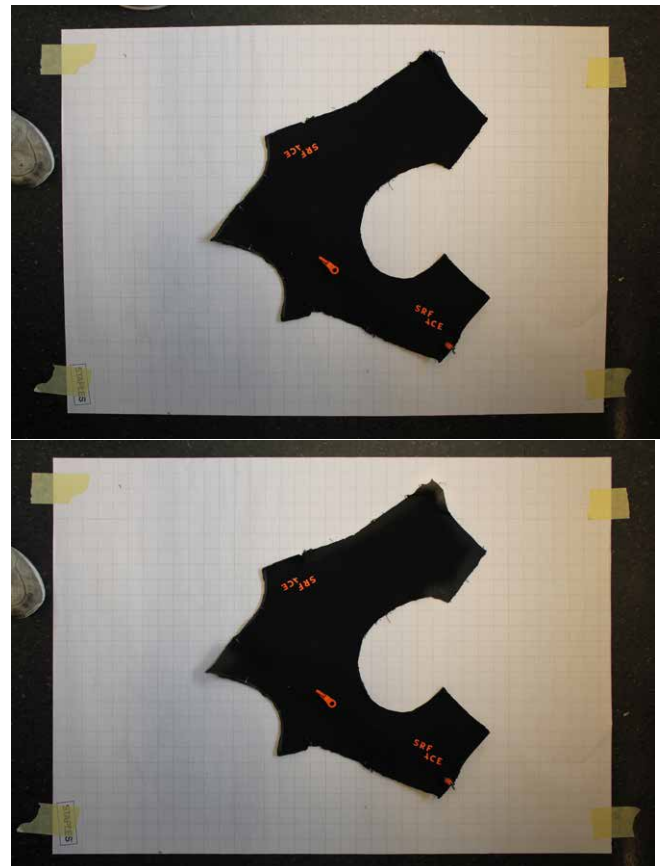


Fig 36: Pattern picture (top), eliminated lens distortion (bottom)

STEPS

The following steps were performed in creating the SRFACE wetsuit pattern. The resulting pattern can then be used as reference for gaining future pattern dimensions.

OUTLINE TRACING

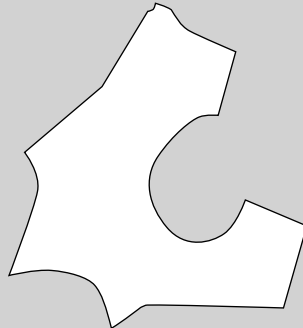
1



The outlines of the panels were then traced using Adobe Illustrator. Combining all the panel outlines resulted in a digital recreation of the wetsuit pattern.

SYMMETRY

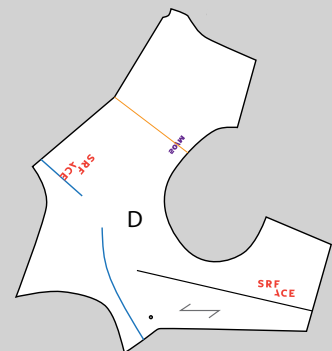
2



The outlines were optimized using the symmetry within the pattern itself. The left side is compared to the right and vice versa. This eliminates any imperfections in the cutting and tracing of the panels.

PATTERN SYMBOLS

3



All the pattern notations are added. Panel names, top and bottom stitches, sewing notches, grain direction and print locations.

PATTERN ANALYSIS

Now that the original SRFACE wetsuit pattern is recreated and the material properties are measured, the pattern can be analyzed on fit and performance. The focus will be on determining the tightness of the wetsuit. The goal is to use the tightness as a reference in future wetsuit design to establish the same fit as the current wetsuit.

PATTERN SIMULATION

Figure 38 show the overall stress and strain simulations within the pattern. These simulations can be isolated on warp, weft or bias directions. These visuals can serve as a reference when comparing the fit of different wetsuit designs or sizes. But even though the simulations can be done for different directions it is hard to determine the specific tightness in a certain circumference. To establish specific tightness values the pattern will be measured in 2D.

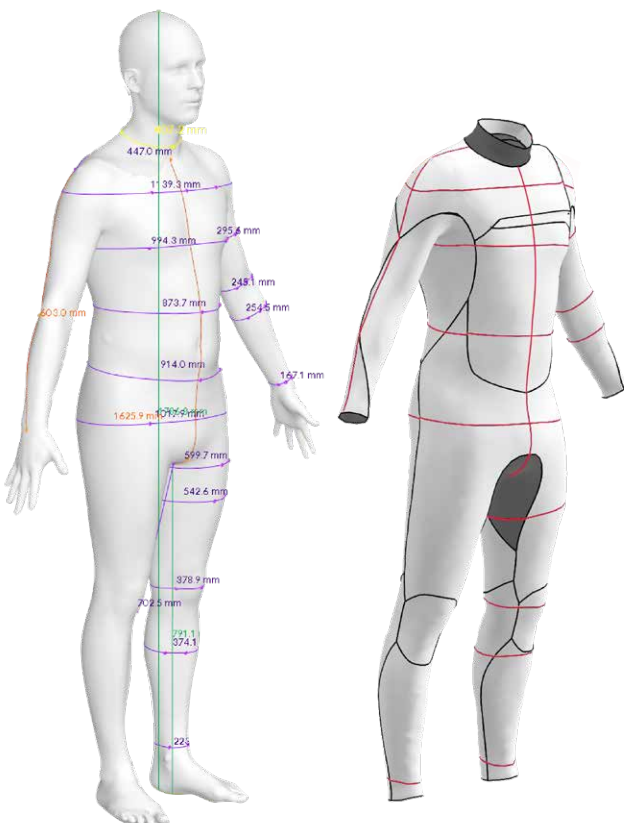


Fig 37: 3D measurements

DETERMINING TIGHTNESS

Both the user and the product dimensions need to be obtained to assess the tightness. The created SRFACE medium mannequin is measured in figure 37 using the 18 measurements established in the chapter Relevant Measurements. This mannequin is dressed with the original pattern and the measured circumferences are then projected on to the pattern. Figure 37 shows the pattern together with these measurement lines. The difference between user and product dimensions is calculated as a percentage in table 13. This percentage indicates the amount of strain within the circumferences of the product on the medium body type. These values can now be used as a reference in future wetsuit design.

TABLE 13: STRETCH CALCULATION OF ORIGINAL SRFACE PATTERN

| | Pattern (cm) | SRFACE M Body (cm) | Stretch (%) |
|------------|--------------|--------------------|-------------|
| Chest | 88,4 | 100,7 | 12,18 |
| Wasit | 73,4 | 83,2 | 11,74 |
| Hips | 81,4 | 99,5 | 18,16 |
| Thigh | 41,4 | 55 | 24,67 |
| Knee | 29,9 | 37,6 | 20,40 |
| Calf | 29,0 | 37,2 | 21,96 |
| Ankle | 16,4 | 22 | 25,32 |
| Upper arm | 28,9 | 29,6 | 2,266 |
| Elbow | 19,0 | 24,5 | 22,32 |
| Underarm | 21,2 | 25,5 | 16,74 |
| Wrist | 13,4 | 16,7 | 19,58 |
| NCN | 145,1 | 162,6 | 10,78 |
| Arm length | 67,5 | 67,5 | 0 |

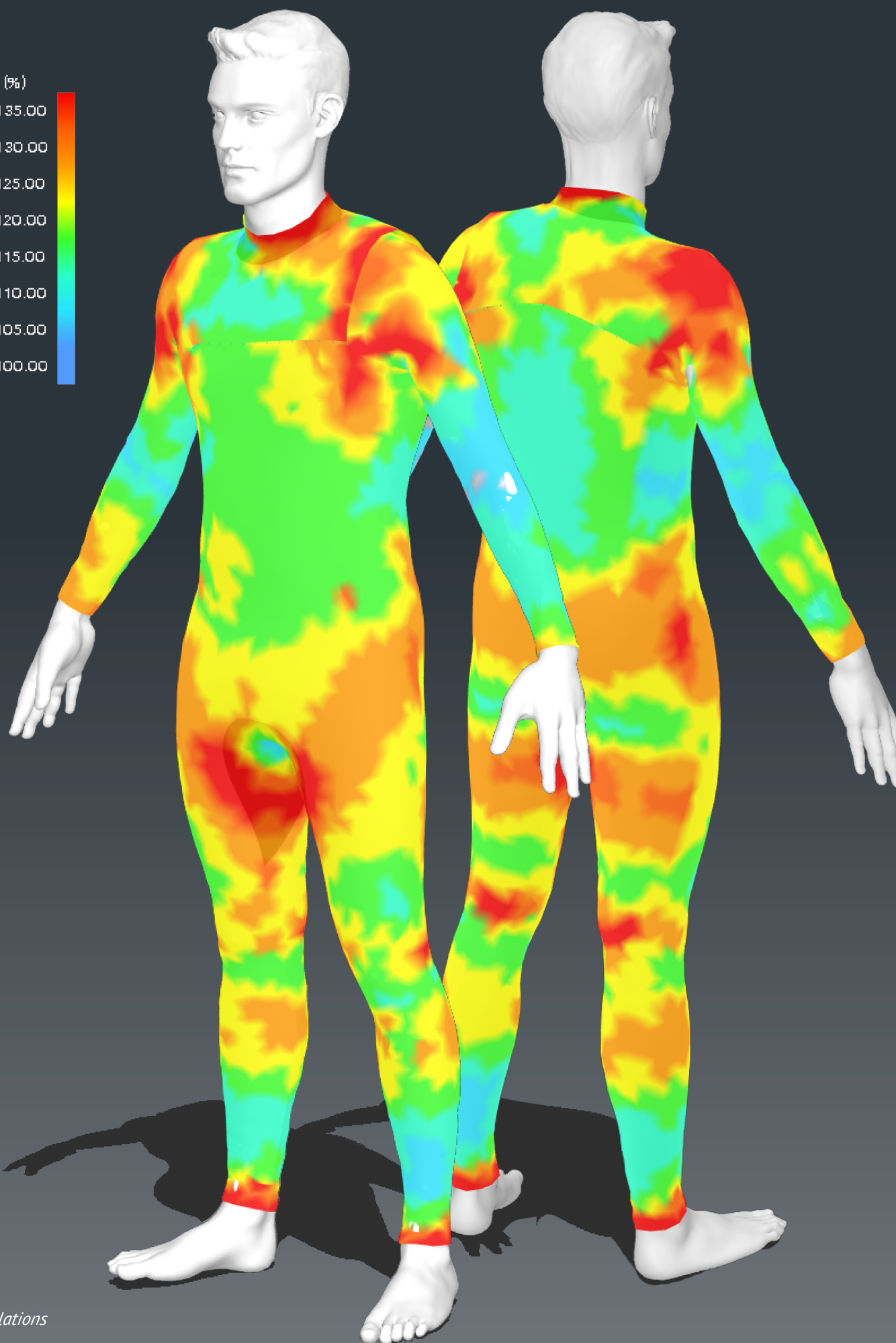


Fig 37: Strain simulations



DESIGN PHASE

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Optimization 82
Technical documentation 84
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PROTOTYPING

This chapter concerns the creation process behind the prototype. The goal is to validate usability of the chosen software package in designing for tight fitting garments. The original SRFACE wetsuit pattern is used as reference for it is a perfected design. The first step is to recreate the original wetsuit pattern with the use of the created mannequins. The resulting pattern can then be compared to the original SRFACE pattern to validate the workflow. The 3D workflow and the simulation capabilities will be tested for its usability for future pattern creation.

METHOD

The first step will be to design the original SRFACE wetsuit with the 3D design tools in Clo3D. The input for this design process will be the original visual design that the production company has used for their pattern creation process. The use of such a design will be the basis for the creation of any new wetsuit pattern. The resulting pattern can then be compared to the original SRFACE pattern to validate the workflow and the use of the Clo3D tools. The materials will be applied to simulate the pattern and adjust where necessary. The tightness will be tested with a strain simulation of the pattern. When the right method is determined in recreating the SRFACE pattern a new design process will be started focussing in creating an improved wetsuit design. A prototype will be created of a new design to validate the pattern creation method as a whole.

FIRST FLATTENING

The SRFACE wetsuit is recreated using the medium mannequin based on the current sizing chart. The steps include drawing the styling curves on the mannequin and flattening the different panels. Fig 38 shows the flattening result of the panel design and the original wetsuit pattern. Comparing both patterns shows that the flattening result has bigger panel dimensions. The desired product tightness should still be incorporated in the pattern.

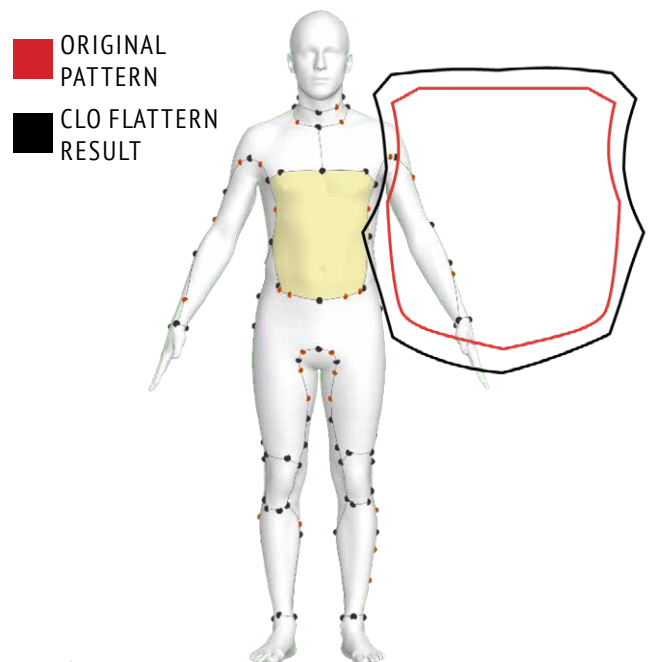


Fig 38: Riggin method

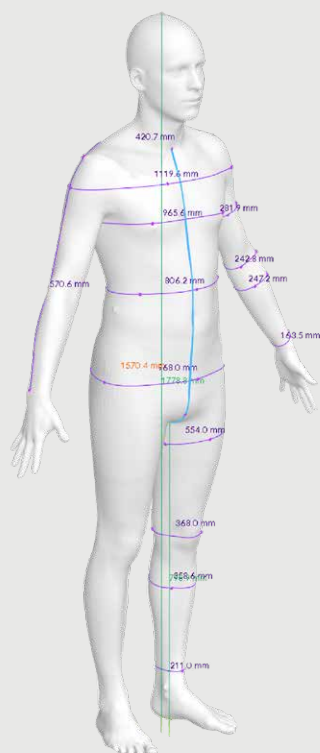


Fig 39: Medium Mannequin

| | New M Body dimensions | Desired Stretch % factor | Wetsuit dimension |
|------------|-----------------------|--------------------------|-------------------|
| Chest | 96,6 | 10 | 86,94 |
| Wasit | 80,6 | 15 | 68,51 |
| Hips | 96,8 | 20 | 77,44 |
| Thigh | 55,4 | 25 | 41,55 |
| Knee | 36,8 | 20 | 29,44 |
| Calf | 35,9 | 20 | 28,72 |
| Ankle | 21,1 | 25 | 15,825 |
| Upper arm | 28,1 | 3 | 27,257 |
| Elbow | 24,2 | 25 | 18,15 |
| Underarm | 24,7 | 15 | 20,995 |
| Wrist | 16,3 | 20 | 13,04 |
| NCN | 157 | 10 | 141,3 |
| Arm length | 68,5 | 0 | 68,5 |

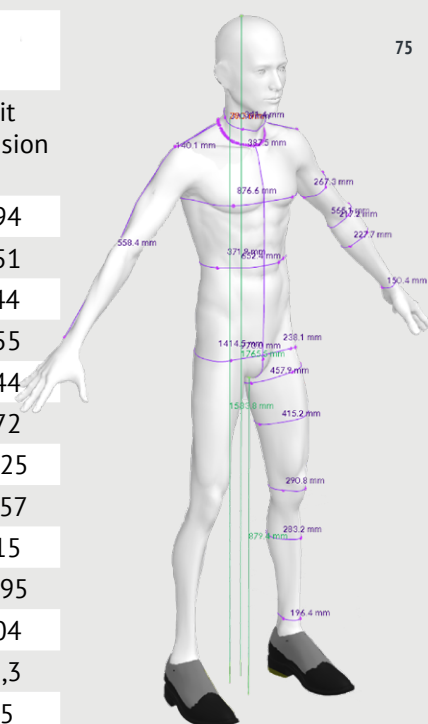


Fig 40: Design Template

INCORPORATING PATTERN GRADING

The right product dimensions can be gained by grading the pattern towards the desired pattern dimensions associated with the product tightness. This step requires a finalized pattern design and a complex sizing tables for every panel. This is a time consuming process. Another approach will be investigated were the mannequin is adjusted to match the final product dimensions. When a design will be flattened the result won't have to be graded to incorporate the desired tightness.

