Shape-Integrated Knitting For Circular Knitting Principles And Enhanced Zero Waste Fashion Design.

Master Thesis
By Sem Janssen

Integrated Product Design

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Abstract

The fashion industry's significant global environmental impact, primarily driven by low-cost, high-volume production through wasteful and traditional manufacturing, necessitates sustainable alternatives that overcome limitations associated with current solutions, such as zero waste fashion design. This research investigated the potential of modern circular knitting techniques as a zero waste solution for garment production. Using an iterative Research through Design approach, this research developed a method for shaped circular knitting, integrating textile manufacturing and zero waste fashion design as a holistic process. By leveraging the inherent dimensional properties of knit structures, the research realised the versatile personalisation of garments without the need to redraw their pattern. The results demonstrate the feasibility of this approach based on the principles of existing large circular knitting machines by delivering a design toolkit and proof of concept through detailed designs and prototypes. These provide opportunities to eliminate pre-consumer cutting waste, simplify and reduce production, and improve garment design flexibility and personalisation.

(left) Blue zero waste jacket and (right) beige zero waste overcoat prototypes made as part of this research. (left) Modelled by Myrthe Coster and Sem Janssen.

Acknowledgements

After seven years as a student at the Industrial Design Engineering Faculty, I will finish with this thesis. IDE felt like the perfect combination of technical and creative doing when I started. And since my first course, I have never doubted this decision. This was my kind of place. And now, I am proud to present the last six months of this journey. In my first year, I picked up a sewing machine for my first project, and I haven't looked back since. So, I am incredibly grateful that I was able to combine industrial design research and my fascination for textiles and fashion.

And this project would not have been possible without my excellent supervisors, Holly and Eleni. Holly, my chair, when I first approached over a year ago about doing this project, I never imagined it would go this far. Thank you for all the countless hours you've spent thinking along, discussing, and showing me the world of textiles and fashion. Thank you for showing me new ideas, connecting me to the industry, and involving me in courses. You've changed how I look at my favourite things to design. Eleni, my mentor, from our first conversation, I knew you would fit this project perfectly. Thank you for your insights. Your expertise in industrial design and visualisation completed this project. Every meeting with you helped me organise my thoughts, and our shared design experience made for great conversations. To both of you, I genuinely feel we made an excellent team.

I also want to thank Linda and Rebekka for teaching and letting me use Günter (the STOLL industrial knitting machine). My apologies for all the broken needles and errors, and thank you for helping me fix him and not get mad. With perhaps some trust issues, I look back fondly at all of the adventures we've had with the machine. I also want to thank Danielle Elsener for teaching me about zero waste and lending me her design. With your help, I could focus on what mattered in the project. And a big shoutout to Bart for taking the amazing photos in this report.

To my family, thank you so much for all the encouragement, the enthusiasm when I brought new samples, and taking time to help me. To my friends and fellow industrial designers, thank you for taking me on breaks, seeing the sun, stretching my legs, and creating a space for my thoughts and feelings. To my roommates, thank you for the dinners, parties, adventures and being a great place to come home to.

My sincerest appreciation to everyone for being part of my journey.

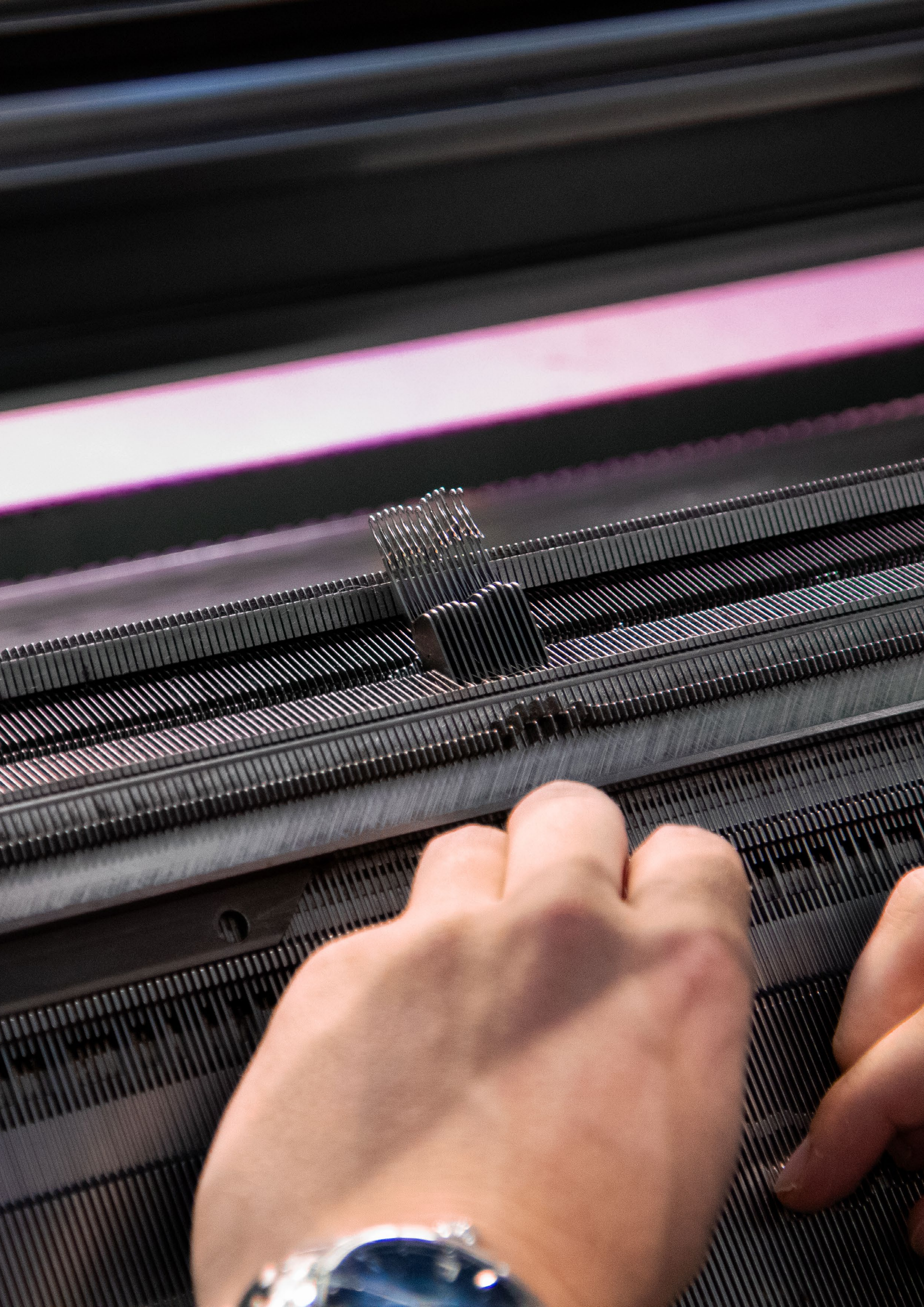
Toward Textile-Form Futures

This research, part of and funded by the Toward Textile-form Futures research group, envisions a future where textile-based products are sustainably produced on demand, locally, and free from waste and pollution. We aim to develop a strategy for implementing a local example of circular textile-form systems, like an integrated circular micro-factory. These systems serve as the foundation for larger funding initiatives aimed at exploring localised models of production across Europe. This strategy encompasses network development and the creation of preliminary methods, models, and prototypes tailored to the context of the Dutch and Greater Rotterdam Region. Ultimately, our project seeks to make a significant impact by nurturing societal resilience through offering sustainable, adaptable textile options to end-users while fostering innovation in the local textile industry.

Through a transdisciplinary approach, Toward Textile-form Futures stimulates collaboration with experts spanning spatial and urban planning, sustainability transition in fashion and textiles, creative entrepreneurship, circular economy, textile engineering, garment and form design, and computational design. Together, we strive to pioneer a future where textile production is ethical, sustainable, and deeply rooted in circular principles [89].

Table of Contents

**The text references to literature and other sections of the report are clickable.*



1. INTRODUCTION

1.1 Summary

The fashion industry faces a massive problem. Today, the industry drives overconsumption through high-volume, low-cost production and encourages unsustainable consumption habits, exploiting individual expression for profit [33]. This culture of disposability causes an endless cycle of trend-driven wardrobe updates, resulting in substantial environmental consequences [28]. Progress remains slow despite attempts to promote sustainability through initiatives like recycling and sustainable sourcing [38].

Garments are made with fabric often produced by the knitting industry [69]. This makes the knitting industry a significant contributor to sustainability issues, as it prioritises speed and cost over sustainability and consumer-benefit-focused innovation [55]. We need a comprehensive approach to reducing demand and implementing new garment design and production methods. Pre-consumer textile waste, particularly cutting waste [12], remains a massive issue, with traditional cut-and-sew garment production wasting approximately 15% of the material [1]. Zero waste fashion design (ZWFD) offers a promising solution to pre-consumer waste by combining garment pattern pieces like puzzle pieces to utilise the whole fabric [35, 74]. However, when used with rectangular textiles that are not designed for zero waste, this pattern design method has drawbacks that limit its adoption by the industry. Over recent years, researchers explored other opportunities to improve the functionality, expression, and sustainability of textiles and garments through new approaches to weaving [8, 56], knitting [50, 64, 77, 83], and material innovations [69, 78, 79], which enable new form creation within textiles.

This research is a three-part endeavour that has established a novel method for shaping circular knitted textiles. It has also developed a design process to implement this shaping method in existing zero waste and traditional pattern-designed garments. This process simplifies the design process and incorporates the zero waste methodology, while also addressing its associated shortcomings. The outcomes of this research are a design toolkit (Phase 1), a design process, and prototype jackets (Phase 2 & 3). These jackets are tailored to fit the human body and offer flexibility in style, similar to traditional garments, but without the associated waste.

1.2 Motivation

This research aimed to develop a method for designing zero waste garments through shaping circular knitted textiles in combination with digital design tools. Building on existing zero waste fashion design research [25, 48, 74], composite pattern weaving [5, 68] and research exploring fully fashioned and whole garment knitting and weaving [46, 57, 93], this research sought a function-integration method for the production of circular knitted textiles. It focused on improving the designability of zero waste cut-and-sewn knitted garments, the quality of garments for consumers on an individual level, and streamlining the production process compared to traditional cut-and-sewn garment manufacturing.

In preparation for and as part of the Graduation Project's learning goals, I learned the fundamentals of machine knitting on a domestic Brother knitting machine, followed by a knitting course from Knitwear Lab in October 2023. I programmed, knitted, and assembled all samples produced during this research.

1.3 Stakeholders

This research aims to design and develop a solution that benefits all relevant stakeholders, including the user/consumer, producers, designers, and the environment. The section below describes the needs and tensions of each stakeholder.

Consumers

Personal Expression

Consumers seek garments and textiles that allow them to express their individuality and personality [84]. They prefer specific colours, patterns, styles, or designs that resonate with their unique tastes and identities. Manufacturers that offer customisable options or unique designs cater to this need for personal expression, allowing consumers to feel a sense of ownership and authenticity.

Quality and Price

Consumers value garments and textiles that exhibit high-quality craftsmanship and materials. Quality encompasses factors such as durability, comfort, fit, and longevity. They expect their clothing to withstand regular wear and tear, maintain its shape and colour over time, and offer comfort and functionality [86]. Brands prioritising quality assurance and using premium materials and manufacturing techniques appeal to consumers seeking long-lasting and well-made garments. Positive reviews, testimonials, and brand reputation influence their purchasing decisions [6]. While some consumers prioritise quality over price, others are budget-conscious and seek value-oriented options that balance quality and affordability.

Social Influence

Consumers use garments and textiles for social expression and identity representation. They seek clothing that aligns with their cultural, social, or community affiliations and values. Fashion trends, cultural movements, and social media influence consumer preferences and purchasing behaviour, driving demand for clothing that reflects current styles and cultural zeitgeist [51]. Brands and manufacturers that embrace diversity, inclusivity, and social responsibility resonate with consumers seeking representation and connection through their clothing.

Manufacturers

From a production standpoint, material, time, and labour efficiency are crucial in the textile and garment manufacturing process to ensure speed, affordability, and quality [72]. By integrating form creation and functionality into textiles, manufacturers can minimise the need for additional assembly steps, offering cost and time savings opportunities without requiring new or extensive modifications to existing equipment.

The reproducibility and consistency of product quality are imperative in manufacturing. Consistently high-quality products command higher prices and boost the manufacturer's reputation [71]. Conversely, any deviations in quality can deter buyers and tarnish the factory's reputation. Assessing the reproducibility of the manufacturing process, including factors like skill requirements and inherent process inconsistencies, is essential for ensuring consistent product quality and efficient production.

Brands

Brands face a dual challenge of balancing profitability and sustainability. While there is increasing pressure to meet sustainability goals to maintain brand value [36], the fast-paced nature of fashion trends necessitates designing products that align with consumer preferences to sustain sales. Brands often compromise profits, production, consumer demand, and sustainability efforts [70].

The demand for a fast, adaptable, and efficient design process poses a barrier to adopting new design methods like ZWFD [40]. These methods traditionally lack flexibility once a pattern is established, hindering efficient grading/marking for new seasons. Chapter 2.2 explores this issue in detail. The lines between designer, brand, and manufacturer can blur with emerging methods and tools. While multiple parties performing various stages of the process can enhance efficiency, clear boundaries are essential to avoid redundant work.

Environment

As Chapter 2.1 further explains, the environment is a casualty of the colossal fashion industry. The planet has limited resources, and even renewable resources require time and space to cultivate. Therefore, any project should consider its impact on the planet and aim for a reduction compared to the state-of-the-art.

Sustainability efforts pose a difficult question for the existing business model where profits are king. Saving on waste is good for the planet as it reduces material needs, which require raw materials, water, and energy. Reducing raw materials saves costs, but if the necessary changes cost more money elsewhere, like expert staff, new hardware or software tools, or time, it is not beneficial for the manufacturer to adopt the new method. Furthermore, with consideration for regulations and the UN goals for sustainability, a new method should not be a step back in terms of sustainable impact.

Designers

For designers, a thorough understanding of the subject and proficiency with essential tools for framing, conceptualising, prototyping, and evaluating design ideas are vital for an effective process. A better process can facilitate iterative refinement, allowing for more iterations of the process with the same resources. Prioritising tasks and perspectives becomes more manageable with a well-defined workflow, ensuring optimal use of time and resources.

There is a lack of integration between textile design, production, and garment design workflows. This research aims to advance the integration process of these professions. Anticipating iterations between the pattern and projected structures and documenting these steps will refine the workflow.

Effective design tools are essential for precise and efficient operation. Too many tools can overwhelm designers and require a large workforce, increasing management complexity and cost. Hence, minimising the tools required ensures accessibility and adoption within the industry.

Back to table of contents

2. CONTEXT

This chapter discusses the context of this research. It explains the current state of the fashion industry, sustainability, and consumer behaviour, followed by looking to the future and what methods exist to reach each stakeholder's goals.


REVERSE
SINGER
Heavy Duty

2.1 Sustainability

Current State of The Fashion Industry

In today's fashion landscape, overconsumption is a growing challenge fueled by the prevalent model of producing high-volume, low-cost items [33]. While clothing and fashion serve as vital means of individual expression, the industry often capitalises on this and leverages individual representation to increase sales. Consumers are introduced to trends each passing season, enticing them into a perpetual cycle of wardrobe updates. Companies build complex supply chains to keep up with consumer demand whilst keeping prices low, disregarding the negative impacts of the system. Due to the complexities of the industry, overproduction is inevitable and an accepted consequence [7]. Of the approximately 150 billion garments produced annually, 10 - 30% are never sold and rarely recycled [11]. This needless production encourages unsustainable consumption habits and breeds a culture of disposability, where yesterday's fashion is swiftly discarded in pursuit of the latest trend. Consequently, individuals feel pressured to keep pace with fleeting hypes, while garments that don't align with the latest aesthetic are unfairly stigmatised. This systemic issue strains environmental resources and undermines sustainability principles [91], underscoring the urgent need for a paradigm shift towards more conscientious consumption practices in the fashion industry.

The fashion industry's environmental impact is enormous, contributing as much as 10% of global carbon emissions [29], illustrated in Figure 1. and devouring 391 kilograms of raw materials per person in the EU in 2020 [28]. From a global lifecycle standpoint, textile consumption in Europe ranks fourth in environmental and climate change impact on average in 2020. Additionally, on average, textile consumption has the third highest impact on water and land use and the fifth highest regarding resource consumption and greenhouse gas emissions [27].

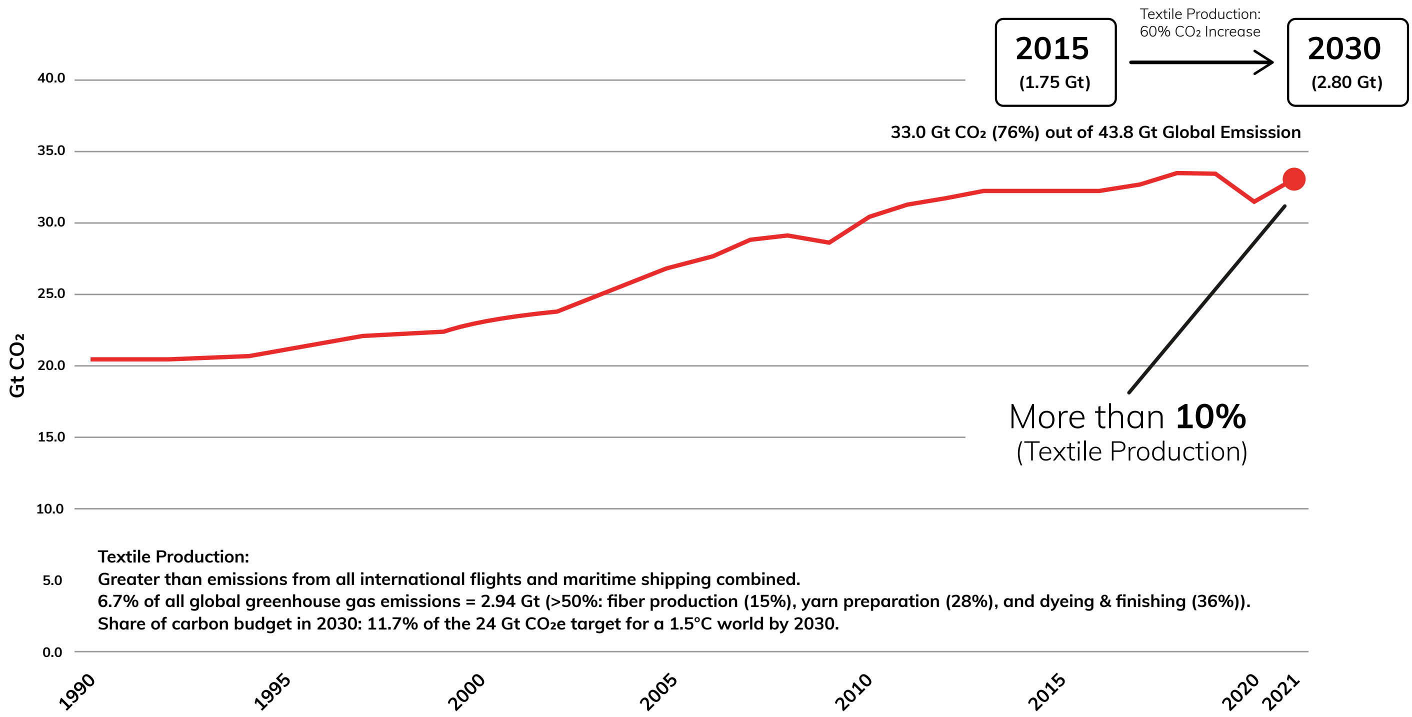


Figure 1, The contribution of the textile industry to global emissions [31].

Despite advancements in fabrication methods, which Chapter 2.3 discusses further, fabric waste during garment production remains a persistent challenge. It ranges from 10% to 20%, illustrated for a pant pattern in Figure 2, depending on the type of garment and fabric used [1].

This fabric waste means that out of the annual 400 billion square metres of textiles produced, approximately 60 billion square metres go to waste (Chung, 2016), with 87% ending up incinerated or landfilled [29].

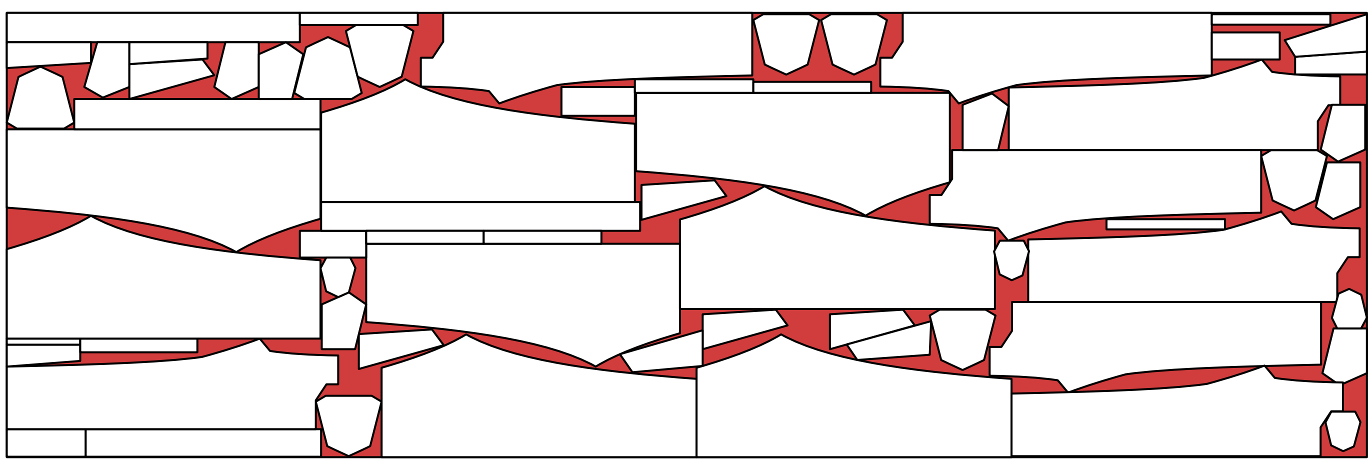


Figure 2, Nested jeans pattern [44]. The empty space (roughly 15%) between panels highlighted in red.

From a Life Cycle Assessment (LCA) perspective, yarn spinning is the most significant contributor to the environmental impact of a base textile, and the energy consumption of a kilogram (kg) of yarn is inversely proportional to the yarn size, meaning thinner yarns have a smaller impact. This result typically means that woven textiles have the greatest environmental impact, followed by knitting and non-woven textiles, since knitting, on average, utilises thinner yarns for production [92]. Furthermore, the market size of the knitting industry was €105 billion in 2022 [54], contributing 30% of the total textile production [52]. The market share of large circular knitting machines is only 1.9 billion [16], compared to 5.4 billion [43] for flatbed knitting machines. However, this is not comparable in terms of utilised material, as circular knitting machines are much more efficient in their production, although those numbers are not publicly available.

Furthermore, knitwear and knitted textiles like underwear and tops, integral to garments requiring stretch or close contact with the skin, are typically the garments that come closer to the 20% wasted material [30]. Knitting as a textile manufacturing method has enormous potential to improve the fashion industry's environmental impact.

Efforts to foster sustainability in the fashion industry are increasingly gaining momentum, mainly through initiatives targeting sustainable materials and promoting recycling and repurposing practices. With consumers increasingly demanding eco-friendly options, the industry has started prioritising sustainability in material sourcing. This includes efforts in adopting recycled fibres, implementing improved dyeing processes to minimise environmental impact, and creating more eco-friendly material alternatives.

Despite these undertakings, there is still a long way to go to a sustainable future. The rate of textile recycling remains alarmingly low, hovering around a mere 1% [38]. While donating clothes and encouraging hand-me-downs offer avenues for extending the lifespan of garments, there remains a notable absence of focus on reducing consumer demand and production volumes. Currently, the industry works from a linear system of consumption (Figure 3). It largely overlooks initiatives for reducing overconsumption and facilitating easier garment repair on a large scale, highlighting the industry’s attitude of prioritising profits over sustainability efforts.

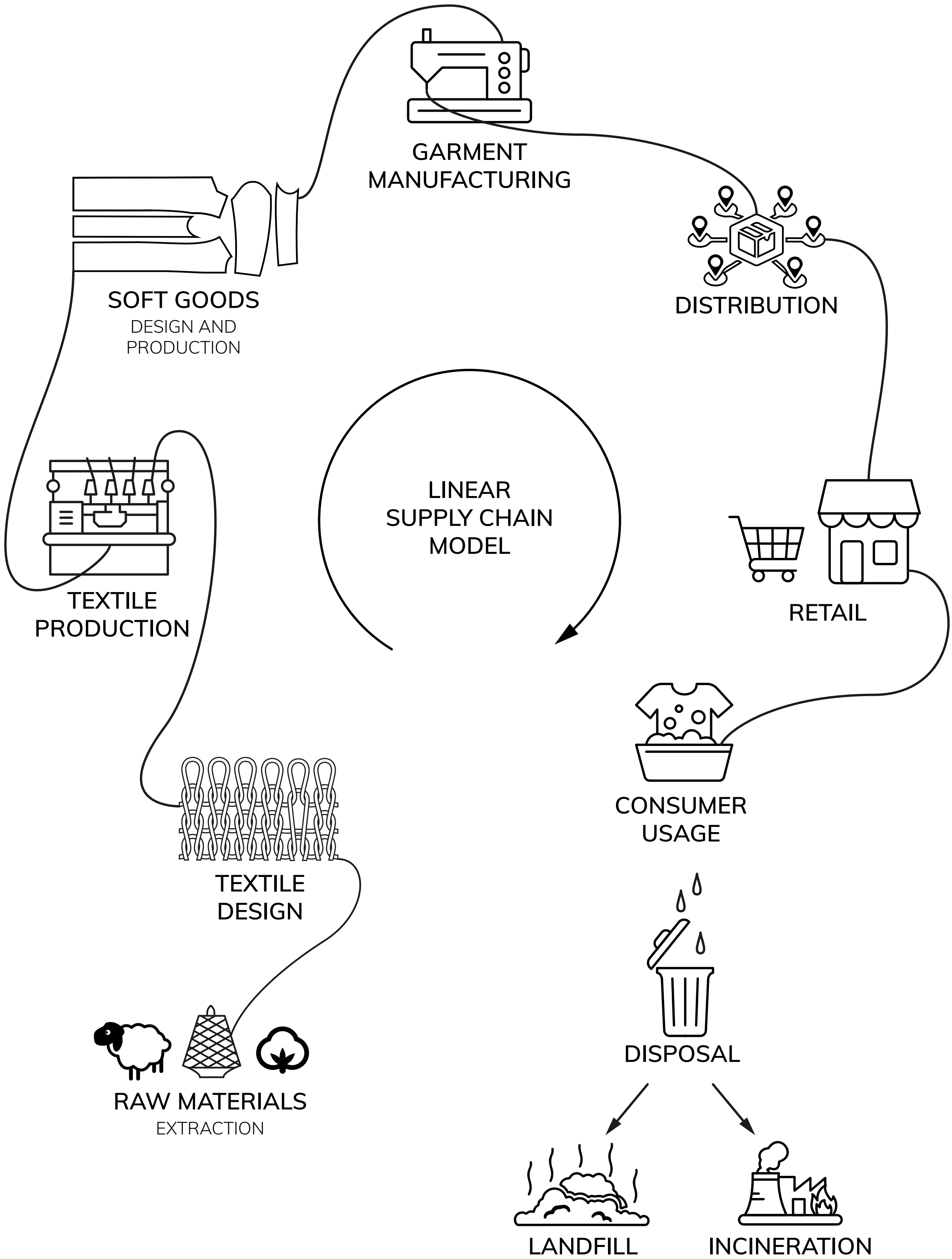


Figure 3, Current linear system of materials and consumption of the fashion industry.

A Circular Economy

As previously illustrated, the fashion industry, specifically the knitting industry, contributes to many unsustainable practices, operating within a predominantly linear system that extracts resources, manufactures products, and discards the materials. The fashion and knitting industries must undergo a profound reinvention, fundamentally altering how garments are produced and utilised [18]. Sustainability efforts advocate [23] to transition from a linear fashion system to a circular fashion economy, which presents a comprehensive approach to addressing pressing global challenges such as climate change, waste, pollution, and biodiversity loss.

At its core, the circular economy framework (Figure 4) revolves around three guiding principles grounded in design: the elimination of waste and pollution, the circulation of products and materials at their highest value, and the regeneration of nature [24].

This means 'ensuring that products are used more, are made to be made again, and are made from safe and recycled or renewable inputs.' [23]. This incorporates strategies such as enhancing garments' emotional and physical durability, promoting reuse and repair, and embracing design approaches that facilitate composting, disassembly, recycling, and remaking. This research aims to address the waste and pollution inherent in knitted garments while upholding their quality and preserving consumers' personal connection with their clothing.

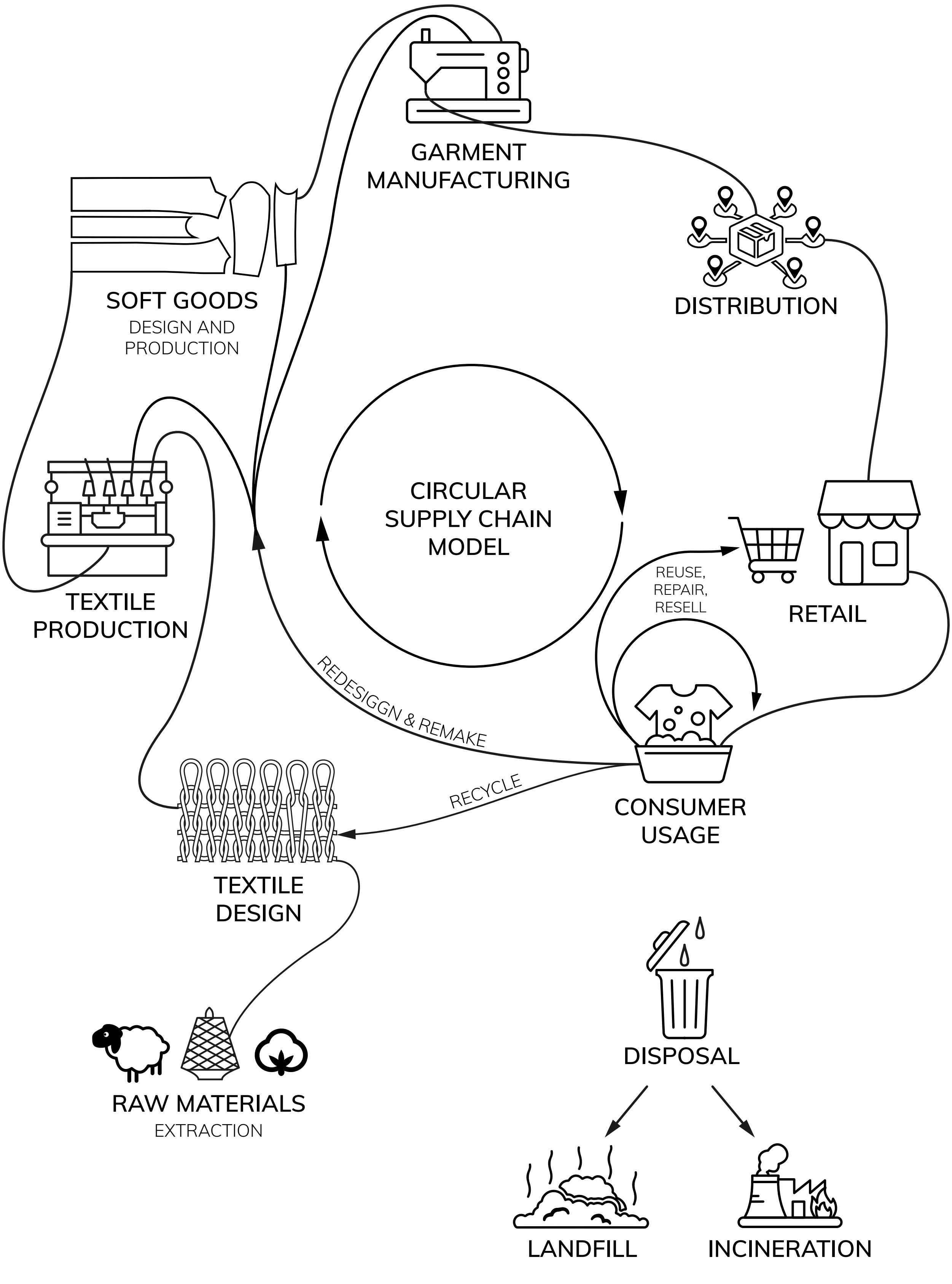


Figure 4, Proposed future system for materials and consumption of the fashion industry.

Achieving a Future State

To reduce the impact of knit textiles and garments, innovative strategies can revolutionise production processes, minimising pollution and waste while enhancing efficiency. One approach involves streamlining the garment production process to reduce the number of production steps, thereby diminishing the environmental footprint associated with manufacturing. Formed textiles offer a promising solution, enhancing garment fit while reducing material usage and labour requirements. Circular knitting is a significant area within textile manufacturing where research could integrate form creation.

Knitting has enormous potential for improving the fashion industry's environmental impact, and circular knitting is used for everything from underwear and T-shirts to sportswear and medical garments [69]. By integrating form creation into circular knitting, formed textiles can streamline production and enable the creation of new garment designs that were previously unattainable with conventional methods. Inspired by the success of whole garment weaving and 3D weaving techniques [8, 56, 57, 93], this approach has the potential to tackle the exploitative, time-consuming and wasteful practice of the cut & sew construction method of how garments are made now by combining knit textile and garment manufacturing.

Research has shown that consumers play a crucial role in reducing the fashion industry's greenhouse gas emissions. By expanding the lifespan of a garment from 30 to 60 uses, its greenhouse gas emissions footprint can be reduced by almost half [22, 75]. This significant reduction in emissions is possible when consumers use their clothing more frequently and for longer periods. Therefore, a shift in consumer behaviour towards consuming less and utilizing clothing more efficiently is a key step in minimizing the environmental impact of fashion consumption.

Changing the consumer's perspective on clothing ownership and usage can be achieved through the clothing's perceived value. Generally, custom-made and high-quality garments are better cared for [66]. Additionally, personalised clothing is made to order and thus prevents overproduction and the necessity for stock that needs to be stored and discarded if it is not sold [76]. Moreover, personalised garments fit better and are more thoughtfully produced, which means consumers tend to view these more like investments. Consumers wear these garments more and better care for them; however, for many, custom-made garments are not accessible. To improve this, a combination of local production and automated tailoring could help bring costs down, since labour is the largest cost factor in Western countries [26]. This approach not only reduces costs but also enhances the quality and sustainability of the garments, making them more accessible to a wider consumer base.

By shifting manufacturing closer to the end consumer, the industry can reduce the environmental impact associated with transportation and enhance the customer experience by minimising the delay between purchase and ownership. Embracing localised production means transferring manufacturing operations to regions like Europe and sourcing materials and other inputs from local suppliers. This approach creates a more sustainable supply chain and builds stronger connections between producers, consumers, and local communities.

Finally, advancements in digital design tools have streamlined the garment design process. Software programs like CLO3D [15] empower designers to iterate rapidly in a digital environment, resulting in material prototype savings during the design phase. This reduces costs and enhances the fit and quality of the garments, as illustrated in Figure 5. By leveraging digital solutions, designers can achieve greater precision and efficiency in their work, ultimately leading to more sustainable and high-quality clothing production [34]. However, these programs are tailored for conventional garment design and thus are limited in their ability to simulate on the yarn level or accurately represent complex morphing materials.

Figure 5, Comparison of a garment simulated in CLO3D and the real-life version [15].

2.2 Current Textile and Garment Context

This section clarifies how textiles are made and what they are used for in the broadest terms. It narrates the principles related to different forms of textile production and goes more in-depth into the principles of knitting and its benefits.

This section also explains the general steps for garment design and manufacturing. This includes designing a garment, the pattern, what labour is involved in cutting and sewing a garment and finishing.

From Yarn To Textile

Nearly all garment textiles are made with weaving or knitting. Both approaches take yarn and interlace it either with other yarns or with itself, creating a fabric that functions as a resource for manufacturing products. Textiles can have many different combinations of properties, like drapability, flexibility, elasticity, tensile strength, wear resistance, weather protection, insulation, breathability, conductivity, etc. The yarn material and manufacturing method are usually chosen based on the required textile properties. Chapter 4.1 discusses these and other textile production variables further. Weaving is typically used for inelastic materials that are stronger for garments, like pants or other applications. Knits have a natural stretch, and knitting processes have more opportunities for shaping; thus, knitted textiles are more commonly used for garments worn close to the skin. Chapter 2.3 dives deeper into the details of shaped knitting.

Material Process

Textiles are in nearly every aspect of daily life and industry. They are used for clothing (also known as garments or apparel), furnishing, accessories, and technical and industrial applications. From start to finish, the production of textiles can be summarised in five steps (Figure 6). Firstly, (1) sourcing the base material, which can be grown, extracted or mined and turned into a fibre. (2) These fibres are spun into yarn, and (3) woven, knitted, or otherwise turned into textile. The textile is then (4) finished before it is (5) assembled into the final product.

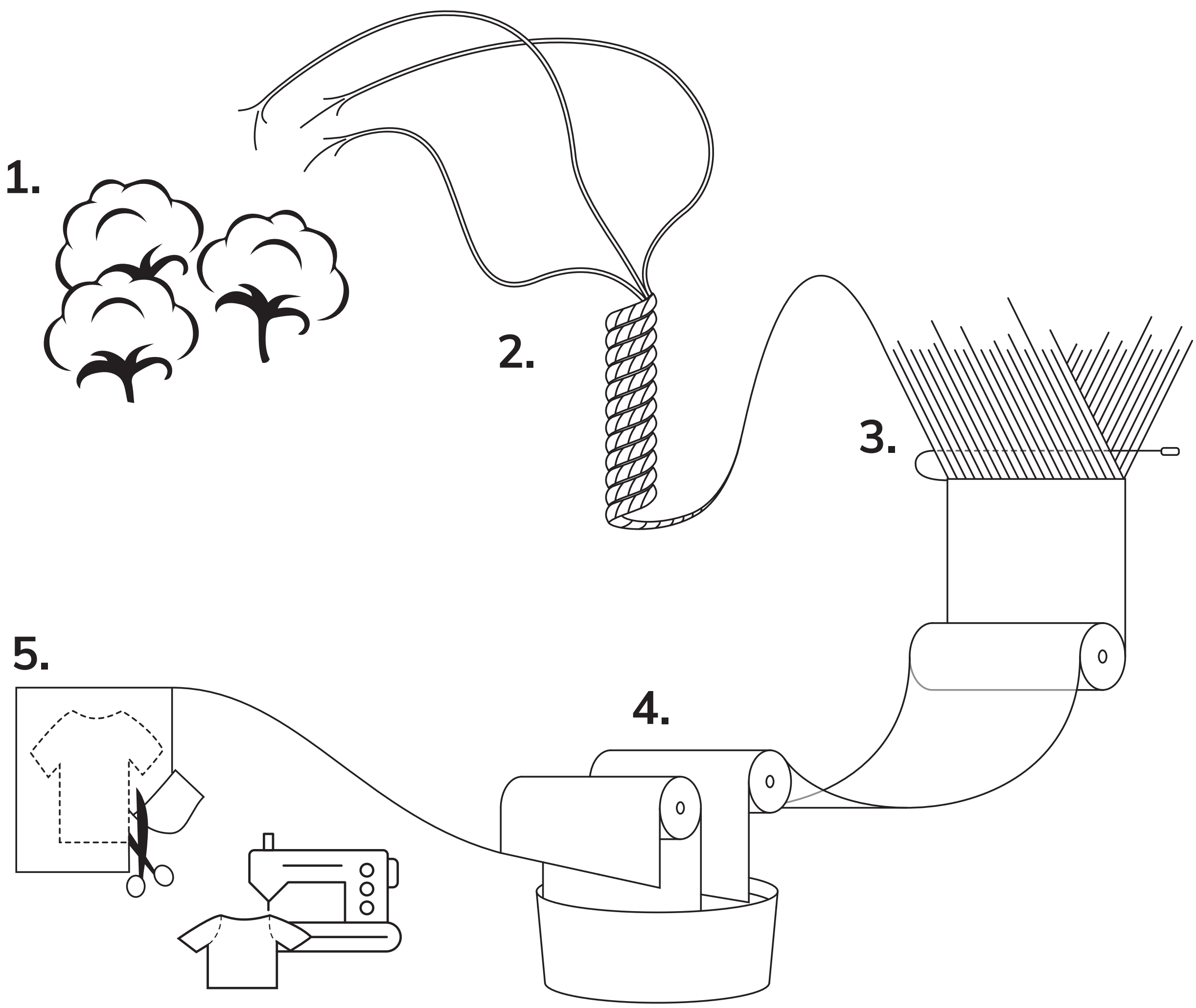


Figure 6, Process steps of yarn, textile, and soft goods production.