DESIGN TEMPLATE

A new mannequin is created with the purpose of eliminating the grading step in the pattern creation process. The new mannequin will serve as a design template and is based on the Medium mannequin from the chapter Mannequin Creation. The mannequin is shrunken down based on the tightness of the original SRFACE wetsuit. This gives the mannequin the dimensions of the final product. Table 14 shows the tightness in every bodily circumference and the resulting wetsuit dimensions. The new mannequin seen in figure 40 is created in Clo3D with these dimensions.

MANNEQUIN STANCE

The SRFACE wetsuit design is recreated with the mannequin template to validate the workflow. Design curves are applied based on the visual design in shown in the technical documentation in Appendix 7. The design is simplified in the shoulder area which makes the flattening process easier. The resulting pattern will still incorporate the shapes and curves needed for comparison.

Figure X shows these design curves on the mannequin template. Panels are drawn using the black points. Red points are used to create curvature between to points. When the design curves are finalized the pattern is flattened

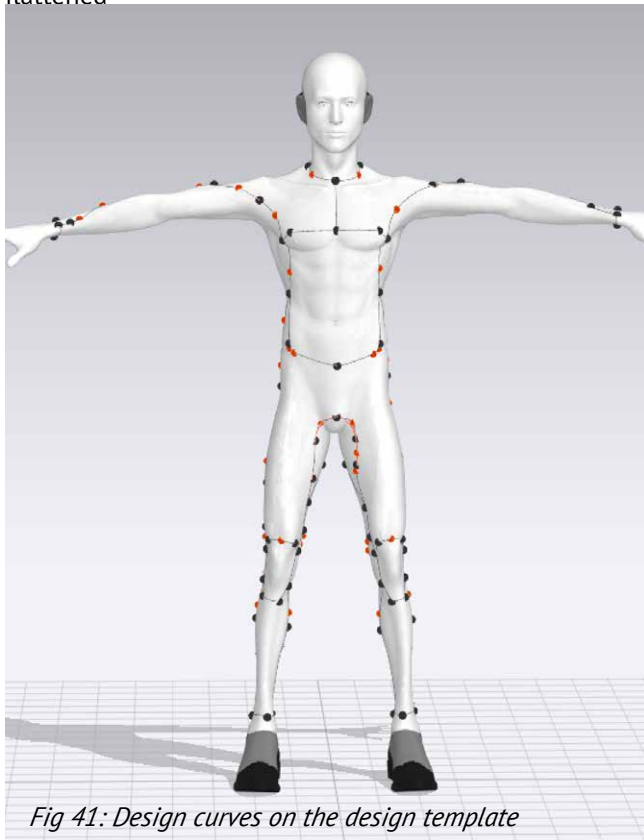


Fig 41: Design curves on the design template

MANNEQUIN POSITIONING

Within a wetsuit design the tightness plays a big role in the level of comfort. The tightness needed for a snug fit can also restrict the movements of the surfer. The stretching and friction behaviour of the neoprene opposes the force of the muscles. To reduce the stress within the wetsuit during these surfmotions a wetsuit is commonly designed for a specific positioning of the arms and legs. This can be achieved by adjusting the mannequin before flattening.

The rigged mannequin enables the designer to adjust the positioning of the limbs during the design process. Different degrees of extension and/or abduction in the arms and legs can lead to different flattening results. Increasing the amount of abduction in the arms before flattening will decrease the amount of stress in the arm panel during abduction in the arms. Different flattenings were created (figure 43) to find the right positioning of the limbs. The flattenings are compared to the original pattern created by the production company to figure out the positioning behind their design.

Comparing the different flattening results the stance of the mannequin is determined. It includes 90 degree abduction in the arms, 10 degrees abduction in the legs and slight flexion in the knee and hips (figure 42).

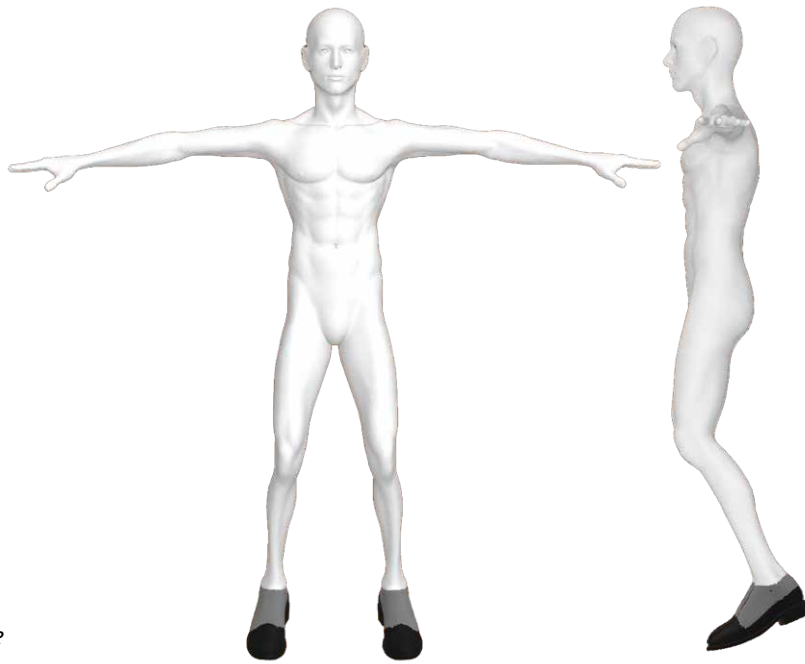


Fig 42: Design stance

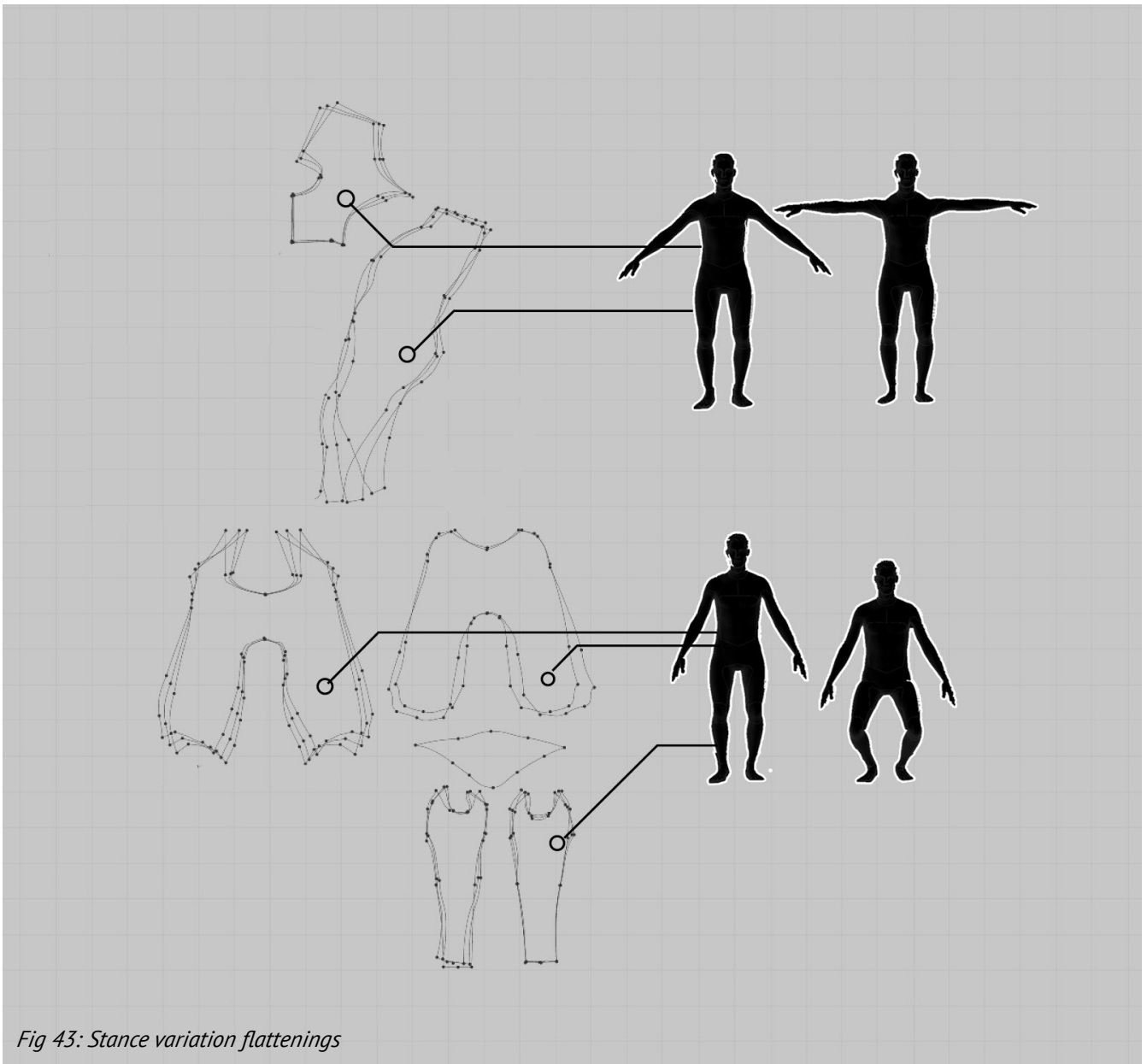


Fig 43: Stance variation flattenings

FLATTENING VALIDATION

To validate the workflow a final flattening is made using the mannequin template with the predetermined positioning. Figure 45 shows both the flattening result and the original pattern. Both patterns have a high similarity. Even though there are some differences, the overall shape and size of the patterns are the same. These differences can be the result of drawing inconsistencies or the flattening method of the software. But aside from these differences the result can serve as a useful basis in creating a new wetsuit pattern. This validates the use of the mannequin design template in the flattening workflow.



Fig 45: Second flatten result

SIMULATION VERIFICATION

To perform a realistic garment simulation the medium mannequin is dressed and the panel material properties have been applied. Custom materials have been created with the results of chapter Material Testing and the grain direction is selected for each panel. To Test the intended stretch factor in the pattern the wetsuit is put on the medium mannequin. Figure 46 shows the warp directional strain simulation around the body circumferences. The color of the different areas show the amount of strain that the garment is subjected to. The specific stain is measured on a couple of points and show a consistency with the original design intentions.



Fig 44: Dressing of mannequin and materials

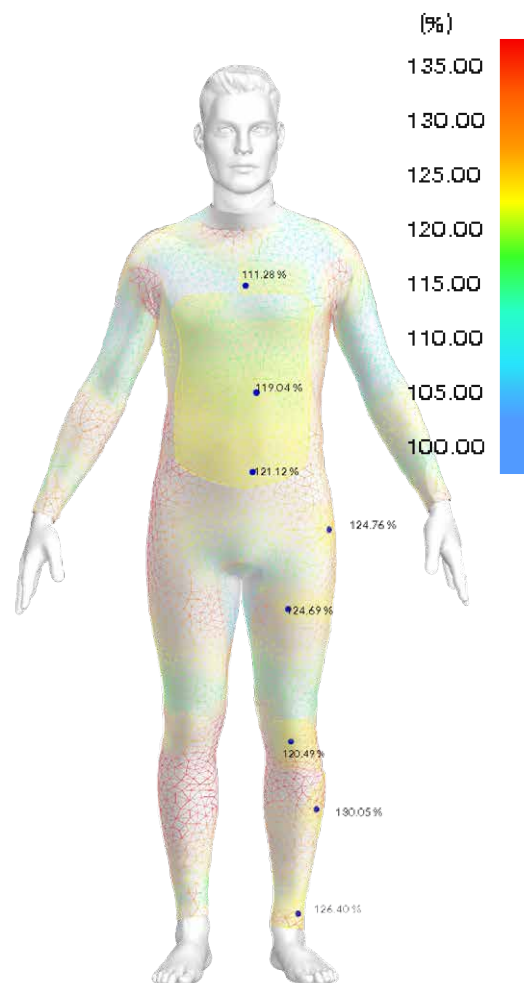
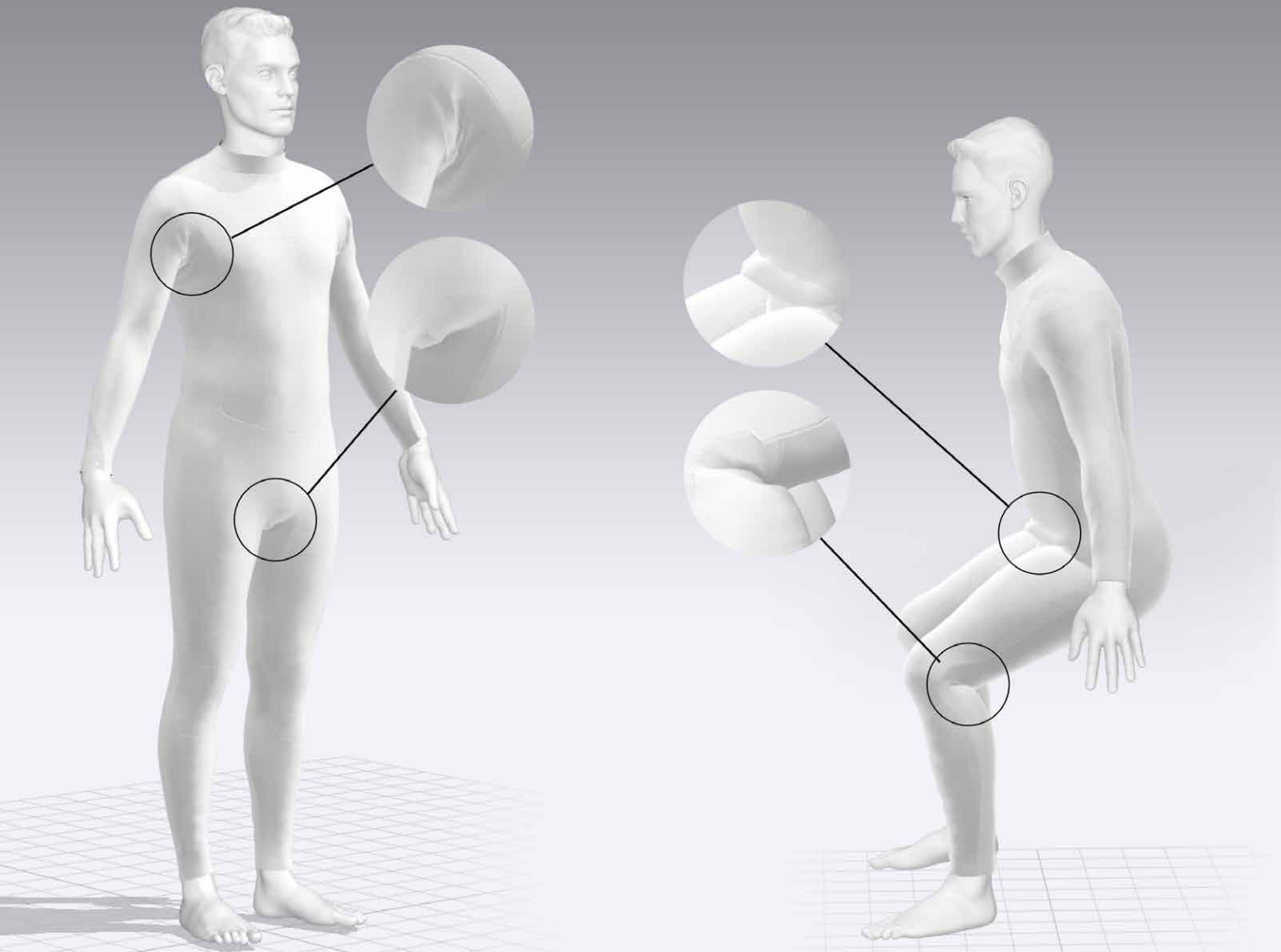


Fig 46: Strain simulation in warp direction



PHYSICAL VALIDATION

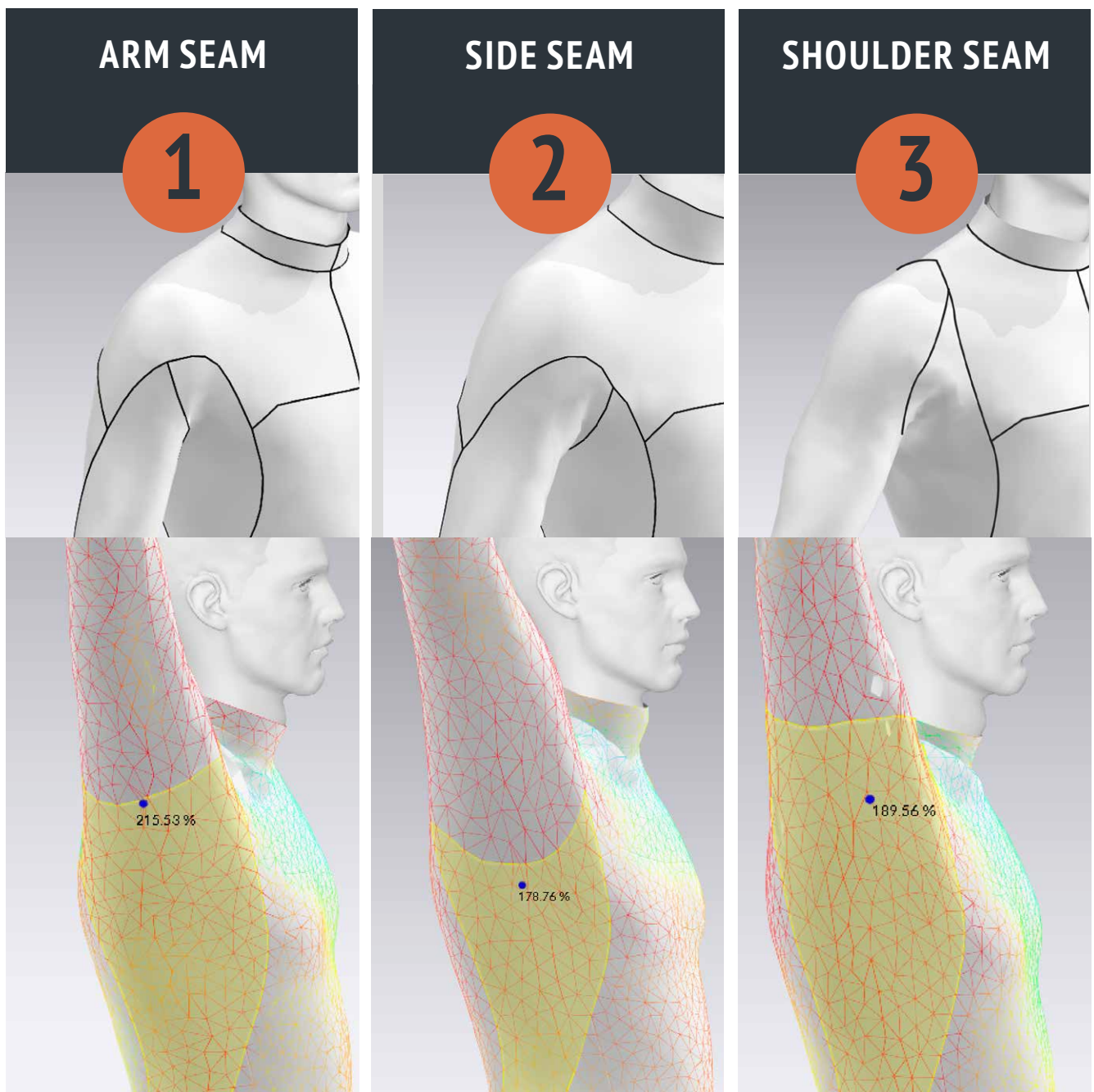
Now that the method is verified the process can be taken one step further. A physical prototype will be created that can verify the workflow as a whole. The pattern for this prototype will be designed for the new medium mannequin using the medium design template. The same SRFACE wetsuit design will be used for this pattern. Small variation will be made with the focus on improving the design. The following aspects will be incorporated:

- New armpit panel design
- Tighter waist
- New overall product dimensions
- New flattening result
- New panel design behind legs
- Tighter NCN
- Looser shoulders/chest (returns)

ARM PANEL

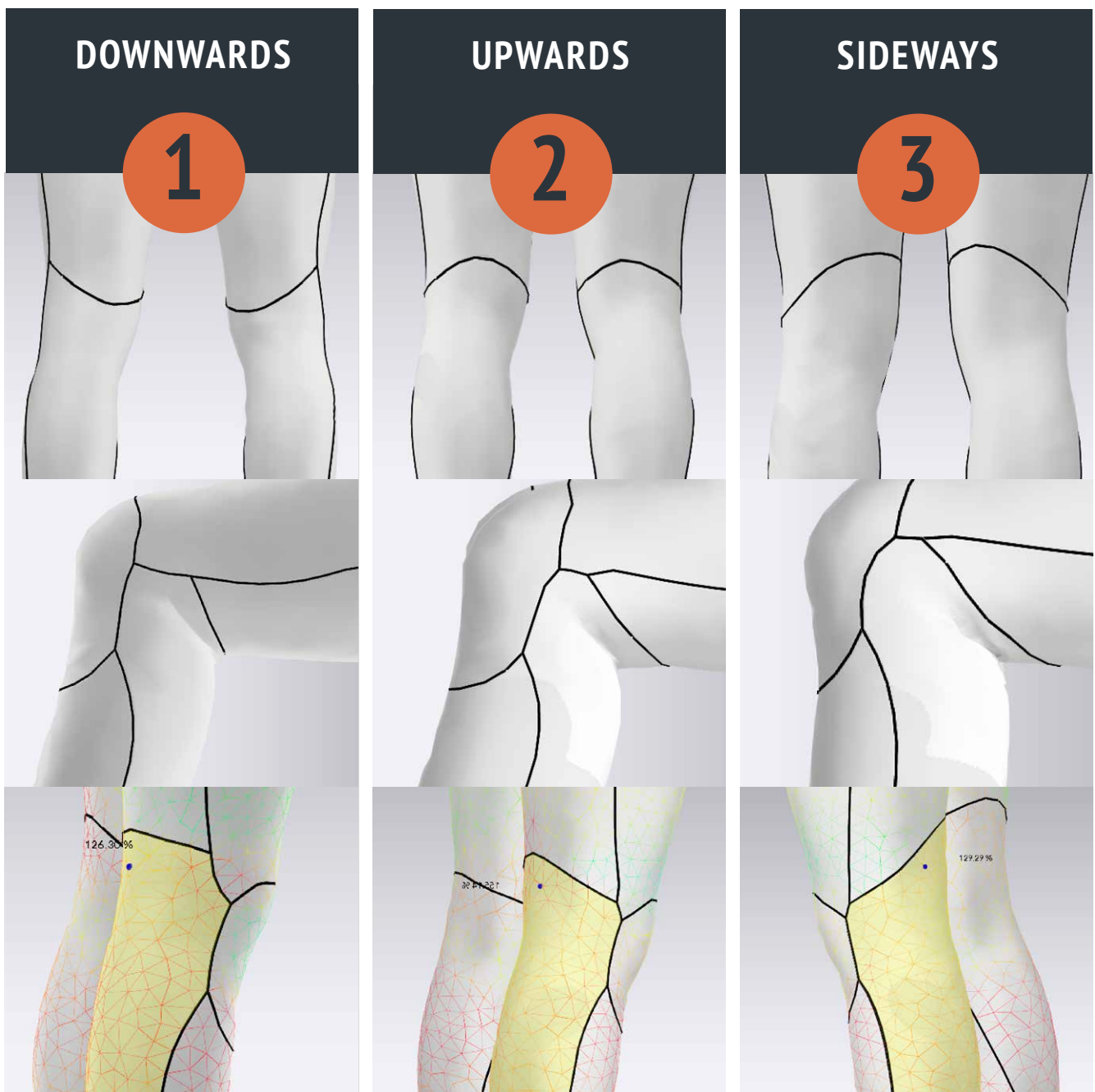
The design is altered in the area of the armpit. An extra seam is added for improving the shaping of the wetsuit. The goal is to reduce the wrinkles in the wetsuit when having the arms downwards. Creating a tighter fit around the shoulders would reduce the wrinkles under the armpits but would increase the amount of stress in the panels when abducting the arms. Three concepts have been created and flattened to a pattern. Without optimizing these patterns they were fitted on the medium

mannequin. The concepts were tested by fully abducting the arms to simulate the extreme arm positioning during paddling. The strain was measured in the area of the armpit. Concept 2 shows the lowest amount of strain compared to the other concepts. This quick assessment will be used to choose a design direction without having to fully optimize the pattern.



KNEE CAVITY DESIGN

The same goes for the design at the back of the legs. Two designs have been created and compared to the original design. New designs were drawn on the template medium and flattened to the following designs. The strain was tested in the knee cavity during full extension of the legs. The second knee cavity design shows the least amount of strain during leg extension. Therefore this design is chosen for further optimization.



Any flattening result should be optimized. The software has a hard time to flatten areas with a high curvature. The resulting panel(s) can therefore have strange outlines. The designer has to correct these irregularities. Figure 47 shows such a flattening irregularity. The irregularities can sometimes make it hard to see the correct shaping of the panels.

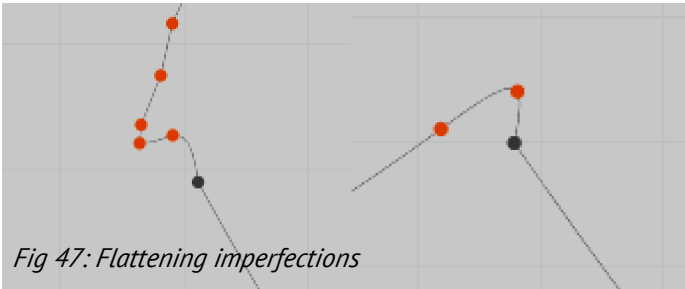


Fig 47: Flattening imperfections

WEIGHING LIMB POSITIONING & PATTERN SHAPING

The positioning of the limbs highly influences the shaping of the panels. Different flattenings are created for the arms and knee cavities. This shows the influence of the positioning on the panel shaping. It is up to the designer to weigh the positioning of the limbs in the panel design. Fig 48 & 49 show the different flattening results for the panels behind the arms and back of the legs. These results are used in creating the right pattern shaping.

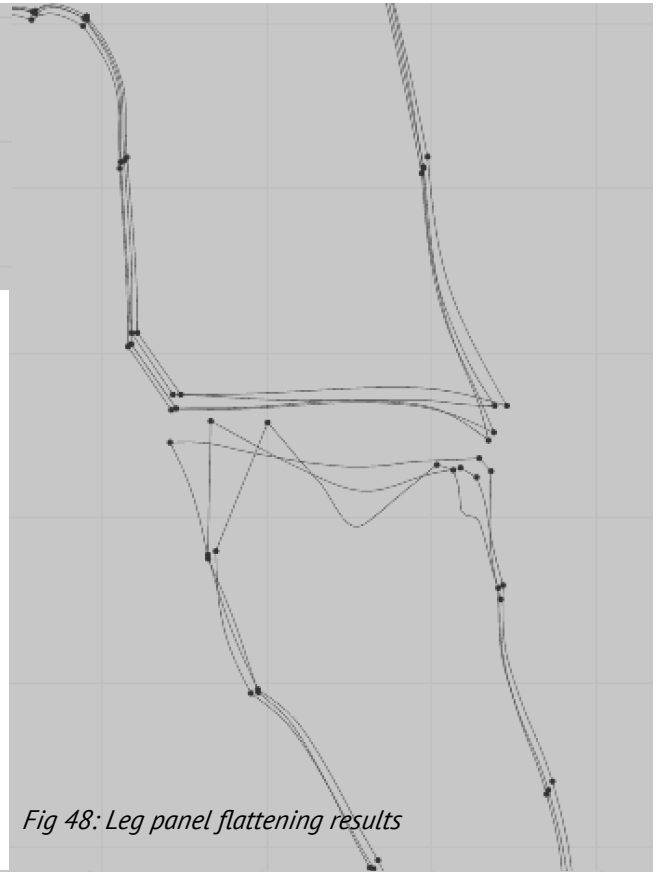


Fig 48: Leg panel flattening results

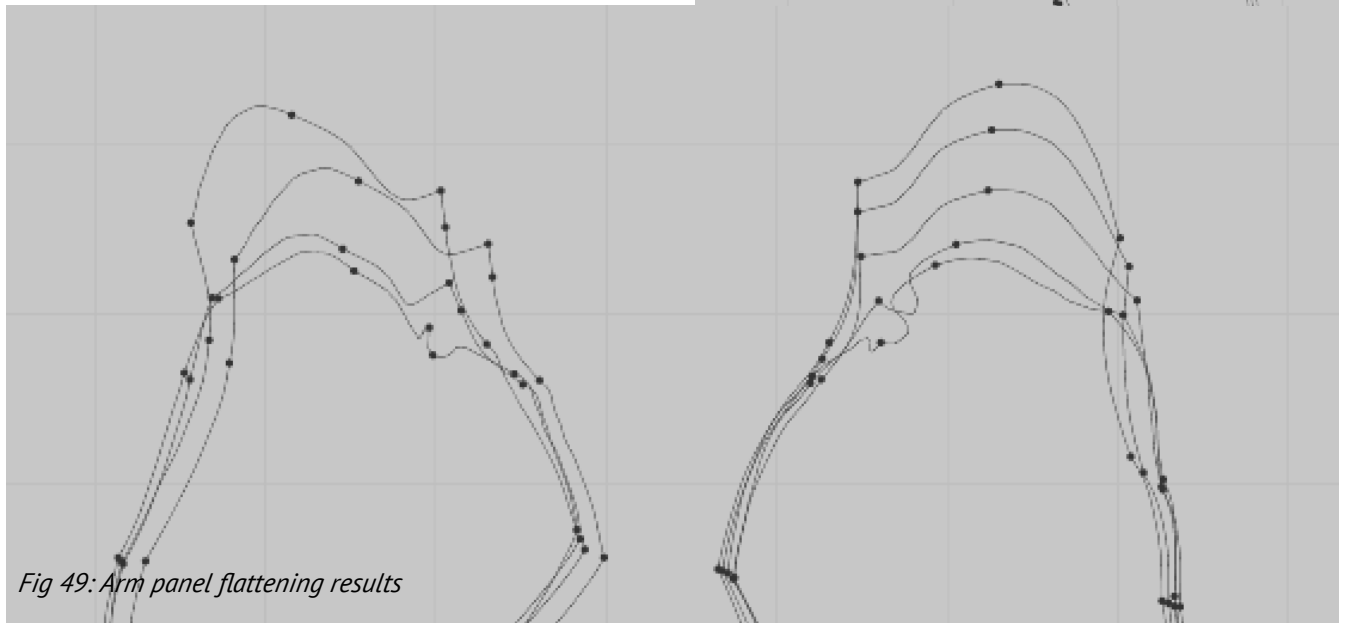


Fig 49: Arm panel flattening results

OPTIMIZATION

After the panel shaping is determined the whole pattern can be optimized. This includes optimizing the panel curvature and symmetry. The pattern is duplicated as a reference and the left side is compared to the right and vice versa. Furthermore the seam lengths are measured and compared between panels. Fig 50 shows the comparison. The highlighted red stitches show a seam length difference of 3%. The panel shaping is adjusted to eliminate the difference. The seam difference located on the crotch panel, shoulder and knee cavity are left unchanged. These panels will be stretched during assembly to ensure the necessary product shaping. As a final step the fit of the whole product is tested with the extreme mannequins and adjusted in the necessary areas.