Garment Design and Production

Conventionally, garments are designed, developed, and produced in larger quantities. The process generally consists of nine steps, divided into design or production stages outlined in Figure 7. Please note some steps exist in both stages. (1) All garments start with the design stage. Designers draw inspiration from various sources and create sketches or digital renders visualising the garment's aesthetic and functionality. This process also includes prototyping and initial sampling. (2) Technical designers translate these ideas into detailed technical drawings, specifying dimensions, materials, and construction techniques. (3) Patterns are created based on the technical designs. Pattern makers use specialised software or traditional methods to draft patterns that serve as templates for cutting the fabric. (4) Meanwhile, the fabric is selected based on the design requirements, including colour, texture, weight, and performance characteristics.

(5) The sourced fabric is laid out in layers and cut according to the patterns. (6) The cut fabric pieces are assembled according to the garment's design. This typically involves sewing the pieces together using industrial sewing machines and instructions to ensure accurate and consistent construction. (7) Assembled garments can undergo various finishing processes. This may include adding hardware like zippers and hemming, edge finishing and steaming to achieve the finished look. These steps are also present in initial garment design, prototype making, and industrial production of garments. This research assesses these steps for the first purpose.

(8) Garments are subject to quality control checks throughout the manufacturing process and checked again when finished. (9) The finished garments are packaged according to client demands and prepared for shipment to retailers, wholesalers, or directly to customers. This process provides a general overview of how clothing is designed and manufactured. However, variations may occur depending on factors such as the complexity of the design, the scale of production, and the specific requirements of the manufacturer or brand.

Normally, these steps are performed separately in sequence, which does not allow for the integration of on-demand personalisation production. Design and production steps need to be considered holistically to ensure effective integration and progress to the future state.

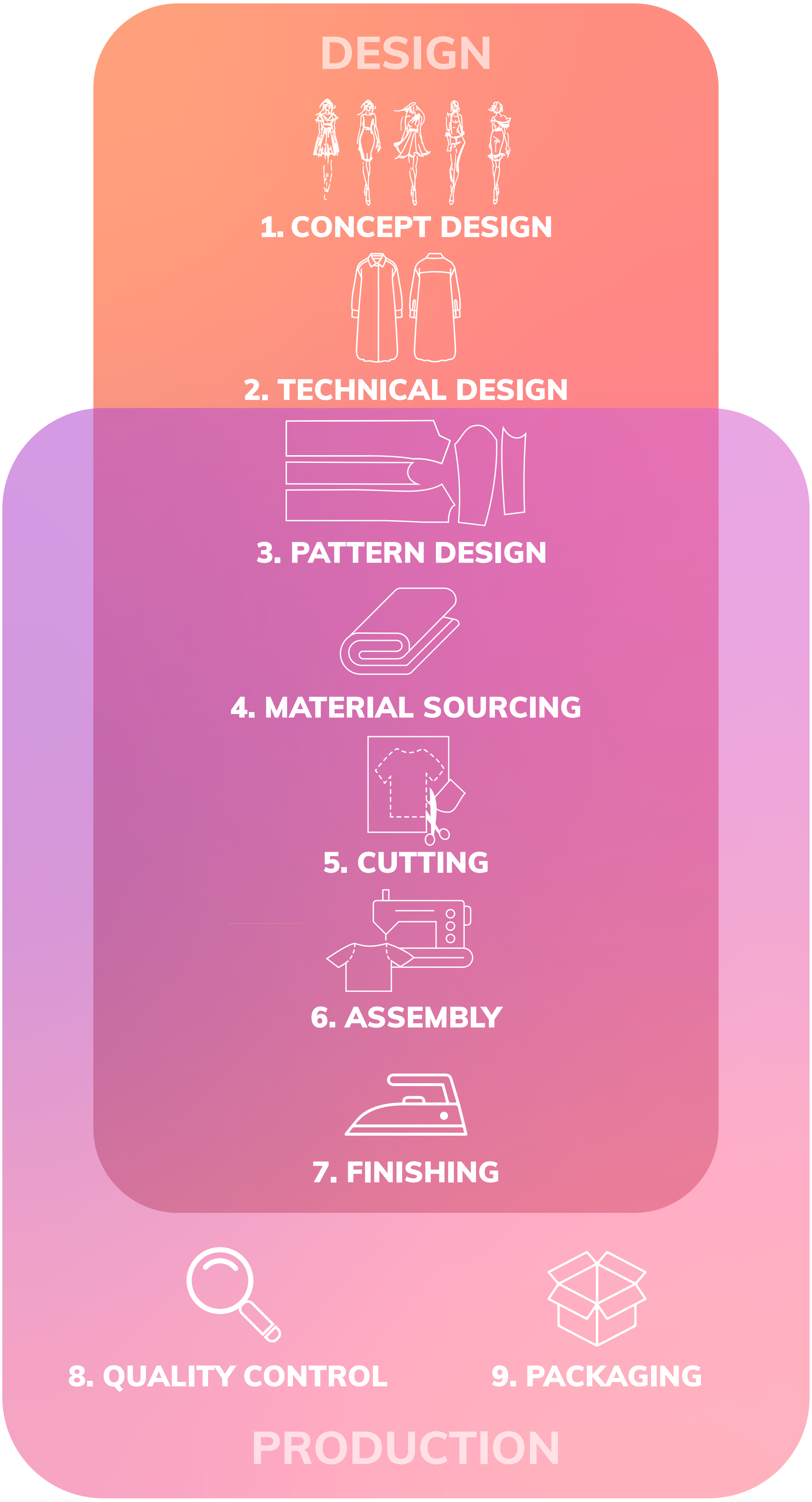


Figure 7, Design and production process steps for a garment.

Zero Waste Fashion Design

ZWFD is a design approach that minimises or eliminates textile waste in the garment production process. Unlike garment pattern designs, which often result in leftover fabric scraps in landfills, ZWFD utilises the whole fabric. Pattern elements of a garment are fitted together so that no fabric is wasted during the cutting. This design approach eliminates these spaces between the pattern pieces (Figure 8). Garment patterns are designed to be interlocking puzzle pieces, or using up leftover pieces of fabric artistically to make decorations is the essence of this technique [35]. Unlike conventional fashion design and manufacturing, which is linear, ZWFD proposes a holistic approach to the process, avoiding a hierarchy and allowing a fluid interplay between all parts [74]. To modernise the approach, development in the automation of the patterning process through computational techniques is also explored with various levels of success [25].

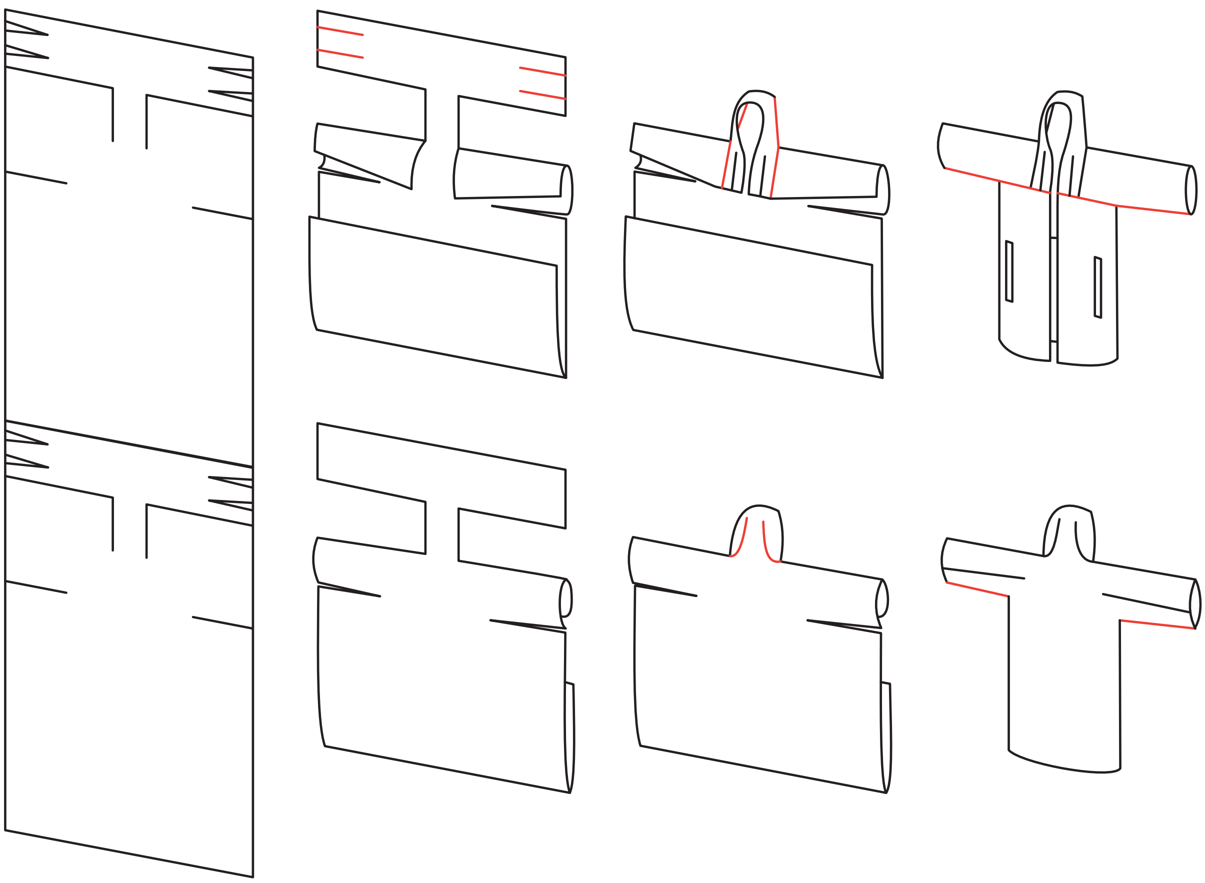


Figure 8, Zero waste garment pattern for a poncho. Shaping is achieved through cuts instead of individual pattern elements. The garment is sewn over the red lines in multiple steps from a single piece of fabric. [73]

Knitting Technologies

Knitting, as an industrial process, is a highly versatile method for creating textiles and clothing on a large scale. It utilises many tiny needles (see Figure 9) in specialised machinery to produce fabrics; these machines can knit various types of yarns and shapes, using various methods. This research focussed on weft knitting with wool. Weft knitting uses a single yarn to form loops across the width of the fabric, creating rows of stitches that interlock with each other (see Figure 10). Weft knitting is done on various machines, namely circular and flat knitting machines.

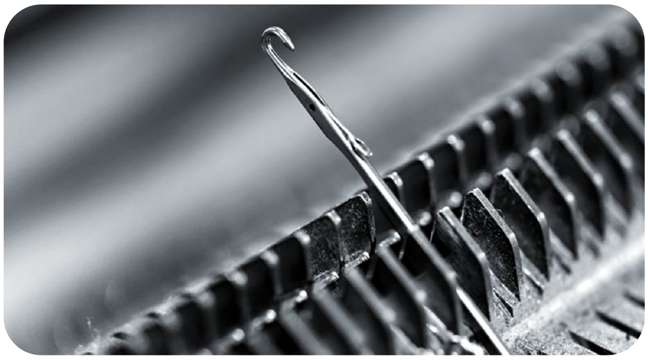


Figure 9, Close up of a machine needle in a flat bed knitting machine.

Knitted fabrics are measured in height and width, called the course and wale length. A course consists of a row of loops (counted by amounts of needles) perpendicular to the direction of the knitted textile, corresponding to the weft of a woven fabric. A wale consists of a column of loops (counted by the number of knitted rows) running lengthwise in the direction of the knitted textile, corresponding to the warp of a woven fabric. A wale is usually knitted on the same needle.

Figure 10, Cross section of a double-layered knitted fabric.

Flat and Circular Knitting

Flat knitting produces fabric in flat panels, with each row of stitches knitted back and forth in a discontinuous motion. The knitting machine's width limits the fabric's width and is thus less suited for manufacturing large rolls of textiles. The discontinuous nature (Figure 11) of the machine lends itself to the shaping of a knit. However, what enables the design flexibility also limits production efficiency, as demonstrated in the comparison between flat and circular knitting in Table 1.

Circular knitting involves knitting fabric in a seamless tube or cylinder shape and having a circular arrangement of needles that knit in a continuous loop (Figure 12), allowing for rapid formation of fabric. Fabrics produced through circular knitting can vary in circumference and diameter, depending on the size of the knitting machine and the number of needles. These machines are widely used in garment factories, knitting mills, and other textile manufacturing facilities worldwide.

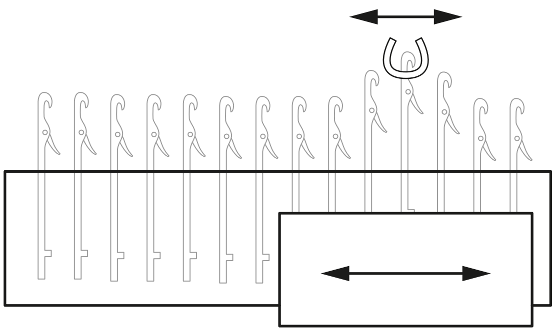


Figure 11, Abstract visual of flat bed knitting. The carriage moves side to side, actuating needles to knit a fabric.

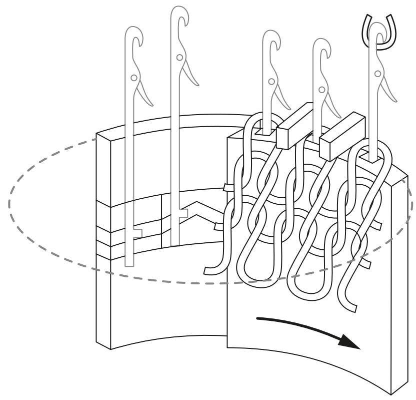


Figure 12, Abstract visual of circular knitting. The system moves in a circular continous motion, actuating needles to knit a fabric.

Circular knitting is fast compared to flat knitting. Exact numbers are hard to determine, because the amount of fabric produced is highly dependent on the yarn material, program settings, and specific machine. However, comparing the lowest and highest speed values for common machine types illustrates a difference of multiple tenfolds.

Machines exist with greater speeds, however are uncommon or prototypes for research purposes and therefore excluded from this comparison.

	Flat Knitting	Circular Knitting
Max. Machine Speed	1.2 - 1.8 m/s	2 - 4 m/s
# of Systems	2 - 4	24 - 96
Production Speed	-	20x - 54x Faster

Table 1, Comparison of the fabric production speed of flat and circular knitting. These values are common machine capabilities, gathered from conversations with Knitwearlab, BYBORRE, Mayer & Cie, University of Boras, University of Aachen, and Textiel Museum Tilburg.

LIMITATIONS

The choice between flat and circular knitting depends on the design requirements. Flat knitting is excellent at creating shapes and complex knitted structures but does so at a relatively slow pace. Circular knitting can produce large amounts of textiles efficiently but is (usually) limited to only producing tubes of textiles at a fixed diameter and continuous material, usually requiring cutting and sewing to realise consumer products.

Textile Finishing Processes

After coming out of the machine, knitted textiles undergo various finishing processes to enhance their appearance, durability, and functionality. Fabrics are commonly washed to remove impurities and sizing agents used during manufacturing. Following washing, blocking shapes and sizes the textiles to their intended dimensions [3]. After blocking, pressing or ironing may remove wrinkles and improve the fabric's smoothness. Sometimes, the fabric is steamed to activate a heat-reactive yarn that shrinks or puffs up, like BYBORRE [9] uses to create a 3D texture in their fabrics. Additionally, treatments such as dyeing and printing are applied to add colour and patterns to the textiles. Finally, various mechanical and chemical treatments, such as fulling (felting) or brushing, modify the surface texture or improve the fabric's hand feel [13]. These finishing processes ensure that knitted textiles meet the desired quality standards and performance characteristics before reaching the market, and the selection and order of these processes differ per fabric.

(Mono) Materiality

Part of why textiles are hard to recycle is because they are often made of a compound of natural and synthetic materials. In jeans, for example, elastane is frequently added for stretch and comfort, but this small addition (often no more than 5%) means that the whole fabric cannot be recycled in a cotton recycling plant because it cannot process elastane [37]. Wool is demonstrated to be a morphic mono-material and shows promise for embedding shaping elements into textiles, which Chapter 2.3 discusses further. Additionally, wool, particularly merino wool, is a popular and sustainable material choice for garments, including jackets and coats, because of its many benefits listed in Appendix B. Furthermore, different materials have different properties, and combining them exponentially increases the number of variables at play. For these reasons, this research explored options made with only wool. All material used for prototyping is 17-micron merino wool, at a yarn weight of 2/30 NM, sourced from Knitwear Lab.

2.3 Related Works

This section analyses methods and technologies within the textile domain that aim to tackle sustainability issues for the aforementioned stakeholders. Specifically, this section looks at approaches and related works about 3D / shaped textile innovations that serve as an inspirational foundation for this research. The start of each section is given an overview.

Sample GR_Baseline_1:1 (Appendix E)

Fully Fashioned

BENEFITS

- TEXTILE-FORM SHAPING IS POSSIBLE
- (ALMOST) ZERO WASTE
- BROAD APPLICATION RANGE

LIMITATIONS

- SLOW IN PRODUCTION
- LABOUR INTENSIVE
- EXPENSIVE

Fully Fashioned Knitting

Fully fashioned is a term for garments that are manufactured in shape [47] and do not require cutting out the panels, so there is minimal material waste, and it reduces the cutting and finishing steps. This approach of creating garments is often used for hand-knitting or machine knitting of higher-end garments since flat knitting takes more machine time, and assembly can be labour-intensive. Flat-knitted textiles are shaped by transferring stitches, which takes a disproportionate amount of time during knitting. Examples of fully fashioned garments are sweaters (Figure 13) and dresses, but they are also present in knitted shoe uppers or tech accessories [47].

Fully Fashioned Weaving

Although fully fashioned commonly refers to knitted garments, there are also examples of a fully fashioned approach to weaving. Research has focused on creating seamless garments to reduce the need for cutting and sewing [2]. However, existing methods face limitations in production speed, labour intensity, and equipment requirements. Techniques like circular weaving machines are explored for their ability to produce tubular textiles. Other efforts include the combination of ZWFD and jacquard weaving to apply added functionality and integrated aesthetics to a garment [68] or digitalisation to enhance the design process [61]. Various approaches include tubular weaving, warp manipulation on looms, loom machinery adaptations, and jacquard weaving integration. These methods offer promising methods for form-integrated weaving.

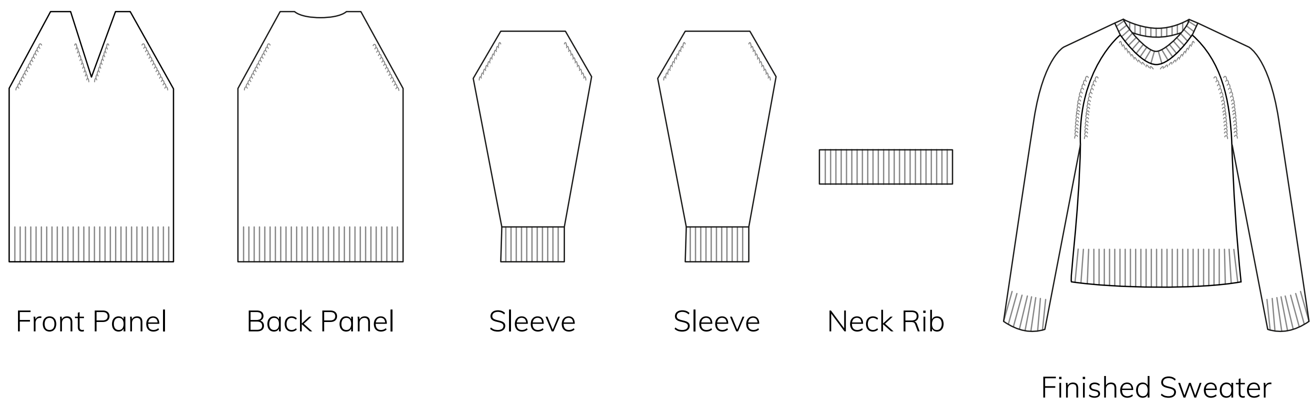


Figure 13, Fully fashioned sweater elements that are knitted in shape with transfers and include ribbing for the cuffs and hem.

On-Pattern Knitting

BENEFITS

- FUNCTION INTEGRATION
- ENHANCED DESIGN POSSIBILITIES
- INTEGRATION OF PRODUCTION STEPS

LIMITATIONS

- NO SHAPING
- INCREASED DESIGN COMPLEXITY
- INHERENT CUTTING WASTE

Multi-Layer Knitting

Another take on the term 3D knitting is to knit two layers separately from each other, with a connecting yarn between layers, which is possible on some circular knitting machines that contain a double bed (cylinder and dial). Through clever programming, it is possible to selectively separate the two knitted layers and inlay a special yarn that puffs up when it is steamed. These approaches can add functionality (like targeted insulation in Figure 14) and tactile and visual effects to fabrics. [10], utilises computer-aided design to create low-volume artwork textiles to enable smaller brands and creators to create high-quality clothing for their customers, increasing the consumer's choice.

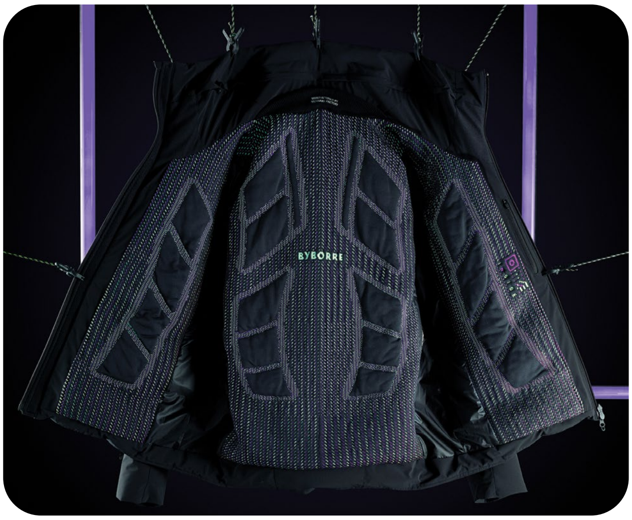


Figure 14, Pattern knitted fabric liner from BYBORRE x Descente Allterrain. Areas with seperated layers allow for more insulation. [10]

Seamless Circular Knitting

Knitted on circular machines, seamless knitting machines enable the creation of fabric tubes with diverse patterns, such as jersey, mesh, rib, jacquard, and embroidered logos, in multiple colours and stripe variations. Exclusive to seamless garment knitting machines, this technology was initially utilised for innerwear manufacturing, offering greater comfort due to minimal seams absence of elastic bands, and tags. Moreover, the ability to customise compression in specific areas has expanded the applications of seamless technology to protective, maternity, and support care garments (Figure 15) [77].

Figure 15, Seamless pattern-knitted sportswear with integrated graphics, ventilation. Minimal cutting and sewing is required for assembly. [20]

3D Textile-From Production

BENEFITS

- LARGE FORM FREEDOM
- LITTLE ASSEMBLY REQUIRED
- INTEGRATION OF DESIGN AND PRODUCTION STAGES

LIMITATIONS

- LIMITED APPLICATION
- EARLY STAGES OF DEVELOPMENT
- SLOW IN PRODUCTION

3D Knitting; Whole Garment Knitting

Going further than fully fashioned knitting, it is possible to knit complete 3D products (see Figure 16). The design freedom of these products depends on the number of beds in the machine and the software that programs them. Common knit structures like a rib, links links, or cardigan require two beds for one layer of fabric. Shima Seiki is the first company in the world to produce machines with four beds, thus allowing for multiple tubular shapes and the freedom to knit a variety of structures within these tubes [81]. The whole garment is knitted in one piece, using only the required material for one product and is produced one at a time, enabling on-demand manufacturing.

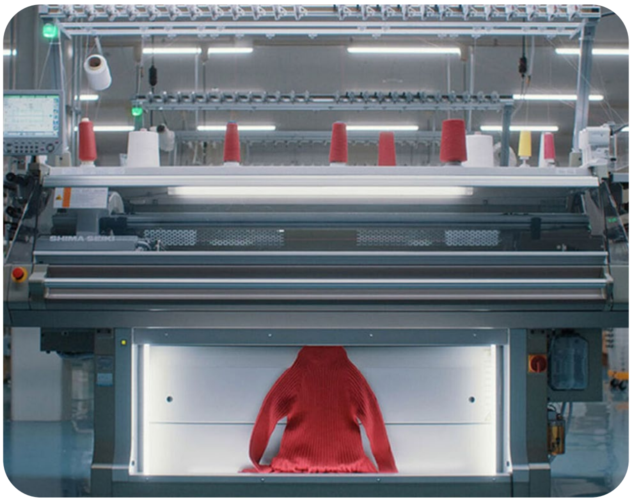


Figure 16, 3D Whole garment knitted sweater by Uniqlo, made on a Shima Seiki flat bed knitting machine. [90]

3D Weaving

3D weaving builds upon traditional weaving techniques and enables the weaving of multiple layers on top of each other. All warp and weft yarns are interlaced in a standard single-layer structure to create a dense textile. However, in a multi-layer structure, the warp is distributed across the layers [65], resulting in individual layers with a fractional density compared to a single-layer structure. This method enables the integration of garment assembly into the weaving process and weaving full garments [56] (see Figure 17), addressing some of the bad practices of traditional cut-and-sew assembly.

Figure 17, 3D woven pants where the legs and pockets are woven into the fabric in different layers. [57]

Morphic Textile-Forms

In exploring the intersection of sustainability and technology in Human-Centered Interaction (HCI) textiles, McQuillan and Karana [58] introduce Multimorphic Textile Forms (MMTF) as a design approach aimed at addressing sustainability challenges while enhancing user experiences. Developed through a lens of multiplicity and extended life cycles, MMTF facilitates change in design, production, and use-time by considering the qualities and behaviours of both material and form. This section explores various materials and how they are applied with MMTF to add or increase the shaping of textiles.

Heat-Shrinking Yarn Morphic Textiles

BENEFITS

- PERSONAL TAILORING
- CONTROLLED MORPHING
- PRODUCIBLE WITH MODERN EXISTING MACHINES

LIMITATIONS

- IN RESEARCH STAGE
- HARD TO RECYCLE (MIXED MATERIALS)
- ADDITIONAL PRODUCTION STEPS

Research has also combined low-melt polyester yarn (NSK) with 3D weaving techniques. Specific behaviour can be programmed through weave structures that restrict or increase the response, resulting in complex topological and textural woven forms that can morph over time. This concept was presented in two experiments, a tunic and trousers, showcasing the opportunity to integrate a reactive yarn throughout a woven textile and selectively place it in some layers [8]. Once woven and on a model, these garments can be activated with heat to mould around the wearer, creating a personal and tailored fit (Figure 18)

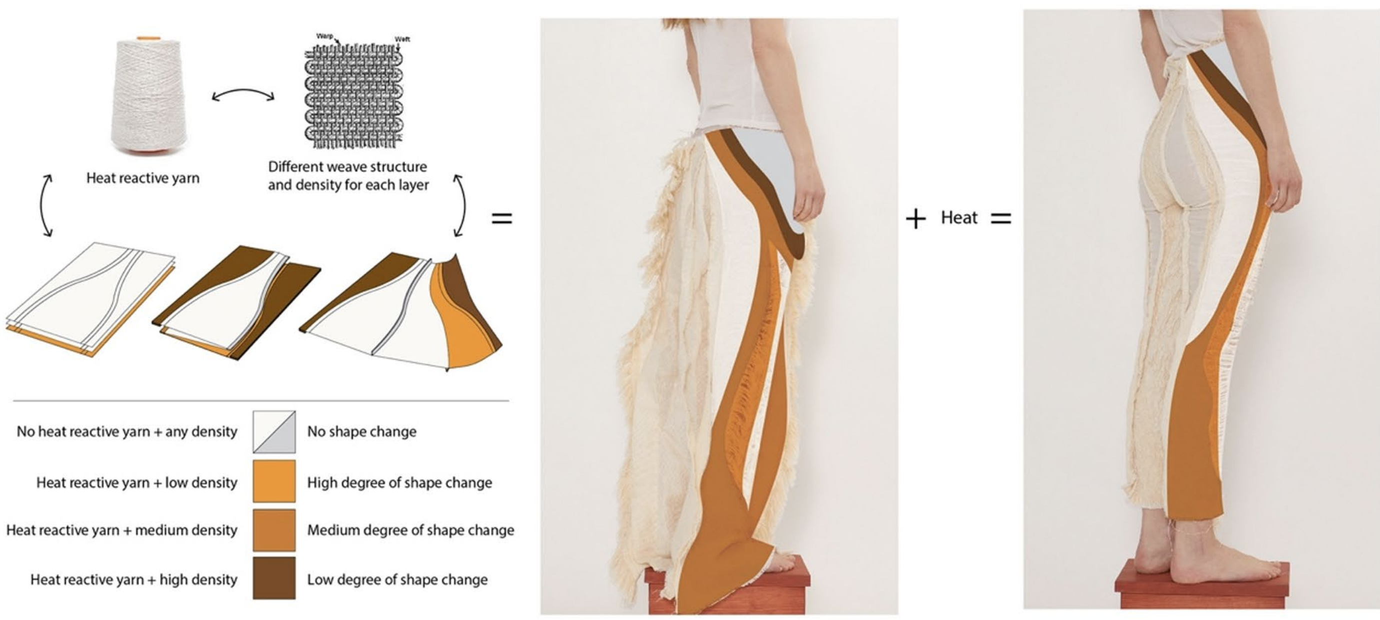


Figure 18, Yarn, weave structures, and textile-form construction wok in symbiosis to produce specific shape change behaviours. [8]

The 4D Knit Dress also applies these principles, combining heat-activated yarns, computerised knitting, and a 6-axis robotic activation process [79]. Heat-activated yarns, integrated within a unique knit structure, facilitate controlled transformation while preserving softness, stretch, and resilience. Using efficient tubular knitting techniques for flat knitting, a 6-axis robotic arm, commonly utilised in automotive manufacturing, applies heat to specific areas, mimicking the traditional tailoring process of pinning and tucking (Figure 19). This real-time transformation process creates a perfectly fitted garment or a distinctive aesthetic, improving the possibilities for personalised clothing design.

Figure 19, 4D Knitted dress by MIT shrinks around a body to create a personalised fit, using a robotised heat application process. [79]

Natural Material Morphic Textiles

BENEFITS

- MONO-MATERIAL
- CONTROLLED MORPHING
- PRODUCIBLE WITH MODERN EXISTING MACHINES

LIMITATIONS

- IN RESEARCH STAGE
- COMPERATIVELY SMALL SHAPE-CHANGE
- LIMITED USABLE MATERIALS

This approach to implementing morphing material into textile and controlling the behaviour can be extended to knitting and other (natural) materials like linen and wool, showcasing the potential for further exploration [78]. Wool, in particular, can be exploited for shape-change textiles through felting. If wool is exposed to heat and friction, the wool fibres roughen and tighten, causing a shrinking effect. Similar to heat-shrink fabrics, the amount of shrinkage can be controlled with the weave structures, enabling controlled shaping, even with a mono-material [4] (Figure 20).

Figure 20, Woven sample with multiple layers and seperated long floats that shrink more, creating a 3D textured fabric. [4]

BENEFITS

- MORE ACCESSIBLE DESIGN
- OPPORTUNITY TO INTEGRATE SHAPE
- SIMULATION IMPROVES ITERATIVE PROCESS

LIMITATIONS

- IN RESEARCH STAGE
- TUNED FOR SPECIFIC SETUPS
- LIMITED TEXTILE VARIETY

Computational Knitting

Knitted items currently require manual designing using machine-knitting-specific tools accessible only to experts. However, recent research has improved this process by developing software that makes knitting machines similar to 3D printers. Yarn- and stitch-level knit simulation tools [14, 45, 60, 82] produce impressive visualisations of knit structures, focusing on generating predictive models for deformation behaviour. Research [63] developed a workflow that automatically translates a 3D triangular mesh (Figure 21) into instructions for an industrial knitting machine, significantly easing the design and resizing processes and reducing the expert knowledge required.

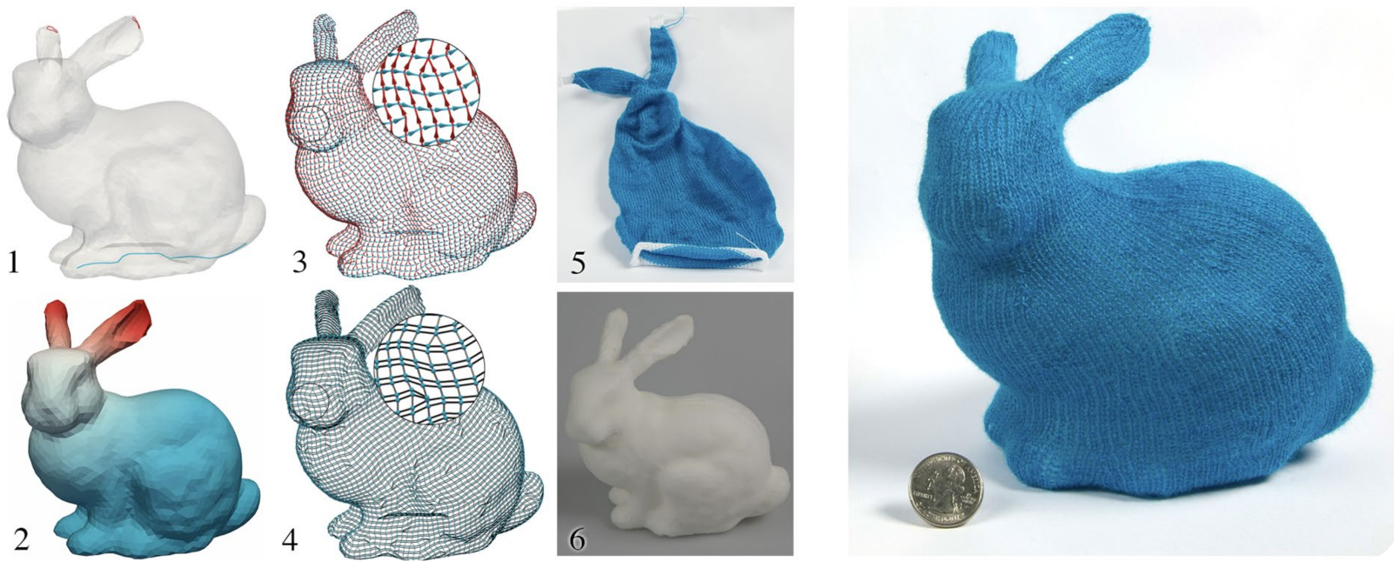


Figure 21, Automatically knitting the Stanford bunny. The system begins with an input mesh with user-specified starting and ending cycles (1) that are interpolated to define a knitting time function (2), remeshes the surface to create a row-column graph that represents the knit structure (3), traces the graph (4), and generates stitch instructions that are scheduled for machine knitting. The machine-knit skin (5) is a good fit for a foam replica of the input model (6). [63]

Computational Weaving

To expand the potential of morphic textiles, researchers [59] developed a library of woven behaviours, providing a functional vocabulary for weaving techniques (Figure 22). Leveraging software programs like Rhinoceros and CLO3D enabled larger-scale simulations of these woven behaviours. Compiling a library of key geometries with predictable effects enhanced the efficacy of experimental weaving techniques and designs. Some behaviours, like boundary distortion, have inspired practical applications, such as the design of garment sleeves. Fabrics capable of transitioning from rectangles to specific pattern pieces while acquiring decorative textures offer an innovative alternative to conventional cut-and-sewn apparel construction and manual fabric manipulation techniques.

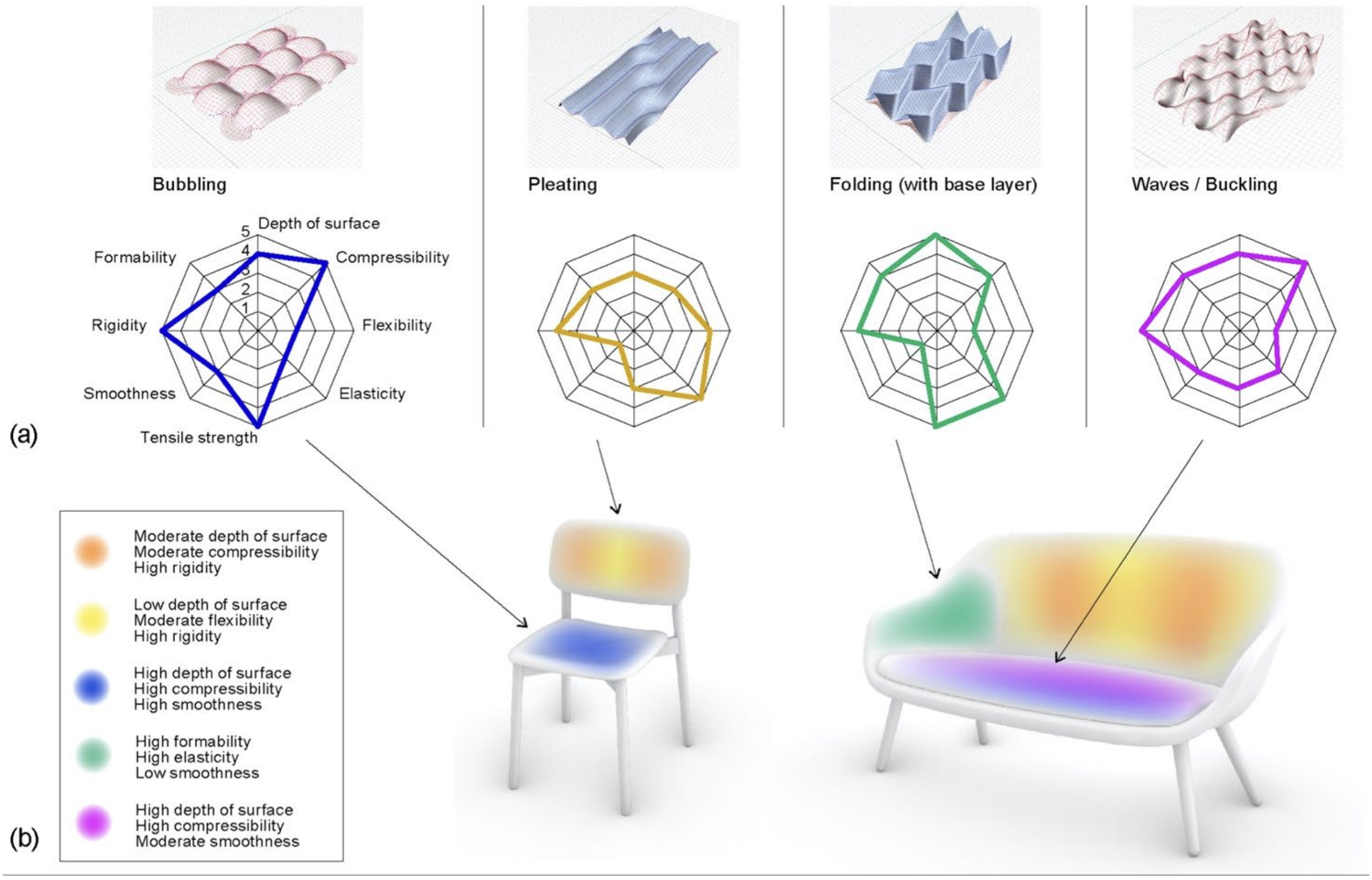


Figure 22, (a) Typological characterisation of behaviours evaluated by key criteria for seating, (b) Desirable fabric properties mapped onto genertic seating forms. [59]

Sew-Like Circular Knitting

BENEFITS

- SHAPING WITH CIRCULAR KNITTING
- EMULATES SHORTROWING / NEEDLE PARKING
- ACHIEVED WITH PROGRAMMING

LIMITATIONS

- ONLY WORKS IN COURSE DIRECTION
- (UNCOMFORTABLE) SURPLUS MATERIAL
- MADE WITH MODIFIED MACHINERY

It is possible to generate form through 3D weft knitting on large circular machines [50, 64, 83]. Standard methods in the garment industry to accommodate the 3D body include reducing surplus area and adding fabric material. The studies demonstrated the ability to 3D-knit prototypes using large circular weft knitting machines. The knitting pattern consists of floats and stitches alternating horizontally in areas that require size reduction (see Figure 23), which enables shaping and does not impede the continuous movement of the machine. However, despite enabling a level of 3D producibility, the sewing-like pattern employed falls short of achieving the same level of flexibility as flat knitting machines.