To summarize the following steps were executed:

- Eliminating curvature irregularities
- Applying symmetry
- Comparing seam lengths of pattern stitching
- Testing with extreme mannequins

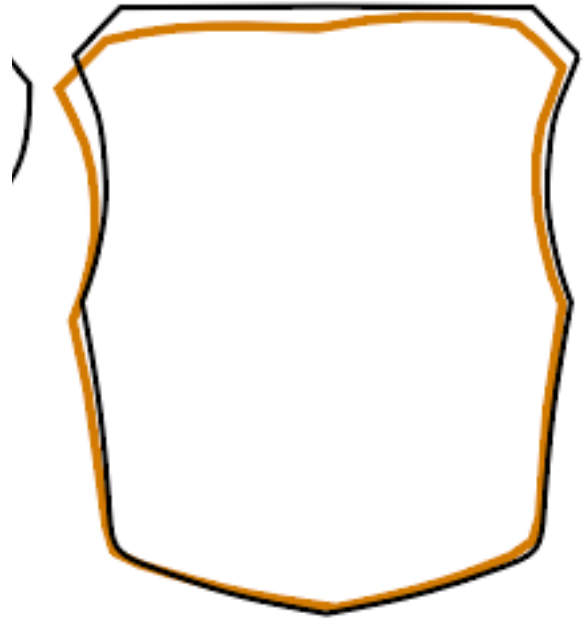
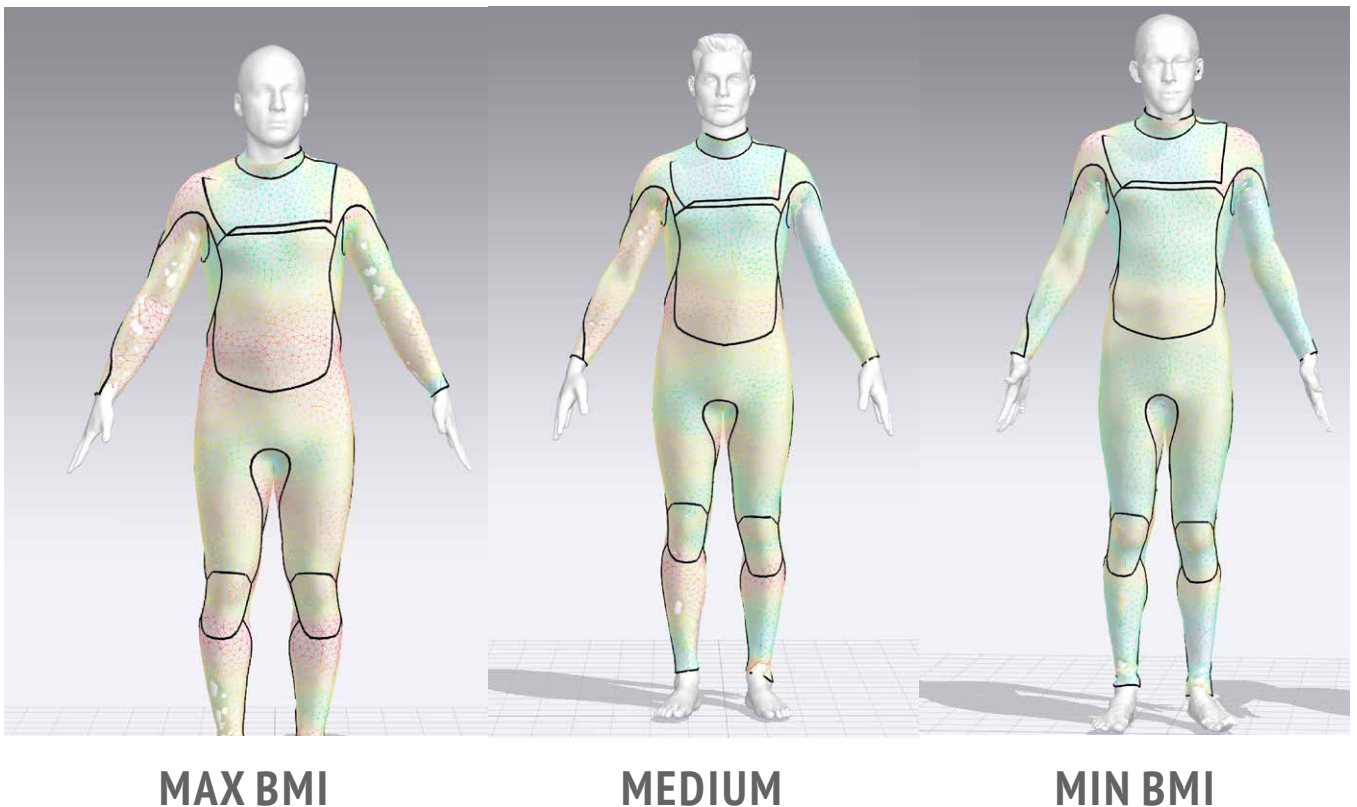


Fig 50: First Flattening and Optimized flattening



TECHNICAL FILE

The final step is to create a technical document to send to the production company. This document can be found in Appendix 7 and covers all the information necessary for the creation and assembly of the wetsuit. It includes a pattern file and a technical file. The pattern itself is added as an dxf (Drawing Exchange Format). The pattern cutting machinery uses this format in reading pattern files. The technical file used by SRFACE for previous orders has been used as a basis.

The Technical document itself contains:

- Panel configuration
- Panel specifications
 - Materials
 - Lining
 - Stitches
 - Reinforcement
- Prints
- Feature specifications

The pattern file itself contains:

- Panel outlines
- Panel names
- Top/Bottom stitches
- Print & Seal locations
- Grain direction
- Notches
- Reference square of 50 x 50 mm

PRODUCTION FEEDBACK

The pattern has been analysed by the production company. Their feedback can be found in Appendix 3.

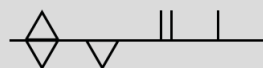
PATTERN SYMBOLS



GRAINLINE



PLACE OF FOLD



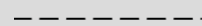
NOTCHES



**BUTTONS &
BUTTONHOLES**

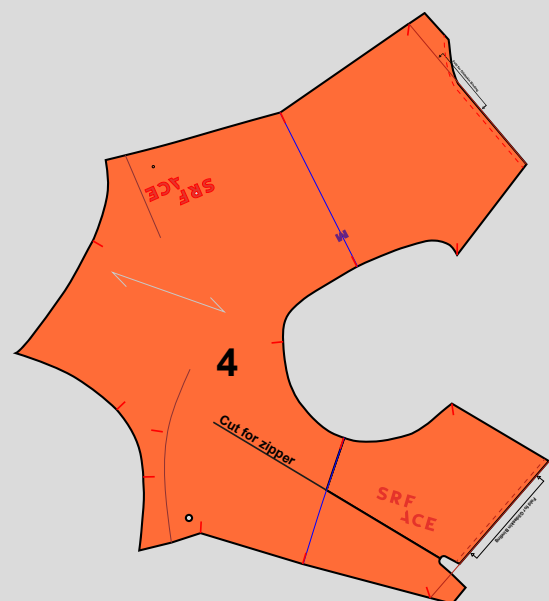


**LENGTHEN OR
SHORTEN**



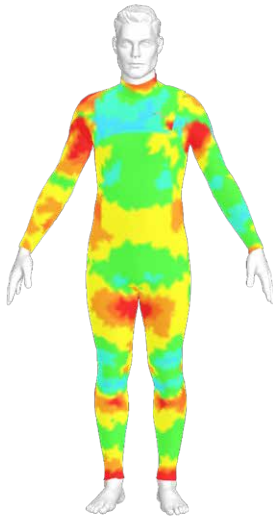
STITCHING LINE

SHOULDER PANEL



PROTOTYPE

PROTOTYPE



ORIGINAL WETSUIT

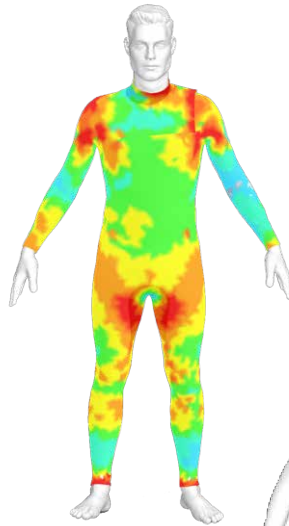


Fig 51 & 52: Strain simulation of the original and new pattern

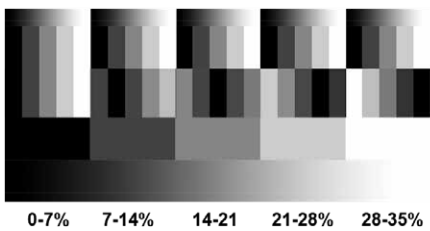


Figure 51, 52 show the strain simulation of the original SRFACE wetsuit and the prototype. Figure 53 shows the difference between both simulations. Looking at the colors the difference in strain lays between the 0 and 14% throughout the whole wetsuit. This indicates a high similarity between both patterns.



Fig 53: Difference in Strain

PROTOTYPE ANALYSIS

A physical prototype has been created by the production company of the M50 pattern in appendix 5. Appendix 7 is used as guideline for the production and assembly of the pattern. In this chapter the resulting prototype will be evaluated to validate the software tools and the overall mannequin based workflow. For this evaluation the prototype will be compared to the original SRFACE wetsuit based on the pattern in Appendix 4. For a good comparison a couple of variables have been kept consistent. Both wetsuits are based on the same visual design. Some panel shaping variations have been made but the overall styling is similar in terms of materials, colors, prints and features. The same goes for durability. Both wetsuits have the same type of seams and reinforcements. Also the insulation capabilities are similar in both wetsuits. The same material thicknesses are used throughout the wetsuit. Within the evaluation the fit, performance and comfort will be addressed.

METHOD

The evaluation is done together with Reinier Krostanje as wetsuit design expert from SRFACE. Both wetsuits are fitted by the a test subject who classifies as Medium body type, to compare both the static fit and the dynamic fit (performance) in levels of comfort. The level of comfort is a subjective experience and will therefore be assessed as such. For the static fit the tightness and comfort is addressed following the relevant measurements from the sizing chapter. The dynamic fit is addressed by evaluating the level of resistance of the wetsuit during motion. The focus is on addressing what should be improved in a next version.

Fig 54: Test subject



SRF ACE



ORIGINAL SRFACE WETSUIT



BENEFITS

Comparing both wetsuits a couple of positive aspects can be stated. The prototype has a tighter waist area and better shaping in the lower back. This reduces the air gap that occurs in the original wetsuit.

When crouching into a sitting position there still are a lot of wrinkles that occur in the waist area.

The arm panel is tighter and has more shaping than the original wetsuit. This results in less wrinkles around the elbow area during arm flexion.

The chest is a little looser than the original wetsuit. This was intended and due to feedback of the customers. The seam design under the armpits is located in a sensitive area but doesn't reduce the level of comfort around the chest.

PROTOTYPE



IMPROVEMENTS

The pre-shaping in the back of the knee can be increased. The original wetsuit incorporates shaping towards a bended leg. This shaping should also be increased in a next design. Figure 48 in this report can serve as basis into changing the pattern.

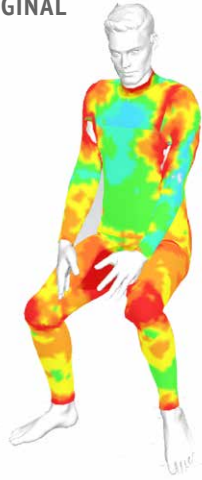
The current panel design results in a small bump on the corners of the chest panel. Previous pattern adjustments have been made to reduce this bump (see production feedback in Appendix 3. In a next design the pattern should be adjusted to fully eliminate the occurrence of such a bump.

The arms and legs are a little too long and should be reduced by 1 cm.

Some prints should be shifted around a little bit to increase the aesthetic level of the product. The shoulder print should be shifted inwards 1 cm. And the print on the under arm can be placed towards the front.

SITTING

ORIGINAL



PROTOTYPE

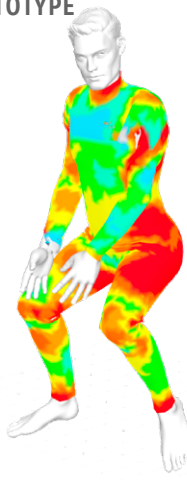
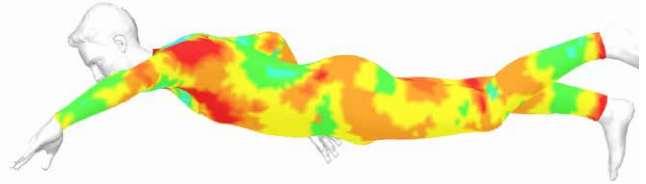


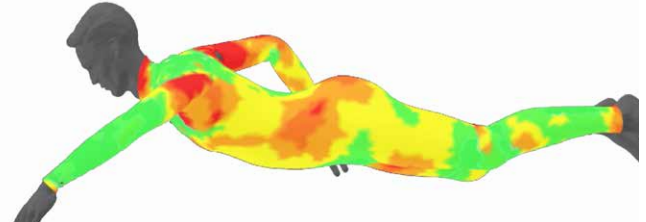
Fig 57: Animation simulation of original and new pattern

PADDELING

ORIGINAL

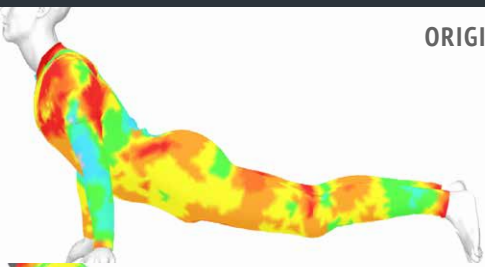


PROTOTYPE

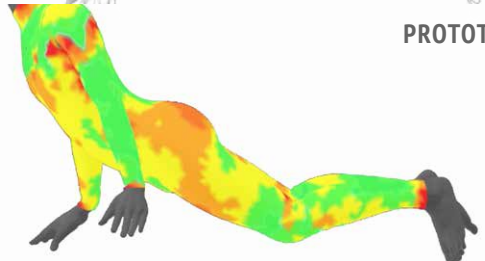


DUCK DIVE

ORIGINAL

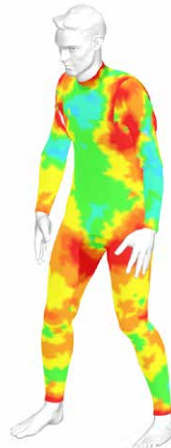


PROTOTYPE

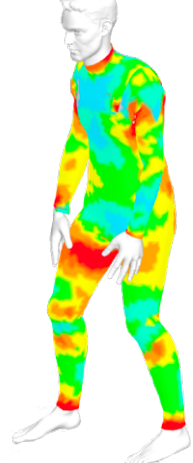


STANCE

ORIGINAL



PROTOTYPE



DYNAMIC FIT

The surfing motions will be used in assessing the dynamic fit. Less resistance and less occurrence of air gaps indicate a better pattern performance and a good dynamic fit. The animation shown in Figure 57 show the strain simulation of the original and new wetsuit design.

There is little to no resistance in the shoulder and chest area that limits the movement of the arms compared to the original SRFACE wetsuit. This is beneficial for it will be less energy draining during paddling.

During a stance position both wetsuits still show a similar amount of wrinkles in the waist area. These air gaps could be reduced further but will never fully be eliminated. Furthermore the prototype incorporates more shaping in the lower back than the original. This increases the level of comfort as it feels like the wetsuit acts like a second skin. Furthermore the crotch area of the prototype is a little more comfortable but very similar to the original SRFACE wetsuit.

CONCLUSION

The prototype has a similar fit and performance as the original wetsuit design. On some levels it even exceeds the original design. But there are still a couple of areas that should be improved. Looking at the simulations from Clo3D these areas could have been assessed digitally. In time the designer will gain experience in reading these simulations.

The use of the design template has proven to generate realistic patterns with the right amount of tightness. For future designs the design template should be updated to increase or decrease the tightness of the resulting pattern. Furthermore the mannequins can be adjusted based on feedback of the customers.

The original SRFACE pattern is created by an experienced pattern creator from the production factory. This factory has over 40 years of experience in the wetsuit design industry. Furthermore the original pattern is a fully optimized wetsuit and has been optimized three times by physical prototype assessment. The pattern created for this project is created by an master student with no prior knowledge and experience in pattern creation. The high similarity in both the prototype and the original wetsuit shows the potential of the 3D design workflow and its ability to generate accurate patterns. The resulting patterns might not be ready after a single prototype but it enables SRFACE to have more control in the creation and optimization of their patterns.

GRADING

The method for the creation of a new wetsuit pattern is established. The next step is to apply grading in order to gain different sizes of the same pattern. There are three types of grading; Cut and Spread, Pattern shifting & Computer grading. These methods are illustrated in

figure 58 - 60 These methods require grading tables for every panel which incorporate the exact measurement changes for every size. A new method will be investigated using the template body created in Chapter Prototyping.

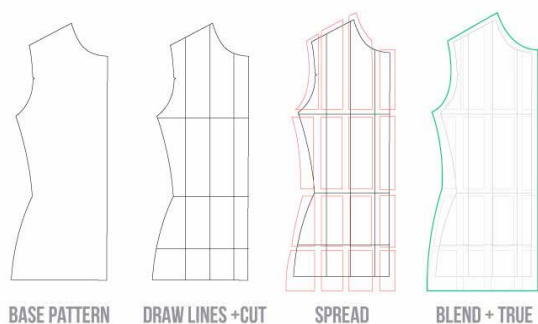


Fig 58: Cut and Spread method

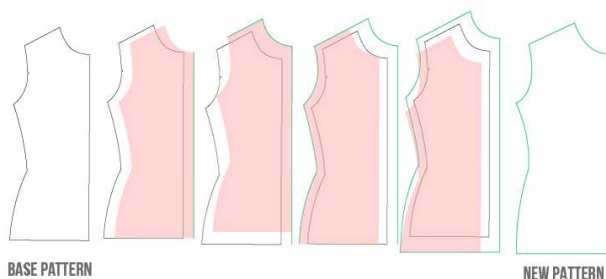
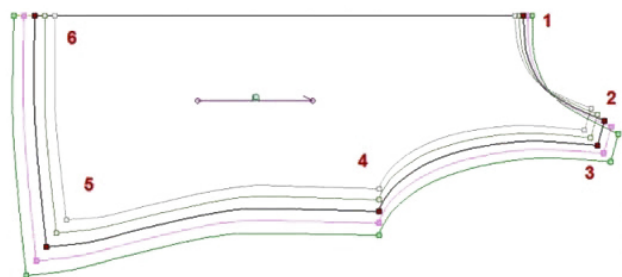


Fig 59: Pattern shifting



| Pt# | XS | | S | | M | | L | | XL | |
|-----|---------|-------|--------|-------|---|---|------|---------|-------|---------|
| | X | Y | X | Y | X | Y | X | Y | X | Y |
| 1 | - 11/64 | 0 | - 3/16 | 0 | 0 | 0 | 3/16 | 0 | 3/16 | 0 |
| 2 | - 9/32 | 1/4 | - 9/32 | 17/64 | 0 | 0 | 9/32 | - 17/64 | 19/64 | - 9/32 |
| 3 | - 17/64 | 5/16 | - 9/32 | 21/64 | 0 | 0 | 9/32 | - 21/64 | 9/32 | - 11/32 |
| 4 | 0 | 15/32 | 0 | 1/2 | 0 | 0 | 0 | - 1/2 | 0 | - 17/32 |

Fig 60: Computer grading

The following method is focussed on using the mannequins as basis just as the creation of the Medium prototype. But instead of redrawing the design curves for every wetsuit size, the original curves will be used for every wetsuit size. This will also ensure a consistency in panel shaping. The process consists of the following steps:

MEASURE

The mannequin is measured in Clo3D using the 18 measurements from Chapter Future Sizing.

CALCULATE

The measurements are converted in to pattern sizes using the intended stretch percentage from the base pattern. This ensures a tightness consistency in every wetsuit size.

DRAW

The design curves should be drawn on the mannequin template. Using the original design curves of the base pattern will give the best result.

ADJUST

The mannequin template is adjusted towards the wetsuit dimensions resulting from the stretch calculation.

FLATTENING

The panels are flattened using the flatten tool of Clo3D.

OPTIMIZING

The resulting pattern should be optimized and compared with the base pattern. Any irregularities should be fixed.

RESULT

This process should be performed for every wetsuit size. The design was simplified for illustrating this method. This grading method is applied for 8 different sizes and shown in Appendix 6. The increase in sizes is noticeable in every panel. The shown patterns are not production ready and have to be perfected manually. The method can serve as a reliable method in establishing the directional grading for every panel. Figure 62 shows the mannequin measurements that have been used for the sizing.

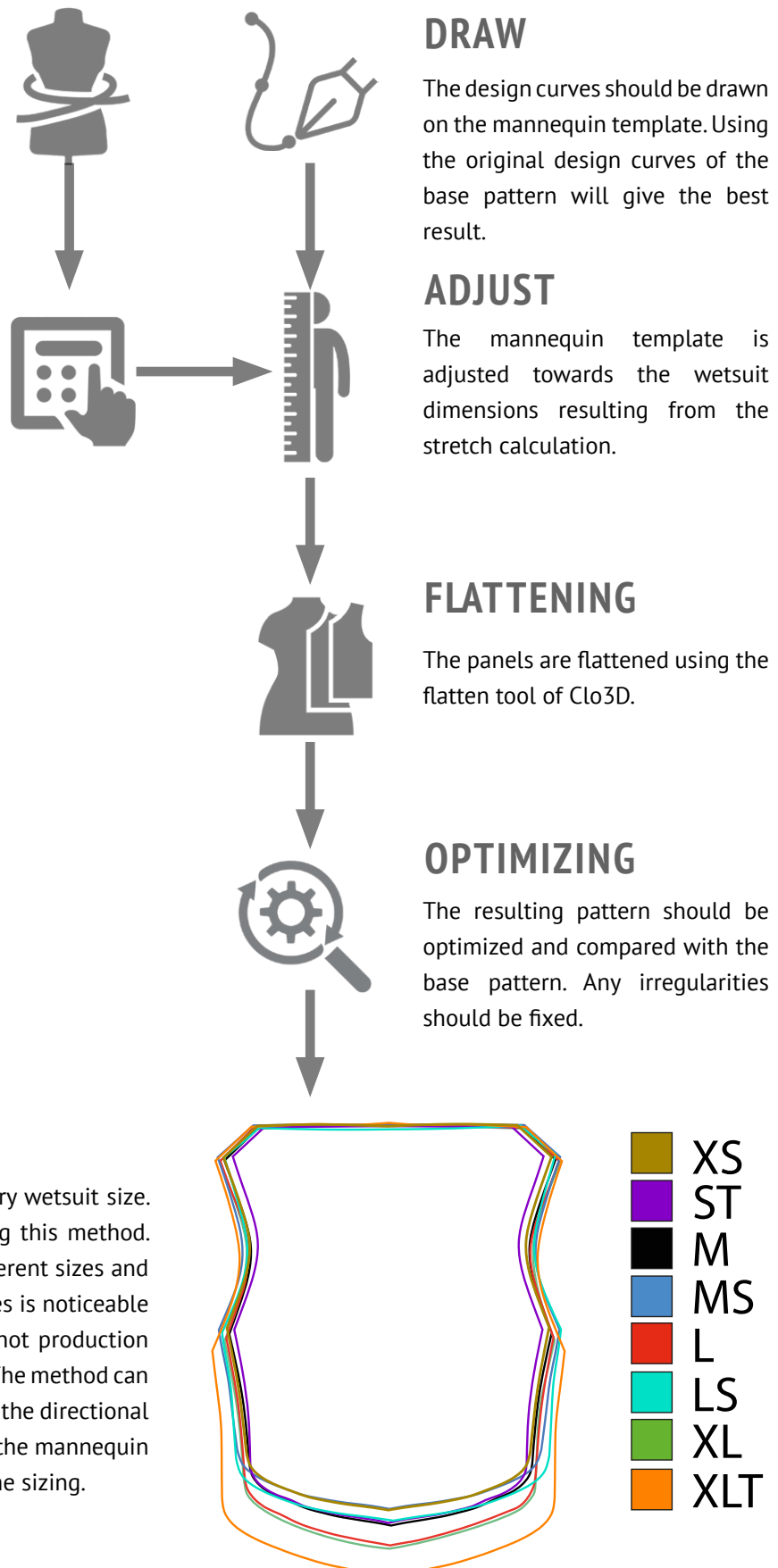


Fig 61: Scaling result of chest panel

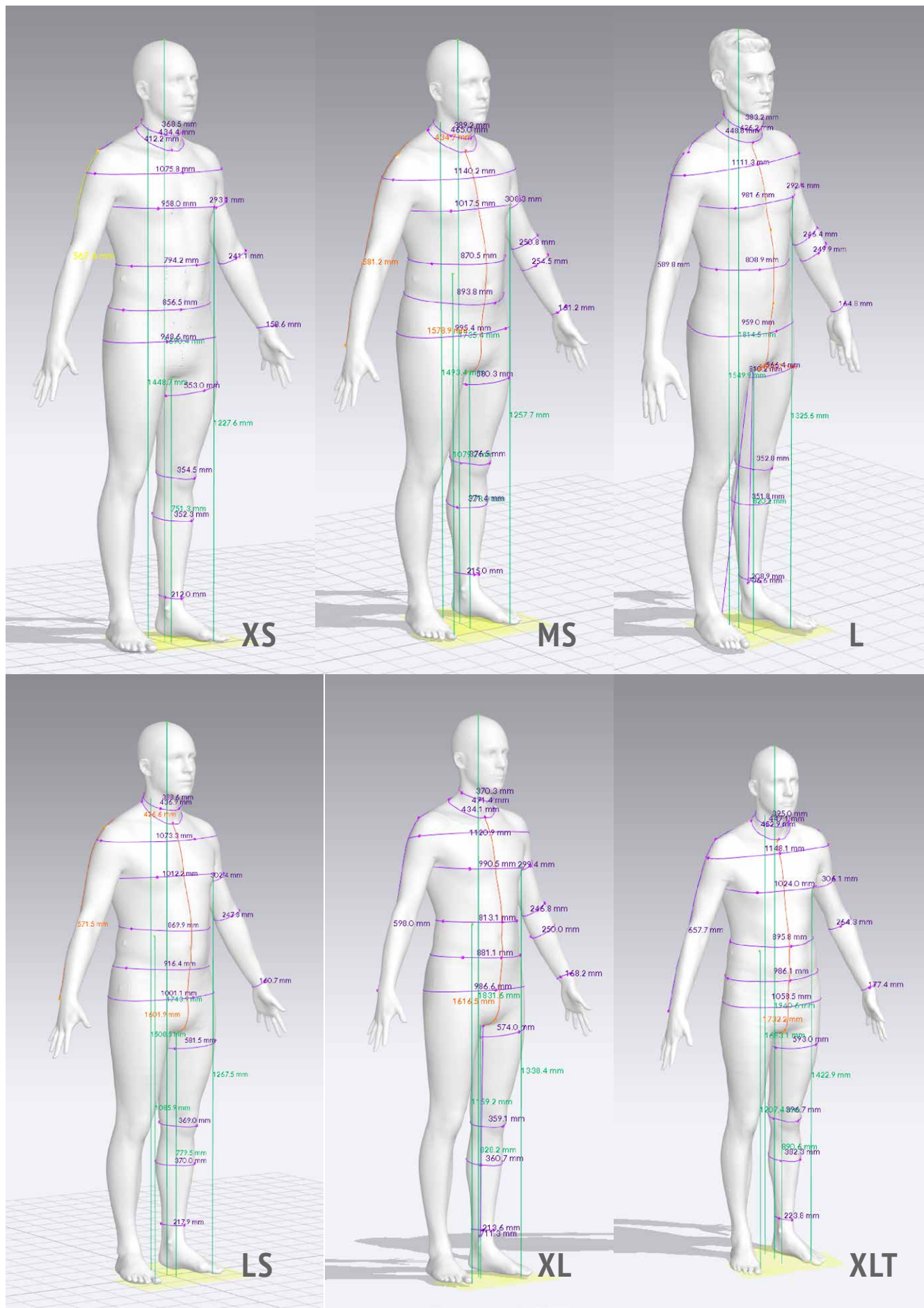
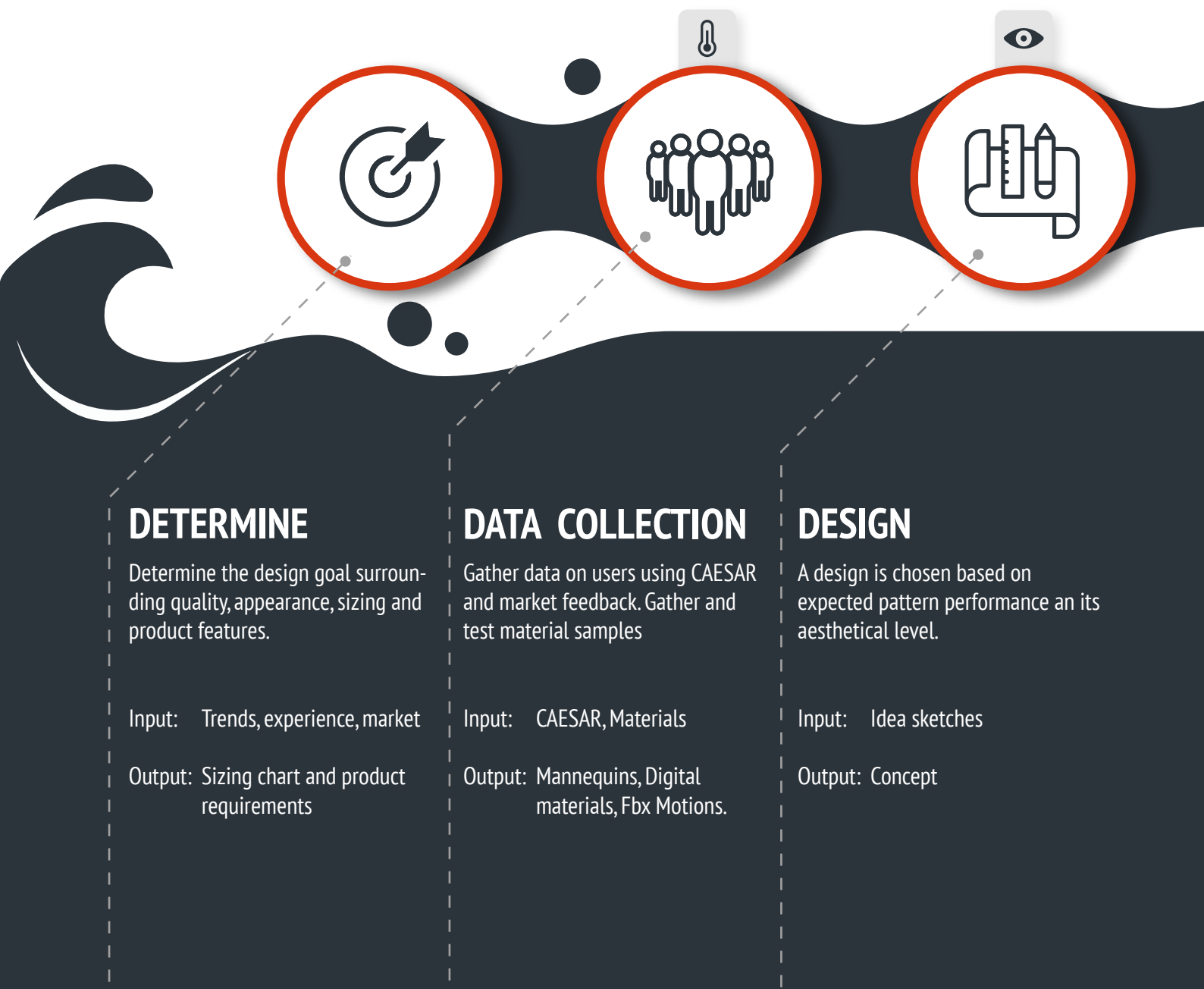