The surplus material pinched between the floats ends up on the back of the material, creating unwanted material that can be uncomfortable to wear (Figure 24). The technique is also limited in the direction of the knitting in combination with the angle at which the 'dart' is applied. Finally, this research only looked at single-bed circular knitting and utilised a modified large circular knitting machine.

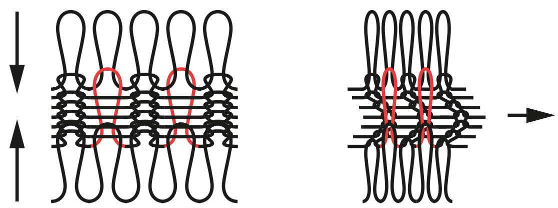


Figure 24, Pinching the knit creates a surplus of knitted material on the back of the fabric.

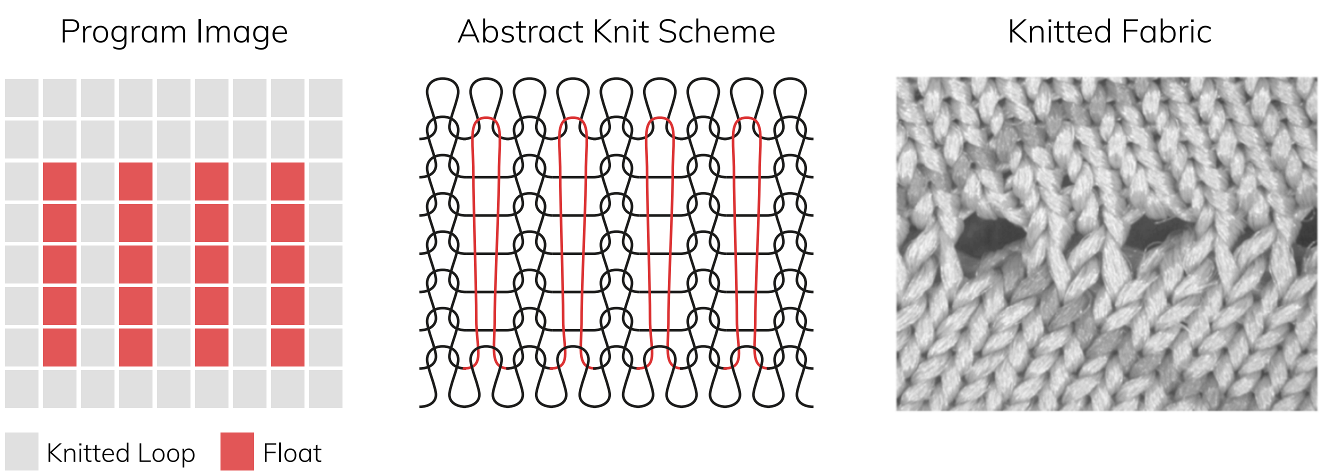


Figure 23, The program image, abstract knit scheme, and subsequent knitted fabric where a reduction of material is applied in order to create a 'dart'. [64]

2.4 Context Conclusion

While flat knitting enables the creation of knitwear without waste, circular knitting is the most common method of knit-garment creation, which is still constrained by cutting and sewing and generates waste. Woven textiles are similar in this regard, and promising research was conducted for form creation through modern methods like 3D weaving and the integration of morphic materials that can alter the geometry of a textile as it is produced. A promising approach is locally implementing a material and/or structure with a specific behaviour to create global, complex, and tunable shaping.

For circular knitting, some research shows promise in creating shapes for circular knitted products, but the examples are few and have other drawbacks. Therefore, there is an identified knowledge gap in controlling the shape of circular knitted textiles (Figure 25). Producing a material between a regular textile and the finished product, with the opportunities of the efficiency and global scale of circular knitting, can address the shortcomings of zero waste to improve adoption by the fashion industry (Figure 26).

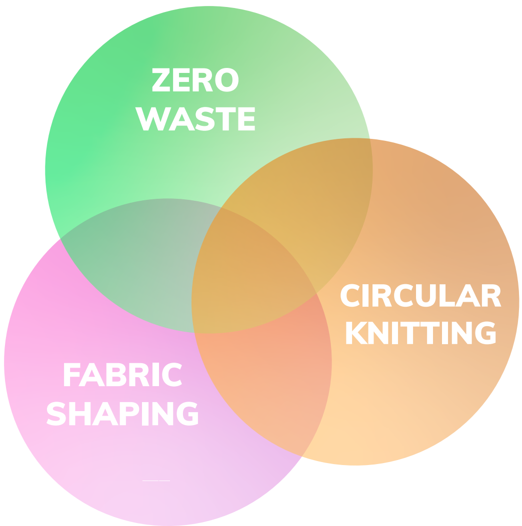


Figure 25, Identified opportunity areas to combine for research.

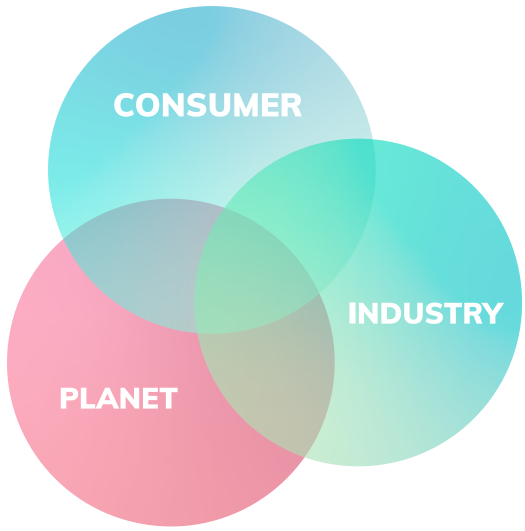


Figure 26, Identified main stakeholders for research.

Back to table of contents

3. VISION

This chapter describes the research objectives, discusses the methods used to achieve them, and explains the structure of the research.

3.1 Project Goal

The research aim was to develop a method for producing knitted textile forms and apply them to zero-waste fashion design to address inherent issues of the approach, enhancing the fit, personalisation, and flexibility of design. Here, shape is a critical factor in realising this ambition. The research goal is formulated in the following two research questions:

The first part of this research is embodied by experimental research constructing a technique for the limitations of circular knitting through exploration and critical analysis of the results. A novel design process embodies the second part: the development of multiple 1:1 prototypes, testing, and defining design tools.

1. How can shape be integrated into the design and production of circular knitted textiles?
2. What design and production methods are required to facilitate shape-integration for zero waste fashion design?
    a. How can this method be applied to an existing zero waste jacket pattern?
    b. How can this method enable a new approach to the design of a zero waste garment?

3.2 Methodology

The research draws inspiration and implements techniques from the Material Driven Design (MDD), which focuses on the material for creating novel material applications. It considers knitting as a 'material' for explorative research. Following the MDD process outlined by Karana et al. [42], this study employed a methodology to understand relevant parameters by framing and reframing complex design problems. Prototyping played a vital role in each phase, involving experimentation with the material and reflection on the making process and resulting prototypes. This iterative approach embodies the Research Through Design method [32].

Back to table of contents

Phase 1 Shape In Circular Knitting

This research approach is splitting the goal into three phases (see Figure 27). Building on the MDD method for the context of textile-form innovation, the first phase analysed the 'material' and produced many material samples through tinkering, explored the behaviour of various knit structures and finishing processes, and conducted technical and experiential testing. Simultaneously, it explored form design methods using digital, paper, and cut-and-sew prototyping to develop an understanding of applying these morphic materials in the garment context. Together, the findings synthesise the foundation for the method.

Phase 2 Shaping For Zero Waste

The second phase applied this knowledge to develop an improved version of an existing zero waste jacket pattern, exploring how programming local material behaviour can enhance form and performance without altering the base pattern. The research achieved this through software solutions, including CLO3D, M1+, the Adobe suite, and physical prototyping. The goal was to refine and implement the method's guidelines to validate the process. The prototypes from this phase were tested qualitatively based on requirements (see Chapter 5.1) and user testing.

Phase 3 Full Integration

Finally, the third phase explores the possibilities with an original jacket pattern that exploits all identified opportunities of the technique. Aside from designing an original pattern, this phase iterates on the process defined in phase two. All prototypes for this research were produced for an industrial context and knitted with a Stoll CMS 530 knitting machine in the Applied Labs at the IDE Faculty. (Read more about this in Chapter 4.1).

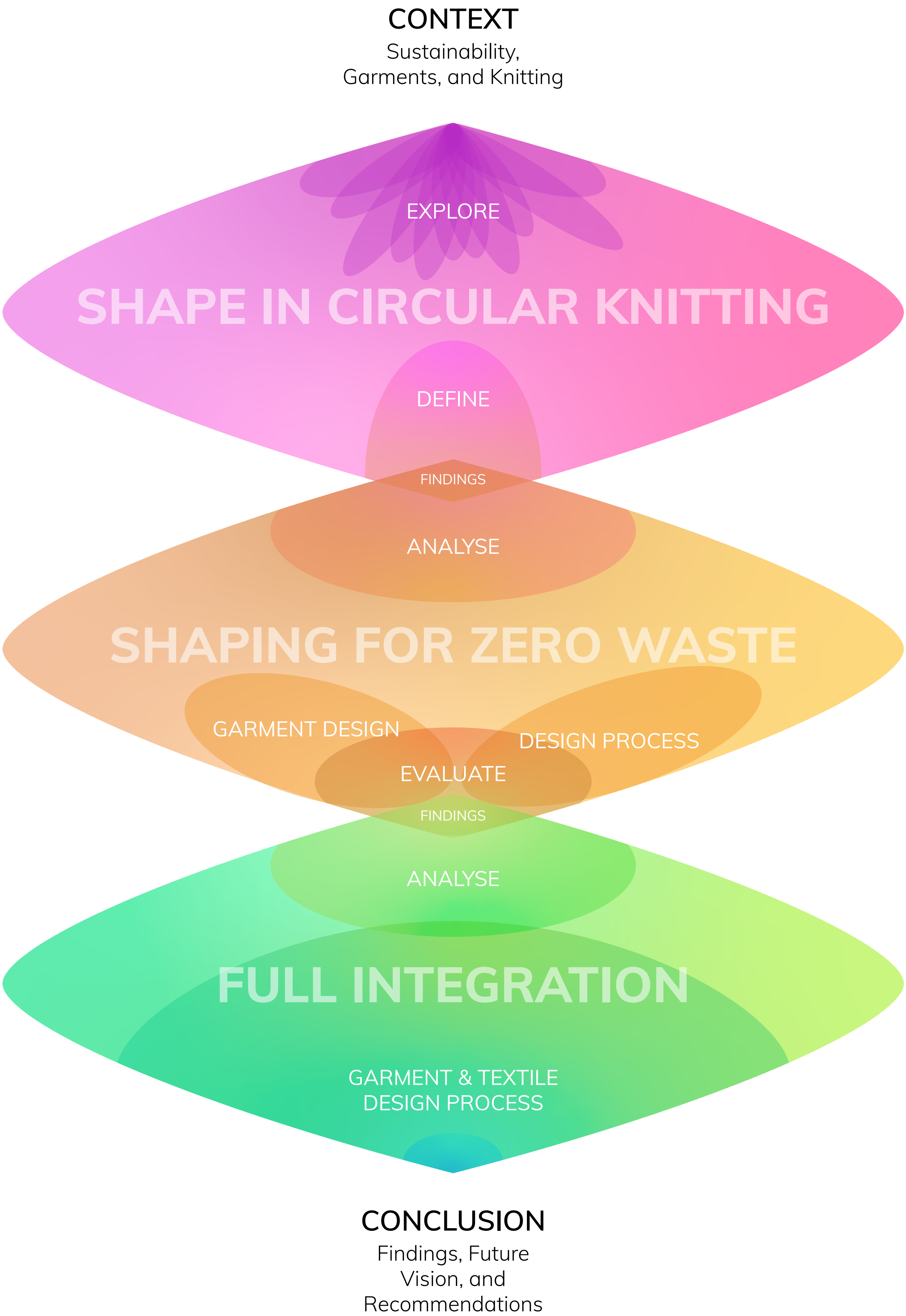


Figure 27, Research structure in three phases.

4. PHASE 1

Shape In Circular Knitting

This phase discusses the research for shape creation in circular knitting. It explores the variables and limitations of circular knitting and systematically analyses multiple approaches, focusing on answering the first research question:

1. How can shape be integrated into the design and production of circular knitted textiles?

4.1 Understanding Circular Knitting

To create a knitted textile, the needles in a knitting machine are actuated to form loops by catching the yarn and passing it through a previous loop that is consequently dropped off the needle. The type of stitch produced depends on the amount of needle actuation. Three main stitch types (Figure 28) are common in circular knitting. These serve as ingredients to create an enormous variety of textiles. How and what designers can create also depends on many other variables for material, machinery, programming, and finishing, which the next chapter discusses.

1. Stitch: Formed when a needle is raised completely, catching the yarn, closing the latch, which pulls it through a previous loop on the way back, and drops the old loop.

2. Tuck Stitch: This stitch is produced when the needle is raised partially so it catches the yarn but doesn't drop the previous loop, resulting in both yarns being knitted into one loop.

3. Float Stitch: No needle actuation occurs, so the needle holds the existing loop while the yarn in the current row floats past the needle.

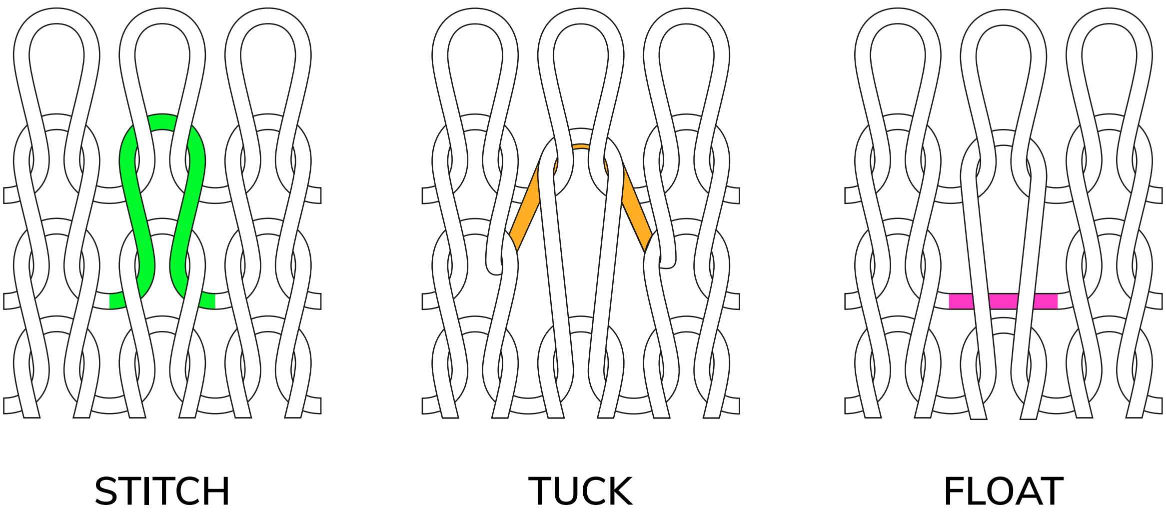


Figure 28, Abstract visual of the three stitch types that are possible to knit with a circular knitting machine.

Material Taxonomy

Taken from the Material Driven Design method, a material taxonomy was performed on circular knitting as a 'material'. The research from the context identified potential material variables for circular knitting, illustrated in Figure 29.

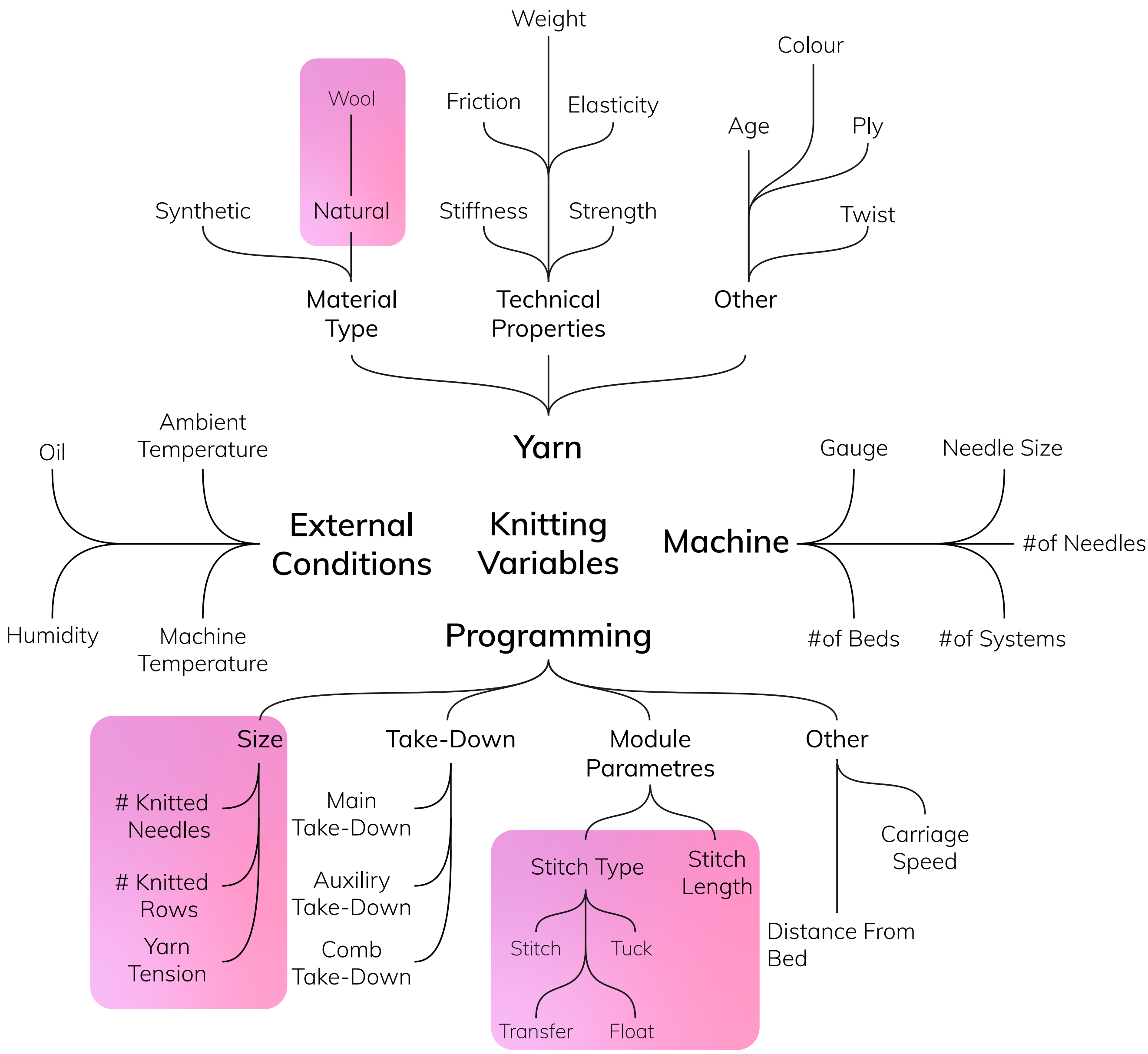


Figure 29, Material Taxonomy of identified variables for circular knitting. The variables that this research investigated are highlighted in pink.

Circular Knitting Machine Principles

Fabric is produced by feeding yarn through a system of guiders and tensioners into one of many systems. The system then guides the yarn through needles as they are actuated, resulting in the formation of loops in a continuous circular motion. This creates a tubular textile that is folded or cut in half and collected on a rotating beam that doubles as the take-down system to maintain tension on the knitted loops. See Figure 30.

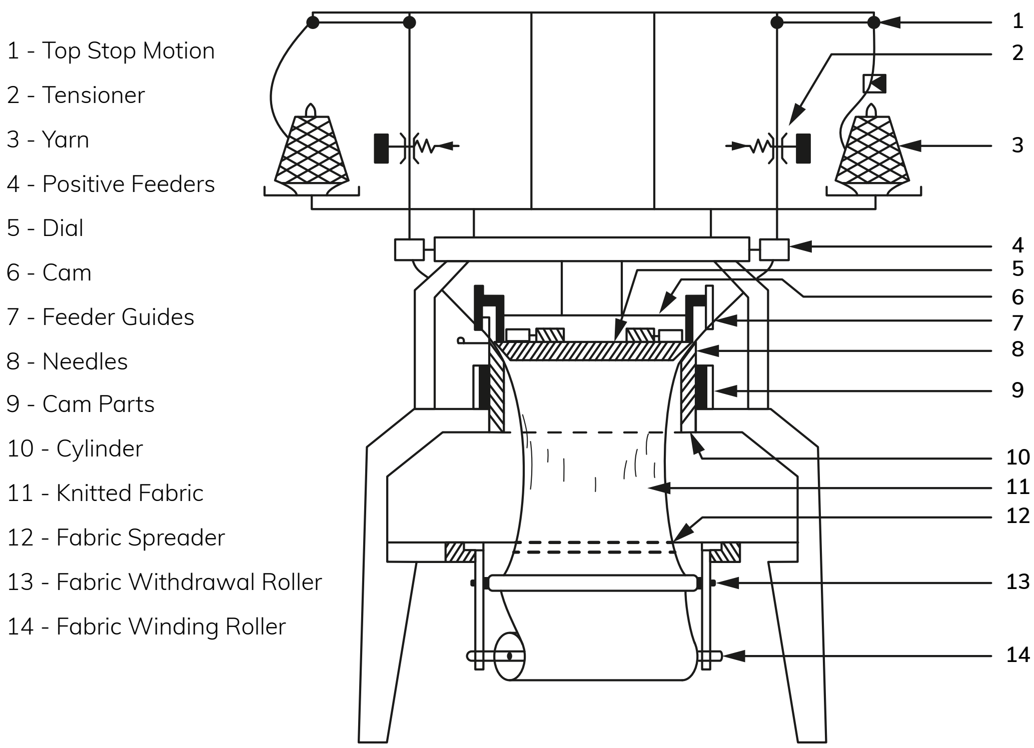


Figure 30, Large Circular Knitting abstract visual with partial cross section. All relevant machine parts are listed.

Limitations of Circular Knitting

Circular knitting has one main advantage: it can quickly produce large amounts of textiles. However, this inherent advantage requires a specific setup, which has drawbacks compared to flat knitting. The considerations for designing for circular knitting are listed below and discussed in detail in Appendix C.

Continuous Motion

Needle Parking

Stitch Transfers

Stitch Length

Take-Down

Needle Usage

Simulating Circular Knitting On a Flat Bed Knitting Machine

Part of the research objective was to produce and iterate many samples quickly during the six-month duration of the research. Large circular knitting machines are not suited for rapidly prototyping small samples. On the other hand, flatbed knitting machines are very suitable for this purpose, and the IDE Faculty has one available for flexible, autonomous prototyping purposes. Additionally, due to time and resource restrictions, securing a circular knitting machine with the correct specifications for validation and the production of larger samples was impossible. Therefore, this research produced prototypes with a flatbed knitting machine. Details about the requirements of the knitting machine are in Appendix D.

To ensure the validity and feasibility of this research, the limitations of circular knitting determined restrictions to the programmability of the flatbed knitting machine. Larger samples, like in Chapter 5.2, were knitted as one or two textiles and cut out accordingly, simulating circular knitting. The following experts evaluated the validity of this method for simulating circular knitting: Stefan Gustafsson, Knit Technician, University of Borås, Henning Löcken, PhD Knit Material Research, University of Aachen, João Paulo Cabral, Senior Knit Technician, BYBORRE, Mathilde Vandenbussche, Product Developer and Circular Knitting Technician, Textile Museum.

4.2 Creating Shape In Circular Knitting

Early on, the research identified an outerwear garment for potential application of the novel knitting technique, described in more detail in Chapter 5.1. Outerwear typically protects the user, so warmer, weatherproof, and stable fabrics are preferable. Double-knitted fabrics fit these requirements better than single-knitted fabrics. Double-knitted fabrics are also inherently stable, whilst single bed curls up without post-processing. Therefore, all samples are double-knitted.

The material taxonomy analysis and related works identified two approaches for shaped circular knitting. Each technique was researched, and the most promising results were combined and analysed. Four researches were performed on the creation and assessment of form-creation in circular knitting. Each section individually documents each study's introduction, method, and results, followed by a section that discusses the results. The complete documentation of all samples are in Appendix E. To keep track of the samples from multiple categories with multiple iterations, tests followed a naming code:

SampleCategory_SampleRound_Method(combination)_Material_SampleVersion

This code is used for the samples throughout the project and can be found in Appendix E, however most samples are not named individually. For the important samples, in discussing the results, an abbreviated version is applied:

SampleCategory_Method(combination)_SampleVersion

1. Stitch Ratio Effect on Knit Size

Introduction

The structure of knitted textiles comes from a combination of stitches, tucks, and floats, each contributing to the fabric's overall appearance and functionality, including the unique size profile of a knit structure. In industrial practice, programming knits combine various knit structures within colour modules, assigning distinct structures to differently coloured pixels. In this practice, maintaining uniformity in stitch counts, and thus in size profiles across structures, is essential to prevent fabric distortion (Knitwearlab, personal communication, October 24, 2023). The balance of stitches over different knit structures is illustrated in Figure 31, showing the program for a twill jacquard.

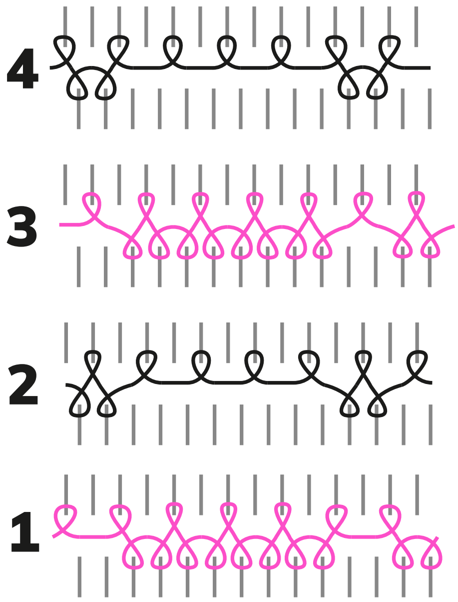


Figure 31, Abstract cross section steps for a two yarn twill jacquard. The back bed carries both yarns, alternating stitches and floats. The front bed can stitch on any needle with either yarn, creating a visual artwork.

In the preparations for this research, manipulation of stitch counts within localised regions yielded form-creation within the knitted fabric (see Figure 33). This observation sparked the idea that altering the ratio of knitted stitches to floats or tucks in a knit structure could manipulate fabric size, as explored previously in a thesis for a single jersey produced with flatbed knitting [53]. For instance, alternating a 50/50 stitch-float ratio across courses results in interlocking knitted rows (Figure 32), reducing the wale length compared to a 100/0 ratio. This concept raised the question of whether a technique within this programmable behaviour exists to facilitate form creation within knitted textiles, adhering to the restrictions imposed on the knitting capabilities of circular knitting.

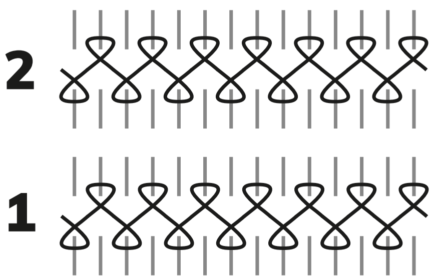


Figure 32, Abstract cross section steps for an interlock knit structure, alternating stitches and floats.

Method

To locally apply structures with different size profiles, the structures that demonstrate the potential first needed to be identified. Therefore, the first step was developing a library of commonly used knit structures and quantifying their unique size profile. For all structures, it was mandatory to utilise all needles within a structure repeat and only use stitches, tucks, and floats, as is explained in Chapter 4.1. The Knitwear Lab course and existing research presented a collection of standard structures, including eleven promising options. Additionally, nine more structures were designed on the premise that increasing the percentage of floats decreases the wale length to test if there is a practical limit to this percentage.

Figure 33, Swatch in preparation for the project with a different ratio of stitches and floats for the outer and inner sections, causing a surplus of material in the middle.

The key variable for this research is the size compatibility of the identified structures. Therefore, all the identified knitting variables in the Material Taxonomy, except for the combination of stitch types, were kept identical for the samples. Each structure was programmed for 100 needles and 100 rows and knitted with two 2/30 merino wool yarns for every row. Adhering to the restrictions of circular knitting, the stitch length for all samples was uniform at 10.5, and the take-down was constant. For each sample, the course and wale length were documented and compared. All samples were ironed flat and measured to an accuracy of 5 mm. Knitted fabrics are inherently stretchy, and the precise dimensions are related to numerous variables, making it challenging to measure knitted samples accurately. This research focused on comparable measurements between samples, where precision is more important. Finally, if the size difference between structures is smaller than the error margin, the ability to exploit the difference for form creation is minimal.

Results

Figure 34 shows the course and wale length for the twenty structures. The samples demonstrate a wide variety of sizes and ratios compared to the square artwork the machine is programmed to knit. The double jersey has the widest and tallest structure and demonstrates a looser texture than other structures. Furthermore, the net jacquard and tubular structures are identical and respond differently since they yield a different physical size than the interlock structure, which has the same percentage of stitches. DS 10 and DS 12 exhibited signs of yarn breakage, suggesting a producible limit to the percentage of floats.

Notably, the structures with similar stitch combinations cluster together, and increasing the percentage of floats or tucks drastically changes the size profile of the structure. The structures (highlighted in orange) are partly made of tucks and have a significantly larger course length and shorter wale length compared to the other structures.

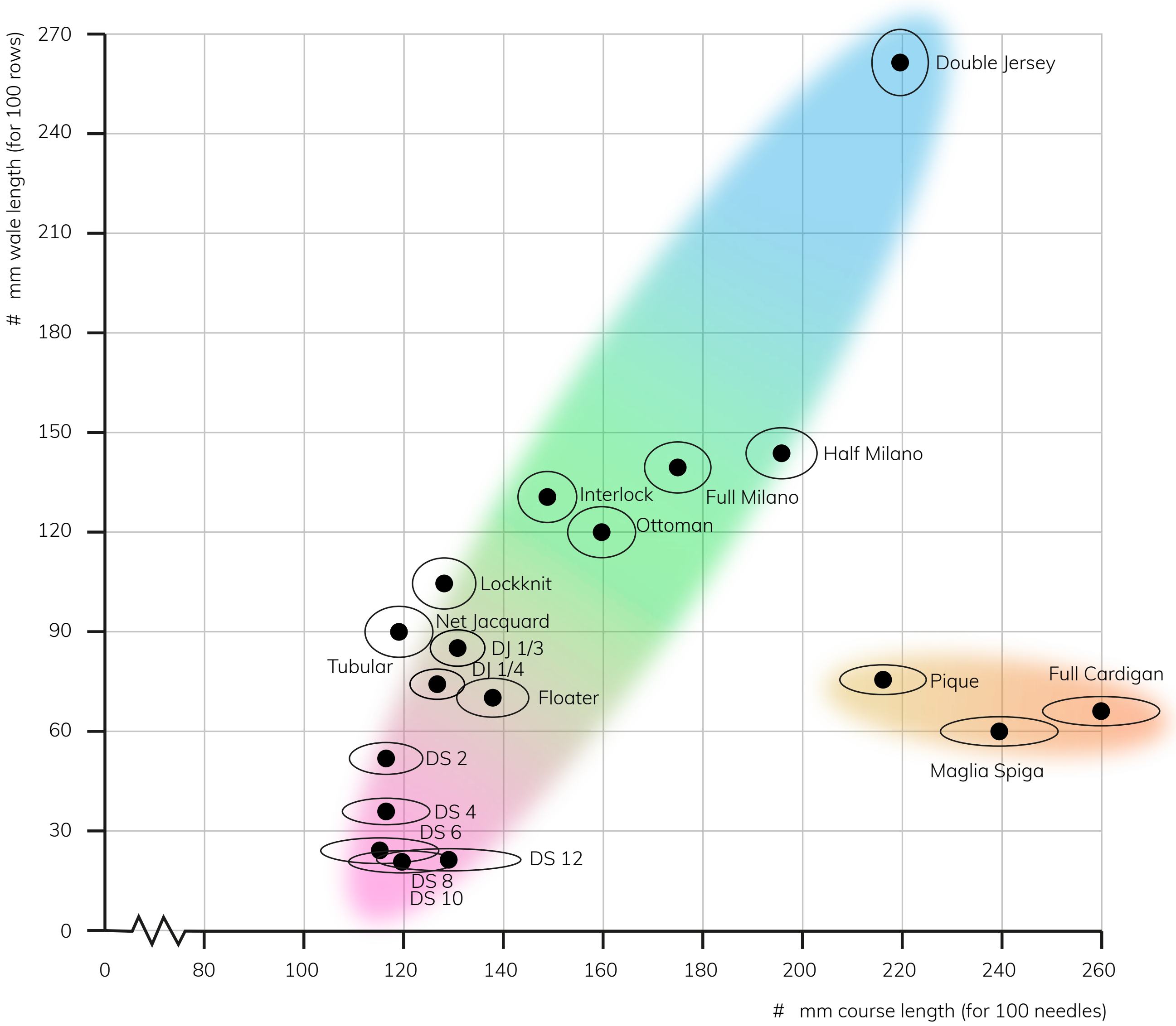


Figure 34, Size graph of 20 tested structures. The coloured areas illustrate the percentage of the stitch types for each sample. Green represents stitches, blue represents double stitches, orange represents tucks, and pink represents floats. Additionally, an ellipse illustrates for each structure the ratio between its course and width length. Note that these ellipses only indicate the length/width ratio and are not to scale.

2. Compound Knit Structure Exploration

Introduction

The previous experiment successfully demonstrated the feasibility of realising knit structures of varying sizes within the constraints of circular knitting. This versatility allows one to manipulate the amount of material in a knitted fabric, thereby introducing curvature or volume (Figure 35). Previous research also explored this concept through an alternative method for reducing knit volume (page 42).

Translating this concept for garment design and production, one application mirrors the use of darts in traditional cut-and-sew garments to achieve shaping around the body, particularly at critical areas such as the hips, waist, and chest. While this approach proves effective, it generates new questions about technique refinement. Given the research's focus on developing a wearable outer garment, considerations extend to texture, stiffness, and visual appearance.

Furthermore, practical concerns surround scalability and the permissible differences between knit structures. This experiment addresses these questions and further advances the application of knit structures in garment design.

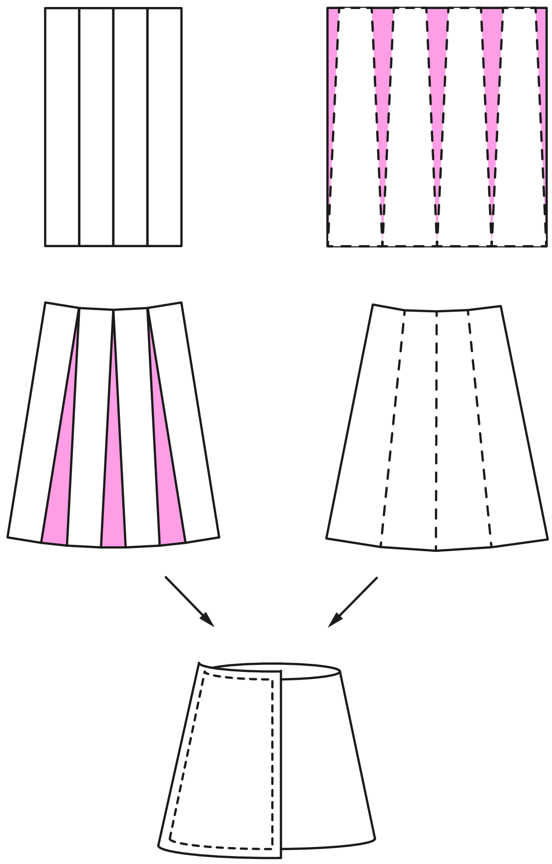


Figure 35, Material addition or reduction as a means to create shape / curvature in a 2D material.

Method

To test the concept's applicability, several artwork patterns resembling darts and other geometric shapes were designed, with colour-blocking, to explore textile behaviour. This includes reproducing the technique from ITA [50, 64, 83], which was translated to a double-knitted structure. Unless otherwise indicated, the samples use interlock and DS 8 knit structures. The interlock is a stable structure with only single stitches, and the DS 8 has the smallest, tested size profile and is also stable enough to knit.

The objective was to understand the technique's directional nature and practical limitations. Therefore, the samples were not required to adhere to the 100x100 swatch size. Other variables, such as the stitch length take-down and material, remained consistent. For optimal results, the samples were more extended with the dart inserted at the top to simulate a take-down in circular knitting. To test the findings from previous samples, the shape response of each compound sample was predicted and compared to the outcome. The section discusses the most valuable samples.

Results

SewLike_1

Purpose and Expectation

This dart was implemented with the ITA method, which floats on every other needle for three rows and knits entirely on the fourth row. The red area (Figure 36) was expected to significantly decrease in size.

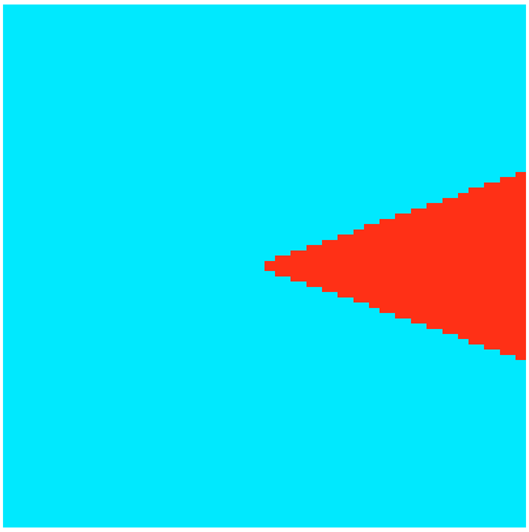


Figure 36 Artwork for SL_1 sample. Red is ITA float method structure, blue is interlock.

Observations

While the dart demonstrates some effectiveness, its impact remains limited (Figure 37). It fails to entirely eliminate the excess material within the red area. Moreover, the stitches within the dart are looser than the surrounding fabric, resulting in an inconsistent texture. The added tension on those loops most likely causes this as the surrounding material is knitted. Furthermore, there is a vertical rib texture that feels rigid and inflexible. Additionally, the darted area exhibits minimal stretch in vertical and horizontal directions, indicating its functional limitations.

Figure 37, Image of SL_1 sample.

SewLike_3

Purpose and Expectation

This sample (Figure 38) had the same form-creating purpose as SL_1 but applied the DS 8 structure instead of stacking floats vertically. Because fewer stitches were present, further material reduction was expected. The texture should also be smoother since the stitches are staggered. The sample also has more knitted material for the take-down.

Observations

The result is comparable to SL_1, but the dart is more effective, pulling down on the top of the sample more noticeably (Figure 39). The texture is also smoother, and the DS 8 is more elastic in the wale direction. The sharp transition between structures still results in an inconsistent global texture.

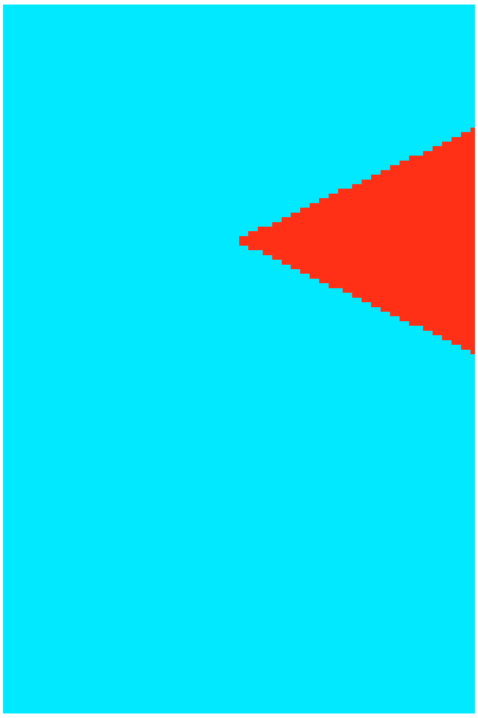


Figure 38, Artwork for SL_3 sample. Red is DS8 structure, blue is interlock.

Figure 39, Image of SL_3 sample.

SewLike_4

Purpose and Expectation

This sample has a circular 'dart' to explore the behaviour of different dart geometries (Figure 40). The expectation was a large material reduction in the middle that could create a useful geometry within the swatch.

Observations

When flat, the reduced middle significantly elevates the edges (Figure 41). However, it lays flat with a curved fold line when folded along the middle. Reduction primarily occurs in the course direction, which follows the established size profile of DS 8. The curved fold lines demonstrate the potential for connecting curved pattern elements in a garment, like at the armpit of a jacket.

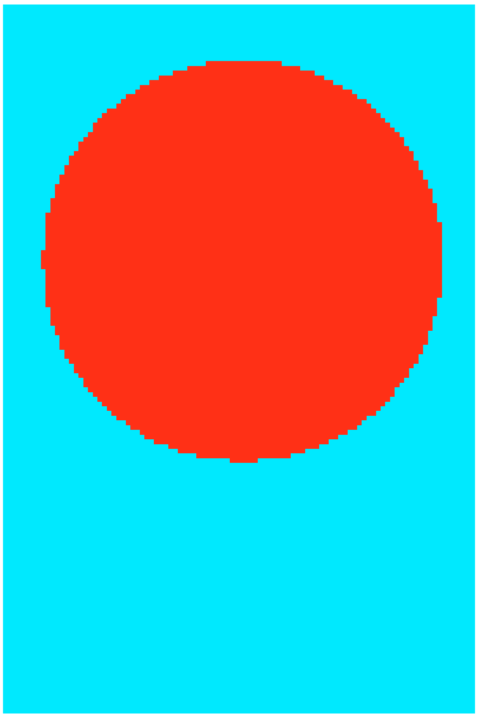


Figure 40, Artwork for SL_4 sample. Red is DS8 structure, blue is interlock.

Figure 41, Image of SL_4 sample.

SewLike_5

Purpose and Expectation

This is another experiment on the fabric's response to different dart geometries (Figure 42). The goal and expectation of this shape is to curve the top edge of the sample successfully.

Observations

Like SL_4, the dart shape reduced the material and warped the surrounding knit. The top of the swatch is curved (Figure 43), which designers could use to create the curved pattern of a sleeve element from a rectangular base pattern.

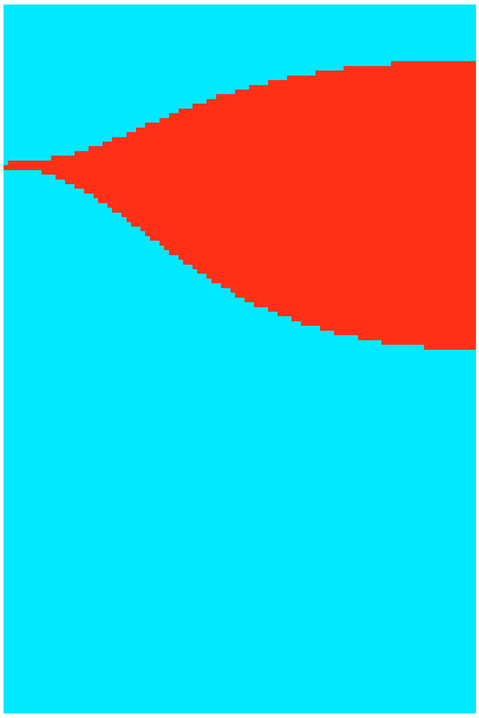


Figure 42, Artwork for SL_5 sample. Red is DS8 structure, blue is interlock.

Figure 43, Image of SL_5 sample.

SewLike_6

Purpose and Expectation

This experiment (Figure 44) aimed to illustrate the gradual shift in size reduction related to the percentage of floats in the structure. The expectation is that there is a linear gradient in the reduced material, increasingly warping the surrounding material. The structure module for this sample is in Appendix E.

Observations

The multiple darts result in a smooth, flowing edge for the swatch (Figure 45). Varied dart densities are noticeable, particularly in the tightness of the stitches, and visually exhibit a gradual change in material reduction.

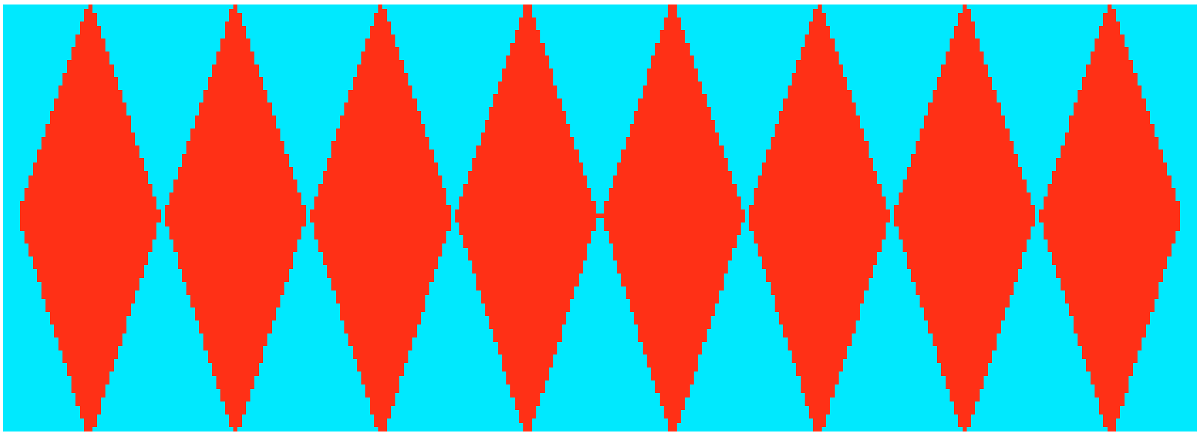


Figure 44, Artwork for SL_6 sample. The artwork is rotated 90 degrees from the knitting direction. Red is DS8 structure, blue is interlock.

Figure 45, Image of SL_6 sample.

Sphere_1

Purpose and Expectation

The purpose of this sample was to evaluate how accurately the shaping can be recreated utilising knit structures instead. The artwork pattern (Figure 46) originates from globe maps. Given the residual size of the DS 8 structure, the expected outcome was that the sample would take on a dome shape rather than forming a fully enclosed sphere.

Observations

The combination of patterns and structures resulted in a distinctly noticeable dome shape (Figure 47). However, the form more closely resembles a half-sphere than a complete globe, as the size profile of DS 8 constrains the inner diameter. This sample highlights the potential utility of such patterns for joint elements in garments, such as the elbow or shoulder.

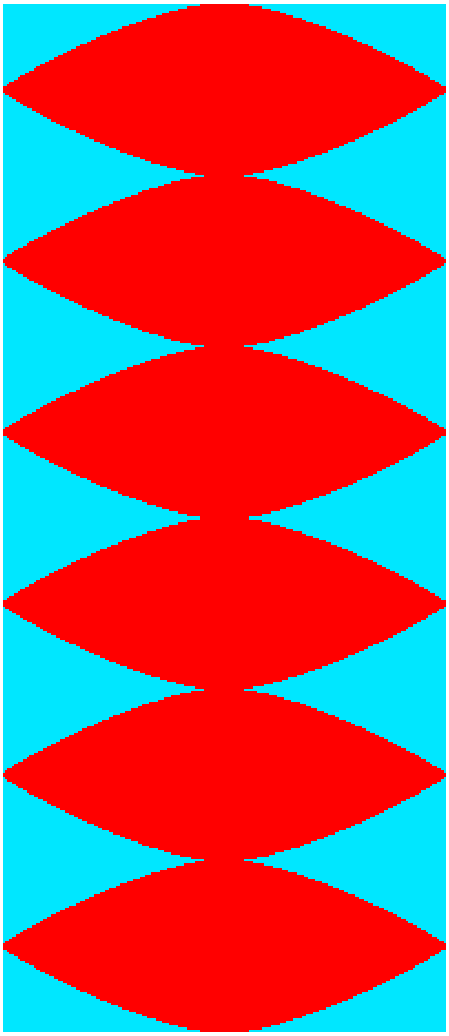


Figure 46, Artwork for Sphere_1 sample. Blue is DS8 structure, red is interlock.

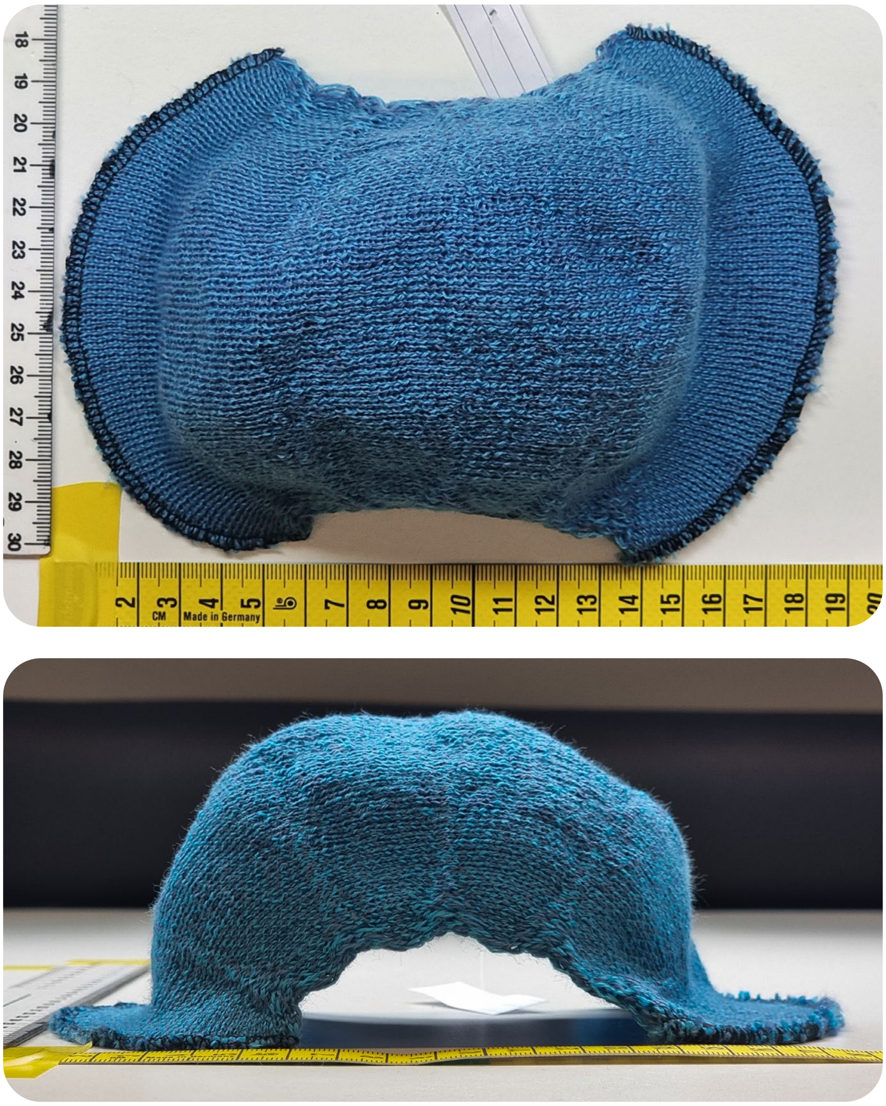


Figure 47, Top and side view of Sphere_1 sample.

3. Controlled Material Morphing

Introduction

This research explored wool to induce shape change in textiles, leveraging the felting process induced by washing to manipulate textile structures. The degree of felting-induced shrinkage is linked to the yarn's freedom within the textile, with fewer bindings in woven samples correlating to more significant shrinkage.

Method

The research identified two primary methods for achieving felting-induced shape change in knitted textiles. The first method is based on longer floats knitted in between the two layers that tighten during felting, exerting localised tension and inducing shape change in the textile.

The second method is felting the previous samples to explore the form-creation potential of different knit structures. Therefore, duplicates were produced, felted, and quantified to compare the size profiles of the non-felted samples.

Results

The first method for shaping yielded samples of different sizes out of the machine, but they equalised in size after felting. Figure 48 shows the results of the second method. The data showcases the same clustering as the non-felted samples. However, the data shifts the shape of the cluster. The difference between structures is also less compared to the non-felted structure. Since this research did not yield an effective way to create shape, a comprehensive version of this research is in Appendix F.

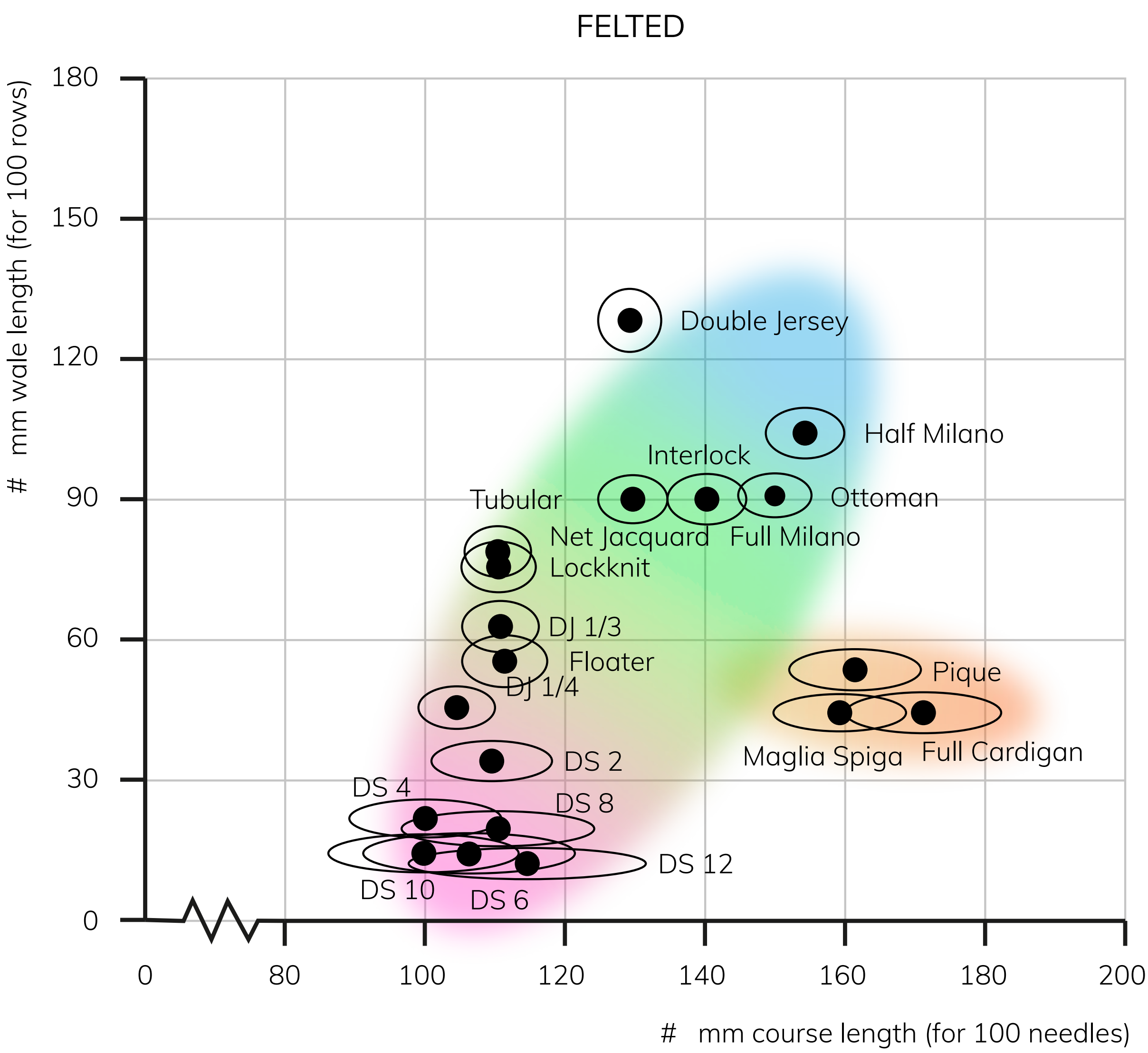


Figure 48, Size graph of 20 felted structures. The background colour and ellipses mean the same as in Figure 34.

4. Single Jersey Applicability

Introduction

This experiment aimed to reproduce the observed behaviour of knit structures, based on their stitch-type ratio, in a single-knitted variation. In the development of this research, it became evident that the adoption of double-bed circular knitting machines with full jacquard needle control for wearable products remains uncommon. BYBORRE is a notable exception but has recently shifted its focus from clothing to furniture. Given the results from previous research [53] and the enormous utilisation of single jersey knitted textiles for clothing [69, 77], this research investigated the approach for shape-integration through specifically developed structures that can effectively be transformed to single-bed knitted textiles.

Method

Phase 2, Chapter 5.2, involved constructing a jacket using a collection of structures with different sizes relative to a base structure. To establish a collection of single-bed knitted structures mirroring successful double-bed counterparts, this research aimed to reproduce the jacket swatch (Figure 62, page 92). The stitch ratios for each structure remain identical, and only the back stitches and back tucks were replaced by their front equivalent, as exemplified in Figure 49.

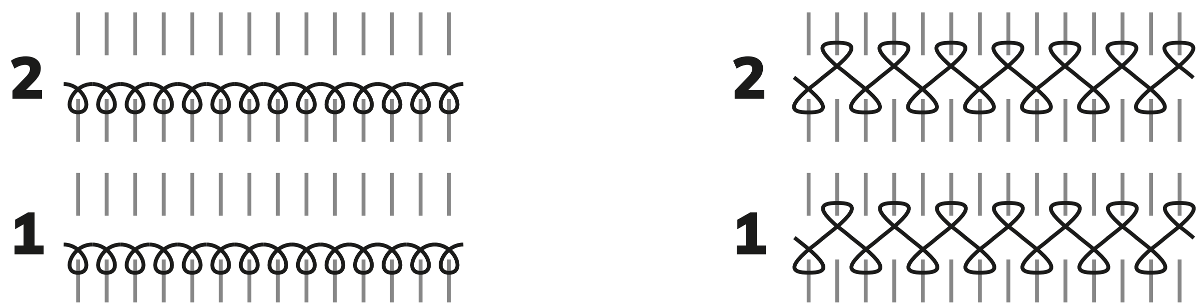


Figure 49, Single jersey (left) and interlock (right) structures. Single jersey is made of 100% stitches on a single bed. Interlock also has 100% stitches on a double bed (50% per bed). Therefore, a single jersey is the single bed equivalent of the interlock for a double bed.

Results

The single-bed knitted swatch exhibited promising outcomes, displaying consistent dimensional differences consistent with the double-bed variants. However, the single jersey presented an anomaly, which was anticipated to have a greater wale length (top of the triangle), similar to an interlock.

The size profiles of each structure, translated to 100 needles and 100 rows, are depicted in Figure 50, revealing that single-bed structures occupy taller ratios than their double-bed counterparts. The data also suggests that single-bed structures yield larger outcomes than double-bed structures.

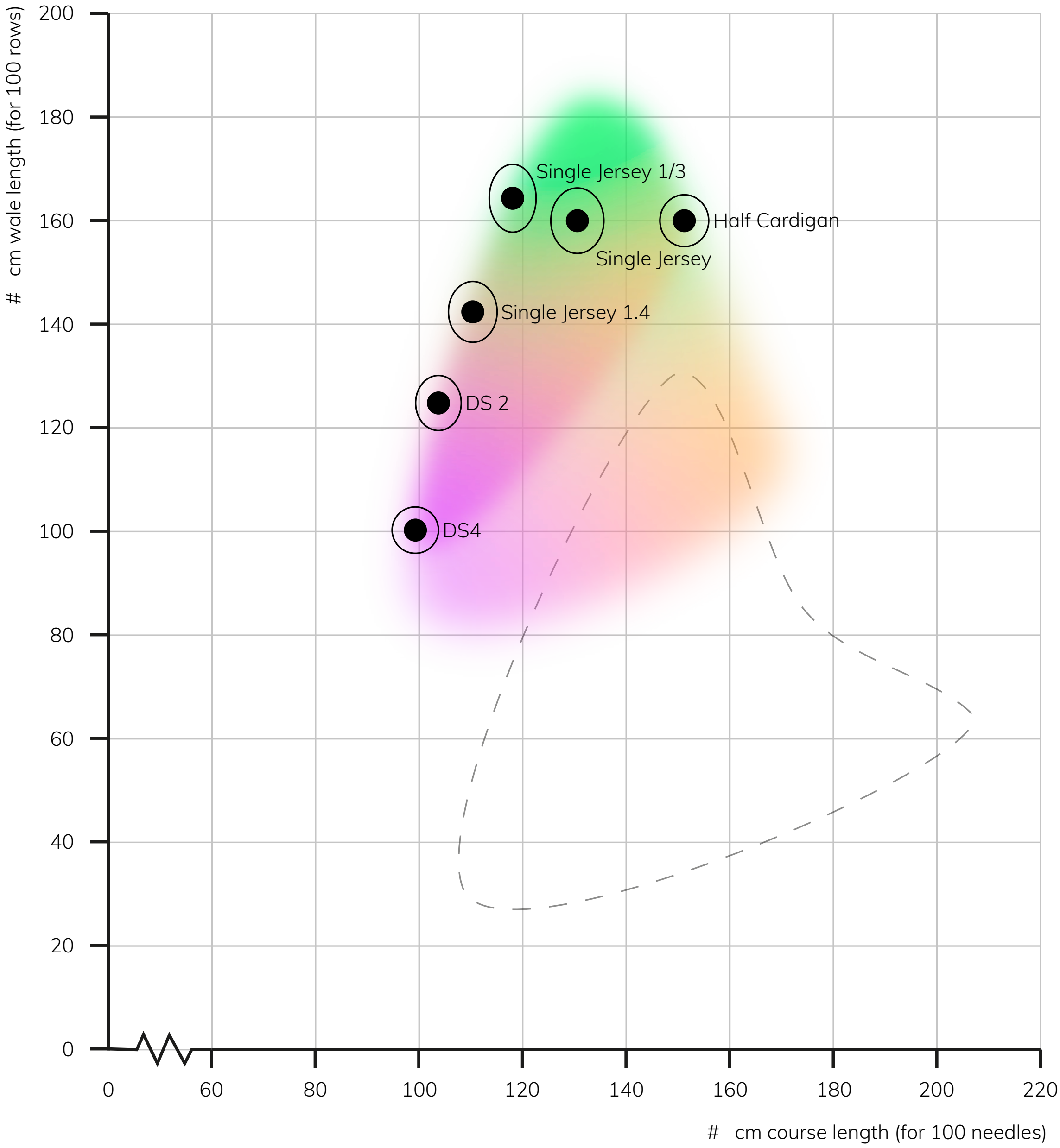


Figure 50, Single bed structure size profiles. The colours indicate the percentage of stitches (green), tucks (orange), and floats (pink). Ellipses (not to scale) indicate proportional size. This study only investigated six structures and did not find measurements of the faded part of the triangle. The dotted triangle represents the equivalent measurements of the double bed knit structure.

4.3 Phase 1 Discussion

Influence of Stitch Type on Size

Stacking floats in dart structures effectively reduced material, significantly shortening the wale length of samples compared to conventional structures like Interlock. The float percentage influences the degree of material reduction, with diminishing returns observed beyond DS 8. The dart structures (DS) also exhibit reduced wale-length shrinkage and diminished moldability post-washing despite blending in more seamlessly with the overall sample.

Including tucks in knitted structures widens the fabric, as illustrated in Figure 34, confirming the effect of float and tuck stitches established in previous research. Tucks effectively add material without contributing to loop formation (see Figure 52), increasing the fabric's course length as well as decreasing the wale length. Structures with a smaller wale length, notably those featuring tucks and floats, prove this observation.

Effect of Stitch Length

In knitting practices, determining the optimal stitch length for a given structure involves testing and refining to achieve the desired knit density because knit structures respond differently to stitch lengths. Consequently, specific structures are expected to exhibit various results when imposing a uniform stitch length across a range of structures.

Single jersey structures, including tubular and net jacquard, yield a tighter knit at the prescribed stitch length. This phenomenon was detected through tactile examination and in the resulting felted samples, where shrinkage is limited to 10% in both directions. Another exception is the double jersey, an especially loose structure at the selected stitch length 10.5. A double stitch is inherently looser than a single stitch. The response of this loose construction is also exhibited in the half and full milano, maglia spiga, pique, and ottoman structures, producing an undesirable and unstable semi-translucent material.

Sewing with Knit Structures.

The samples examined in section 2 present promising outcomes regarding the ability to achieve shaping without using traditional discontinuous knitting methods typically used. Unlike conventional darts that require equal-length seams along both sewn edges, the reduced knitted area offers flexibility in border lengths. Although the method proposed by ITA demonstrated effectiveness in shaping, it had the drawback of generating rigid and harsh ridges in the reduced material. Furthermore, this approach was most effective with an increased number of stacked floats, requiring machinery modifications for implementation.

While applying structures featuring numerous floats yielded success, complete elimination of knitted material was not achieved, indicating that the goal of complete material reductions is not optimal. When applied over a larger area, potentially gradually, this technique still facilitated size reduction but with a smoother, more gradual, and seamless approach compared to traditional

Effect on Elasticity

Structures with more floats exhibit less elasticity in the course direction since stretching looped yarn tightens the loop, and straight yarn cannot be tighter. Floats are straight elements of yarn and, therefore, exhibit less elasticity. Tucks have more elasticity; however, they are less elastic than stitches. This property of float-dense structures must be considered when applying them to product areas requiring stretch or experience movement.

Figure 51, Close up of sample SL_1, which has visible and tactile ridges in the material.

Felting Behaviour

Every sample responded to the felting process. All samples, except double jersey, also maintained their expected relative positions in Figure 48. Analysing Figures 34 and 48, shrinkage in the wale direction appears to be unrelated to the original length or the combination of stitches in the structures. The amount of stitches influences the course length shrinkage, with more stitches meaning less shrinking. Tucks also affect the shrinkage in the course direction, with more tucks increasing the shrinkage, which makes sense because the tucks also create a looser knit in the non-felted samples, providing more opportunity to shrink.

Finally, the felted samples portray very desirable fabric qualities for outerwear garments. The material is dense, soft, insulating, and still stretchy. Regular weft knitted fabric can unravel quickly and requires finishing on all cut edges with an overlock or other seam-covering sewing technique. The felted material does not unravel and can, thus, be left unfinished, which has the potential to reduce seam bulk, improve comfort for the wearer, and reduce assembly steps, improving the efficiency of production.

Single Bed Knitting

Although the swatch generated usable and mostly expected results, challenges emerged due to the inherent instability and stretching tendencies of single bed knits, complicating accurate quantification of geometric behaviour. The stitch length also resulted in different behaviours, where a single jersey produced a tighter knit with an unexpected size profile.

As an experiment, a second swatch was felted in the same manner as previous experiments. The floats on the backside, usually covered in a double knit, felted significantly, causing the material to stick to itself and curl irreversibly. Therefore, the felted sample was not quantifiable.

Assumptions and Limitations

As mentioned in the methodology of Research 1 (page 55), the measurement accuracy is only 5mm, meaning that for the smallest samples (DS 2 - DS 12), the wale length measurement can be off by 25%. This could cause scaling issues when applying structures to full garments. To address this issue, samples could be produced larger, reducing the scaling error, or future research should develop a new measuring approach to increase the accuracy. Chapter 5.2 and Chapter 8.1 discusses these solutions in more detail.

Knitting, infamous for its variability in physical dimensions across different machines, settings, and materials, has inherent challenges to achieving consistent results. While programmed knit files can replicate samples, the consistency of the results needs to be evaluated. Technicians fine-tune knit programs for specific machines to optimise consistency in industrial practice.

The experiment results and their interpretations are limited to the specific settings of the knitting machine and program. Generalisations regarding knit structures' reproducibility and dimensional behaviour require further research across multiple materials, settings, and machinery.

Moreover, it's important to acknowledge that the samples were produced on a flatbed machine and are not validated for reproducibility on circular knitting machines. Circular knitting was simulated on the Stoll machine with well-considered limitations. However, certain machine functionalities could not be perfectly replicated, including take-down and yarn-tension systems.

Furthermore, for conclusions drawn from felted results, it is assumed that the washing machine treated all samples equally. Felting consistency was evaluated on a small scale with three individually washed samples; however, these samples are not representative of the scale at which textiles are commercially produced.

Finally, all conclusions depend on the assumption of faultless sample production and identical measurements upon reproduction using the same material, machine, and settings. Variations in these factors may impact the results' applicability and generalizability.

Back to table of contents

4.4 Shaping Toolkit

The research from Phase 1 concludes with a set of tools. These tools answer the first research question of this thesis and serve as the foundation for designing circular knitted products that require shape outside of cutting the fabric.

Sample GR_Sphere_1:1 (Appendix E)

Base Structure

Knit structures are the building blocks for a fabric, offering the potential to create desirable and undesirable outcomes. To effectively utilise these structures as building blocks, it's essential to establish a base platform composed of one or multiple structures that comprise most of the garment. The selection of these structures is influenced by the garment's intended function and desired shaping.

For instance, the fabric requirements differ significantly between a pair of pants and a jacket. Opting for a larger structure proves more influential in shaping garments with relatively smaller structures. Conversely, if the base structure is smaller, the impact of reducing material will be subtle and more applicable for fabric addition. Figures 34 and 48 (non-felted and felted) illustrate each quantified structure's size and enable more

Wale Length Control

Structures with a larger float percentage produce smaller knitted fabrics for equal needles and rows in both the course and wale direction (Figure 52). Structures with tucks also have a shorter wale length but an increase in course length. These structures shine in emulating darts or seamlessly connecting pattern panels without requiring cutting and sewing. However, this method is most effective in the wale direction.

Additionally, it is important to note that floats and tucks influence the course direction, so applying these structures does not equate to perfect vertical material reduction. DS 8 - 12 proves particularly effective in reducing knitted material, requiring approximately 300 - 500 knitted rows per 10 cm compared to 80 - 110 rows, which are necessary for an interlock structure (non-felted and felted, respectively).

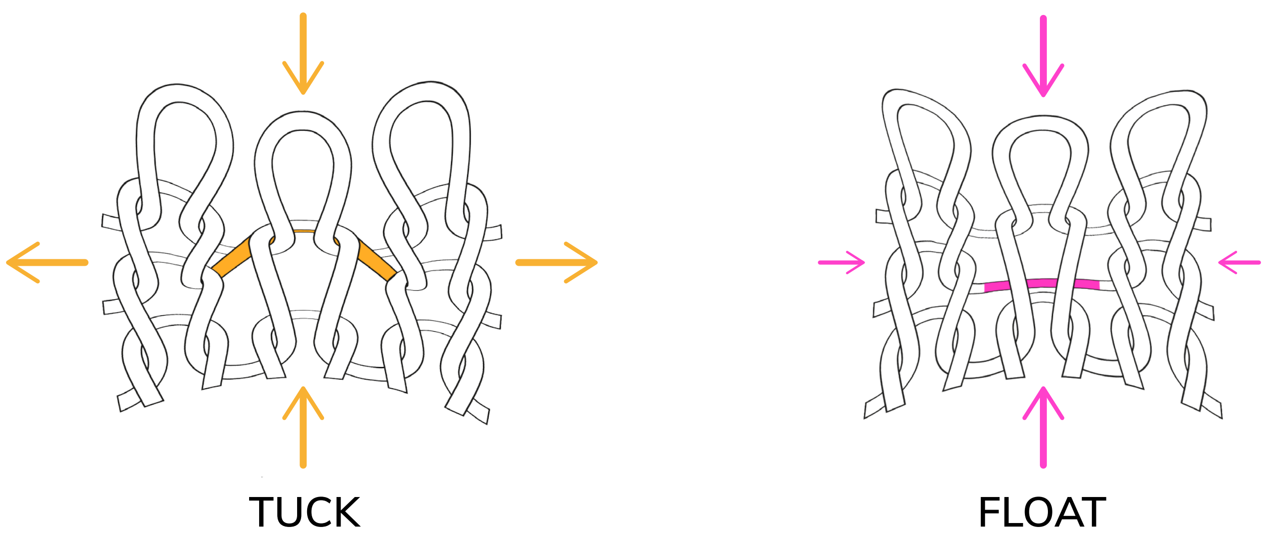


Figure 52, (left) The effect of a tuck stitch on the size of a knitted fabric, increasing in coarse length and reducing in wale length. (right) The effect of a float stitch on the size of a knitted fabric, decreasing the course and wale length.

Course Length Control

Incorporating tucks widens the resulting structure while maintaining a similar wale length to structures that replace the tucks for floats, keeping the percentage of stitches. Effective structures for this purpose include the Full Cardigan and Maglia Spiga. It's important to note that these structures exhibit high stretchiness and softness due to their intended use with a different stitch length compared to structures like Interlock or DJ 1/4. The difference in the textures of these structures is reduced after felting.

Depending on the chosen base structure, replacing tucks with floats can also reduce the course length. However, this also decreases the wale length, so both axes must be considered in the design phase.

Figures 53 and 54 illustrate the approximate correlation between the size profile of a knit structure and the ratio of stitches, tucks, and floats. Since knit structures cannot comprise only floats and/or tucks, the tested limit is illustrated with higher saturation. The double jersey is excluded because it creates undesirable textile qualities.

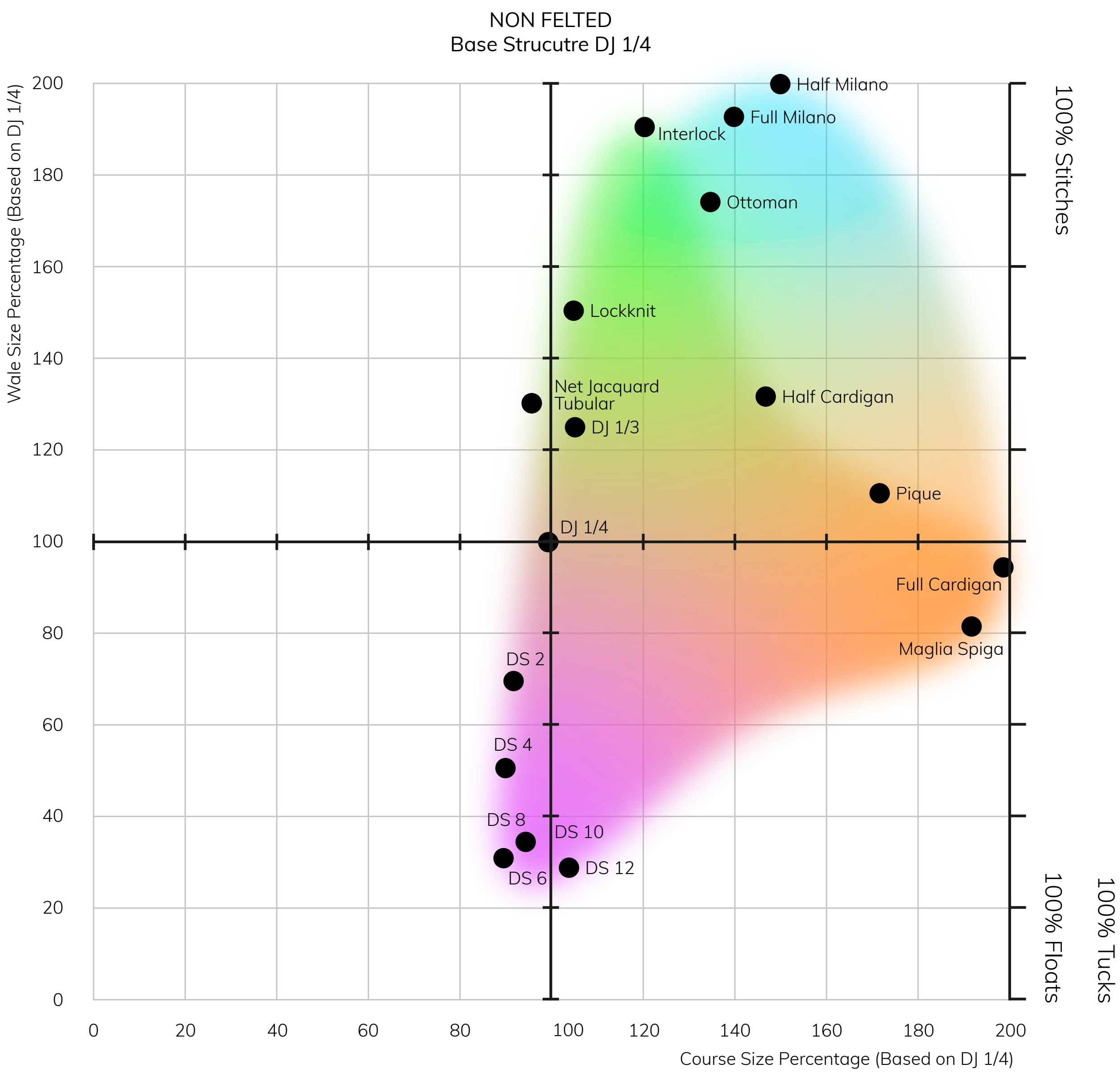


Figure 53, Structures are mapped based on the proportional size relative to 50% stitches and 50% floats (the DJ ¼ structure). Green represents 100% stitches, pink 100% floats, and orange 100% tucks. The greater cluster also includes double stitches, signified in blue. The colour also serves as a predictor for untested structures.

Felting

Felting wool was explored experimentally to assess its potential applications in shaping. The experiments have confirmed that wool undergoes shrinkage, with varying shrinkage observed across different structures. Generally, looser knits exhibit more significant shrinkage, which can be controlled by adjusting stitch length. However, since stitch length remains constant when knitting on a circular machine, all structures must be knitted at the same stitch length, resulting in varying levels of looseness among different structures. Structures like Double Jersey, Full Cardigan, Half and Full Milano, Pique, and Maglia Spiga tend to be looser in this scenario.

Felting introduces additional property shifts in the fabric, which must be carefully considered before implementing this processing step. While felting reduces the inherent stretchiness of knits by intertwining wool fibres, it also enhances the fabric's strength and protective qualities, which may be desirable for specific applications such as jacket fabrics. Moreover, felting can equalise textural and visual properties, resulting in a more cohesive appearance among samples.