Fig 62: Mannequin measurements

NEW METHODOLOGY

To finalize this project all research is combined into a new methodology proposal. This methodology incorporates all the steps that have been investigated throughout this report. This new methodology focuses on mannequin based wetsuit design. 3D body scans are used incorporating the anthropometric dimensions of sizing populations. It incorporates the creation and grading of wetsuit patterns within the company.

This gives them more control in the optimization of their product. Furthermore the methodology contains digital prototyping to reduce time and costs in physical prototyping. The important wetsuit design aspects are mapped as labels in the methodology to indicate their position in the workflow. A short summary will be given concerning each phase.



FIT 
INSULATION 
PERFORMANCE 
COMFORT 
DURABILITY 
STYLING 



CREATE

Create the wetsuit pattern using the design Template. Evaluate the design, Iterate and optimize using the digital simulations.

Input: Design Template, Concept drawing, Mannequins

Output: Base size Pattern, Prototype

SIZING

Create different wetsuit sizes using the design template and optimize the flattening results.

Input: Base pattern, Mannequins

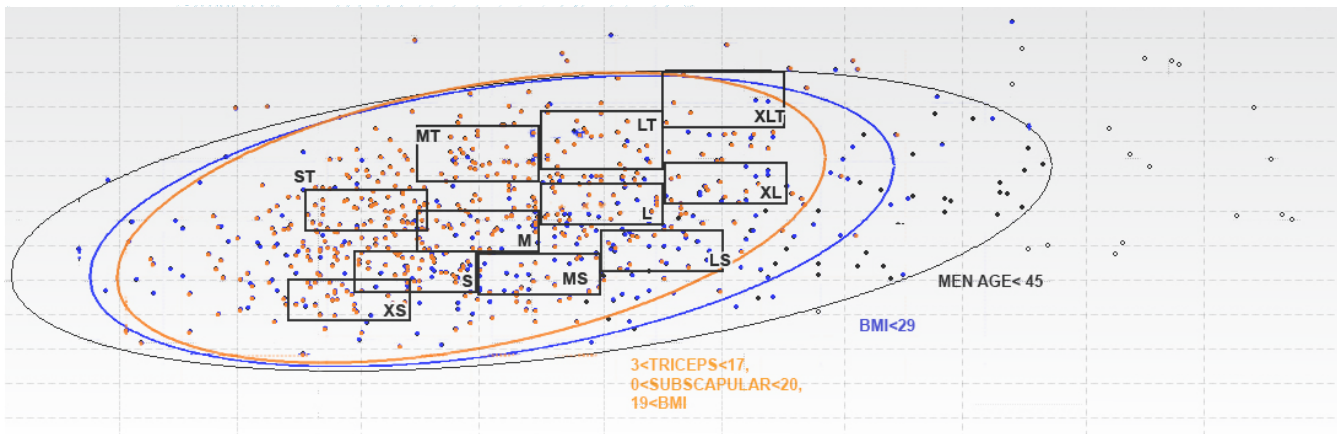
Output: All wetsuit pattern sizes.

FINALIZE

Finalize Patterns with pattern notations and create a technical document for production and assembly.

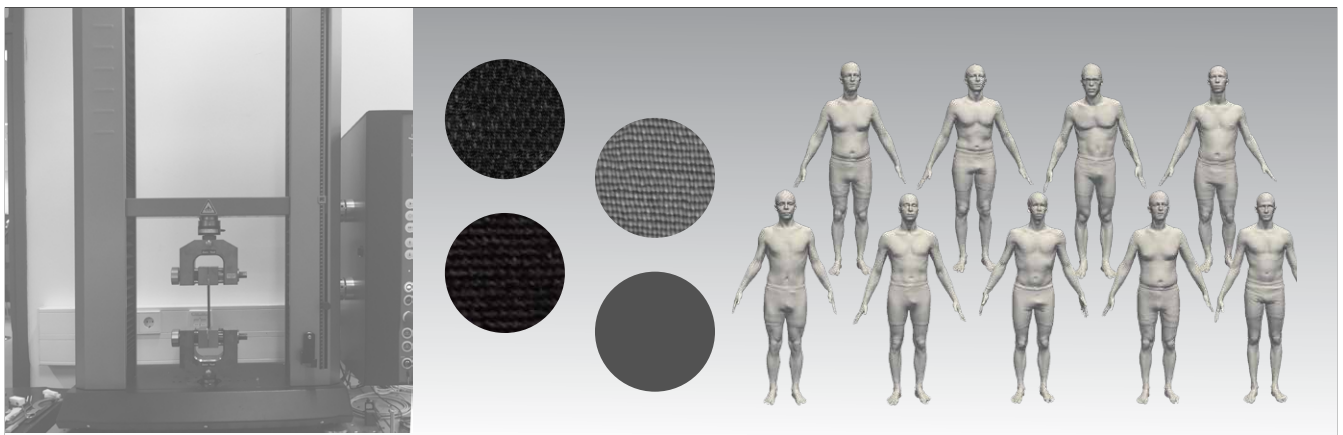
Input: Patterns

Output: Technical Document, Production ready pattern.



DETERMINATION

Before a wetsuit design is created SRFACE decides on the overall design goal. They decide on the overall appearance that they want to establish and what kind of features their product should incorporate and what wetsuit thicknesses they would like to offer. Input for this phase is their current branding, trends in the current market and their previous experiences. This leads to product requirements for their new design. Furthermore, the sizes can be determined using the Ellipse tool used in chapter X.



DATA COLLECTION

The Data Collection phase focuses on gaining all the data needed to start the design process. Using the sizes established in the Determination phase, different CAESAR populations can be created which resemble sizing populations. Average and extreme mannequins can be created using these populations. After rigging and assigning surfing animations, these mannequins are ready for assessing digital patterns. Furthermore, the materials have to be investigated for the new design. Samples have to be ordered in different thicknesses. A stress test has to be performed to determine the stress and strain behaviour in the weft, warp and bias direction. And after an additional bending test, the results can be computed into digital materials in Clo3D.



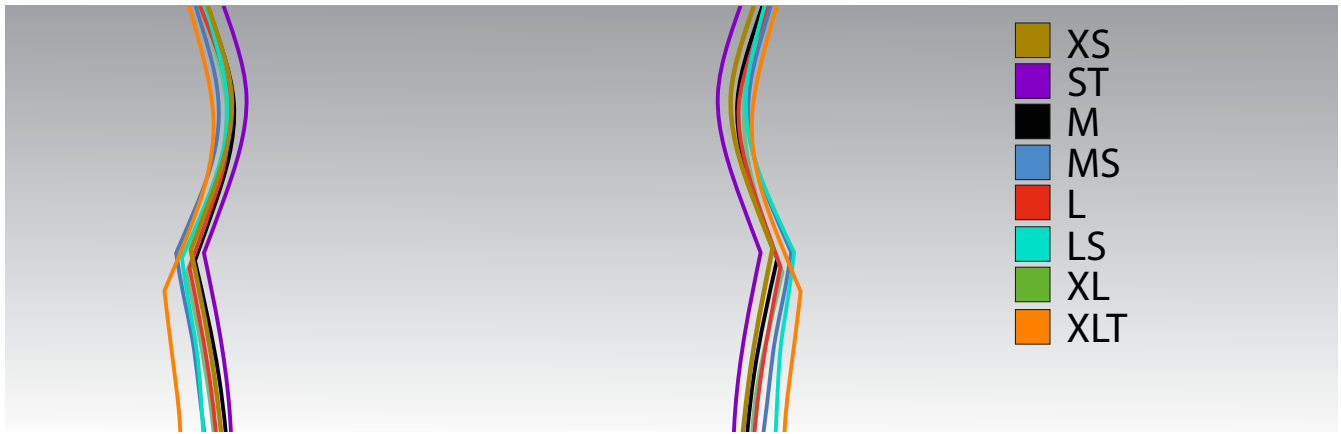
DESIGN

The design goals established in determination are used as basis for ideation. Different ideas are sketched on a male outline just as in the original methodology. With the chosen features in mind, the designer draws the seam placements on the body outline to show the different panel placements. Knowledge and pattern drawing experiences are used to come up with feasible designs. Multiple ideas are generated and colorized to indicate the aesthetics of the final result. Ideas can be chosen or combined into concepts. This phase results in at least one promising concept drawing. An addition to this phase is it is also possible to directly sketch pattern ideas in 3D using Clo3D. The 3D sketching requires a little more effort compared to 2D sketching. But at the same time it helps the designer in visualizing an idea. Flattening different ideas can help the process of finding the right pattern shaping



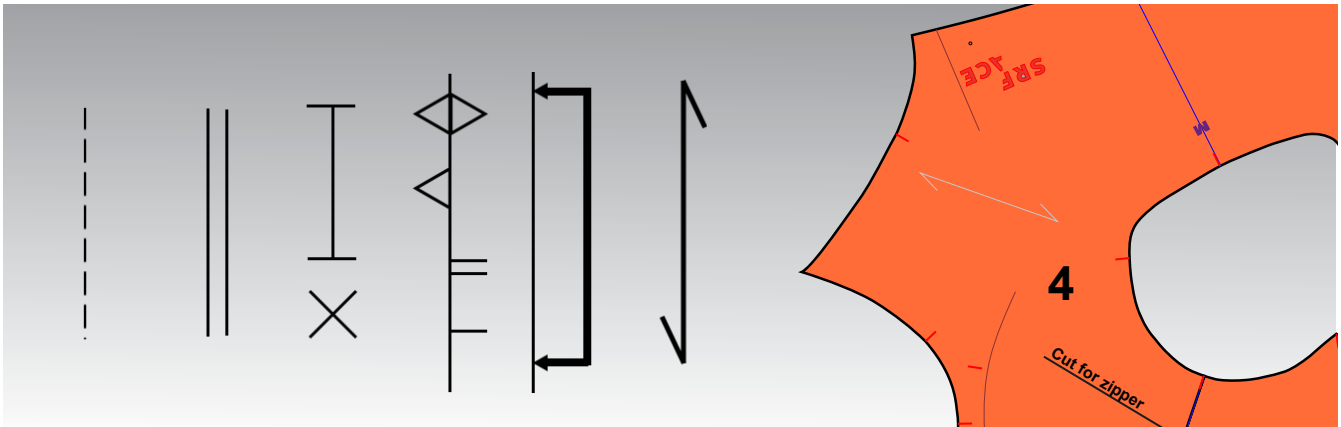
CREATE

The Creation phase starts with the adjustment of the template mannequin based on the created mannequins. This template will incorporate the desired amount of tightness of the final product. The panel design is drawn on the template and flattened into a pattern. From this point on this phase will mostly consist out of simulating, iterating and optimizing the flatten result. Digital stress and strain simulations are used as feedback to assess the (static) fit and performance (dynamic fit) of the pattern. This is a fluid process which continues until the designer is confident with the established pattern. This phase ends with a fully designed base pattern that will be send to the production company. Assessing the resulting physical prototype will validate the design and conclude the Creation phase.



SIZING

In the Sizing phase a new sizing method is performed to gain the different pattern sizes. This method uses the template mannequin with the design curves used for the creation of the base pattern. Depending on the amount of iterations in the Create phase the design template and the design curves have to be updated. To create a new pattern size the mannequin is measured and the product dimensions are calculated. The mannequin template is then adjusted towards the product dimensions of the new wetsuit size. The panel design scales with the template and can then be flattened as a new wetsuit pattern. This is repeated for every wetsuit size. Every new pattern should be simulated on the average mannequin and extreme mannequins. If necessary some adjustments can be made to support the body type of the mannequins. This phase results in an outline of the different wetsuit sizes. Prototypes can now be ordered of the different sizes to validate the designs.



FINALIZE

The last step concludes the design process. Pattern notations are added to the patterns for production and assembly. Furthermore a technical document is created containing all the information needed by the production company. This consists of material information, colors, prints. The full list can be found in Chapter X.

OLD VS NEW













The biggest benefit of this new methodology is the higher level of control in the design process. Where the previous methodology outsources the pattern creation and scaling, the new one relies on SRFACE to execute these steps. On the downside, SRFACE has to build up some experience in this area while the current production factory has over 40 years of pattern making experience. This makes it challenging to create patterns that match the quality of the outsourced patterns. But this new method proposition incorporates a potential new workflow that is new to the wetsuit industry. It incorporates digital prototyping where the fit and performance of a pattern is assessed and optimized before a physical prototype is created. Currently prototyping is only done physically which is a time and cost consuming process.

A big disclaimer is that the new methodology will include much more time and effort for SRFACE during the design of a new wetsuit. The different softwares have a moderate learning curve and will require a relatively long implementation period. But when fully implemented, it enables SRFACE to create and experiment with new wetsuit patterns without having to wait on physical prototypes.

Furthermore the new method builds on experience. Going through the different phases of the methodology, the tools will be updated and become more reliable for further use. The design template for instance, incorporates the desired level of tightness of the final product. The template is updated with every prototype and is adjusted based on customer feedback. It is assumed that with every adjustment its dimensions will become closer to the ideal product dimensions. The same goes for the mannequins. New mannequins can be created based on customer feedback and sale rates.