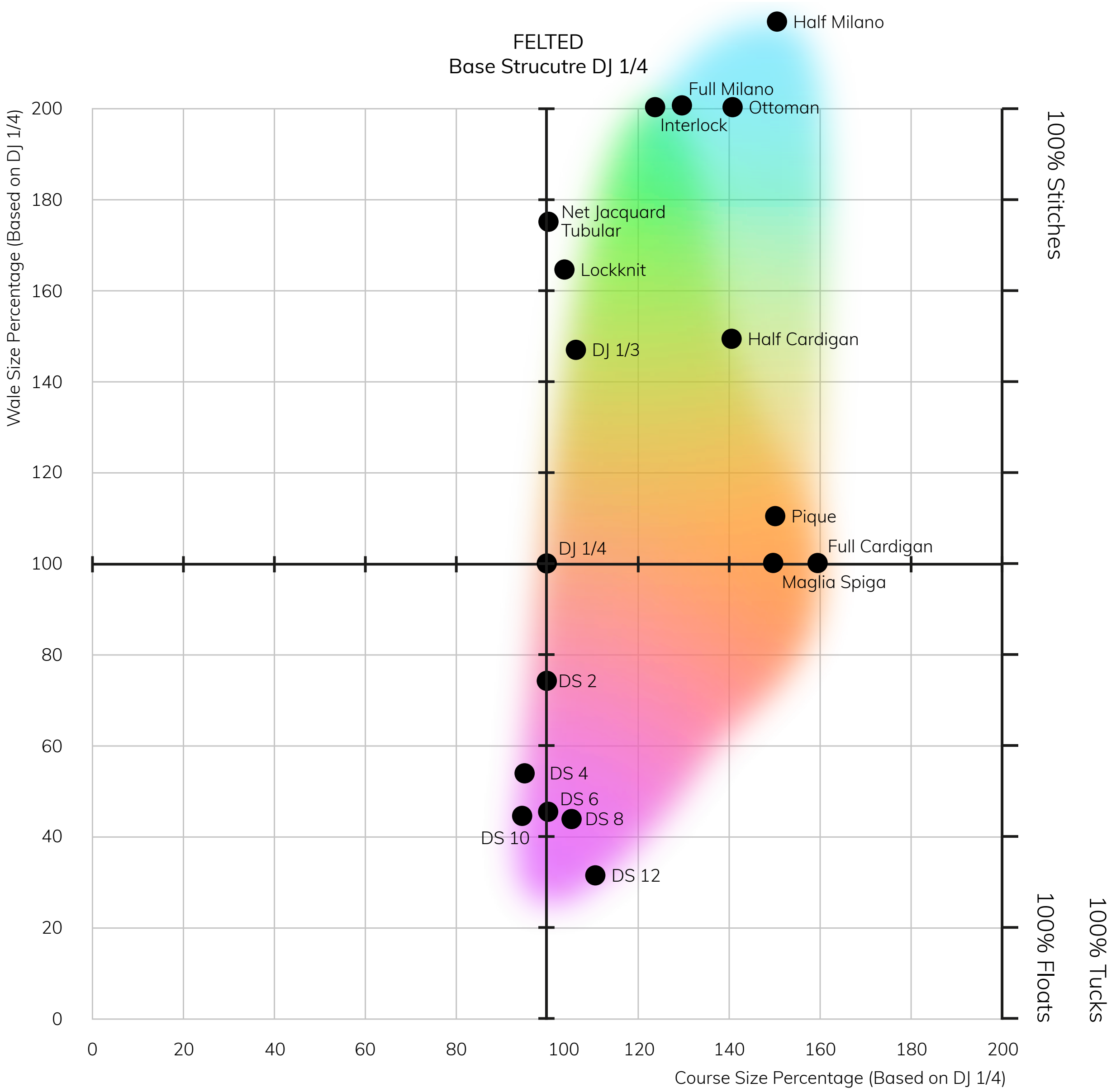


Figure 54, Felted structures are mapped based on the proportional size relative to 50% stitches and 50% floats (the DJ ¼ structure). Coloured indicate the same stitch-types as Figure 53.

5. PHASE 2

Shaping For Zero Waste

This research has identified a technique for applying form creation in a knitted fabric. But how do different knit structures interact, and can they be applied effectively to a whole garment? The resulting design process is presented through examples, clarifying each step and how to apply them as a designer. This part of the research focuses on answering the second research question:

2. What design and production methods are required to facilitate shape-integration for zero waste fashion design?

- **a.** How can this method be applied to an existing zero waste jacket pattern?
- **b.** How can this method enable a new approach to the design of a zero waste garment?


10-14

5.1 Understanding (ZWFD) Garments

Zero Waste: Good But Not Perfect

To answer this question, it is important to identify the shortcomings of ZWFD and the relevant requirements for a complex outerwear consumer garment. ZWFD is a promising solution to improve the future state of the fashion industry. Designing a garment and subsequent pattern to nest perfectly within the textile it is made from has the opportunity to eliminate any cutting waste, which for regular clothing is between 10-20%.

However, the approach also has drawbacks that, in combination, make it a challenging design method. Each of these is a reason for the fashion industry not to adopt the methodology, as they directly interfere with the industry's profit and speed attitude. However, for any given zero-waste design or project, not all reasons are necessarily valid. In the design process, it is possible to focus on solving predetermined requirements, but these negatively influence other factors. Figure 55 illustrates this balance.

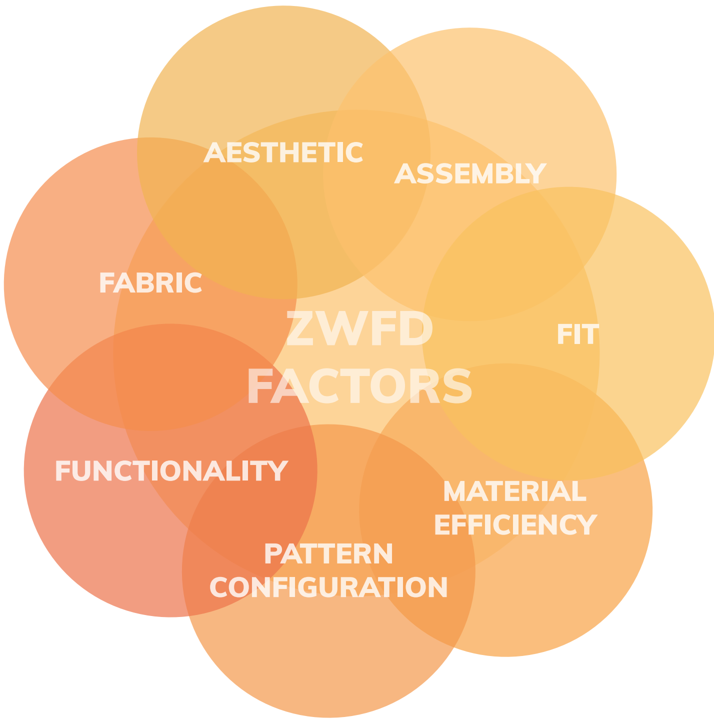


Figure 55, Design factors for ZWFD, showcasing the interdependencies for designing a zero waste garment.

Shortcomings of ZWFD

1. Time Investment

Zero-waste pattern design compromises the complexity of tailoring, fit, and aesthetics with the challenge of integrating all pattern elements without dead space, which leads to significant time investment (DECODE, personal communication, February 6, 2024).

2. Compromised Aesthetic

Zero waste patterns may compromise the look and feel of garments compared to traditional retail counterparts, including a boxy fit, more seams, asymmetrical elements, etc., which are sometimes required to make all pattern elements fit within a fabric [49]. These are consequences of the design method and can be seen as features, not bugs, but are often viewed as weird or different and not something the average customer looks for in clothing.

3. Increased Assembly / Labour

The segmentation of pattern elements is a common method to facilitate pattern design, but it also increases assembly steps and labour requirements. For complex curves that are symmetrical on a pattern, like the sleeves, cutting up the panels can be effective for nesting [74]. However, cutting and assembling a garment with more elements costs time and labour, which are undesirable if manufacturers avoid it in traditional cut-and-sewn garments.

4. Inflexibility

The pattern elements are interdependent, making it challenging to modify patterns for different styles or sizes [40]. Decreasing the size of one element influences the size of others. Apart from having to conform to human measurements, it is important for a garment that seam edges are of equal length unless designed otherwise. Therefore, any change to a ZWFD pattern element also means consideration for all other elements.

5. Material Yield

Many ZWFD garments, especially those with more pattern elements, have scraps in odd shapes or sizes applied as decorations. The design still has the same fabric yield in these cases, but the material is sewn onto the consumer product instead of the landfill. Ideally, ZWFD patterns reduce the fabric yield for a garment, requiring less material to produce the same amount of garments [57].

Garment Application: A Jacket

Why

This research aimed to develop a design process through designing and producing a knitted outerwear garment. Unlike pants and jeans patterns, which exhibit relatively efficient fabric utilisation, jackets present a challenge, with approximately 20% of fabric wastage due to the complexity of multiple elements and unique shapes. Furthermore, with their intricate shoulder joint structure, jackets offer an ideal canvas for exploring the project's objective of enhancing fit and comfort in zero waste patterned garments. Phase 1 researched multiple small-scale applications of knit structure mapping and found that certain combinations of shape and structure also lend themselves perfectly to the shoulders' geometric complexity. Finally, the developed material, especially the felted sample, presents remarkable similarity to existing woollen material, typically used for (over)coats.

Moreover, while sportswear is witnessing a surge in popularity and pioneering advanced knitwear technologies [69], this research focuses on minimising cutting waste and optimising garment fit. This project prioritises the creation of a wearable jacket suitable for urban settings, emphasising product styles from fashion brands that prioritise sustainability and collaborate with sportswear or lifestyle clothing companies rather than those catering solely to high-performance sports apparel.

Consumer Considerations

To determine the design requirements of a jacket for the consumer, a market analysis was performed on large brands that include knitting in their product line, based on their sustainability effort, pricing, innovation, and prevalence for use-environment (see Appendix G). Consumer perceptions of outdoor clothing, exemplified by brands such as Arc'Teryx and The North Face, categorise upper garments into three main types, commonly referred to as jackets:

Shell jackets are primarily designed for weather protection, while insulated jackets serve to provide warmth and comfort, with occasional weather resistance. Mid-layers or fleeces offer warmth either as an underlayer beneath another jacket, during milder weather conditions, or indoors. Insulated jackets typically incorporate a liner to enhance wearer comfort, conceal seams, and create insulation space between the jacket's interior and exterior layers.

In the context of producing a jacket entirely from knitted fabric, opting for a liner would double the required material, rendering it impractical. Moreover, knitted textiles, irrespective of their composition, inherently lack waterproof properties. Considering the attributes associated with various garment categories, this research focused on a single layer jacket for moderate temperatures in dry weather. The chosen textile, based on the material developed in Phase 1, was a felted double-knit merino wool knit, resembling woollen (over)coats in terms of fabric weight, stiffness, and insulating properties.

Product Composition

This study focuses on enhancing the ergonomic aspects of jacket patterns to achieve a personalised fit and testing and validating the consumer product required, considering practical elements like pockets and seam finishing, which contribute to the perception of a finished product. The emphasis lies on objective factors that influence garment functionality and user experience. Subjective design aspects like expression, status, and style were excluded from the scope.

Building on personal knowledge and the performed market analysis, three types of pattern construction for a jacket garment were identified and analysed for their composition, as visualised in Figure 56. This analysis concluded that a jacket comprises four pattern categories: The body, front and back, sleeves, collar, and other detailing.

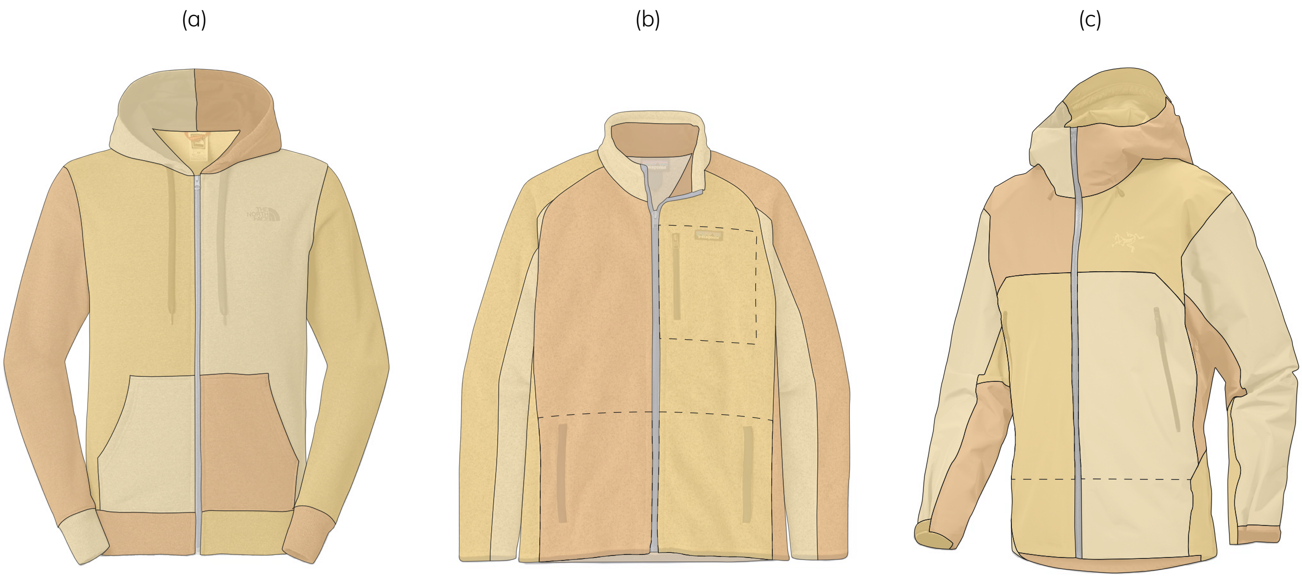


Figure 56, (a) North Face hoodie with 12 pattern elements (not including lining). (b) Patagonia mid-layer with 13 pattern elements (including pockets, but not lining). (c) Arc'Teryx shell jacket with 20 pattern elements (including pockets, but not lining)

5.2 Shaping Design Process For ZWFD

Existing research presents various approaches to creating sections with a specific desired functionality and the material is produced to integrate all of these functionalities. Viewing garment design and production as a holistic process, and analysing the general process in Chapter 2.2, the order of operations up until the material is actually produced can be adjusted to combine garment/ pattern design and textile manufacturing. If the desired size, shape, texture, etc is determined, the produced material can incorporate these features/ functionalities, instead of later addition with sewing or other finishing processes.

This concept resulted in an iterative design process that provides opportunities for quick iterations, including simulation and calibration, and applies to existing and new zero waste designed garments. Figure 58 illustrates the process.

Starting Point

As a starting point for developing this process, the concept is to take an existing design by Danielle Elsener (Figure 57) (DECODE). and apply the technique to target specific areas of improvement. This jacket was designed for an archetypal look and tailoring but was limited to only the pattern. The jacket was analysed for potential enhancements, and appropriate knit structures were applied to realise the envisioned improvements.

Digital design (Adobe Suite) and simulation tools (CLO3D) are used to identify, ideate, and validate the design considerations. The structures are programmed and knitted into the textile, after which the garment is assembled, considering the design changes that require different assembly/ finishing methods.

For validation purposes, two jackets were produced and compared based on their production process, steps involved, materials used, and user testing evaluating comfort, wearability, and aesthetic appeal. One jacket is made from the original pattern as a baseline. To ensure accurate testing of ergonomics without distraction, both jackets are made from the same base material, with only one jacket incorporating different programmed structures into the pattern. Consequently, both jackets undergo identical treatment from the knitting step onward, minimising differences, including cutting, sewing, and post-treatment procedures like washing.

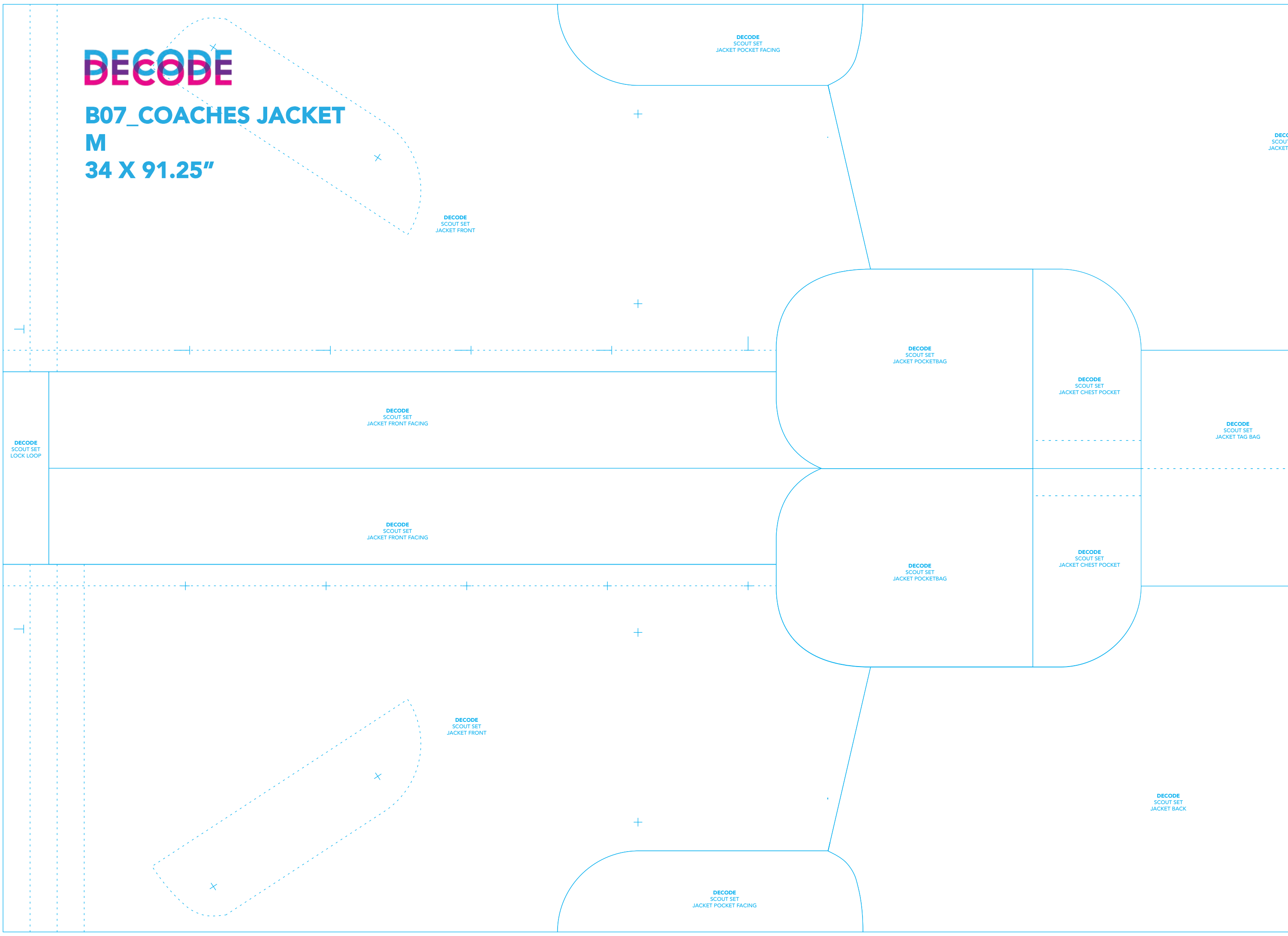


Figure 57, Decode Coaches jacket pattern by Danielle Elsener. IP owned by DECODE (2024).

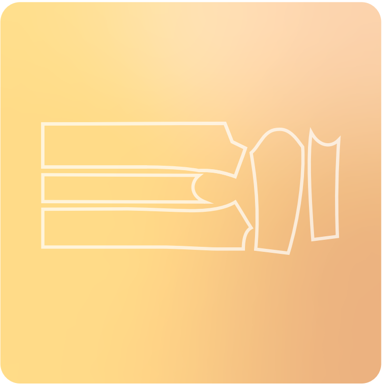
Design Tools

Sketching

For ideation purposes, hand sketching and computer sketching were applied to explore, realise, and communicate the desired shape.

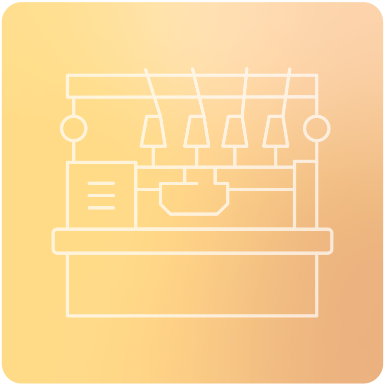
Simulation

An essential aspect of fashion design is crafting prototypes, which can be done digitally in the first stages of a design. For this research, the knit structure size profiles were modelled in CLO3D at the design stage to estimate the knitted result.



Vector Drawing

To design with great accuracy, Adobe Illustrator was applied to create vector files of the pattern and its adjustments. Formulas define vectors which do not require a resolution and improve cross-platform compatibility.



Production

The Stoll CMS 530 was used to produce the textile, which was programmed with the associated M1 Plus software. The garment was then finished using standard sewing methods on consumer machines.

Design Process

Summary

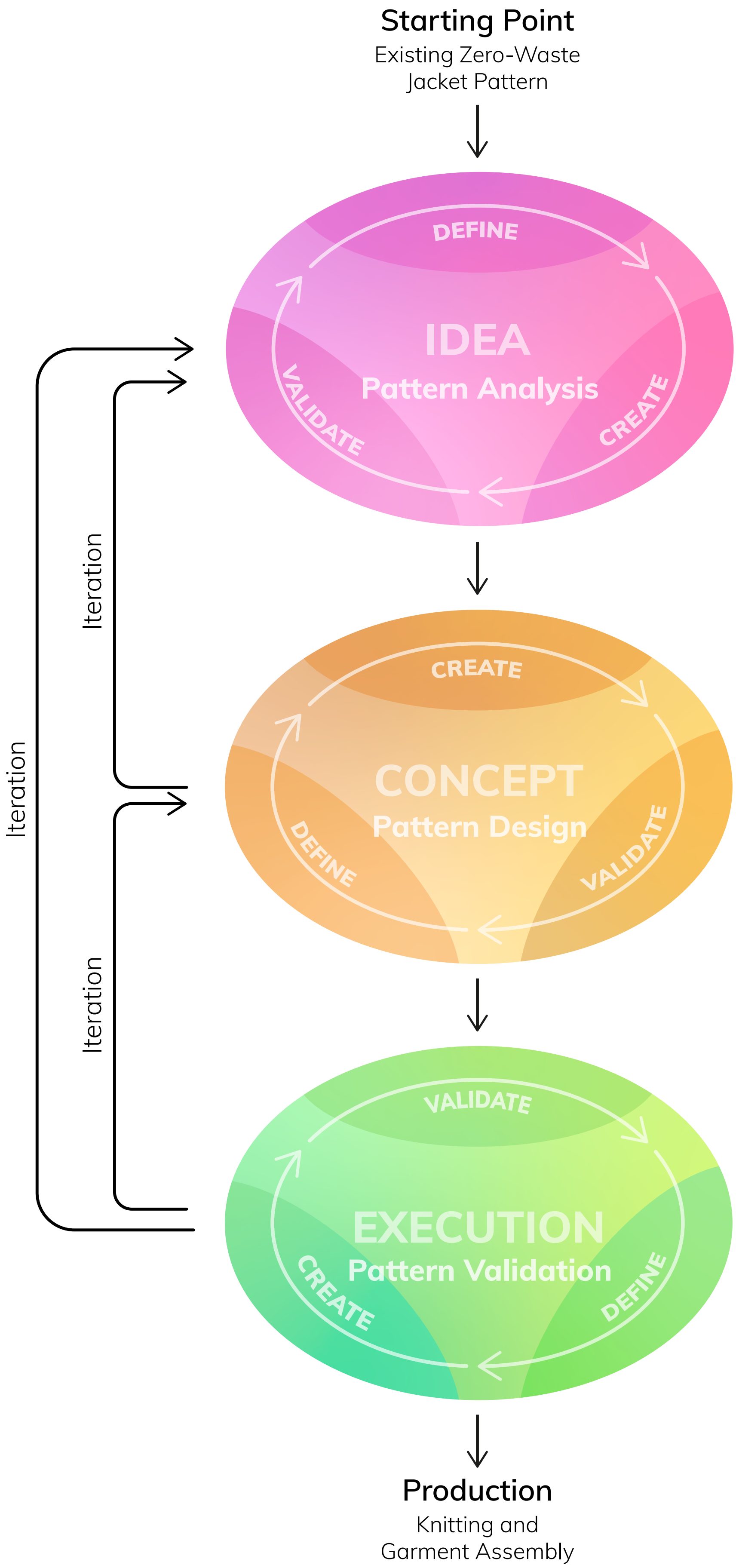


Figure 58, Design process flow overview.

Analysis of Desired Functionality

To analyse the existing design and identify opportunities, the pattern provided by Danielle Elsener was imported and optimised for CLO. The software has a feature to project the strain (the percentage of elastic deformation) of the fabric onto a garment (Figure 59), which enables effective identification of suboptimal ergonomic areas, compared to creating a physical prototype, which can have defects and cost significantly more time and material. The size of the model is a female, 38 US.

Based on the simulation in Figure 59, in combination with an interview with Danielle, in which she shared her objectives and compromises for the jacket design, the following enhancement areas were determined.

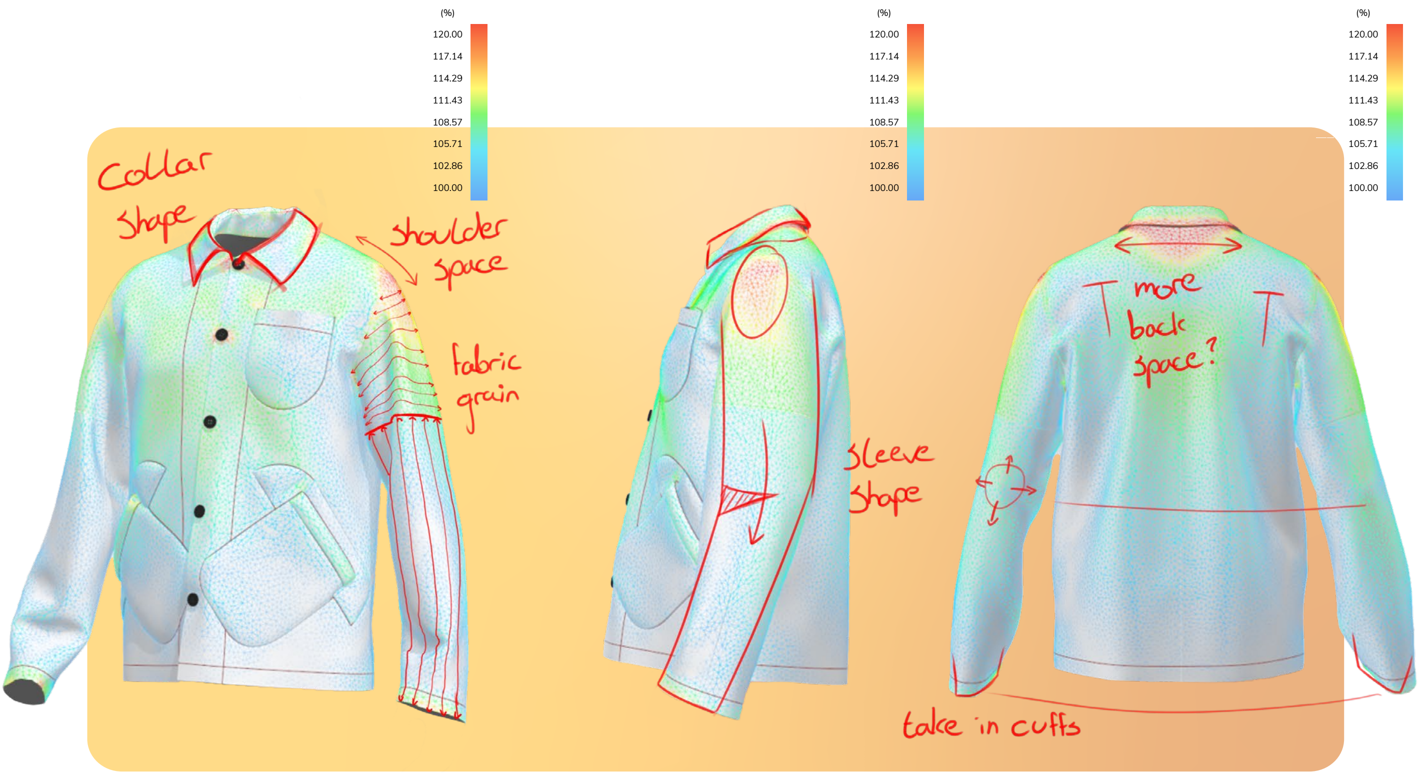


Figure 59, DECODE Jacket modelled in CLO3D and overlayed with a strain map to identify ergonomic pain points. Red areas indicate high strain (20%) and the sketched overlay indicates suggestions for improvement.

Articulation

Currently, there's no shaping around the arm's shoulder and elbows. The arm panels are segmented into four sections to form a standard arm panel, common in sweaters and hoodies (Figure 56 (a)). However, to mimic the curvature of suit jackets, Danielle desired more articulation, particularly at the elbow.

Fit

The jacket design accommodates various closures, with this version featuring a front placket for buttons, elastic cuffs, and a drawstring hem for adjustment. Danielle emphasised the importance of maintaining adjustability for ease of wear, especially around the shoulders. The simulation shows that the jacket cannot conform to the shoulders and across the back. For the collar, the current pattern utilises two rectangles that align with the block but lack the desired aesthetic resembling a fitted suit jacket. Additionally, there was an opportunity to integrate the cuffs into the textile instead of sewing in an elastic.

The top elements of the sleeve are rotated 90 degrees in the pattern, which is undesired when working with an elastic material. However, this issue can only be addressed in the pattern design phase.

Look

The jacket aims to blend seamlessly with conventional non-zero waste jackets on the rack, prioritising a refined and standard appearance. Different samples from Chapter 4.2 yielded varying colour shades, which can be mitigated using a single yarn colour or amplified by incorporating more colours. Considering that the garment aesthetic is not the focus of this research, the general garment should be neutral. However, different patterns per structure can visualise the structure composition. Critically, these should not compromise the ergonomic improvements' primary focus on the zero waste design method.

Felting

Even though the research from Chapter 4.2 did not yield effective tools for form creation from applying wool's morphic properties, felting creates a sturdy, protective, and soft fabric, all desirable attributes for the jacket material, as discussed in Chapter 5.1. Equally important, Danielle designed the original jacket for a woven cotton rip-stop, which is non-elastic. Felting the knitted material significantly reduced the elasticity of the sample from Chapter 4.2 and is, therefore, the selected finishing method for the jacket.

Designing Enhancements

The concept involves integrating structures of varying sizes into specific areas to modify their shape. This process started by adjusting the pattern in CLO3D until the desired fit was achieved with a non-zero waste pattern inspired by the jacket types from page 83, as depicted in Figure 60. The new pattern was compared to the zero waste pattern, and structures were applied to bridge the gap (Figure 61). With the general knowledge of size profiles, based on the database collected in the previous research of this report, six structures were suitable to create the desired shape from the original zero waste pattern.

Figure 60, Front view render of desired jacket shape with non-zero waste pattern.

Figure 61, Each designed segment with the intended pattern shape, based on the desired shape changes.

Table 2 lists the structures used. The weight of the material motivated the choice of the base structure. After felting, the double-layered merino wool becomes very dense, especially in structures with more floats. Therefore, the main body of both jackets is DJ 1/3, a larger structure. The desired size profile, in combination with the stability and texture of the knit, determined the surrounding structures, as selected from the sample library of Phase 1.

Structure Name	Desired Proportional Course Length	Actual Course Lenght	Desired Proportional Wale Length	Actual Wale Length
Interlock	~110%	109%	~140%	139%
Half Cardigan	~125%	131%	~100%	100%
DJ 1/3	~100%	100%	~100%	100%
DJ 1/4	~90%	88%	~75%	72%
Full Cardigan	~130%	128%	~75%	66%
DS 2	~80%	81%	~50%	56%
DS 4	~70%	71%	~30%	36%

Table 2, Table with size profiles of selected knit structures. The desired and measured relative size compared to DJ 1/3 is listed per structure for the course and wale length.

Structure Development

Research from Phase 1 tested and quantified the knit structures using small samples measuring 100 needles by 100 rows. While suitable for rapid exploration and finding an initial correlation, this low-resolution approach carries a higher margin of error when scaling up for garment production. Furthermore, the size profile of a structure can vary depending on factors like stitch length, yarn material or even yarn colour. A general-purpose swatch was devised to ensure validation, comparison, and generation of applicable data (Figure 62), featuring larger knit sizes for each structure: 200 needles by 150 rows. This resolution balances accuracy and time, considering the extended knitting time for additional rows across six structures. While M1 Plus visualises knit structures using square pixels, real-life structures often deviate from this shape. Hence, the swatch incorporates circles to visualise the size ratio of each structure, similar to the graphs in Chapter 4.4.

Programming the Stoll industrial knitting machine begins with creating artwork, where each pixel corresponds to a knitted stitch in the final product. Coloured pixels are then assigned to modules, representing repeatable blocks of stitches for specific yarn colours. The colour module for the jacket swatch, known as JD_1_Swatch_M32_3, is included in Appendix H.

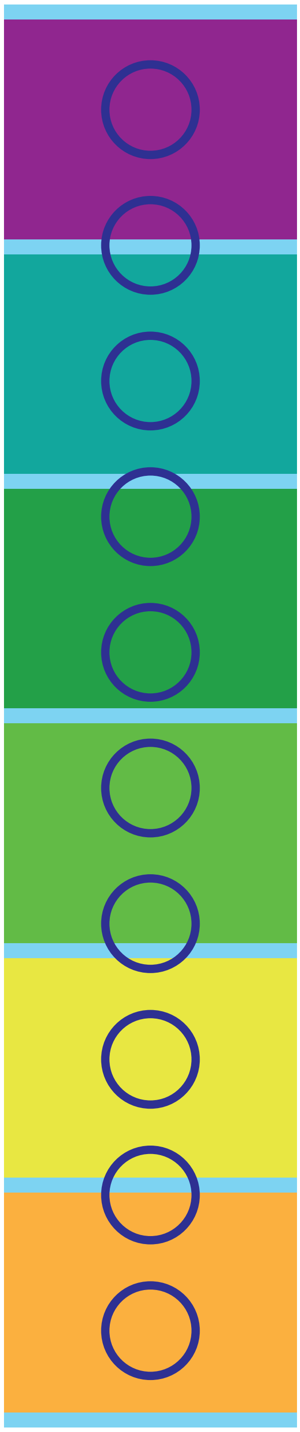


Figure 62, General purpose swatch artwork for testing and quantifying selected knit structures.

The swatch was knitted with identical settings to the samples from Phase 1 and felted with the same washing machine settings. The measurements for each structure are in Table 2 and visualised in Figure 63. They follow the same triangular pattern, demonstrating that the measurements align with previous findings. However, they also demonstrate that the previous measurements were off, especially for the structures with a larger difference ratio compared to the base structure.

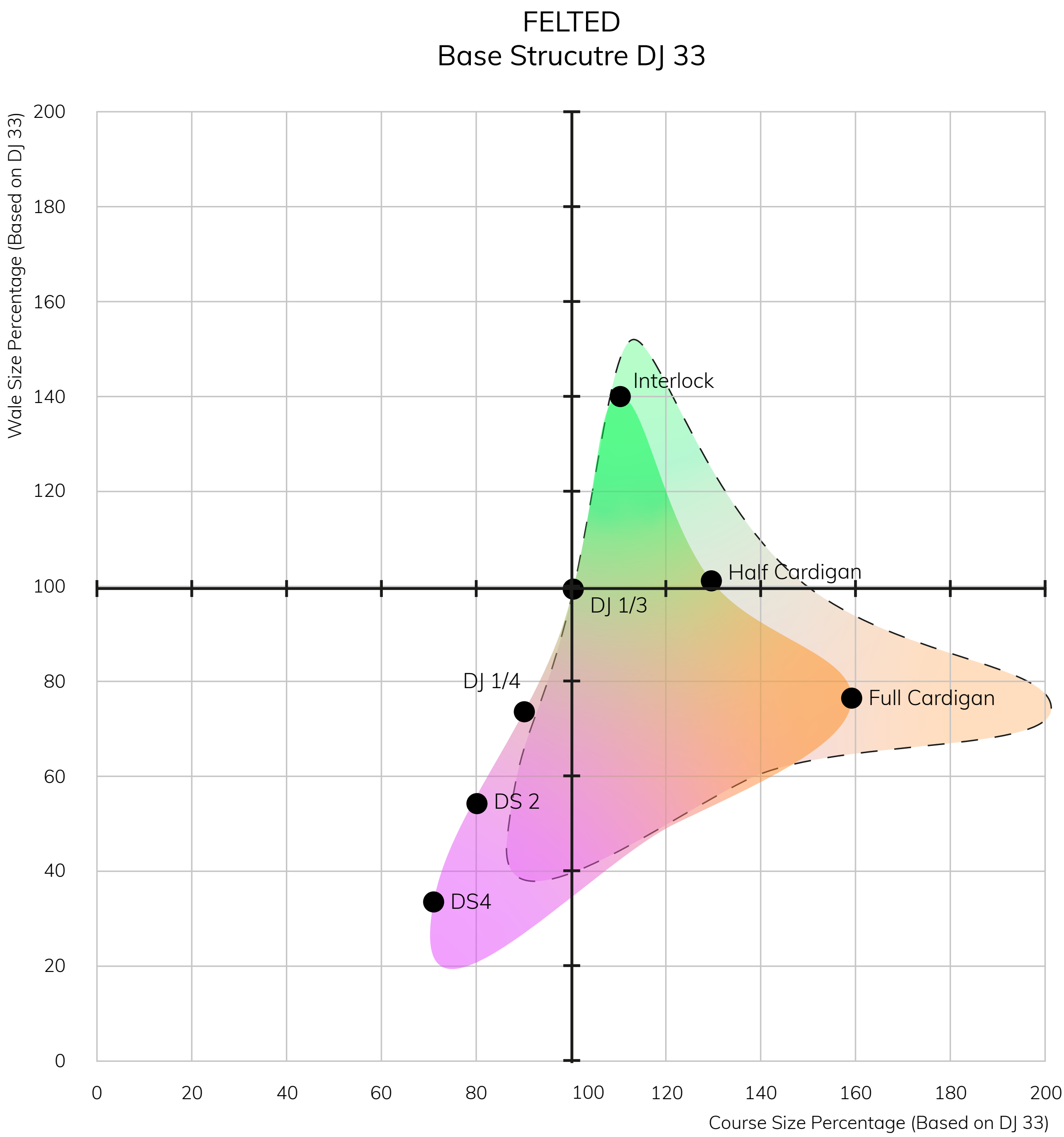


Figure 63, Graph with quantified size profiles of the 7 identified knit structures for the jacket. The colours indicate the percentage of stitches (green), tucks (orange), and floats (pink). The dotted line indicates the size profiles of the structures from measurements in Phase 1.

Digital Validation

The structure map was refined based on the data gathered from the swatch. Then, similar to modelling the original pattern in CLO3D, the designed structure pattern was also simulated using CLO3D, which involved exporting vectors from Illustrator into CLO3D and tracing them onto the existing pattern. After cutting and sewing the pattern segments, each segment was programmed to the proportional size profile identified in the previous chapter. While this method provided an approximate simulation of how the structures influenced the jacket's shape and size, it has limitations, particularly where sewn edges can create tension and distort the strain map. Therefore, the simulation's accuracy was assessed based on the visual appearance of the garment on the avatar. Figures 64 and 65 showcase the shaping lines of the original and adjusted jacket. Comparing the silhouette lines, it is evident that the adjusted jacket has more shape in the arm and collar. The back also has fewer creases, indicating a better fit.

Figure 64, Side by side comparison of the side view for the original zero waste jacket and the adjust jacket. Silhouette lines indicate the lines of the jackets.

Figure 65, Side by side comparison of the back view for the original zero waste jacket and the adjust jacket. Silhouette lines indicate the lines of the jackets.

Production

Jacket Artwork

The structure artwork was mastered in Illustrator and projected on the original pattern (Figure 66). Since the pattern is knitted into the material, adding additional graphics on the pattern to aid manufacturing is practical and time-saving. Therefore, the artwork also included elements typically found on graded patterns. This includes seam allowance, sewing markers, button and pocket markers, and hem allowance. The whole pattern requires 730 needles of knitting width. However, the CMS 530 only has 699 needles in width, so the pattern was divided in half (Figure 67). The baseline jacket was knitted with a plain DJ 1/3 in the same dimensions for time-efficient production.

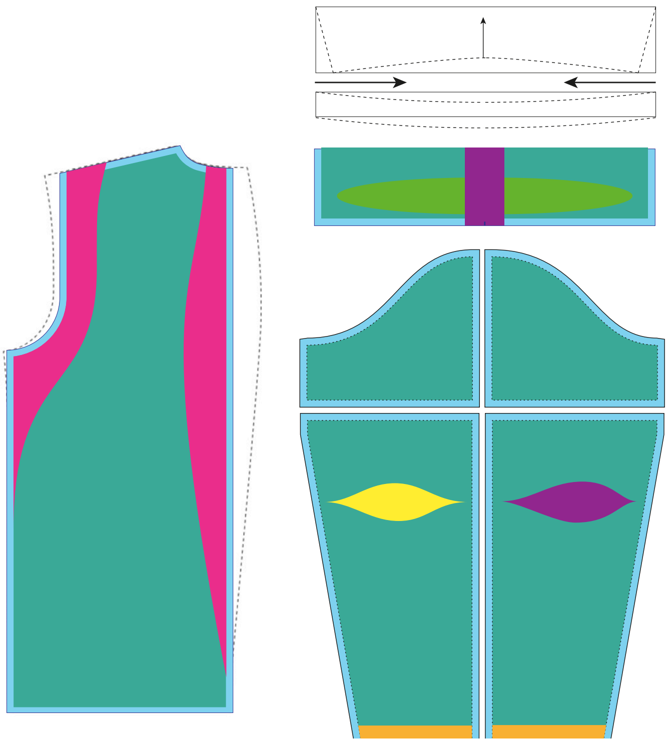


Figure 66, Artwork for sleeves, back, and collar pattern elements. The colours correspond to the assigned structures.

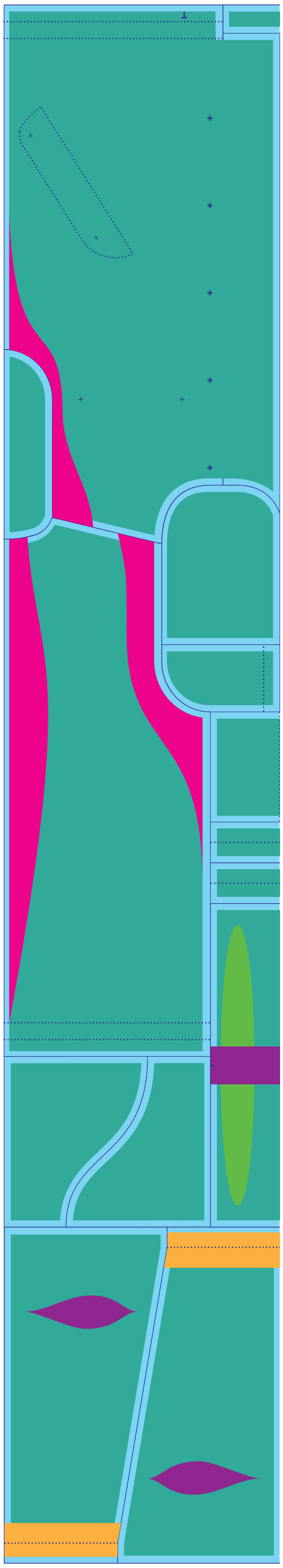


Figure 67, Artwork for left side of the adjusted shaping pattern for the DECODE Jacket. Note that the pattern is not to scale.

Order of Operations

The sequence of knitting, cutting, sewing, and felting can impact the outcome. Multiple identical swatches were produced in different orders of operation to explore various sequences.

1. knitting, washing, cutting, and sewing
2. knitting, cutting, washing, and sewing
3. knitting, cutting, sewing, and washing

Results showed that production order indeed affects the final result. Those cut before washing appeared the smallest and stiffest, while the directly washed sample was slightly larger due to support from surrounding knit structures during shrinkage. The sewn sample exhibited uneven felting near the seams, causing curling due to overlocking the seam before shrinking, which slows drying and affects material quality. Washing stabilised the fabric, reducing fraying during subsequent cutting, which resulted in the most finished product.

Knitting and Assembling

From turning the knitting machine on, the design and production process for both jackets is identical. Each jacket was knitted in two parts, washed for felting, air-dried, and cut. Cutting the adjusted jacket was straightforward and accurate, but the baseline jacket required a paper pattern for tracing and cutting, resulting in more production steps.

The final material was ~900 g/sm, which is extremely heavy and dense. For this reason, several sewing techniques were tested and graded with a Harris profile (Appendix I). A regular straight stitch close to the edge was used for all general seams, followed by a cover stitch to flatten the seam. Bias tape was used to finish the fabric edges to avoid folding the material. Here, the most significant difference in assembly was the sleeve hems, which did not require hemming in the adjusted jacket because of the applied structure at the sleeves (orange in Figure 66 and 67).

User Testing

Phase 2 had multiple goals in developing a design process for application on zero waste garments. One of these goals was to modify an existing design to improve the ergonomic comfort of the consumer product. To validate the efficacy of the modification, the baseline and adjusted jacket were user-tested. The user test evaluated the jackets' visual and tactile impressions, fit, comfort, perceived value, and storytelling elements.

Observation and interviews were employed as evaluation methods to conduct the user test. Participants were selected based on their size matching the approximate jacket size (female 38 US). Participants were recruited from the faculty, with a brief 10-minute test session to assess the jacket's performance (Figure 68). Before the main test, a pilot test was conducted with a friend, which revealed that the jackets were primarily judged on their appearance, texture, and colour, not their fit. Interview questions were created to extract relevant information from the participants listed in Appendix J. The interview results are in Appendix K.

Figure 68, Zero waste jacket with structure mapping that was used for user testing. Modelled by Myrthe Coster.

User Testing Findings

Conclusion 1: Size Matters

Based on their current coat size, interviewing a range of women from size S to M/L revealed that those wearing size S did not fit well into either jacket initially. Only upon pointing out the differences did they notice a distinction. Participants in larger sizes noted a significant difference in fit, particularly in the shoulders and back, preferring the adjusted jacket for its better fit. Sleeve hems evoked varied preferences, with some favouring a looser style and others preferring better-sealed sleeves for added protection.

Conclusion 2: Personal Taste

Initial opinions on the jackets varied, with an overall appreciation for the protective yet unrestrictive feel of the bulky material. However, some participants disliked the jacket length, while others likened it to a denim jacket, reflecting individual style preferences. Regarding the visibility of different structures, opinions ranged from preferring plain material for everyday wear to appreciating visible structures for artistic effect or personal storytelling since the shape and size of a structure are based on individual fit.

Conclusion 3: Perception of Quality

Participants unanimously described the jackets as bulky, stiff, warm, and cosy, all associated with positive perceptions of jacket quality. Feedback also highlighted the jackets' high-quality appearance and perceived value despite the absence of price indications or brand associations. This perception illustrates the importance of materials and design in shaping perceived quality and value. Despite personal reservations about the jackets' quality due to their prototype status, participants perceived them as high-quality due to their labour-intensive construction, quality materials, and thoughtful design.

5.3 Phase 2 Discussion

The Design Process

With an existing pattern design for an outerwear garment, the design process follows a series of logical steps navigated in small iterative circles. The process deviates until the actual production of the fabric. It integrates the garment, fabric, and tailoring into the design process, where all of these factors influence each other, resulting in a considerate design with the potential for integrated personalisation. The shaping method developed in Phase 1 allows for precise tailoring through material reduction or addition across the pattern. As a result, the adjusted structure placement, initially derived from a digital avatar with a predetermined size, can alternatively be tailored to a personalised avatar.

Simulating Structure Mapping

Incorporating simulation into the design workflow proved effective and relatively straightforward. CLO3D's tools provided a decent simulation of the effects of different structures, although there were limitations. Since the final material for the jackets was unknown during the simulation, the fabric representation in CLO3D was inaccurate, leading to a slight misrepresentation of the shape. However, user testing demonstrated that the sought-after enhancements were noticeable between the two jackets, especially when sized correctly.

Disparities between the arm and sleeve visuals in CLO3D and the real jacket stemmed from the clean borders between structures in CLO3D, compared to the inherent gradual blending of tensions of structures during the knitting process. This resulted in a softer shaping effect, particularly pronounced in areas with greater differences between structures.

Limitations

Designed Garment Fit

While the redesign addressed most identified problems, the changes were subtle. While differences were noticeable in CLO3D, the final results were less visually apparent, although noticeable to participants. The pattern and orientation of the jacket's elements constrained the type and shape of structures that could be applied to enhance fit and comfort. A great example was the sleeves, made from four segments, which required additional sewing compared to a traditional jacket. The top half of each sleeve is also rotated 90 degrees, which is not an issue for a non-elastic woven ripstop but is far from ideal in combination with a stretchy material.

Assembly Optimisation

Shaping the fabric offers the hypothetical benefit of requiring fewer panels for a form-fitting garment, potentially reducing assembly steps and labour. However, this jacket's pattern was not designed with assembly reduction in mind. The sleeves, made from four segments, required additional sewing compared to a traditional jacket. Therefore, the adjusted jacket highlighted a difference in fit rather than assembly efficiency.

Fabric

The shaped knitting technique is independent of the yarn material, but utilisation in a consumer product necessitated the design of a suitable material. The chosen knitted and felted woollen fabric proved very stiff and dense, impacting movement and complicating assembly. The desired elegance of the method was not reflected in the final look of the garment, highlighting an opportunity for refinement in textile production and assembly techniques. In addition, exploring visualisation methods for the different knit structures, such as colour, texture, or graphical pattern, presented additional opportunities for this method.

Back to table of contents

6. PHASE 3

Full Integration For ZWFD

Incorporating structure mapping to manipulate shaping within an existing pattern proved feasible and enabled tailoring without altering the base pattern. This result raised the question of how far the research can push the technology's benefits with a garment pattern designed explicitly for structure mapping.


Industrial Design

Introduction

The concept is that by keeping panels simple and using structure mapping to realise complex geometries, the resulting elements could nest together easier and faster. It also minimises unnecessary elements like hangtags or pocket reinforcements, which were present in the previous jacket design. With a simple fit, shape could be added in either direction, depending on the base structure, accommodating various body types.

Another theorised benefit of structure mapping is reducing production steps, as features like darts can be integrated directly into the material during knitting, eliminating the need for additional sewing time and labour. The concept of simplified pattern geometries also poses the possibility of speeding up the pattern design process, which can traditionally be extensive. Instead, detailing can be left to the structure mapping design step, which can be built on an existing block to implement any desired size or shape change without redesigning the entire pattern.

With an enhanced understanding of the technique and design process, this phase aimed to extract and demonstrate the potential benefits of ZWFD and how these design goals interact (Figure 55, page 80), as they are interlinked similarly to the elements of a zero waste garment pattern. Phase 3 is an extension of the design process described in Phase 2.

6.1 Garment Design Process

For ZWFD structure mapped products

Similar to the design process in Chapter 5.2, the design process for a garment with zero waste as its foundation considers multiple aspects simultaneously. This results in an iterative approach, addressing each process step several times as the design progresses. Figure 69 illustrates these steps.

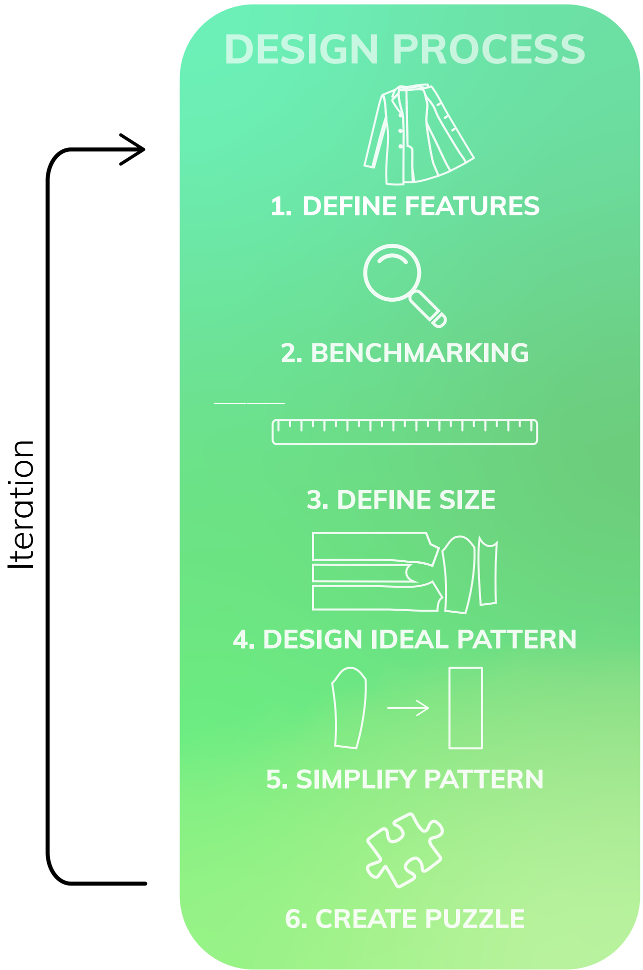


Figure 69, Design process for designing a non-zero waste garment that can become zero waste through structure mapping.

Garment Specifications

Essential to designing a garment is defining the desired properties. In this case, the goal of the design was to extract the same benefits as Phase 2 but expand on it from a perspective of efficient product assembly and personalised tailoring and utilising the high-quality material appropriately. The industry can only achieve the future state of fashion regarding sustainability if the perception of limited-use clothing is changed. Demonstrating this requires a garment that can last for decades and be desirable for that same period. In reality, most clothes are thrown out because they no longer desire to be worn instead of being worn out and falling apart [37]. Therefore, this research selected an overcoat as the appropriate jacket style.

Overcoats are an archetypal garment style that embodies timeless sophistication and functionality. Originating centuries ago, they have evolved from military attire to a staple of men's and women's fashion, transcending trends and seasons [41]. Characterised by their long length, tailored fit, and structured silhouette, overcoats embody elegance and refinement, which resemble the sophistication of integrating shape into clothing with structure mapping. An overcoat's versatility makes them effortlessly transition from formal occasions to everyday wear, making them a wardrobe essential for both men and women. With their rich history and enduring appeal symbolise classic style and lasting elegance in contemporary fashion [62].

Therefore, an analysis established the main features of an overcoat from Dior [21] (Figure 70). Pockets and neckline variations were optional elements, allowing flexibility based on zero waste block patterns. Additionally, the fit around the shoulder and arm areas, crucial for ergonomic comfort, could involve different panelling and geometries, with the final selection determined by the combination of tradition and shaping potential. As these optional elements contribute to functionality without significantly increasing waste, they are integrated into the design process to optimise garment utility and minimise environmental impact. There is also a gender factor concerning the differences in shaping men's and women's garments. Therefore, a unisex design approach is proposed, initially derived from a male block pattern, to ensure versatility and adaptability across genders through structure mapping.

Figure 70, Overcoat pattern analysis with 14 pattern elements (excluding pockets and lining) (Dior coat as underlay [21])

Designing The Starting Point

The objective is to create a pattern design that maximises the advantages of structure mapping rather than focusing on designing an overcoat as a consumer product. However, the overcoat should maintain a high-quality appearance to showcase its potential for consumer product application, matching the standards set by the previous jacket design.

Sketching and Digital Design

It all starts with a pattern goal, defined by designing a jacket. Sketches (Figure 71) were made based on the analysis of Figure 70 and creative ideas to embody the elegance of the structure mapping technique. The (b) jacket from Figure 56 (page 83) was previously modelled in CLO3D to understand the shape and interaction points of the 2-piece sleeve and body-side panels. This pattern was adapted for the overcoat by extending the bottom hem, altering the collar shape and fold, and replacing the zipper with buttons. The resulting pattern is illustrated in Figure 72 For detailing, two hand pockets were selected as essential, where an inside or chest pocket might be the consequence of the subsequent zero waste pattern.

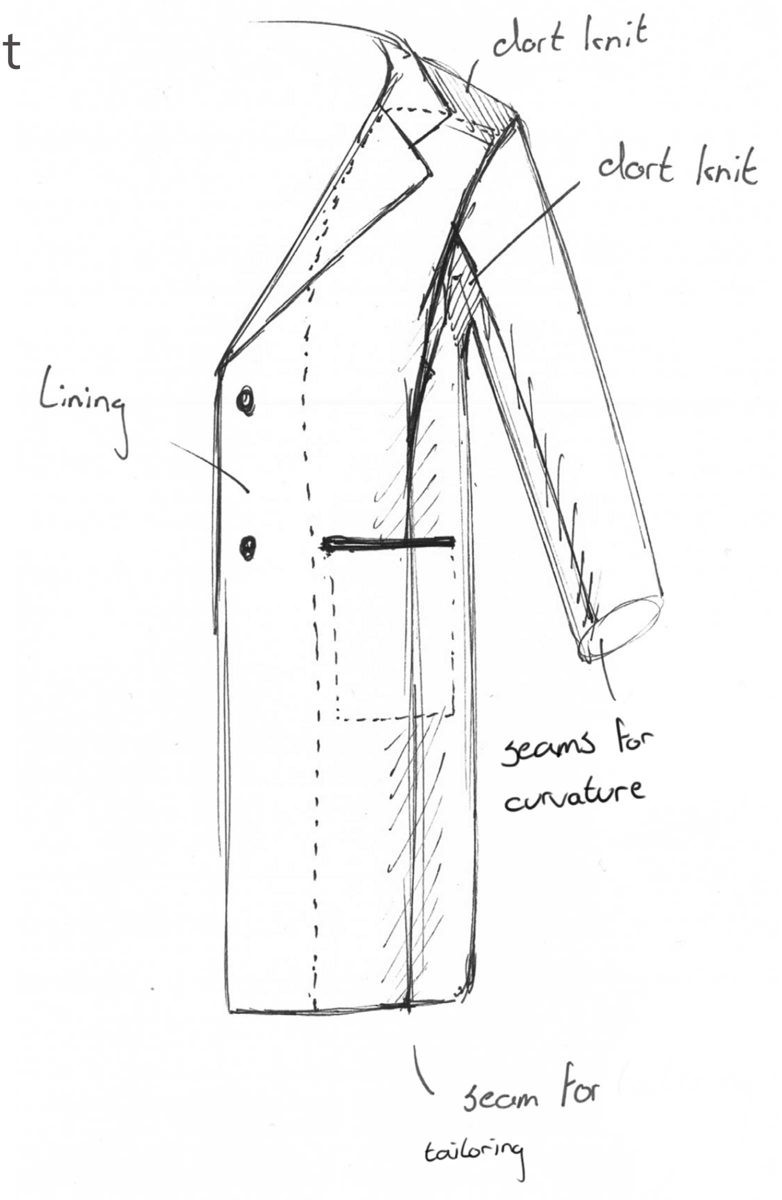


Figure 71, Sketching of the desired overcoat shape and features.

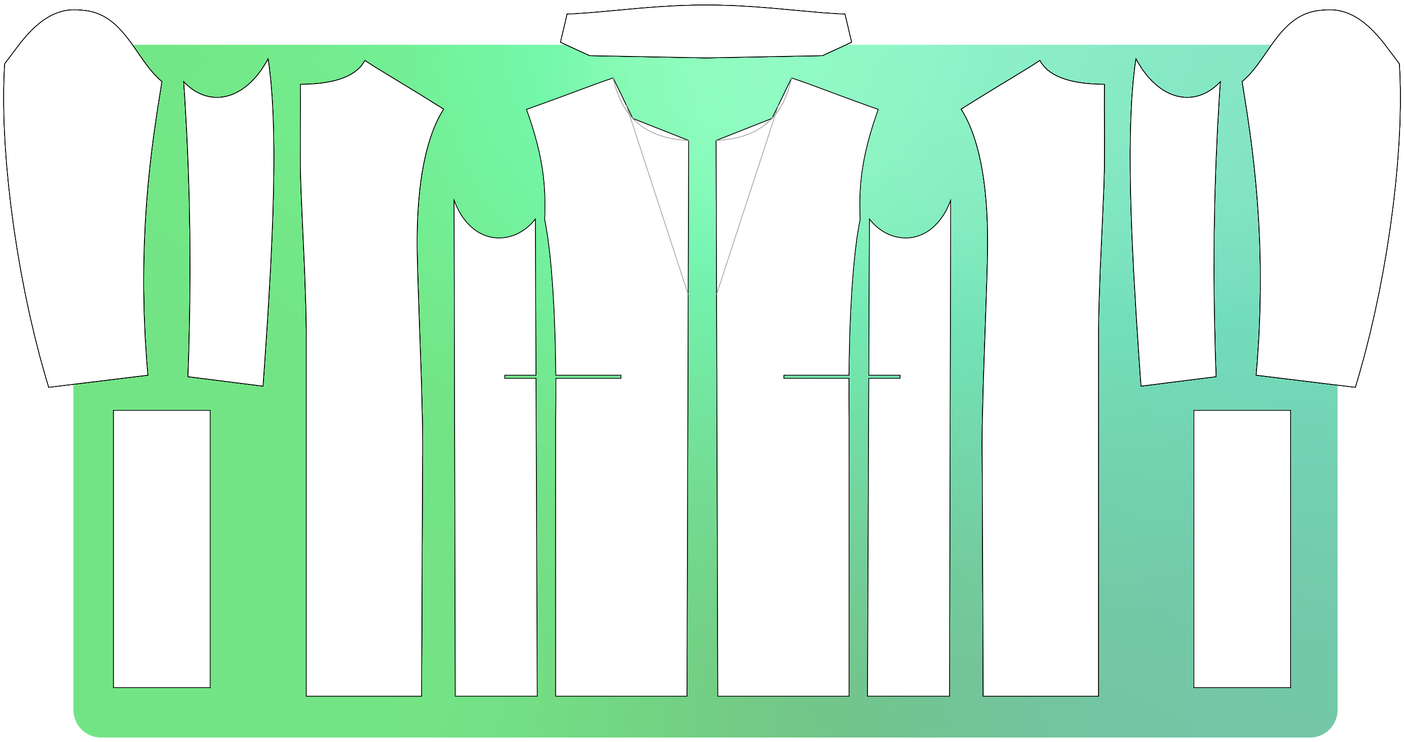


Figure 72, 2D view of the 13 pattern elements for the desired overcoat.

Sleeve Articulation

A particular area of importance in an overcoat is the invisible articulation of the sleeve. Where commonly a sleeve is achieved by a tubular element, this type of sleeve is achieved by a 2-panel pattern that curves with the arm (Figure 73), removing the need for sewn or knitted darts, as was utilised in the design of the previous jacket.

Since there are two seams instead of one, this pattern style also allows for better tailoring without adding more seams or sewing steps simply by adjusting the curvature of the sleeve panels.

Tailoring

Following the overarching goal of this research, the aim is that the overcoat has a tailored and personalised fit. For this purpose, an avatar was created in CLO3D with custom measurements. Then, the block pattern was adjusted to eliminate all strained areas and remove any undesired creases. The final non-zero waste overcoat is illustrated in Figure 74.

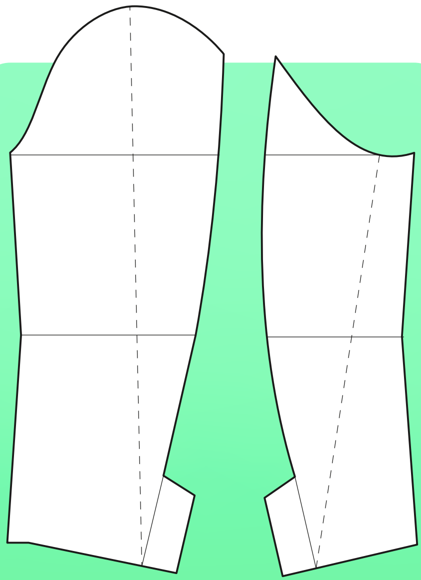


Figure 73, Classic 2-panel sleeve pattern for formal or fitted jackets, including overcoats.

Figure 74, Render of desired shape for the overcoat, based on a non-zero waste pattern.

Zero Waste Pattern Transformation

Assembly Through Structure Mapping

The experiments conducted in Chapter 4.2 showcased various approaches to integrating structure mapping as an alternative method for connecting curved seams. Two samples stand out for their ability to blend specific pattern elements of the overcoat (SL_3, SL_4, page 60 and 61).

A smaller structure like DS8 can merge the body side panel and the under sleeve, similar to the technique employed in the original samples. To facilitate this joining method, both panels' widths at the connecting seam were designed for equal length. This technique can also be extended to the front and back panels, effectively replacing the conventional shoulder seam.

Simplification

The next step was to simplify the pattern elements to facilitate easier nesting. This abstraction required a general understanding of the available knit structures to evaluate which shapes could be achieved by adding or reducing material. After assessment, all pattern elements could be simplified into rectangles of varying dimensions (Figure 75).

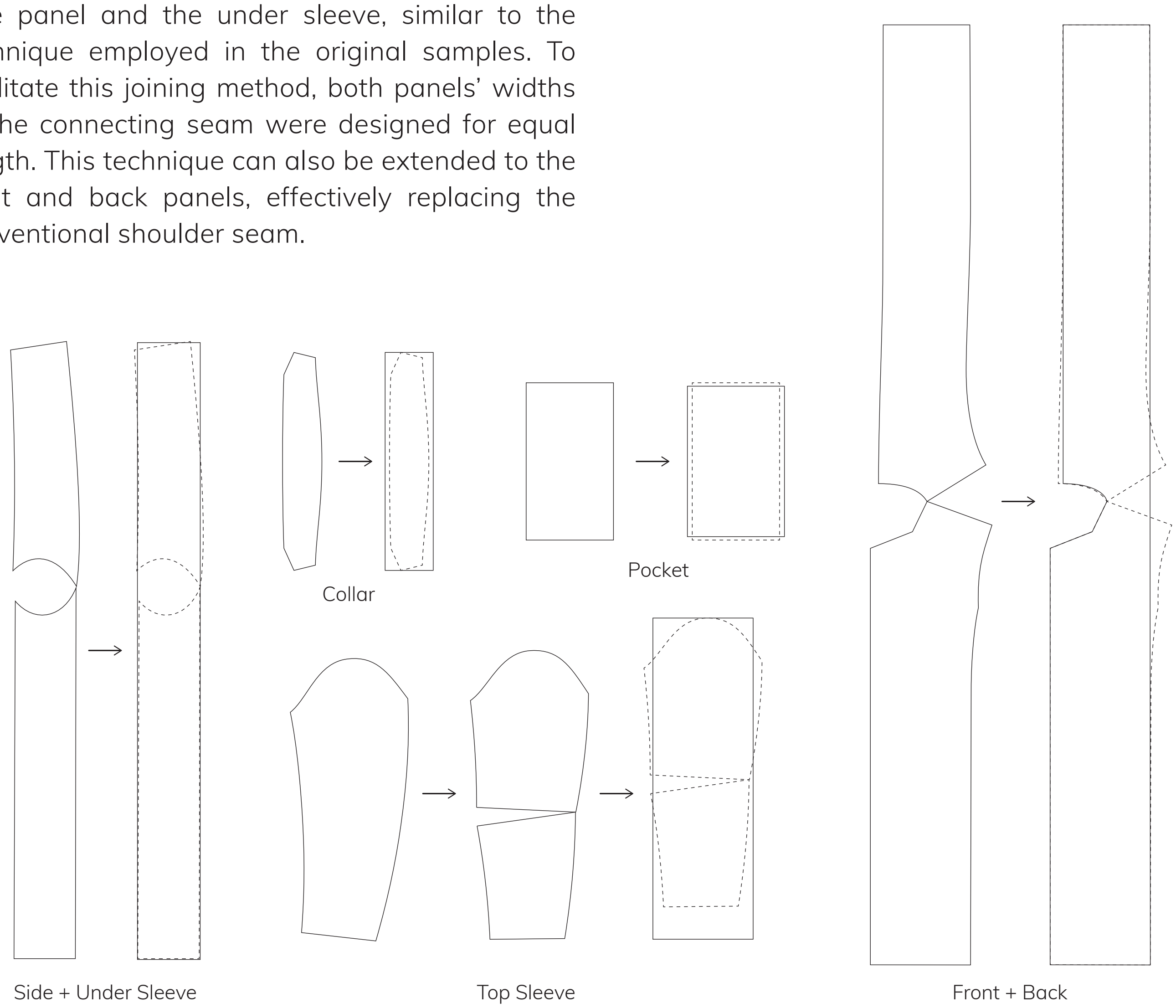


Figure 75, Simplification of pattern elements with complex shapes to rectangular shapes.

Combining the elements into a zero waste pattern demanded creative input from the designer, as there were only guidelines on how panels should interlock. A common practice in pattern grading is to have size Medium garments positioned adjacent to each other on a fabric, with one pattern piece occupying half the fabric's width. Although the exact fabric width was unknown at this stage, the pattern aimed for a width of approximately 75 centimetres, considering the standard fabric width of 1.5 metres. Furthermore, the orientation of panels in the pattern was kept consistent, except for the collar and pockets, which were successful in the previous jacket.

The outer seam of the lining is not attached to any other jacket element and could be creatively shaped as part of the design. Therefore, only the inner edge, which connects to the front opening, was considered in the initial nesting step.

This process was further aided by the merger of front and back panels and the side and under sleeves since the shoulder is notorious for nesting in the pattern, which could now be ignored and simplified to rectangular areas.

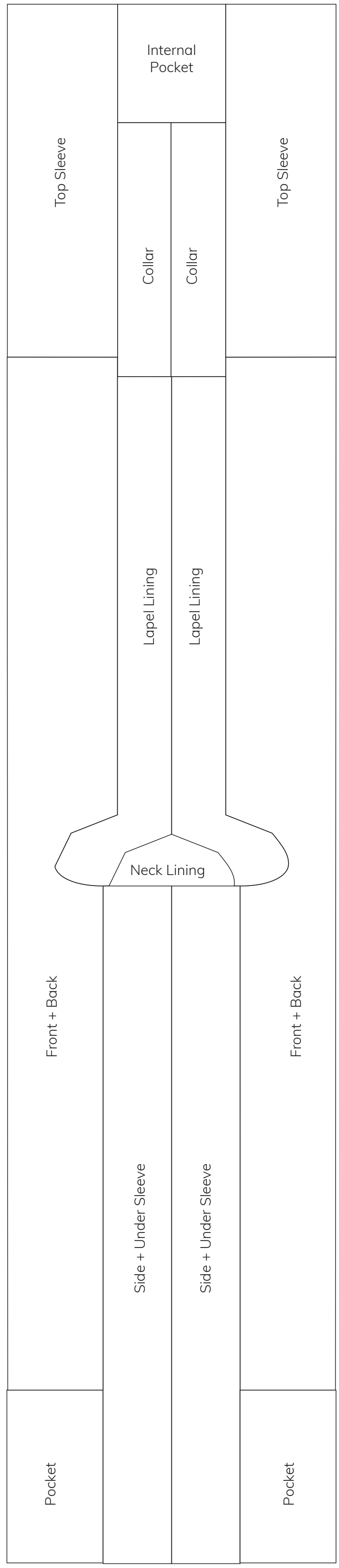


Figure 76, Zero waste pattern for overcoat, to be used as a base layer for structure mapping.

The Result Without Structure Mapping

The final pattern underwent further adjustments to individual elements, ensuring they were perfectly aligned in a rectangular layout. Figure 76 illustrates this pattern, and the render in Figure 77 depicts the zero waste garment pattern created from plain fabric. Notably, the differences in panel sizes become evident, causing wrinkles and requiring structure mapping to compensate for the difference between the ideal and zero-waste patterns.

Figure 77, Zero waste overcoat before adding structure mapping to create the necessary shape.

One Base, Many Options

A theoretical benefit of structure mapping involves adjusting the block pattern's size by choosing a different base pattern. Figure 34 and 79 illustrates various size profiles, showcasing the potential for smaller, wider, taller, or shorter garments depending on the selected base structure. The choice of base structure influences further shaping possibilities, limiting flexibility. Nonetheless, structure mapping promises significantly greater tailoring flexibility than traditional zero waste garment pattern design

6.2 Structure Mapping; An Overcoat

True Ratio Structure Naming

Until now, the report has utilised the conventional approach of naming knit structures according to their historical designations. While familiar to those within the knitting industry, these names lack descriptive clarity regarding their relevance to the research objectives. Consequently, new structures devised for the overcoat were labelled based on their ratio:

$$a/x \text{ - } b/x \text{ - } c/x$$

Where a + b + c = x, and a = stitches, b = tucks, c = floats.

For example, the structure formally known as DJ 1/4 is now 1/2 - 0/2 - 1/2.

Shaping Requirements

Merging the zero waste pattern portrayed in Figure 76 with the desired overcoat pattern showcased in Figure 72 resembles the foundational elements outlined at the start of Chapter 5.2. Superimposing the individual pattern components onto their desired forms highlights the disparities requiring adjustment. In Figure 78, a sketch overlay illustrates the overcoat elements, their corresponding knit structures, and approximate contours. This creative exercise identified eight necessary size profiles for structures, listed in Table 3, employing symbols +, -, and = to indicate the desired alterations in size profile relative to the base structure (bright blue).

Structure Colour	Desired Course Length	Desired Wale Length
	+	+
	+	=
	=	=
	-	=
	-	--
	=	-
	=	---
	+	---

Table 3, Desired course and wale length for each identified structure. The size is indicated proportionally with + (larger), - (smaller), or = (equal)

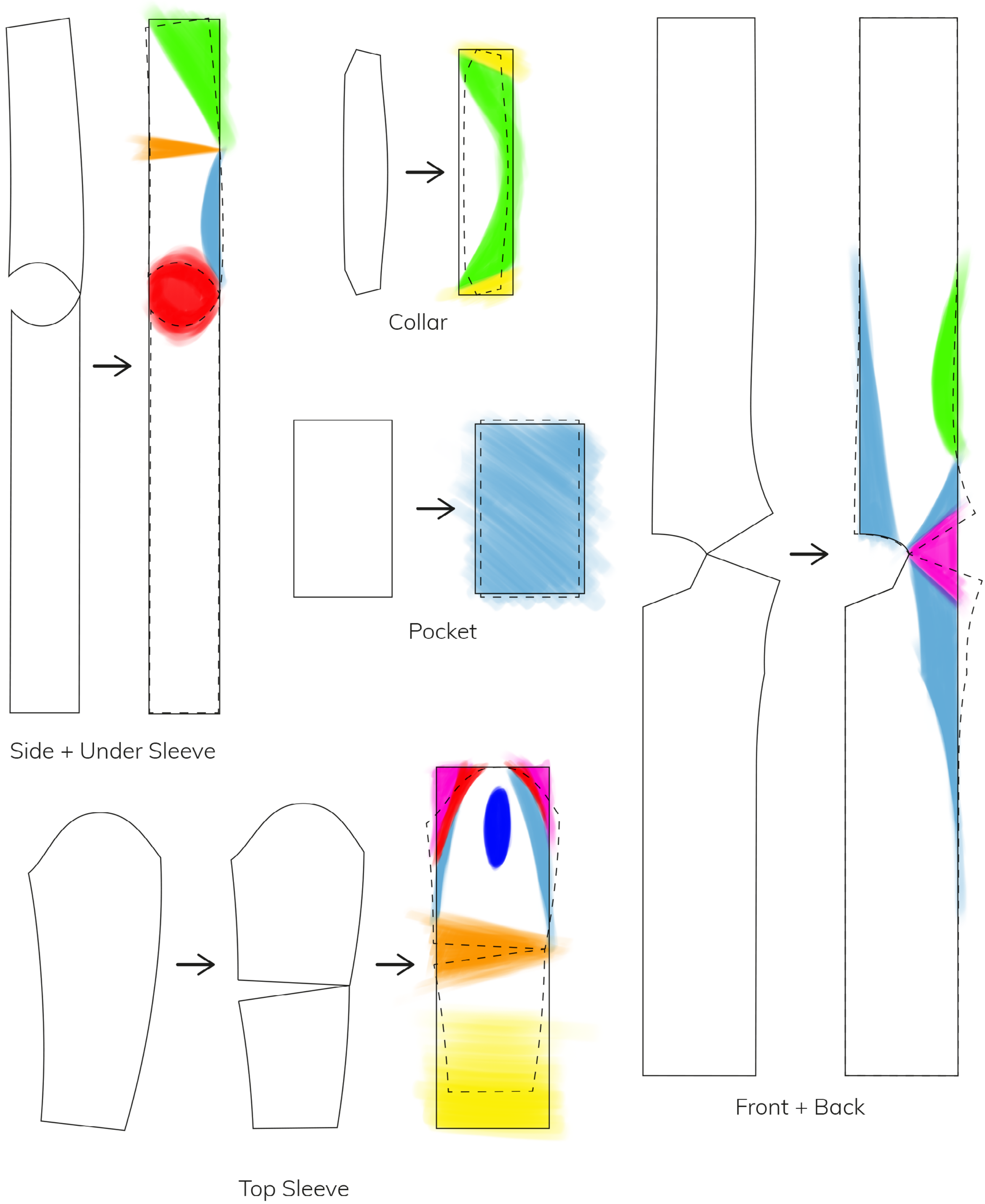


Figure 78, Overlay of ideal pattern with zero waste pattern, structure application is sketch in areas that need shape compensation.

Structure R&D

Material Density

The material used for the jacket in Phase 2 proved excessively heavy and dense. Consequently, an experiment was set up to reduce the fabric density and weight. Up to this point, every sample and prototype was knitted with a stitch length 10.5. Reducing the stitch length globally results in a tighter knit, regardless of the specific structure. A tighter structure initially yields initial smaller dimensions but undergoes less shrinkage during felting, in line with the principles explained in Chapter 2.3 [4, 8].

This theory was tested using two identical swatches for the overcoat. A swatch was knitted at a stitch length of 10.5 and 10.0. The 10.0 swatch proved to be 8% lighter and 4% smaller initially, but after felting, it was 2% larger. Thus, reducing the stitch length to 10.0 effectively decreased the fabric density while remaining compatible with machine knitting, as proven by the production of multiple swatches containing each knit structure.

Swatch Production

Improving on the swatch from Chapter 5.2, each knit structure is produced on 200 needles by 200 rows to further increase the accuracy when scaling up. To ensure consistent results, four swatches were produced for felting.

Colour

The colour of the overcoat should embody its archetype. Hence, there are five traditional options: Black, Brown, Beige, Marine Blue, and Grey [88]. The chosen colour should also complement the jacket's features, particularly its tailoring. Darker shades are effective for concealing imperfections and silhouettes, making them less suitable for emphasising the silhouette. Therefore, beige emerged as the optimal choice, given its brightness.

Furthermore, integrating the narrative of the various structures, achieved by using multiple yarn colours, into the knit is desired, based on the user testing in Phase 2. Consequently, a range of yarns was selected to blend into a beige shade, comprising off-white, two shades of beige, and a darker brown. The lightest and darkest yarns enable the knit structures to manifest distinct hues through their unique stitch ratios. Post-felting, the yarns harmonise into a consistent beige hue, with subtle variations in depth and tone between structures.

Defining Structures

To determine the appropriate structures for the previously established requirements for shaping the overcoat, Table 3 was compared to the triangular correlation model from Chapter 4.4. Knowing that structures are required to be either larger or smaller in either direction, with more structures that need to be smaller in wale length, the selected base structure was 4/6 - 1/6 - 1/6. Approximate ratios could be deduced using the known correlation, as Figure 79 illustrates, with each structure represented by the colour from Table 3. This deduction required multiple iterations, as precise size profiles remain unknown until produced and quantified with a swatch.