A final benefit of the new methodology is that SRFACE does not have to rely on their current production company anymore. This opens up many opportunities to try out different materials and production techniques.

The following requirements were set up for the methodology and can now be used as validation.

1. Incorporate the creation and grading of own patterns. 
2. 3D human models as basis. 
3. Design for fit approach. 
4. Incorporate digital analysis of the static fit. 
5. Use validated software packages. 
6. Build on current branding. 
7. Sizing for European anthropometry. 
8. Incorporate pattern sizing. 
9. Analyse the performance/dynamic fit. 
10. Design with the available materials from the production factory. 
11. Alternate between different materials and lining combinations during pattern design. 
12. Incorporate minimization of seam length. 

The methodology meets ten of the twelve stated requirements. The last two requirements are not fully met but are not fully incorporated in the new methodology. Minimization of the seam length is now still left to the designer. The best way to minimize the seam length of a pattern is during the Design phase. It should be taken in account during the sketching of wetsuit designs. During the Create phase the software offers the option to manually measure the seams but does not incorporate any tools to assess or compare seam lengths of designs.

Furthermore the use of different materials and linings are fully integrated in the new workflow. But playing around with different materials during the Create phase is still a time consuming task. Especially when deviating from the currently used materials. When using a new material a test sample has to be ordered. Multiple material tests have to be performed in order to create a digital material with accurate properties. Through time an extensive library will be set up containing relevant materials. A non discussed option might be to order separate samples of different linings and Neoprene foams. Instead of performing the material tests with different foam and lining combinations, everything could be tested separately. The results could then be combined into any possible material combination.

Looking at the list of requirements it can be stated that the methodology is proven its potential for future wetsuit design.

CONCLUSION

This project resulted in a new methodology for the design of wetsuits. The new methodology complies with the goals set in the scope. With this methodology SRFACE will be able to create and grade their own wetsuit patterns. It also enables them to assess the fit of their product digitally with stress and strain simulations. This will reduce the time and money spent on physical prototypes.

DESIGN ASPECTS

The new methodology enables the designer to assess the fit and performance of a wetsuit pattern during the design process. Optimizing based on these aspects will benefit the level of comfort in the final product. Furthermore, the styling, insulation and durability are not left out of the equation but are limited by availability of materials and production techniques. It is up to the designer to make choices that will benefit the product on these aspects.

WORKFLOW

Currently the wetsuit industry uses 2D pattern drawing software for creation and production.

This new methodology introduces a 3D workflow for the creation of wetsuit patterns. Using Clo3D, SRFACE can easily experiment with different designs and assess the fit of different patterns without having to order a physical prototype. The 3D workflow will help visualize the seam placement and panel shaping. It eliminates room for interpretation that comes with 2D designs.

MANNEQUINS

The methodology incorporates a sizing method based on a selective CAESAR population. It uses this population

as representation of the customer population. The mannequins created in this process are created using 3D body scans of Dutch and Italians. Each mannequin represents an average body type for every wetsuit size. They are rigged and equipped with surfing animations. This enables the designer to test the static and dynamic fit of every pattern size. The use of these mannequins creates a design for fit approach.

DESIGN TEMPLATE

The methodology introduces the use of a design template to ease the creation of accurate pattern dimensions. This template is scaled down according to the desired product tightness. This gives the template the dimensions of the final product. When flattening a panel design, the resulting pattern will have the right dimensions.

SCALING

The methodology introduces a new scaling method with the use of the design template. By adjusting the design template, the 3D curves of the design are scaled towards different sizes. When the design is flattened a new pattern size is generated. This method eliminates the creation and use of complex pattern scaling tables.

FINAL REMARK

The usage of this methodology will increase the knowledge on pattern creation and grading within the company. The experience gained over time will increase the fit and performance of the patterns and reduce the time and costs of physical prototyping.

RECOMMENDATIONS

After the successful analysis of the prototype the methodology is validated in its ability to generate accurate wetsuit patterns with the usage of 3D body scans. A few recommendations are made concerning this project.

First of all, implementation of this methodology will require a lot of effort from SRFACE. Learning to work with the different software packages will take some time. In the current methodology the production company provides the engineering of wetsuits for free. This is a huge benefit of working with this production company but is also the result of the longer optimization period. It is unclear how much the new methodology will speed up the design process. But it will definitely lead to more control in the optimization of the product. At first the methodology might still lead to the production of multiple prototypes to optimize the design. But in time, SRFACE will build up the experience to generate patterns that are production ready after one prototype. To speed up this process SRFACE could join a course in Clo3D at the HvA in Amsterdam.

The sizing research performed in this project has room for expansion. First of all the intervals used in the sizing are directly taken from the sizing of other wetsuit brands. The reason behind the short length of these intervals is clear but has not been researched. Using a larger interval will enable SRFACE to get a higher coverage. More research can be performed into how large this interval could be without leading to an uncomfortable fit for extreme body types.

The usage of digital mannequins will be new to the design of wetsuits. These mannequins serve as representation of surfer body types. But it is unclear how much they can be used as representation of the SRFACE customer population. SRFACE recently implemented a data log in their online size finder that saves the measurements of (anonymous) customers. The data that will be gathered can be used to verify the sizing and mannequins from this project.

The stretching properties in the seams and the effect that it has on the pattern performance is not assessed in the current design workflow. Further investigation has to be done into the effect of different seam types. This will result in better simulations and digital prototyping.

The rigging used to incorporate motion in the static mannequins results in unrealistic skin deformations. The level of unrealistic deformation increases when adjusting the limbs further from the original mannequin stance. There are methods that could improve the skin deformation of these mannequins. Muscles can be added to these models in Maya or Cinema 4D. But this process requires an experienced model rigger or animator. A possibility would be to outsource the rigging of these models.

REFLECTION

First of all I would like to say that I am happy with how this project turned. I have learned a lot during this process and gained experience in a number of new software packages. First of all I would like to thank SRFACE for guiding me during this project and sharing their knowledge with me. A lot of thanks to Toon Huysmans and Johan Molenbroek for helping me with the sizing and creation of mannequins.

Furthermore, there are a couple of things to be said in reflecting on the process. First of all, a good thing was that the project didn't deviate too much from the initial planning. But due to prototyping deadline some parts were rushed and reassessed in a further stage. The sizing with use of the dined tool was introduced in a later stadium of the project and discussed during the greenlight. New insights on the sizing were therefore not incorporated in the creation of mannequins, but implemented as a recommendation in the sizing chapter.

Also the knowledge and experience on a lot of facets in this project were quite limited. This is not necessarily a bad thing because it lead to learning a lot about pattern creation, grading, 3D scanning and animation/rigging. In the process I learned to work with a lot of new software packages. But this was also a limiting factor. Having to learn the software packages during my graduation resulted in a lot of time spent experimenting and looking for the right way to achieve my goals.

Furthermore, I would have liked to gain some experience in the usage of python. But after a couple of failed attempts and limited prior knowledge I gave up. The main contribution to this project would have been the measurement of the waist circumference of the CAESAR database. The measurements would have been useful in assessing the current sizing and creation of new sizing methods. But in the absence of this measurement the preferred waist circumference was used. This measurement is not used by other wetsuit brands. The creation of average mannequins also required the wrapping of the CAESAR database and the creation of a VTK filter. This part of the process is made possible by Toon Huysmans and has been a major contribution to the process.

Overall I am very pleased with the results of this project and happy to learn and expand my capabilities and knowledge as an industrial designer.

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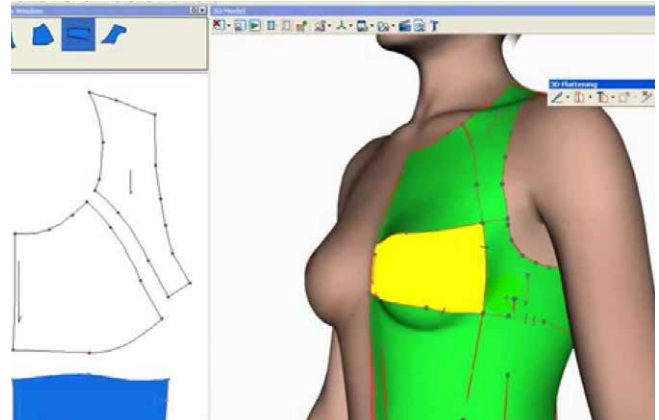
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APPENDIX 1: SOFTWARE ANALYSIS

The following list contains software that could contribute in a new methodology. The following software focusses on pattern creation, pattern grading and flattening techniques:

- Optitex
- Tuka3D
- Clo3D
- Accumark
- Lectra Modaris 3D
- Assyst Human-Solutions
- Rhino

OPTITEX



Optitex offers a CAD/CAM software package for the textile industry. The software has an 2D and 3D work environment for designing clothing patterns. The 3D workflow offers 3D anthropometric dimensioning of a human body. With the specialized fitting tools a design can easily be optimized for an optimal fit. Optitex has a pricing of \$1350 p/y.

Link: <https://optitex.com/solutions/odev/3d-production-suite/>

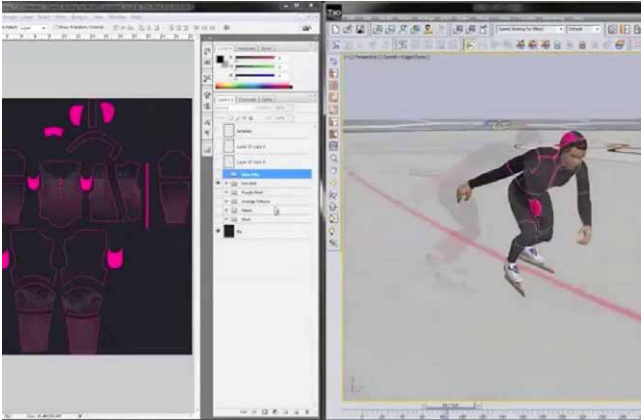
Advantages

- Intuitive workflow
- offers 2D and 3D pattern design
- It offers 3D simulation
- Able to import body scans
- Adjustable human model
- Input material properties

Disadvantages:

- Unknown if software can simulate the properties of neoprene

TUKA3D BY TUKATECH



Tukatech is an easy to use 3D apparel design and development software with an accurate virtual fitting simulator. The software is able to import 3D body scan data to replicate a 3D avatar.

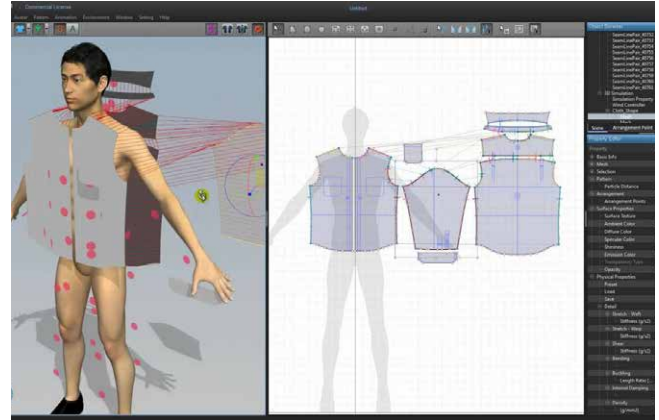
Advantages:

- pressure mapping and transparency view to locate problem areas.
- animation draping to analyse the stretch

Disadvantages:

- 2D approach to pattern design.

CLO3D BY CLO VIRTUAL FASHION



This company is founded in 2009 and offer different products for different garment design applications with a true-to-life 3D garment simulation technology. One of their products is Clo3D, which is a design software for apparel designers and brands. They also offer Marvelous Designer which is aimed for the design of virtual garments for games and animations with a real time draping engine. Clo also offers a virtual fitting platform called Benefit by CLO. People can make a personal avatar and can visually assess the fit of a product.

Price 600\$/m, 5400\$/p/y (50\$/m, 450\$/p/y for students)

Advantages:

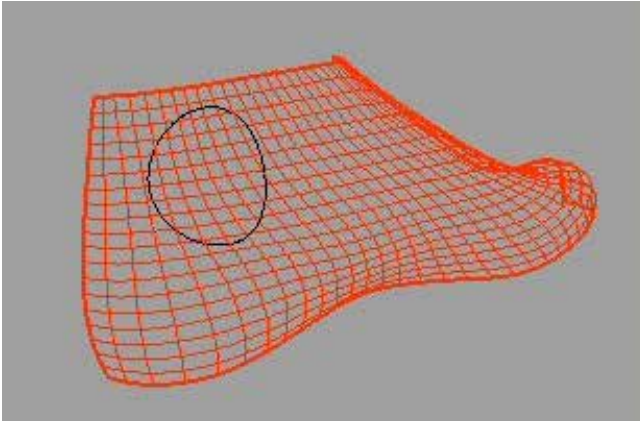
- Easy to use
- Combines multiple platforms for online fitting.
- Includes a 2D and 3D workflow
- Adjustable Mannequins
- Able to import body scans
- Personalized material input
- Specialized tools for stress and pressure analysis

Disadvantages:

- High focus on virtual garments
- expensive material property testing kit

APPENDIX 1: SOFTWARE ANALYSIS

RHINO TOOLS



There are a couple of flattening tools available in Rhino that can be used for flattening 3D surfaces into 2D surfaces. For instance Squish and D-Loft. In combination with the plug-in grasshopper, Rhino could be used for the creation and scaling of clothing patterns.

Advantages:

- These tools are free for Rhino users
- Accurate flattening technique
- Can use a body scan as basis

Disadvantage

- Not specialized for garment design
- No virtual simulation
- Extensive Rhino experience is required
- Doesn't incorporate material properties

LECTRA MODARIS 3D



Modaris 3D is a software package by Lectra for the design of soft materials. Their software is specialized for cutting systems in a wide variety of markets including fashion (footwear, apparel, accessories), automotive (interiors, car seats and airbags) and furniture.

Link: <https://www.lectra.com/en/fashion-apparel/product-development-modaris>

Advantages:

- Virtual draping
- Good integration with cutting hardware

Disadvantages:

- No 3D pattern creation

ACCUMARK GERBER



Gerber Technology is an American company that delivers CAD software and automation solutions for the apparel industry. One of their software packages is called AccuMark and is one of current industry-leading software for the fashion industry. AccuMark also offers a 3D design module that lets you visualise your design. Furthermore it is compatible with other hardware and software tools such as AccuScan, AccuPlan and AccuNest.

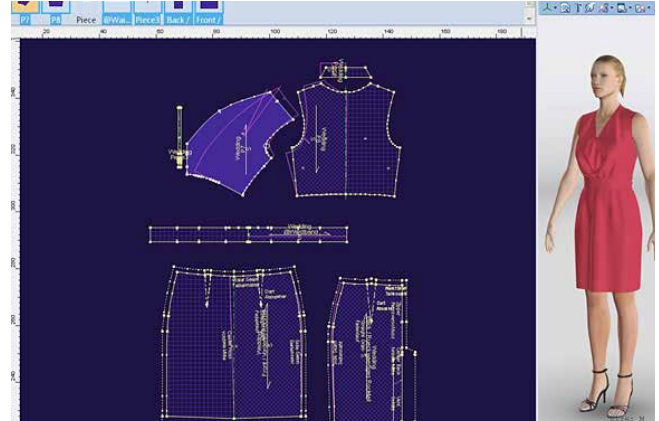
Advantages:

- Offers a 3D workflow
- Good integration with manufacturing hardware and software.
- Includes specialized grading features

Disadvantages:

- Doesn't offer 3D design input

ASSYST HUMAN-SOLUTIONS



This pattern design software offers powerful tools used to bring a design to the production phase. The focus is on automation of the cutting of clothing, upholstery, composites, leather, automotive and technical textiles in the UK and Ireland.