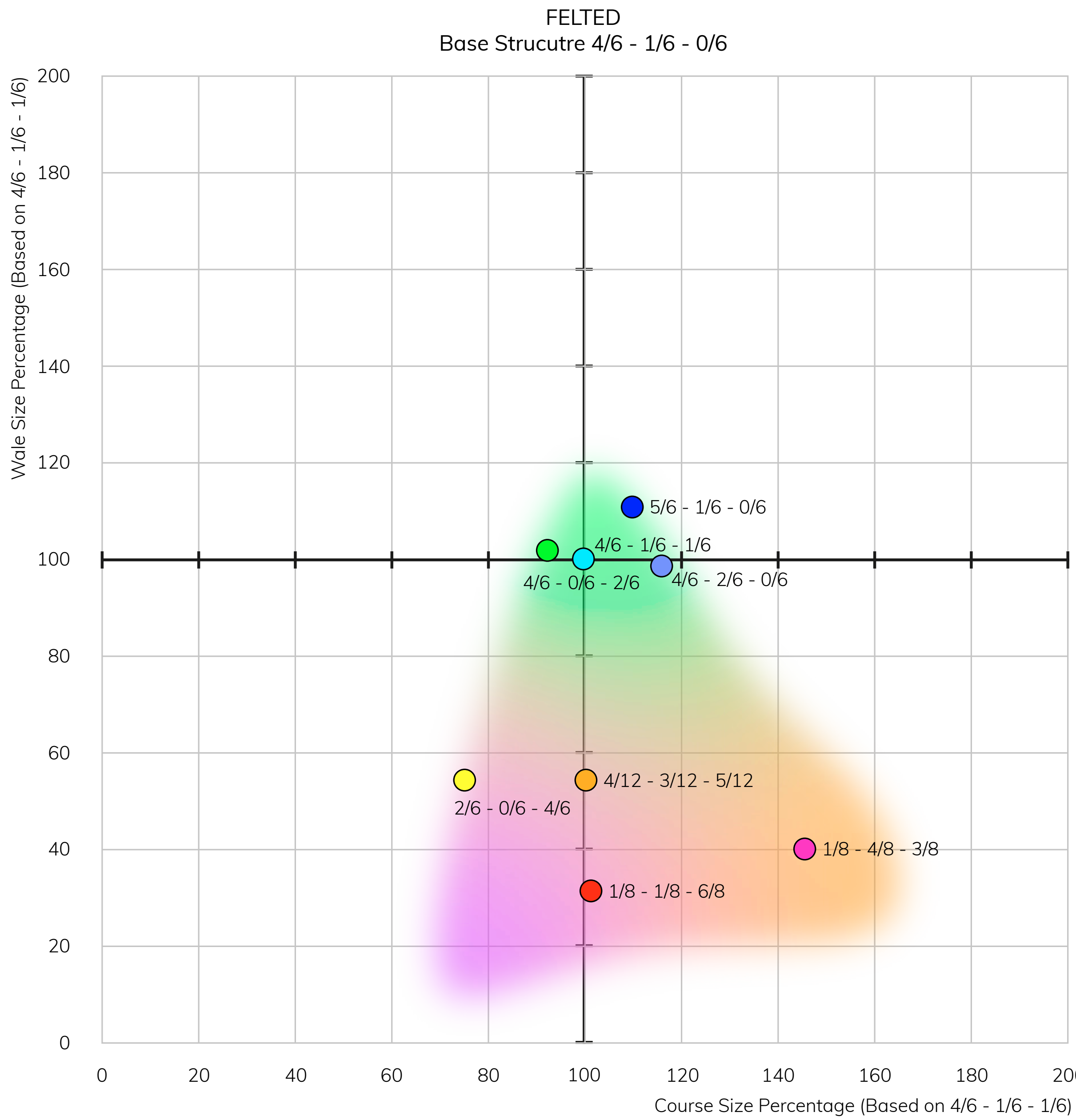


Figure 79, Graph with quantified size profiles of the 8 identified knit structures for the overcoat. The coloured dots correspond to Table 3 and 4. The coloured background indicates the percentage of stitches (green), tucks (orange), and floats (pink).

Gradients

The fabric from Phase 2 yielded hard edges between structures and limited visual storytelling of the technique. Therefore, an experiment explored the implementation of a gradient into the artwork, merging different knit structures more smoothly. Appendix L describes the whole experiment.

The results demonstrated a method to successfully merge knit structures smoothly, creating a uniform texture and attractive visual aesthetic. However, the results also showed a size discrepancy that cannot be simulated with the currently available tools. Therefore, the application of gradients should be limited to linear gradients or areas in the pattern that do not interact with the edge of a panel.

Vector Structure Mapping

The initial sketch demonstrates a large increase in complexity in the usage and distribution of structures, requiring additional design refinement before it was imported into CLO3D for digital validation. Figure 80 illustrates the final structure map. The colour module for the overcoat is in Appendix O. The following formulas and the data (Table 4) gathered from the felted swatches from the previous chapter determined the size of the knit structure element. Following the design from Phase 2, cutting lines and other manufacturing aids are included in the artwork, so it is knitted into the fabric.

The following formula was applied to calculate the required size of a knit structure in width or length in cases where the size ratio was smaller than 1.

$$C = A + x$$
$$x = -(AB)/(B-1)$$

The following formula was applied to calculate the required sizes of knit structures for ratios larger than 1

$$C = A/B$$

A = Size to be reduced, B = size ratio, C = Required size.

Please note that the colours are not tied to the colours used to represent the knit structure in the jacket of Phase 2.

Structure Colour	Structure Name	Course Length	Wale Length
	5/6 - 1/6 - 0/6	105%	111%
	4/6 - 2/6 - 0/6	109%	97%
	4/6 - 1/6 - 1/6	100%	100%
	4/6 - 0/6 - 2/6	93%	103%
	2/6 - 0/6 - 4/6	76%	54%
	4/12 - 3/12 - 5/12	99%	55%
	1/8 - 1/8 - 6/8	103%	33%
	1/8 - 4/8 - 3/8	145%	43%

Table 4, Proportional course and wale length for each structure, which has a distinct colour and name based on their stitch ratio.

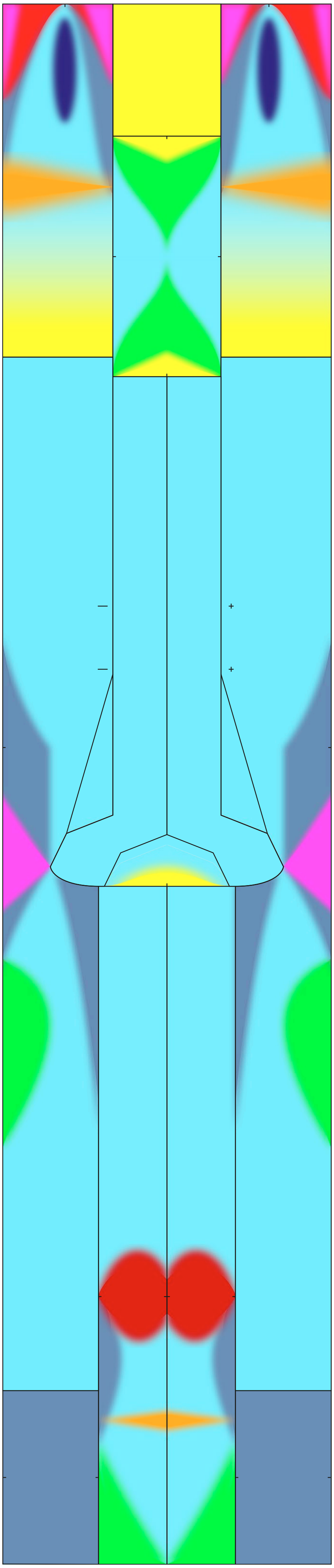


Figure 80, Structure mapped artwork for the zero waste overcoat.

Digital Validation

Mirroring the simulation approach detailed in Chapter 5.2, the artwork was imported into CLO3D and used as a template to create subsections in the base zero waste pattern, with size profiles linked to each coloured panel (Figure 82).

After rendering all components, (Figure 81) the outcome falls between the intended jacket shape and the zero-waste block pattern. It becomes apparent that the body of the overcoat has sufficient room to conform to the body rather than wrapping it tightly, and the sleeves exhibit the desired articulation. However, the evaluation of the designed structure map is constrained by CLO3D's inability to sew panels of varying size profiles, resulting in wrinkles that do not exist in the actual knitted fabric.

Figure 81, Front and back render of the men's overcoat with structure mapping. Each colour coincides with the previously chosen knit structures.

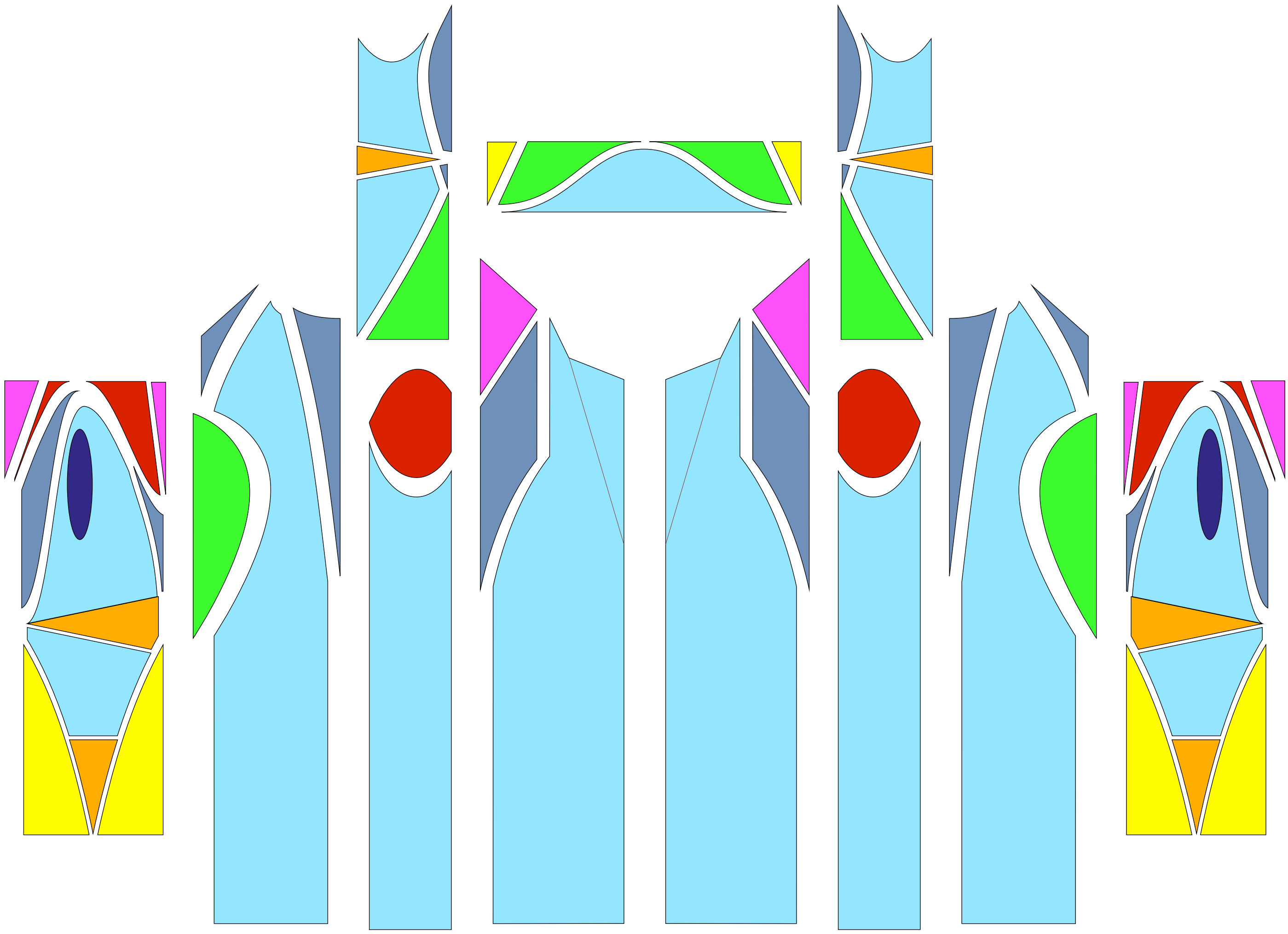


Figure 82, Overcoat pattern with structure mapping as programmed in CLO, cutting the panels in the shape of each knit structure, assigning individual size profiles, and sewing the jacket back together.

Production

The fabric for the overcoat was knitted in one piece and felted (Figure 83 (c) using the same principles as in Phase 2). For construction, all seams, except for the sleeves, were assembled using an industrial cover stitch machine to merge seams without creating bulk. Two passes were performed for increased durability and tightness between the panels. The rest was finished with a regular straight stitch on a heavy-duty sewing machine. Most of the fabric edges were left unfinished (Figure 83 (a)), which provided a cross-section of the knit, showcasing the unique fabric for the overcoat. Since the material is felted, the edges do not fray. The material was steamed and ironed repeatedly to create the required shaping. Nonetheless, the thickness of the material, especially in the collar and sleeve seams, resulted in noticeable bulk. Figure 83 (b) shows the final result.

Figure 83, (a) Close up of unfinished edges, showcasing the cross section of the knit structure, (b) 3/4 Front of the finished overcoat, (c) Overcoat fabric after knitting and felting.

(c)

User Testing

The goal of this phase was to design a versatile and simple zero waste pattern that is transformed with structure mapping into a garment that resembles a non-zero waste pattern. Therefore, users evaluated the quality of the material and the overcoat design. The same interview approach, with slightly adjusted questions, from the jacket in Phase Two was applied to evaluate the wearing experience, including ergonomics, wearing sensation, and aesthetics. The interview questions and answers are in Appendix M and N, respectively.

User Testing Findings

Quality

The experiential feedback from participants was remarkably similar to the jacket from Phase 2. Again, the feedback emphasised the jackets' high-quality appearance and perceived value without price indications or brand associations. They consistently described the jackets as bulky, stiff, warm, and cosy, all qualities linked to positive perceptions of jacket quality. They also appreciated the subtle texture of the body and sleeves of the jacket after they had been informed of the purpose of the structures, highlighting the power of explaining the story behind a design to improve their understanding and appreciation for the product.

The First Time Is Not a Charm

Designing a garment traditionally requires iterations to fine-tune the fit and finish. From personal experience, a garment is never perfect in its first version because certain flaws only become visible once constructed. That includes this overcoat since the first version had flaws, as multiple users said that the collar was dragging down and the sleeves were restrictive in movement. The inflexibility was partly explained by the rigidity and weight of the material, but this is also the pattern's responsibility. Luckily, improving the original pattern and optimising the structure map can address these issues, which would tackled in the design and production process, if for retail purposes.

Public Comments

In addition, impressions were collected from people in public when wearing the overcoat for testing. In all cases, people did not notice that the overcoat was handmade. Notable comments were that it looked refined and recognisable yet unique and had a large presence. Some people also noted the perceived warmth of the jacket. But the takeaway was that people had the notion that this was a normal store-bought overcoat from a high-quality brand.

6.3 Phase 3 Discussion

Time Efficiency

Creating a zero waste block pattern required 8 hours and an additional 8 hours per structure map to tailor the block pattern. A further 6 hours were allocated to construct and adapt a CLO3D version of the design to validate the intended shaping characteristics of the structure map. Consequently, from inception to production, a garment could be conceived, tailored, and manufactured within a week. It's worth noting that the timeframe may vary depending on the garment's complexity and the skills and resources available. Nonetheless, this represents a swift process that eliminates cutting waste entirely.

Integrated Flexibility

The block pattern defined in Chapter 6.1 was successfully modified with a structure map to change the size and tailoring to a specific avatar. Although the jacket's fit did not perfectly resemble the non-zero waste version, the fact that the coat comes from a pattern that barely resembles an overcoat showcases the flexibility structure mapping has when integrated with a pattern designed for this method.

Form Follows Function

In both iterations of the jacket, the structure map evokes a distinct aesthetic, intensified by the contrasting vibrant colours., resulting in a unique aesthetic driven by functionality and presenting the opportunity to amplify or soften depending on design needs. This versatility enables expressive storytelling about the tailoring embedded within the fabric. While the physical prototypes exhibit a more nuanced functional aesthetic, knitted in a uniform shade of beige, a closer examination reveals that different knit structures still convey this aesthetic, particularly at the boundaries where colour blocks blend, prominently expressing the structure map.

Fabric Optimisation

Adjusting the stitch length effectively reduced the density of the knitted and felted fabric. While seemingly a minor design aspect within the project's scope, it underscores the robustness and flexibility of the shaping technique for circular knitting, adapting a fabric for the specific needs of a product. The method from Phase 1 is solely dependent on stitch type rather than material or specific machine/program settings. These variables only influence the precise size profile of each knit structure, a factor quantified during the swatch production step.

Limitations

Close To The Known

Adhering to the familiar, traditional pattern design typical of overcoats and replicating seams to emulate the desired aesthetic constrained the pattern design. This approach was chosen considering the designer's existing skills and knowledge, coupled with the time constraints of the research. However, as demonstrated with the samples in Chapter 4.2, articulation could be achieved through a different approach, shaping a garment pattern distinctly. Thus, this demonstration in garment design represents not the culmination but rather a step toward realising the full potential of structure mapping.

Simulating in CLO

CLO3D is limited in its capability to only simulate colour blocks rather than individual stitches. This overcoat project exposed another drawback of the program for this specific purpose. Sewing only works using unedited panel dimensions, making it challenging to accurately join structures undergoing significant shrinkage or expansion, unlike in physical production. Consequently, this can lead to wrinkling along seams in the render (Figure 81). While some wrinkles may be mitigated through creative sewing on original pattern seams, this isn't feasible for seams created by segmenting garment panels for different knit structures

Knitting Instead of Sewing

Although structure mapping reduces some seams in the overcoat, even compared to a non-zero waste pattern, it's essential to recognise that merging panels can only be implemented if the associated fabric panels are also connected in the pattern. This limitation constrains the number of connections that can be integrated during the knitting phase via structure mapping. As an alternative to the shoulder seam, connections could be established between the front, side, and back panels, albeit at the expense of the shoulder connection. It would also complicate the nesting process of zero waste pattern design, demonstrating the delicate balance of requirements.

6.4 Future Vision

This research envisions a future where shaped-circular knitting becomes a seamlessly integrated process, leveraging automation and modern production technology to realise sustainable and desirable consumer products and experiences. Imagine a retail environment where customers are scanned in 3D, their measurements automatically applied to a garment block of their choice, incorporating personalised tailoring and design details. A program then extracts the necessary specifications, and in the store's workshop, a state-of-the-art knitting machine produces the required material on demand. A skilled seamstress assembles the product, allowing consumers to enjoy their personalised purchase quickly. Figure 84 illustrates this process.

This approach yields sustainable, locally producible garments of exceptional quality tailored to individual preferences without the need for stockpiling or extensive shipping. By addressing local production, enhanced customer experience and improved perceived quality of products, this concept embodies the vision articulated in Toward Textile-form Futures (Acknowledgements), paving the way for a more sustainable and personalised future in consumer garment production.

Back to table of contents

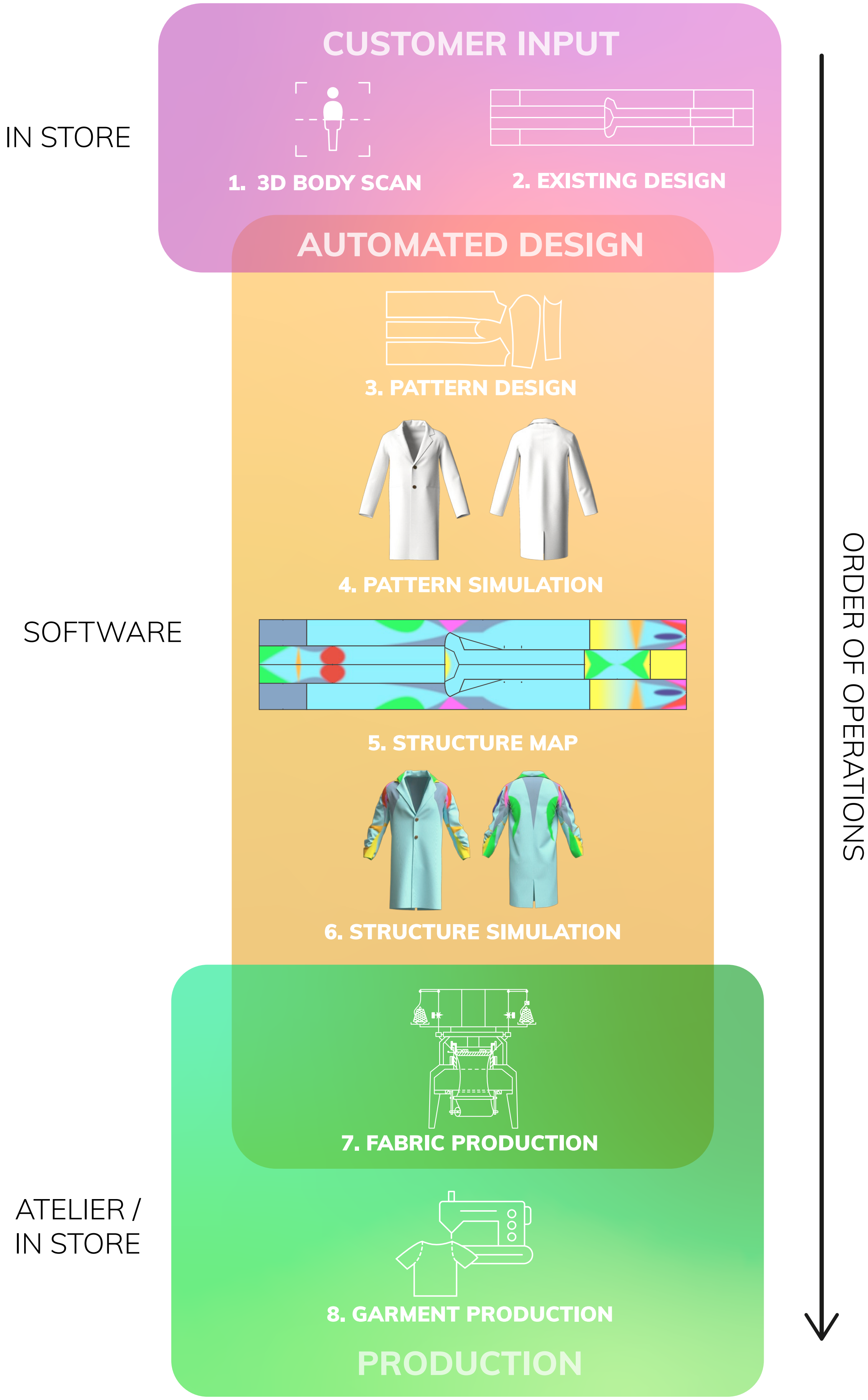


Figure 84, Development process for a bespoke consumer garments according to the future vision.

7. DISCUSSION

The results from this thesis provide opportunities and challenges for fashion design, production, and consumers. Paragraph 7.1 provides an overview. Paragraph 7.2 discusses the possible implications, including the new perspective on fashion design, the applicability of technology, and consumer perception. Paragraph 7.3 discusses the research limitations.

7.1 Overview

This research's vision and overarching goal was to develop a novel technology and design process for the fashion industry to design and produce knitted garments using ZWFD. The fashion industry has grown into an unsustainable behaviour, particularly in the overproduction of garments, which generates waste and is largely unaddressed since the system is locked on optimisation for speed and profit, whilst people and the planet are secondary considerations. Existing research addresses the need to improve consumer garments' sustainability and quality, offering solutions applying novel textile fabrication methods and shape-integration in textiles. However, existing research fails to address all of these factors combined, usually sacrificing one for another, which limits the acceptance of these techniques on a larger scale. Therefore, this thesis proposes a new approach to ZWFD by answering the following questions:

1. How can shape be integrated into the design and production of circular knitted textiles?
2. What design and production methods are required to facilitate shape-integration for zero waste fashion design?
   a. How can this method be applied to an existing zero waste jacket pattern?
   b. How can this method enable a new approach to the design of a zero waste garment?

These questions were addressed in three phases. In Phase 1, a correlation was established between stitch types and the width and length of the knitted fabric. In clever combinations, locally implementing larger or smaller knit structures, several shapes demonstrated shape integration, staying within the limitations of circular knitting. Chapter 4.4 presents a toolkit that allows designers to integrate shapes in circular knitted textiles.

Then, to answer the first part of the second research question, firstly, an existing zero waste jacket design was redesigned to enhance the fit and comfort of the jacket. By utilising modern design tools, like ergonomic simulation in CLO3D, the garment and fabric design steps were merged, allowing for effective shape integration. An additional jacket was produced in the same material to validate the technology's ergonomic benefits and desirability without integrated shaping. Both jackets were user-tested and demonstrated a noticeable and preferred difference for the redesigned jacket, arguing the successful implementation of shape integration in an existing zero waste jacket pattern.

Finally, in Phase 3, a zero waste overcoat was designed based on a traditional pattern, presenting a novel design method that transforms a standard garment pattern into a zero waste pattern. The process employs structure mapping to compensate for shape differences in a pattern. The approach was developed and validated with software simulation and as a physical demonstrator, showcasing the feasibility of a new approach to designing a zero waste garment.

7.2 Implications

Industry Adoption

Currently, zero waste is difficult to implement in a brand's design processes because the designs need to be modified/updated every season, which requires a designer to redo grading, markers, etc. For traditional zero waste, there is little flexibility in changing a pattern. Structure-mapping, the design technique developed in this thesis, poses a solution to this inflexibility, as it moves the tailoring of the garment from the pattern design to the fabric production. This allows designers to adjust the shape and fit of a garment without having to modify the zero-waste pattern. The demonstrated method eliminated cutting waste and resulted in a lower fabric yield since no excess fabric was implemented as decorative elements, a common solution in zero waste pattern design. Designing garments with a lower fabric yield is beneficial since fewer material resources are required. However, this also affects the fabric manufacturer, who will have fewer sales. Or, in a worse case, more garments may be manufactured utilising the same amount of material, leading to further overproduction. This highlights the importance of a fundamental change in the fashion industry towards sustainability because sustainability tools risk being exploited for profit without shifting perceptions.

Since the method poses a shift in process, it cannot be integrated seamlessly into the current industry. Structure mapping demands advanced textile and garment design knowledge and moves fabric manufacturing alongside garment design. Thus, manufacturers and brands must invest time and resources into restructuring that part of the supply chain. However, brands and manufacturing parties can adopt this design process without significant investments in new equipment since the research used widely available hardware and software. The software programs were not hacked or reprogrammed, and the required hardware for circular knitting machines already exists and does not require additions or modifications.

Scaling Production

To address industry-scale cutting waste, the technology needs to be relevant for mass production. The jackets in Phases 2 and 3 were made for specific measurements and were assembled as prototypes, demonstrating the ability to design for a predetermined size with structure mapping. This technology could be applied for commercial applications to generate multiple sizes from a standardised block pattern, simplifying the grading process for zero waste patterns. A standardised structure map can also be used to knit many of the same garment, where the fabric manufacturing would be identical to the current circular knitted fabric production. The cutting is still a manual process that does not scale easily, but the garment assembly and finishing are identical to traditional cut-and-sew garment production. The largest difference in the process is designing the garment and the fabric simultaneously, requiring a shift in how designers, brands, and manufacturers operate. However, this design phase is independent of the number of garments produced afterwards, thus not affecting the scalability of the technology.

The design and production process described in this research was applied to manufacturing a singular garment as if it were a bespoke product, following the future vision, which proposes a tailored product solution which can reduce the amount of clothing purchased as part of the solution to overproduction. This bespoke solution could also be combined with aspects of mass production through an online service system, trading local production with greater availability. Thus, the technology can potentially be implemented at a mass production level, a bespoke level, or scaled from either into a future supply chain that combines elements from both production levels.

A New Aesthetic

The fashion industry has focused on optimisation for speed, which has resulted in the demand for uniformity in textile production, determining the current aesthetic and, thus, the consumer's expectation and perception of fashion. Differently coloured yarns can visualise the effect of structure mapping, and the inherent textural differences produced with structure mapping step away from complete uniformity. These aesthetic results of the process make it recognisable and suggest a new aesthetic that comes as a consequence of the technology; form follows function, resulting in a techno aesthetic [4, 19], and can challenge the perception and expectations of consumers on garments, moving towards an aesthetic that represents sustainability.

The aesthetic and wearing experience are further elevated by felting the merino wool of the prototypes. Felting tightens the material, amplifying the texture and blending the yarn colours. The resulting material was very dense yet soft, creating a unique sensation that differentiated the jackets, according to participants, despite appearing like a conventional garment. This suggests that using existing finishing methods for new or unconventional purposes can also serve as a tool to challenge the consumer's perspective on fashion.

On the other hand, from a perspective of current markets and flexibility, the visual texture of the structured mapped fabric can be tuned or eliminated through the structure map and yarn selection. The aesthetic had mixed reactions in user testing, mainly on the visual aspect. So, by enabling a choice for designers, garments can be designed with or without the visualised knit structures, catering to different audiences and different use cases for a garment.

Shaping and Stitch Behaviours

There is a clear connection between the physical size of a knitted fabric and the ratio of the stitches. The stitch creates a loop of yarn pulled through a previous loop. This loop adds size to the material in both directions. A tuck adds a yarn to an existing loop, adding material to the course length. However, since no new loop is formed, it does not contribute to the wale length of the material. A float does not add size to the knitted material in the observed two dimensions, although some yarn is present between the two knit layers, adding to the thickness. The behaviour resulting from compounding these effects is regardless of the yarn material, posing great opportunities for complex fabric mono-materials, further enhancing the potential sustainable benefit of the research.

The analysis and implementation of the dimensional behaviour for each structure were limited to two dimensions. However, the resulting fabric also has out-of-plane shaping and is designed to fit a 3D geometry. The thickness of the material is acknowledged but has not been a quantified or otherwise analysed variable in this research. Most design tools for fashion are designed to work from a 2D fabric, including Illustrator and CLO3D, making it the go-to approach to fashion design. In addition, expanding from two dimensions to design a fabric is not standard practice, requiring designers to develop a new skill set and design tools that integrate 3D in the pattern design phase.

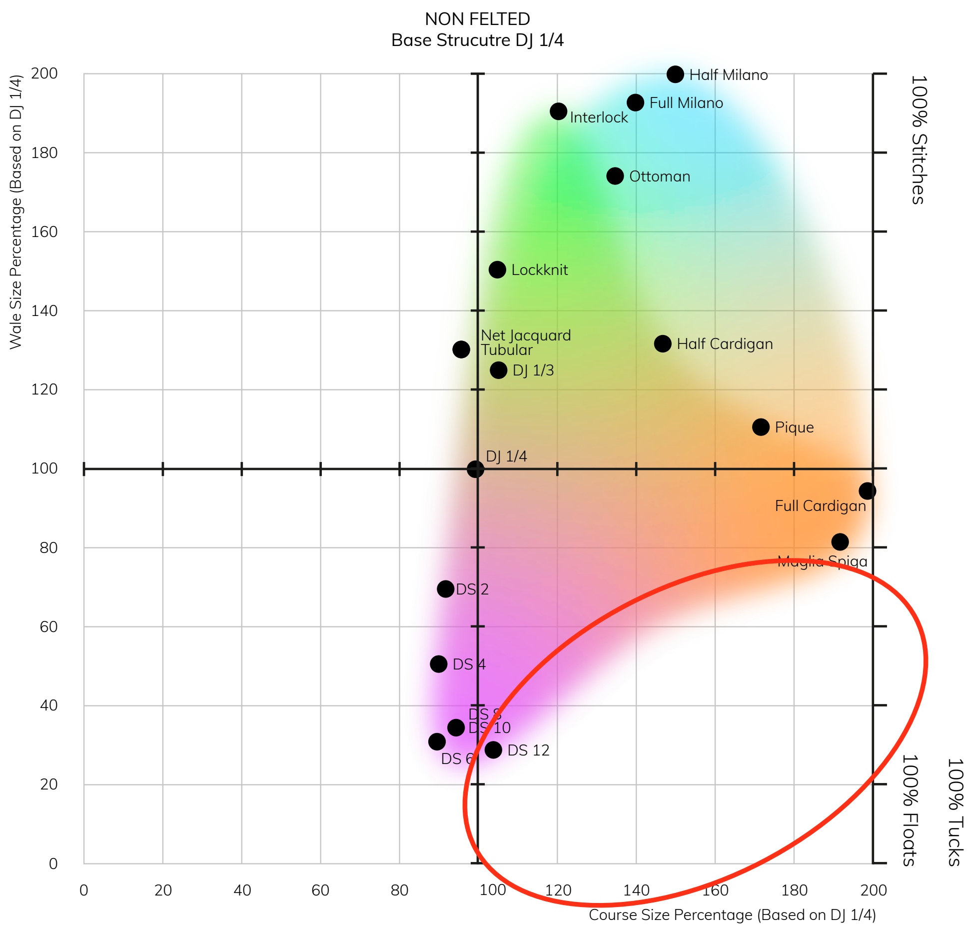
The behaviour concept of the stitch types was used to introduce shape into a fabric. It could also improve current fabric production since this behaviour can help predict the outcome of a knitted fabric. A better understanding of the produced material can save manufacturers on R&D, requiring fewer iterations and thus also speeding up the time to market.

7.3 Limitations

Practical Boundary

In every graph with structures relative to each other, the coloured fields represent all possible knit structure sizes and hint at an existing knit structure that is smaller or wider. Stitches are required to knit a fabric. Otherwise, the yarn would only be stacked in the active needles, breaking the yarn, the needle, or other parts of the machine. Therefore, no knit structures with only floats or tucks could be quantified, keeping those knit structures theoretical. These would otherwise be represented in the red section in Figure 85. Thus, the ratio of stitch types has a practical boundary.

The line between knittable and unknittable highly depends on the machine settings and yarn material. This research was partially successful in producing a knit structure with only 8.33% stitches (the DS12 structure, Chapter 4.2). An even smaller percentage might have been possible with an adjusted stitch length, take-down, and carriage speed. However, this structure already presented knitting problems, and there was a proven point of diminishing returns, which is why this particular structure was not selected for use in any of the jackets, where producibility was more important than the size profile.



(Figure 85, Structure graph from the Shaping Toolkit (Chapter 4.4) Circled in red is the theoretical size area of knit structures with a significant amount of tucks and/or floats.

Circular Knitting Is Not The Same

The experiments, their results, and the deducted method for creating textile forms in circular knitted fabrics can be replicated on a jacquard circular knitting machine. However, the research has failed to produce samples on a real circular knitting machine and can, therefore, not argue a seamless transition and application of the presented design process.

Circles Are Never Circles

Knitting encompasses a complex process influenced by numerous controllable and uncontrollable variables, as described in the Taxonomy (Chapter 4.1). This complexity leads to hard-to-predict outcomes and is magnified in circular knitting, complicating the achieving of precise artworks, such as graphic circles or, more applicable to this report, garment pattern elements.

Given the inherent variability, the data points for the discussed structures hold value primarily compared to one another. Future research is advised to establish distinct data points specific to individual structures, materials, and machines. Improving the controllability of the knitted fabrics' size and ratio will aid in understanding and developing techniques for shaped-circular knitting.

A Designer's Interpretation

Numerous steps in the garment pattern design process are influenced by requirements and preferences that may vary greatly from one designer to another. The showcased process is one of numerous possibilities and could change if repeated. Despite being supported by calculations and digital simulations, the precise pattern shape and structure map are made manually, always leaving space for refinement or alterations.

Equally Divided

When applying a ratio of the three possible stitch types for circular knitting, the structure mapping technique assumes that all the stitches are divided equally within a structure module. This entails that there are the same number of front and back stitches and tucks, which can, in instances, necessitate a larger repetition of a module to avoid a striping pattern on the knit, as was evident in the sleeve hems of the adjusted jacket in Phase 2 (Figure 68, page 98).

8. CONCLUSION

This research aimed to integrate shape into the knitted fabric for production on large circular knitting machines and develop a design process that effectively applies this shaping technology, structure mapping, to ZWFD, addressing its limitations. The thesis consists of three research phases that established a method for shaping, implemented it effectively to the existing design, and developed a novel design process that enables the transformation of traditional patterns to zero waste patterns.

Stepping away from the notion that garment shape is solely created in the pattern, shape-integrated circular knitted textiles demonstrated a feasible solution to improve design flexibility, streamline elements in the cut-and-sew production process, and introduce personalisation to consumer garments that are zero waste. The manufacturing process for shaped knitted textiles is principally achievable on existing machines, regardless of yarn material, and the construction of multiple 1:1 prototypes demonstrates the producibility.

Circular knitting is one of the most considerable manufacturing methods for garment textiles, and the industry continues to adopt modern machines and manufacturing techniques, which provides the potential for the adoption of structure mapping and shape-integrated knitting. However, implementing the material for zero waste requires a shift in the process, where the design of garments and fabric needs to be coordinated instead of executed after one another. This research shows a new approach to fashion design and production, integrating them holistically and providing benefits for brands, manufacturers, consumers, and the environment.

8.1 Recommendations

This research uncovered many previously unexplored areas of opportunity. With the invention of shape-integrated knitting, the research proposes the following recommendations to develop and explore the future potential for sustainable textile design.

Accuracy And Automation

Validation

The results from this research propose benefits for the consumer, industry, and other identified stakeholders. These assumed benefits, like streamlining production and personalisation capabilities, are hypothetical and based on literature research. Therefore, the resulting garments should be validated with consumers, the design process should be validated with designers and brands, and the production of textiles and garments should be validated with manufacturers.

Simulation

Phase 3 highlighted the inadequacy of current simulation methods for accurately representing complex structure-mapped garments. Furthermore, computational efforts have the potential to streamline and enhance the design process, as outlined in Chapter 6.4. Therefore, future research should explore novel approaches to simulating structure-mapped garments and develop a simulation tool based on individual stitches, leveraging the mathematical framework proposed in the previous recommendation

Mathematical Approach

This research proposes a correlation between stitch types and suggests further investigation into the fundamental understanding of stitches and their macro-level influence on textiles. And to quantify results and pursue a mathematical solution that explains the observed behaviour of this research.

Quantifying

The current method for quantifying knit structures, as discussed in Chapter 4.2, lacks precision and reproducibility. Thus, it is important to develop a systematic and reproducible approach for quantifying the behaviour of knitted samples. Future research should prioritise expanding a consistent and quantified data library for these structures, facilitating their integration into garment design processes and computer modelling simulations.

Structure Generation

Could future digital tools generate precise knit structures based on designer-specified size profile demands? While this research primarily used a known structure library, the shaping accuracy could greatly improve with an algorithm creating specific structures for specific needs. For example, transitioning between colour blocks could be smoother and more refined with an intermediary structure instead of the current gradient method.

The Cutting Process

In large, industrial-scale production facilities, fabric cutting is usually done many layers at a time. In some applications, manufacturers use in-line CNC cutting to improve accuracy. However, since the fabric from the structure knitting process is not flat, it is difficult to cut accurately. Therefore, to increase adoption by the industry, research should be done on how the cutting process of structure mapped circular knitted textiles can be automated and sped up.

Design Possibilities

Soft Goods Categories

Experiments have focused on wearable products made with a specially designed fabric. However, the research also demonstrated that the method has potential in single-bed knits (Chapter 5.2) and can be performed with different materials. This opens avenues for exploring different product categories, not only in garments like underwear and sportswear but also in the field of home and furniture goods.

Technical Material Properties

Knitting with different stitch types not only influences the size. It also affects a fabric's thickness, transparency, insulation, and other properties. Researching these properties and their connection to structure mapping could enable further function integration into knitted textiles.

Sizing

This research explored the application of shape-integrated knitting for a specific size, focusing on the tailoring in combination with zero waste pattern design. Building on the same block pattern, other sizes should also be feasible, and research on sizing might yield a new approach to grading and garment sizing, which can benefit both consumers and the industry.

Life Cycle Assessment

A key driver of this thesis is improving the fashion industry's sustainability, and the research presents solutions that appear sustainable in line with existing, proven solutions. To establish and further enhance the sustainable impact of shaped circular knitting for ZWFD, a Life Cycle Assessment should be performed to quantify the effect of reducing cutting waste, streamlining the assembly process, and creating higher-value garments for consumers.

Colour Representation

Initially theorised during the research, is there a way to integrate distinct colours and hues into different knit structures whilst maintaining their size profile? Research into the visual storytelling of structure mapping could enable designers to further enhance the product value for customers, encouraging use, which improves long-term sustainability.

Back to table of contents

Cross section of knit structure 1/8 - 4/8 - 3/8.




Overcoat modelled by Bart Coster and Sem Janssen.
Coach jacket modelled by Myrthe Coster.


32

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Back to table of contents

10. APPENDIX

Table Of Contents

Appendix A Project Brief

TUDelft

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

Family name	Janssen 7101	IDE master(s)	IPD ✓ Dfl SPD
Initials	SJJ	2nd non-IDE master	
Given name	Sem	Individual programme *(date of approval)*	
Student number	4685113	Medisign	
		HPM	

SUPERVISORY TEAM

Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Holly McQuillan	dept./section	SDE
mentor	Eleni Soerjo	dept./section	HCD-HICD
2nd mentor			
client:			
city:		country:	
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Date: 2024.03.20 15:37:31 +01'00'

Name ______ Date ______ Signature ______

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Name student Sem Janssen **Student number** 4,685,113

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Exploration of morphic properties in circular knitting for a zero-waste jacket.