The price starts at around \$1500 for a one-time user.

Link: <http://assystbullmer.co.uk/products/software/>

Advantages:

- Offers virtual simulation
- Offers pattern nesting and optimization of the cutting path for hardware
- User friendly grading tools

Disadvantages:

- No 3D pattern creation

APPENDIX 2: MATERIAL PROPERTIES

The tested materials were gained from the current SRFACE Medium wetsuit. Swatches of 30*120 mm were cut out of the panels of this wetsuit. The following table shows the type of Neoprene, thickness, lining and weight of each swatch. The swatches were cut out in different directions to gain their directional stretching properties.

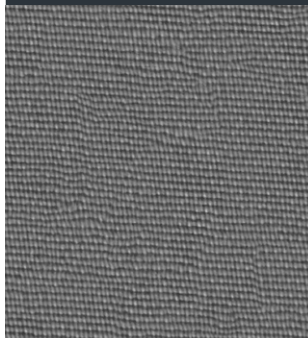
Weft, Warp and Bias swatches were tested. Not every material is tested in these three directions. This is because not every wetsuit panel was large enough to cut out 3 different swatches. On the bottom of the page the different textures are shown for the creation of digital materials.

| Panel location | Foam type | Thickness | Outside | Inside | Swatch weight |
|----------------|-----------|-----------|----------------|-----------|---------------|
| Upper Leg | X-FOAM | 5 MM | Nylon | Plush | 4,50 g |
| Chest/Back | Y-FOAM | 5 MM | Nylon | Plush | 4,98 g |
| Knee | Y-FOAM | 4,5 MM | Abr. Resistant | Plush | 3,97 g |
| Shoulder | X-FOAM | 3,5 MM | Nylon | Nylon | 3,34 g |
| Calf | X-FOAM | 4 MM | Nylon | Nylon | 4,13 g |
| Shone | X-FOAM | 5 MM | Nylon | Nylon | 4,10 g |
| Neck | X-FOAM | 2,5 MM | Nylon | Glideskin | 2,89 g |

ABR RESISTANT



TEXTURED



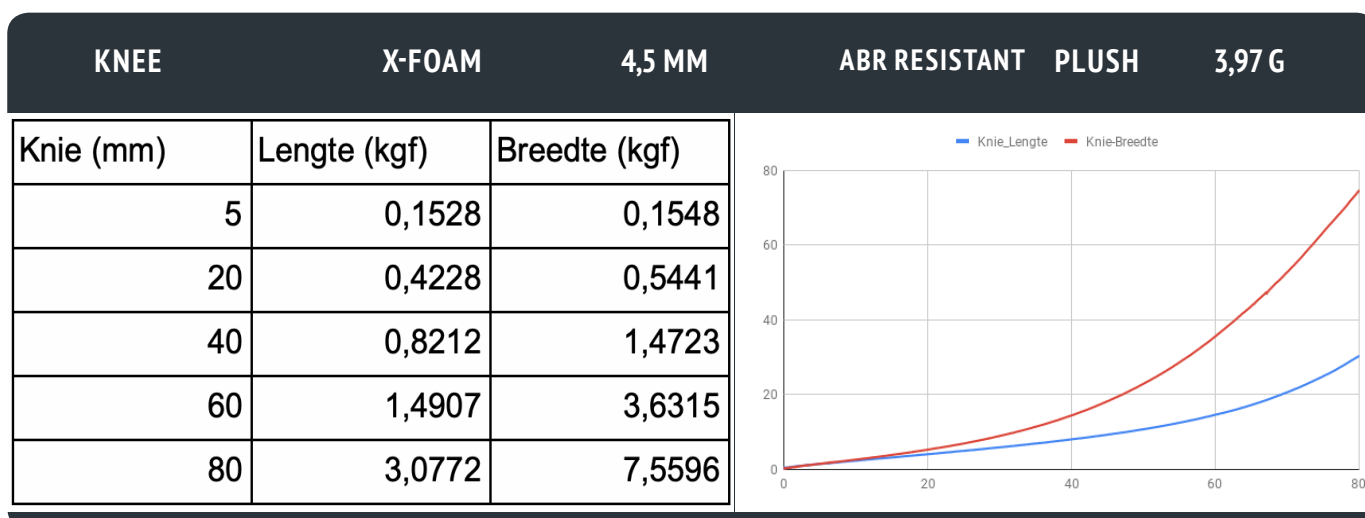
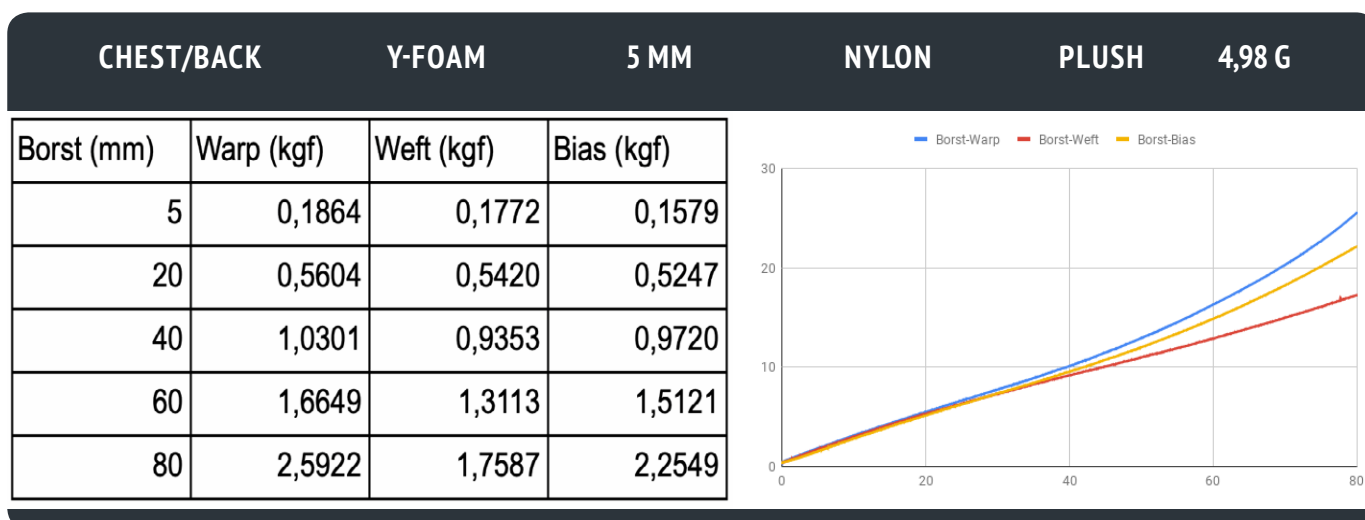
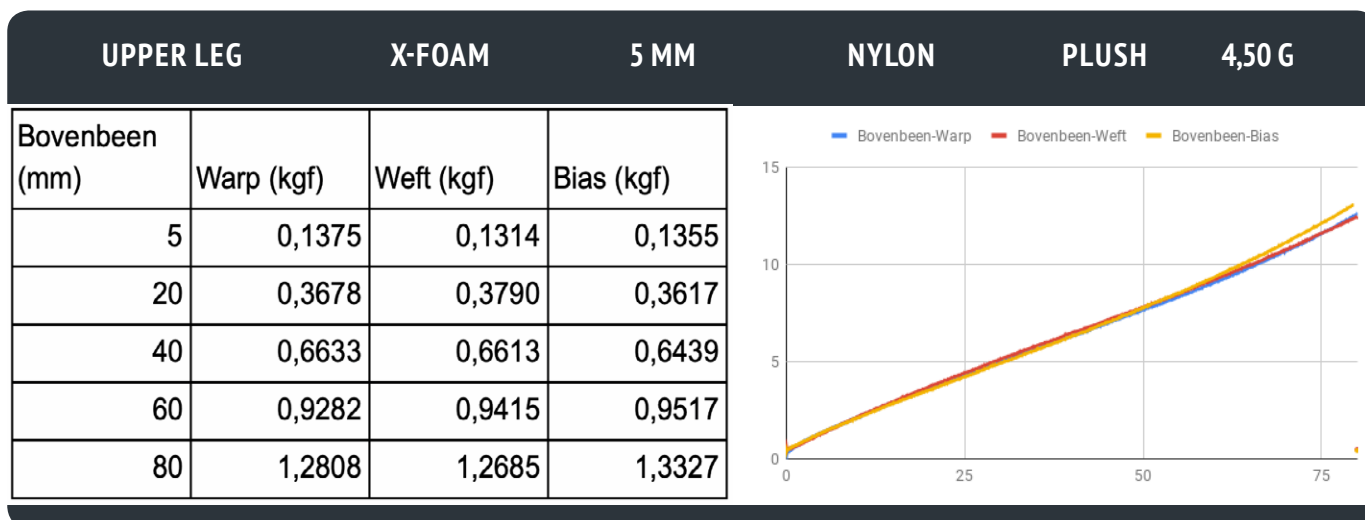
NYLON



GLIDESKIN



STRESS TEST RESULTS



SCHOULDER

X-FOAM

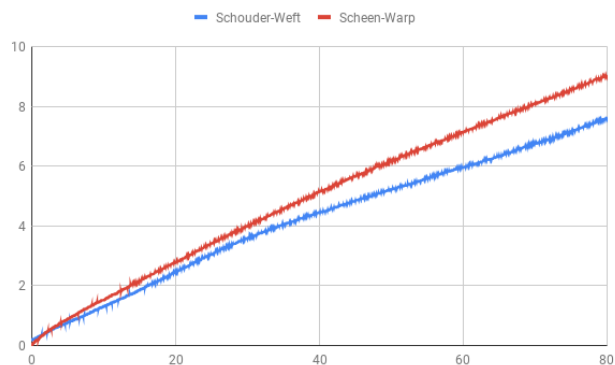
3,5 MM

NYLON

NYLON

3,34 G

| Schouder (mm) | Warp (kgf) | Weft (kgf) |
|---------------|------------|------------|
| 5 | 0,0896 | 0,0917 |
| 20 | 0,2863 | 0,2506 |
| 40 | 0,5237 | 0,4534 |
| 60 | 0,7265 | 0,6052 |
| 80 | 0,9170 | 0,7744 |



CALF

Y-FOAM

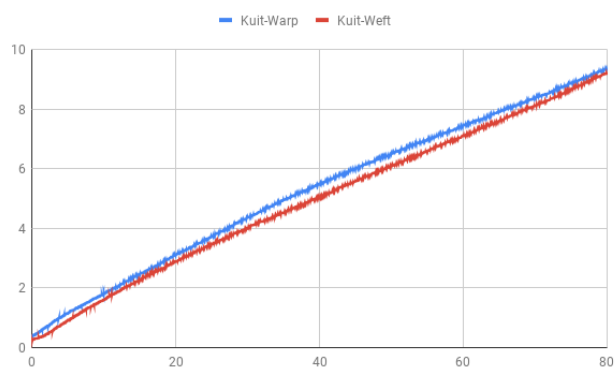
4 MM

NYLON

NYLON

4,13 G

| Kuit (mm) | Warp (kgf) | Weft (kgf) |
|-----------|------------|------------|
| 5 | 0,1202 | 0,0927 |
| 20 | 0,3158 | 0,2934 |
| 40 | 0,5594 | 0,5145 |
| 60 | 0,7550 | 0,7244 |
| 80 | 0,9506 | 0,9394 |



SHONE

X-FOAM

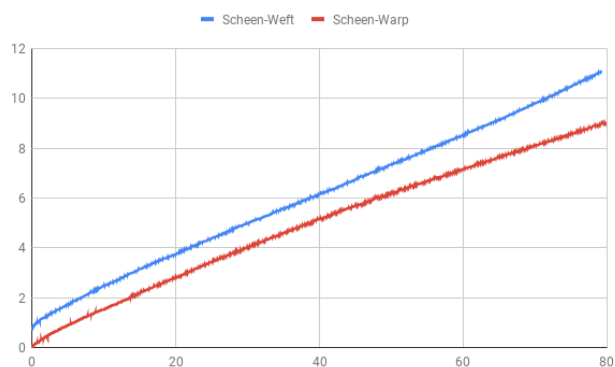
5 MM

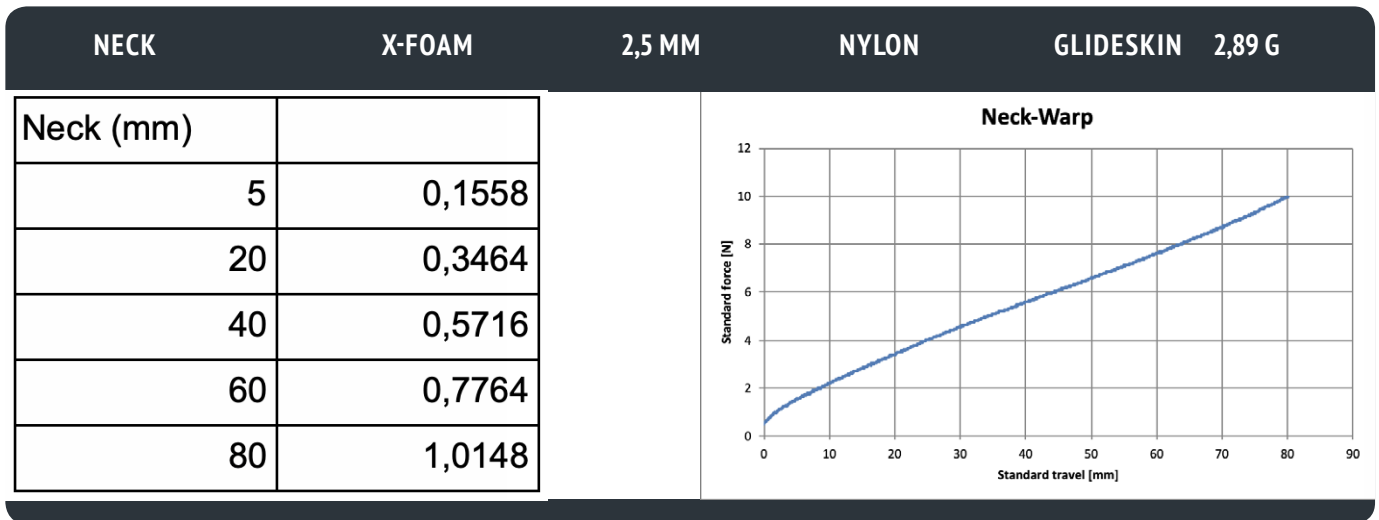
NYLON

NYLON

4,10 G

| Scheen (mm) | Warp (kgf) | Weft (kgf) |
|-------------|------------|------------|
| 5 | 0,0906 | 0,1681 |
| 20 | 0,2863 | 0,3790 |
| 40 | 0,5237 | 0,6215 |
| 60 | 0,7265 | 0,8620 |
| 80 | 0,9170 | 1,1300 |





BENDING TEST RESULTS

| Bending Test | Warp (cm) | | Weft (cm) | |
|--------------|--------------|---------------|--------------|---------------|
| | Touch length | Swatch Length | Touch length | Swatch Length |
| Knee | 7,8 | 8,4 | 7,8 | 8,4 |
| Neck | 5 | 5,9 | | |
| Shoullder | 6,8 | 7,2 | 6,8 | 7,2 |
| Upper Leg | 7,8 | 8,2 | 7,9 | 8,3 |
| Schone | 7,4 | 7,8 | 6,6 | 7,2 |
| Chest | 9,2 | 9,7 | 9,2 | 9,7 |
| Calf | 6,3 | 7,2 | 6 | 6,8 |

STESS TEST & BENDING TEST