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

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The fashion industry struggles with significant environmental issues, contributing to 10% of global carbon emissions and utilizing 391 kilograms of raw materials per person in the EU in 2020 (Textiles, 2023). Fabric waste during garment production, ranging from 10-20% (Feyerabend, 2004; 4), remains a challenge despite modern fabrication methods. Of the annual 400 billion square meters of produced textiles, roughly 60 billion square meters are wasted (MIT Climate CoLab, 2015) and mostly (87%) incinerated or landfilled (European Parliament, 2023).

Traditional cut-and-sew methods, prevalent in garment manufacturing, result in substantial waste. Fully-fashioned knitting avoids a majority of the pre-consumer waste but takes longer to produce and are in many cases not cost-effective. In circular knitting, the fabrication is more efficient and in modern jacquard circular knitting machines there is control over individual needles without repetitive patterns, allowing more design freedom, but does not address fabric waste yet.

Approaching patternmaking as a puzzle can minimize textile waste (Figure 1), but zero-waste patterns may lead to a less ergonomic and visual style in more complex garments. Striking a balance between waste reduction and material efficiency is crucial for addressing the fashion industry's environmental impact and follows the findings of Dr Holly McQuillan in her PhD 'Zero Waste System Thinking: Multimorphic Textile-Forms'. With her as my chair, in this project we aim to combine jacquard circular knitted textile with Dr Holly McQuillan's methods for zero-waste systems and experimental projects with morphic textiles.

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introduction (continued): space for images

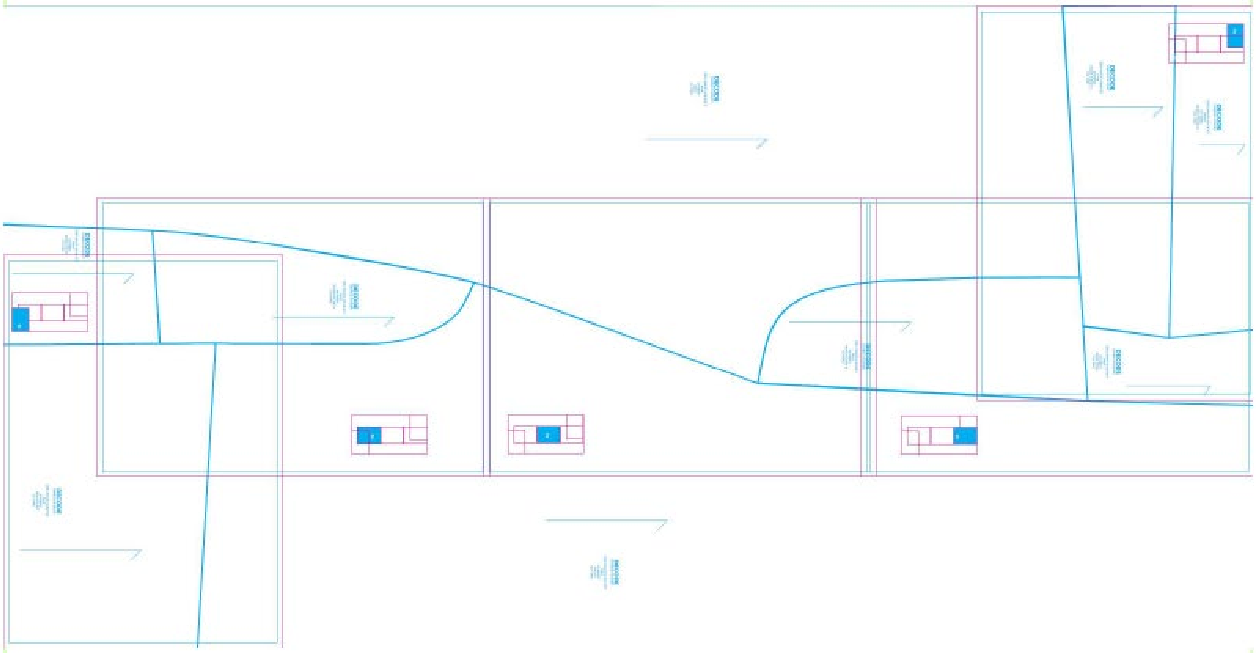


image / figure 1 Zero-waste scrub pants by DECODE https://decode.design/ZERO-WASTE-SCRUB-SET

image / figure 2 Exploration of knit structures and yarn placement (Sem Janssen, 2023)

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

I want to improve the wearability of zero-waste patterned garments, so that they find larger scale adaptation as a part of the solution to eliminate the pre-consumer waste of the fashion industry. Specifically, the pre-consumer waste that results from cutting panels from circular knitted textiles. By using modern jacquard circular knitting machines, specific needles can be activated on each knitted row. This allows us to knit a double layered fabric where the front and back are connected selectively. It can also create different densities on the front and back by alternating skipping needles. Together with active materials such as felting wool or heat shrinking yarn, these effects enable a designer to tune the behaviour of the fabric, which could create enhanced geometry in simple cut panels. Jackets panels stacks the least effecient of all garments, with around 20% off-cut waste. Combined with the shoulder joint complexity and the variations for different weather when wearability is still unknown, a jacket has the greatest opportunities to benifit from this research.

Dr Holly McQuillan's research has mainly focussed on weaving and for this project will be applied on knitting, which will test the fundamentals of the textile principles. Developments in cut-and-sew production for knitted garments, including sustainability and product aesthetics create new opportunities within a saturated industry. For the consumer this means greater wearability in more sustainable clothing, with a unique look and feel. And finally, if this research enables or inspires a reduction in pre-consumer waste in the textile industry, it results in a significant reduction of wasted resources.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence)
As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Develop a set of design guidelines for improved shaping of simple zero waste pattern elements and implement these guidelines into a wearale prototype (jacket) to improve the effeciency of material usage in cut-and-sew knitted garments, saving raw materials and costs for the manufacturer, whilst maintaining the wearability of the garment for the user during daily wear in urban areas.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

My approach is to split the project into two parts. Utilising Material Driven Design for the context of textile-form innovation, I will produce many material samples, exploring the behaviour of various knit structures with yarn variables and finishing processes, conduct technical and experiential testing. Simultaneously I will explore form design methods using digital, paper, and cut and sew prototyping to develop an understanding of applying these morphic materials in the context of products for the body. Together these will aid in the development of initial design guidelines.

In the second part, I will apply this knowlege to develop an existing zero-waste jacket pattern, exploring how tuning knit structure and material behaviour could enhance form and performance complexity while maintianing a zero waste outcome. I will use a combination of software, such as Clo3D and Grasshopper, and physical prototyping, as a way of refining and implementing the guidelines. I will perform user tests and compare against sustainability metrics such as waste production/material use to evaluate and validate the outcomes. Over multiple iterations, the final prototype will demonstrate the design guidelines and their utility. This prototype will be produced for an industrial context either using an external supplier, or simulated on the STOLL knitting machine in the Applied Labs.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting, mid-term evaluation meeting, green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	13 Dec 2023
Mid-term evaluation	28 Feb 2024
Green light meeting	24 Apr 2024
Graduation ceremony	22 May 2024

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

Over the past six years, I've independently taught myself textile production, patternmaking, sewing, and other methods of construction for garments and accessories, which I turned into a business after three years. My education at TU Delft fuelled my fascination with the fashion industry, inspiring me to integrate its elements into my projects. My aim is to test these skills with a complex project, which concerns real players in the industry. I also want to use this graduation project as a stepping stone to explore potential career paths within the fashion industry.

My goal is to transcend designing with existing fabrics and explore the possibilities of implementing product design at the fabric level. I started with weaving in the elective Multimorphic Textiles, and I now intend to explore knitting and broaden my skills to design various knitted fabrics and be able to independently program and operate the knitting machines to produce my designs. To kickstart this, I have followed a 5-day course at KNITWEARLAB in Almere and started practicing with knitting since October of 2023.

Finally, I want to take charge of this project by effectively managing multiple stakeholders, considering their (potentially conflicting) interests, to achieve a successful outcome.

Appendix B Wool Properties

Biodegradable

When a wool fibre is disposed of, it will naturally decompose in soil in a matter of years, slowly releasing valuable nutrients back into the earth.

100% Renewable

Every year sheep produce a new fleece, making wool a completely renewable fibre.

Wrinkle Resistant

At microscopic level, each Merino wool fibre is like a coiled spring that returns to its natural shape after being bent. This gives Merino wool garments a natural resistance to wrinkles.

Naturally Breathable

Merino wool is one of the most breathable fibres. Wool fibres can absorb large quantities of moisture vapour then move it away to evaporate into the air.

Warm and Cool

In contrast to synthetics, Merino wool is an active fibre that reacts to changes in body temperature. So it helps you stay warm when the weather is cold, and cool when the weather is hot.

Odour Resistant

In contrast to synthetics, Merino wool can absorb moisture vapour which means less sweat on your body. Merino wool even absorbs the odour molecules from sweat, which are only released upon washing.

Soft on Skin

Merino wool fibres are extremely fine, enabling them to bend far more than traditional, coarser wool fibres. This makes Merino wool feel soft and luxuriously gentle next to your skin.

Naturally Elastic

Merino wool is one of the most breathable fibres. Wool fibres can absorb large quantities of moisture vapour then move it away to evaporate into the air.

Fire Resistant

Wool's inherent chemical structure makes wool naturally flame resistant. It is a highly trusted natural fibre in public areas such as hotels, aircraft, hospitals and theatres. Whilst cotton catches alight at 255°C, the temperature must reach 570-600°C before wool will ignite; while polyester melts at 252-292°C and nylon succumbs at an even lower 160-260°C, wool never melts so it can't stick to the skin like many common synthetics.

UV Resistant

Merino wool clothing provides good protection from the sun, compared with the protection from other fibres. As a natural fibre, evolved over millions of years to protect sheep against the elements, Merino wool absorbs UV radiation providing protection from the sun. This makes it a good choice for a wide range of outdoor activities.

Easy to Care for

Most Merino wool garments can be machine-washed and tumble dried, providing a simple solution to the common question of 'How to wash wool?'

Stain Resistant

Merino wool fibres have a natural protective outer layer that helps prevent stains from being absorbed. And because Merino wool tends not to generate static, it attracts less dust and lint.

(The Woolmark Company, n.d.)

Appendix C Limitations of Circular Knitting

Continuous Yarn

In a large circular knitting machine, the yarn carriages move continuously during the knitting process. Therefore any knitting techniques that require discontinuous carriage movement cannot be performed on large circular knitting machines. This means limited changeability in colour/material, like Intarsia patterns. These can be achieved with special thread guides, but are not typically used for commercial purposes

Needle Parking

In flat knitting, the carriage, moving from side to side, does not have to move across all active needles. This method is called needle parking and allows the machine to knit non-uniformly, called short rowing. The continuous movement of circular knitting means needle parking is generally impossible. There is an exception for smaller machines that have a pendulum function, often used for knitting socks. However, these machines cannot produce larger fabric rolls and therefore fall outside of the scope of this research.

Stitch Transfers

Transfer stitches offer design flexibility, enabling shaping, texturing, and creating holes in knitted textiles without cutting or breaking yarn. This function is highly utilised for flat bed knitting as it enables fully fashioned and whole garment production (see Chapter 2.3). However, this feature can be time-consuming because it requires more machine passes and thus time to produce the knit (Knitwearlab, personal communication, October 24 , 2023). For that reason, along with the continuous nature of circular knitting that increases the complexity of the technique, it is uncommon in large circular knitting machines, with most of the industry excluding them from textile production. Thus, for the purposes of the project, research will be limited to the first three types of stitches.

Stitch Length

In larger machines that operate with many weft yarns, typically 24 or 48 (Textile Museum, personal communication, January 19, 2024), the setup for the yarn is much larger than the knitting system itself, so the needles themselve rotate within the machine, instead of the whole machine rotating around the needles. This approach is fundamentally different from flat knitting, where the needles remain in place whilst a carriage moves across them. This also means that, even in modern, electronic machines, the stitch length is set mechanically by hand, so it is typically constant during knitting. Whilst in flat knitting, the stitch length can be programmed to be different per structure and row.

Take-Down

The take-down of a circular knitting machine has two functions. It provides tension on the active knitting area to ensure that loops do not drop from their needles and the take-down collects the knitted fabric at the bottom of the machine. Since the take-down gathers the material, it has to operate at the same pace as the machine produces material. Therefore, the take-down tension is linked to the speed of the machine and is generally held constant. In flat knitting, there are multiple take-down systems that provide tension and can be programmed to be variable depending on what is knitted. For example, in areas where needle parking is required, the tension is set lower so the parked needles are not over-strained. Luckily, because of the other limitations, circular knitted textiles usually do not require a variable take-down.

Stitch Transfers

The lack of transferring stitches also means that a circular knitting machine is limited in varying the type of knit structure within the same textile. Once a needle starts knitting, it cannot stop using that needle, because it cannot transfer the existing loop off the needle, so after a couple of rows the yarn will break on those needles that are no longer used. This means that structures like a rib cannot be knitted on top of structures that utilise different needles.

Appendix D Machine Requirements For Prototyping

For the purposes of prototyping and future commercial production, a suitable knitting machine needs to meet the following requirements, as were described in the previous section. The machine must have one or two knitting beds that have an electronic jacquard with no repeats and all needles must be able to perform a stitch, tuck, or float. The gauge, width (or diameter), amount of systems, feeders, and required software are not specifically required but are relevant for the programming and production of samples.

The IDE Faculty has a Stoll CMS-530.2 [85]. This is a 7.2 gauge machine, which means it can operate at 7 or 14 gauge, accommodating thicker and thinner yarns. It is a fully electronic jacquard double bed machine and each bed has 699 needles for a width of 1.26 metres. However, this width does not equate to a maximum knitted width of 1.26 metres. The machine has three systems, and eight channels and can operate with a theoretical maximum of 16 yarns, but only has eight feeders. It can be programmed with Stoll's M1+ software. The quantity that this machine can produce is significantly different from a comparable circular knitting machine at a similar gauge, which has 24-48 systems and yarns, typically in a multiple of up to four colours and a diameter of 30 inches for a maximum theoretical textile width of 2.4 metres.

Appendix E Samples

Li_1_DJ_M32_1

Library_1_DoubleJersey_Merino1/32_1

24-01-2024

Specifications

Wale Count (needles): 100
Course Count per yarn (rows): 50
Number of Yarns: 2

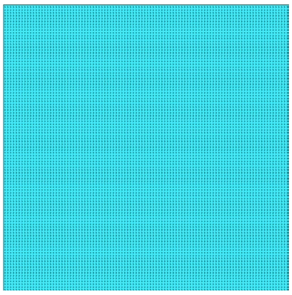
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Double Jersey

Front (in %)		Back (in %)	
Stitches:	100	Stitches:	100
Tucks:	0	Tucks:	0
Floats	0		



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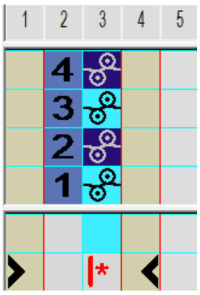


Li_1_DJ_M32_1.mdv

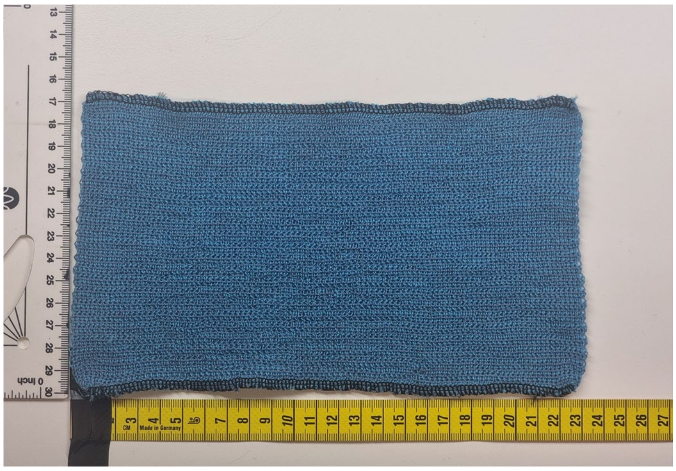
Purpose

Double Jersey is the densest knit structure, utilising every needle, every course for every yarn. The sample is to set a baseline for other structures.

Expectation

I expect a dense, large knit with a lot of stretch because of all the loops.

Result



Observations

The knit is very loose and big. The loops are quite large and loosely knitted. I believe the openness is cause by the distance between the 2 beds whilst knitting.

The swatch shrinks mostly in the course direction. Thickness has increased but the knit still appears loose.

Comments

Quite maluable, I don't think this will be desirable to wear.

Dimensions

Regular
Wale: 220 mm Course: 130 mm Ratio: 1.69 Height: -
Washed
Wale: 165 mm Course: 65 mm Ratio: 2.54 Height: -

Li_1_IL_M32_1

Library_1_Interlock_Merino1/32_1

24-01-2024

Specifications

Wale Count (needles): 100
Course Count per yarn (rows): 100
Number of Yarns: 2

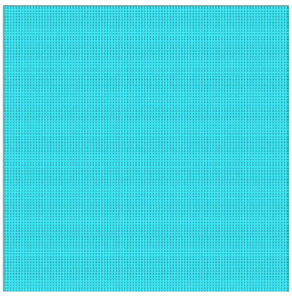
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Interlock

Front (in %)		Back (in %)	
Stitches:	50	Stitches:	50
Tucks:	0	Tucks:	0
Floats	0		



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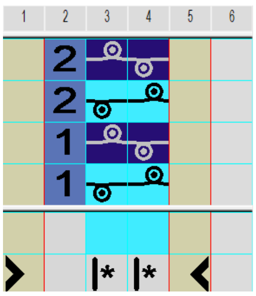


Li_1_IL_M32_1.mdv

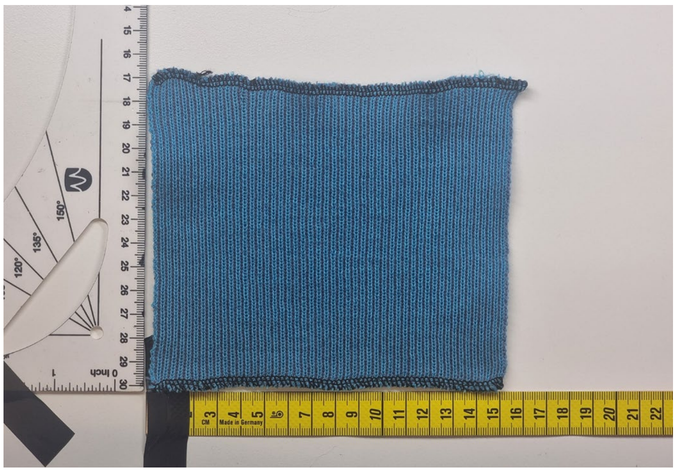
Purpose

Interlock is a very common knit structure, so it is valuable to see what it looks and feels like with standard settings.

Expectation

I expect a tight knit with a lot of stretch. I also expect the shape to be square.

Result



Observations

Very stable knit. The shape is nearly a square, like the artwork it is based on. Also very stretchy, like a rib.

Shrinking mostly in the course direction. Still very stable, just a bit thicker and a lot less stretchy.

Comments

Space for additional comments

Dimensions

Regular
Wale: 150 mm Course: 130 mm Ratio: 1.15 Height: -
Washed
Wale: 130 mm Course: 90 mm Ratio: 1.44 Height: -

Li_1_TU_M32_1

Library_1_Tubular_Merino1/32_1

24-01-2024

Specifications

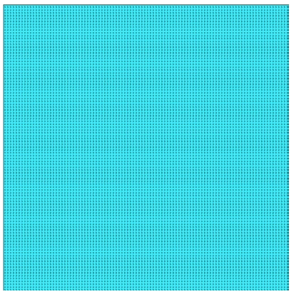
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Tubular

Front (in %)		Back (in %)	
Stitches:	50	Stitches:	50
Tucks:	0	Tucks:	0
Floats	0		



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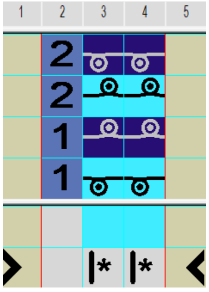


Li_1_TU_M32_1.mdv

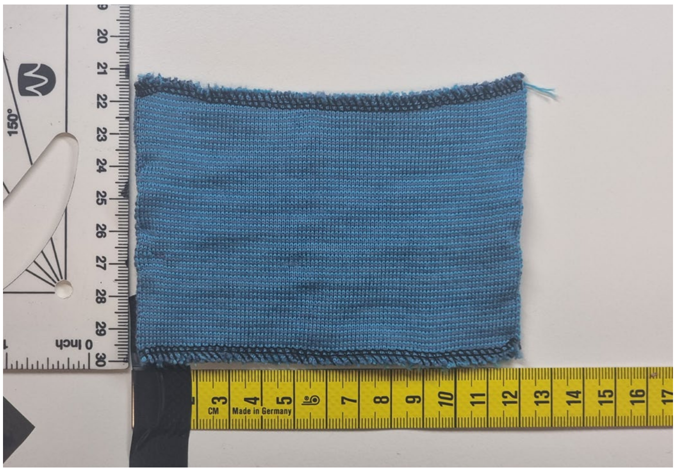
Purpose

Tubular is a very common knit structure, so it is valuable to see what it looks and feels like with standard settings.

Expectation

I expect loose knit, because of the stitchlength. The swatch should also be hollow or tubular, with colour on both sides.

Result



Observations

The tubular swatch is very small and the stitches are very dense. Normally, in flatbed knitting a larger stitchlength is used for single jersey, so it makes sense. Because of the smaller loops the swatch feels smoother and stretches less.

When washed it is a smaller version of the swatch, but still very recognizable. Single jersey, tubular, or net jacquard don't pill as much when felted.

Comments

Space for additional comments

Dimensions

Regular							
Wale:	120 mm	Course:	90 mm	Ratio:	1.33	Height:	-
Washed							
Wale:	105 mm	Course:	80 mm	Ratio:	1.31	Height:	-

Li_1_HM_M32_1

Library_1_HalfMilano_Merino1/32_1

24-01-2024

Specifications

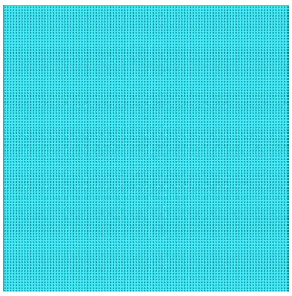
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Half Milano

Front (in %)		Back (in %)	
Stitches:	50	Stitches:	100
Tucks:	0	Tucks:	0
Floats	0		



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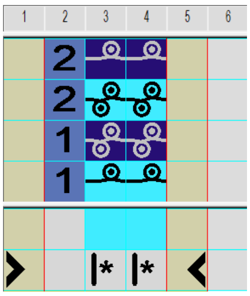


Li_1_HM_M32_1.mdv

Purpose

Half Milano is a common knit structure, so it is valuable to see what it looks and feels like with standard settings.

Expectation

I expect a dense, large knit with a lot of stretch because of all the loops.

Result

Observations

The knit is quite loose and transparent. There is a slight horizontal rib and the material is not stable. It curls towards the front of the knit.

Washing stabilises the knit. Shrinks mostly in the course direction.

Comments

Space for additional comments

Dimensions

Regular							
Wale:	195 mm	Course:	140 mm	Ratio:	1.39	Height:	-
Washed							
Wale:	155 mm	Course:	100 mm	Ratio:	1.55	Height:	-

Li_1_FM_M32_1

Library_1_FullMilano_Merino1/32_1

24-01-2024

Specifications

Wale Count (needles): 100
Course Count per yarn (rows): 100
Number of Yarns: 2

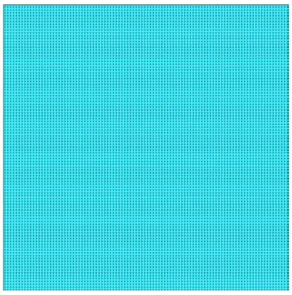
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Full Milano

Front (in %)		Back (in %)	
Stitches:	66	Stitches:	66
Tucks:	0	Tucks:	0
Floats	0		



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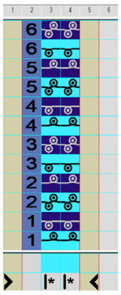


Li_1_FM_M32_1.mdv

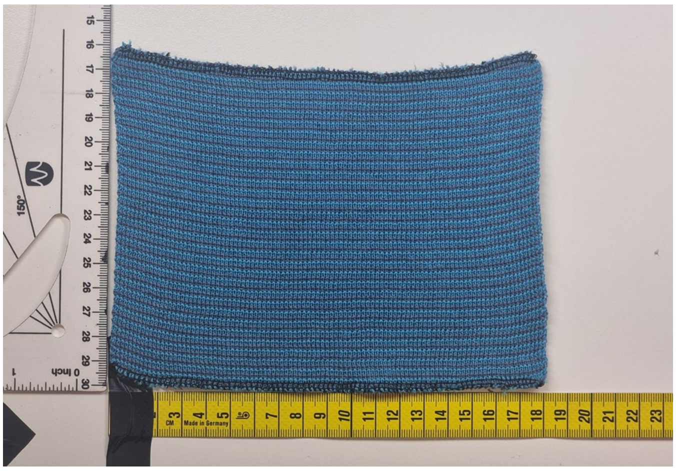
Purpose

Full Milano is a common knit structure, so it is valuable to see what it looks and feels like with standard settings.

Expectation

I expect a dense, large knit with a lot of stretch because of all the loops.

Result



Observations

Appears quite stable and nearly sqaure. A bit wider though. The feel and density is between a Double Jersey and an Interlock.

Washed, the swatch is very stable and rectangular. But slightly more open than a washed Interlock.

Comments

Space for additional comments

Dimensions

Regular
Wale: **175 mm** Course: **135 mm** Ratio: **1.30** Height: -
Washed
Wale: **140 mm** Course: **90 mm** Ratio: **1.55** Height:

Li_1_FC_M32_1

Library_1_FullCardigan_Merino1/32_1

24-01-2024

Specifications

Wale Count (needles): 100
Course Count per yarn (rows): 100
Number of Yarns: 2

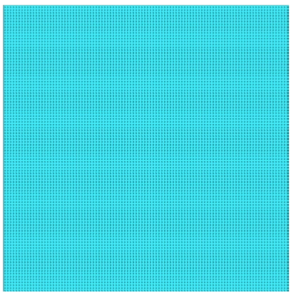
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Full Cardigan

Front (in %)		Back (in %)	
Stitches:	25	Stitches:	25
Tucks:	25	Tucks:	25
Floats	0		



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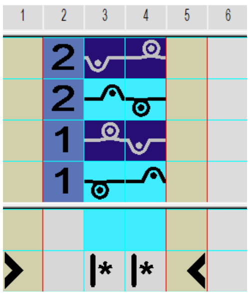


Li_1_FC_M32_1.mdv

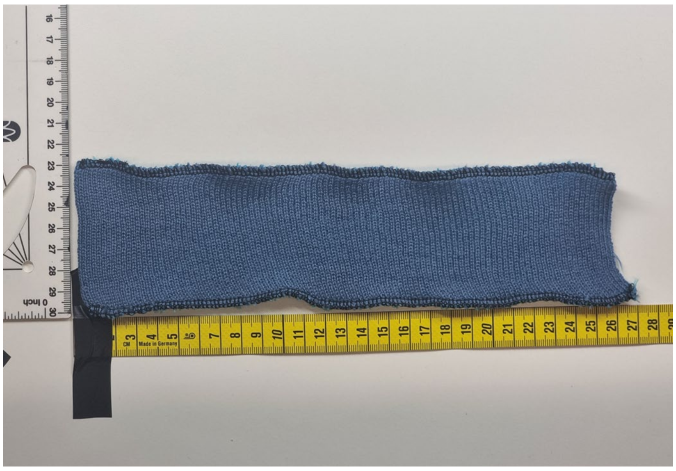
Purpose

Full Cardigan is a common knit structure, so it is valuable to see what it looks and feels like with standard settings.

Expectation

I expect a soft knit because of the tucks. It will also be shorter and wider because the tucks build up less loops.

Result



Observations

The swatch is very wide and not very tall. It is also very soft and feel like a completely different material, compared to a tubular jacquard. It is also very stretchy.

When washed, the swatch looses most of its stretchyness. It also pills more than other swatches and is not as soft. It shrinks pretty uniformly though.

Comments

Space for additional comments

Dimensions

Regular
Wale: **260 mm** Course: **65 mm** Ratio: **4** Height: -
Washed
Wale: **170 mm** Course: **45 mm** Ratio: **3.77** Height: -

Li_1_NJ_M32_1

Library_1_NetJacquard_Merino1/32_1

24-01-2024

Specifications

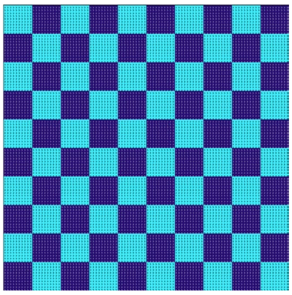
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Net Jacquard

Front (in %)		Back (in %)	
Stitches:	50	Stitches:	50
Tucks:	0	Tucks:	0
Floats	0		



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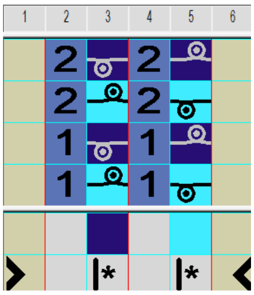


Li_1_NJ_M32_1.mdv

Purpose

Net Jacquard is a very common knit structure, so it is valuable to see what it looks and feels like with standard settings.

Expectation

Very similar to the tubular swatch except for that the yarn switches front to back in a pattern. There is will create pockets.

Result

Observations

Effect is cool and clearly demonstrates how the squares are not square, just like the entire swatch. Just like the tubular swatch, the stiches are very tight like a single jersey. The stretch is good in the wale direction, but barely stretches in the course direction.

After washing, it is still very recognizable. Just smaller, but not pilling like the others. Also shrinks less than other swatches.

Comments

Space for additional comments

Dimensions

	Wale:		Course:		Ratio:		Height:
Regular		120 mm		90 mm		1.33	-
Washed		105 mm		80 mm		1.31	-

Li_1_OM_M32_1

Library_1_Ottoman_Merino1/32_1

24-01-2024

Specifications

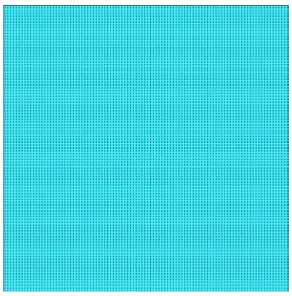
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Ottoman

Front (in %)		Back (in %)	
Stitches:	100	Stitches:	25
Tucks:	0	Tucks:	0
Floats	0		



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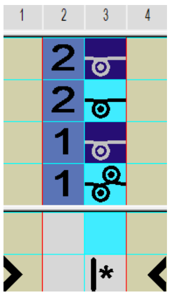


Li_1_OM_M32_1.mdv

Purpose

Ottoman is a common knit structure technique to create texture, so it is valuable to see what it looks and feels like with standard settings.

Expectation

Stacking loops on the front bed should create horizontal ridges in the knit.

Result

Observations

The front of the knit has a slight horizontal rib structure and the back is entirely flat. The stitches on the back are a lot longer/looser, because that hung on the bed for multiple rows, compared to the front. It is also unstable, curling towards the backside.

Washed, it is more stable and barely shrunk in the wale direction.

Comments

Space for additional comments

Dimensions

	Wale:		Course:		Ratio:		Height:
Regular		160 mm		120 mm		1.33	-
Washed		150 mm		90 mm		1.66	-

Li_1_DJ25_M32_1

Library_1_DoubleJersey0.25_Merino1/32_1

24-01-2024

Specifications

Wale Count (needles): 100
Course Count per yarn (rows): 100
Number of Yarns: 2

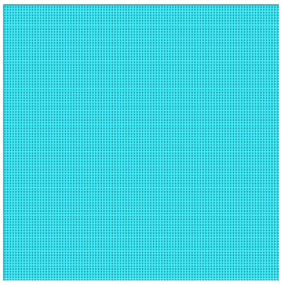
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

1/4 Density Double Jersey

Front (in %)		Back (in %)	
Stitches:	25	Stitches:	25
Tucks:	0	Tucks:	0
Floats	50		



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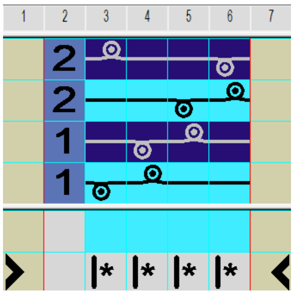


Li_1_DJ25_M32_1.mdv

Purpose

Including more floats will hopefully result in a denser knit for the same amount of knitted rows, compared to only stitches.

Expectation

With a lot more floats, every four knitted rows create one row of stitches. Therefore is should have 1/2 compared to the interlock stitch.

Result

Observations

Its a small rectangle, that is more reduced in height than width compared to a regular interlock. The structure is very stable and stretchy, but less stretchy than Interlock.

The washed version is tiny, even though it has the same amount of wales and courses as all the other samples.

Comments

Space for additional comments

Dimensions

	Wale:		Course:		Ratio:		Height:
Regular	Wale:	125 mm	Course:	70 mm	Ratio:	1.79	Height: -
Washed	Wale:	105 mm	Course:	45 mm	Ratio:	2.33	Height:

Li_1_DJ33_M32_1

Library_1_DoubleJersey0.33_Merino1/32_1

24-01-2024

Specifications

Wale Count (needles): 100
Course Count per yarn (rows): 100
Number of Yarns: 2

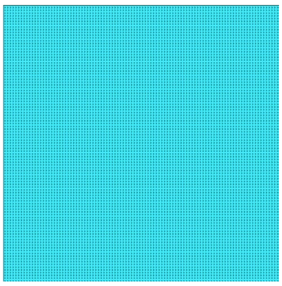
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

1/3 Density Double Jersey

Front (in %)		Back (in %)	
Stitches:	33	Stitches:	33
Tucks:	0	Tucks:	0
Floats	33		



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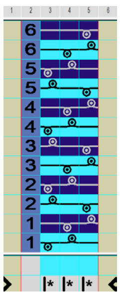


Li_1_DJ33_M32_1.mdv

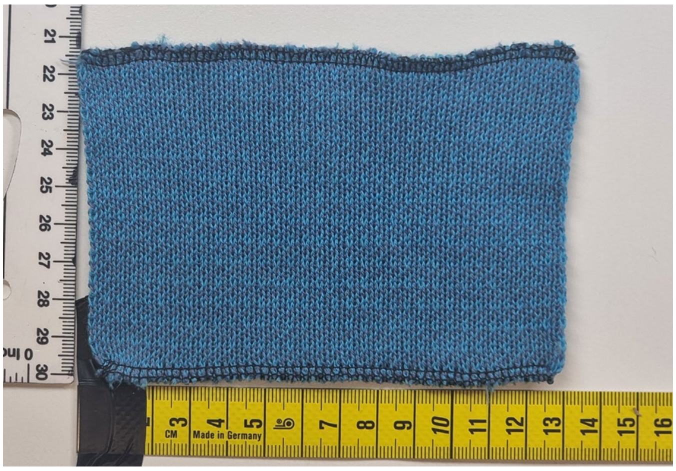
Purpose

Including more floats will hopefully result in a denser knit for the same amount of knitted rows, compared to only stitches.

Expectation

With a lot more floats, every three knitted rows create one row of stitches. Therefore is should have 2/3 compared to the interlock stitch.

Result



Observations

The alternating pattern looks interesting, since it's not stripey. Very stable structure that is smaller in both directions than a regular interlock.

Washed, the swatch is very dense and barely stretchy. It is also quite thick.

Comments

Space for additional comments

Dimensions

	Wale:		Course:		Ratio:		Height:
Regular	Wale:	130 mm	Course:	85 mm	Ratio:	1.53	Height: -
Washed	Wale:	110 mm	Course:	60 mm	Ratio:	1.83	Height:

Li_1_DJ50_M32_1

Library_1_DoubleJersey0.50_Merino1/32_1

24-01-2024

Specifications

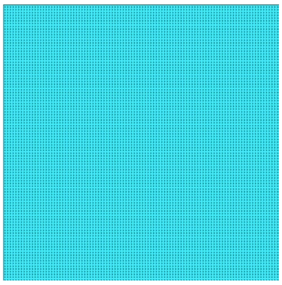
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

1/2 Density Double Jersey

Front (in %)		Back (in %)	
Stitches:	50	Stitches:	50
Tucks:	0	Tucks:	0
Floats	0		



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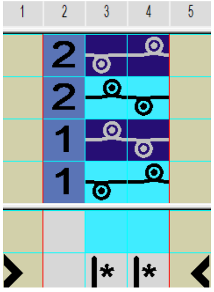


Li_1_DJ50_M32_1.mdv

Purpose

Practically identical to an interlock structure, but now noted as a version of density.

Expectation

I expect the result as the interlock stitch.

Result

Observations

Identical to the initial interlock stitch. Almost square and when washed a more rectangular.

Comments

Space for additional comments

Dimensions

Regular							
Wale:	150 mm	Course:	125 mm	Ratio:	1.2	Height:	-
Washed							
Wale:	125 mm	Course:	90 mm	Ratio:	1.39	Height:	-

Li_1_PI_M32_1

Library_1_Pique_Merino1/32_1

24-01-2024

Specifications

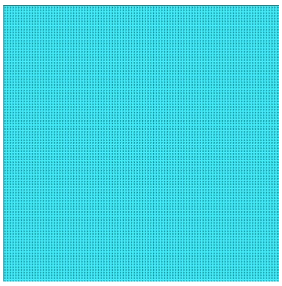
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Double Pique

Front (in %)		Back (in %)	
Stitches:	37.5	Stitches:	37.5
Tucks:	12.5	Tucks:	12.5
Floats	0		



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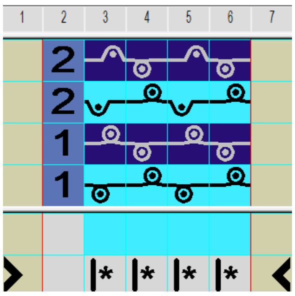


Li_1_PI_M32_1.mdv

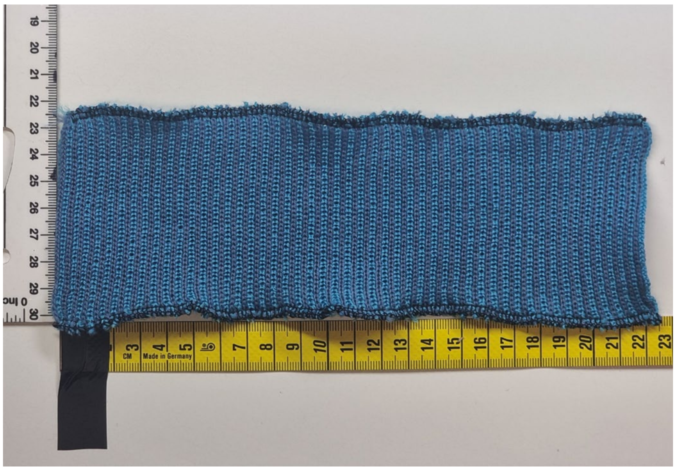
Purpose

This knit structure appeared in a paper about breathability of different knit structures, so I was curious what it would look and feel like. Additionally, it is curious how tucks might influence the 100x100 sample,

Expectation

Similar to a Full Cardigan, I expect a soft and wide swatch.

Result



Observations

Similar to the Full Cardigan, it is a loose knit with high stretch in all directions. It is also quite large for the same amount of needles and rows, compared to interlock variations.

When washed it looses its stretch and shrinks a lot in the course direction.

Comments

Space for additional comments

Dimensions

Regular							
Wale:	215 mm	Course:	75 mm	Ratio:	2.87	Height:	-
Washed							
Wale:	160 mm	Course:	50 mm	Ratio:	3.20	Height:	-

Li_1_MS_M32_1

Library_1_MagliaSpiga_Merino1/32_1

24-01-2024

Specifications

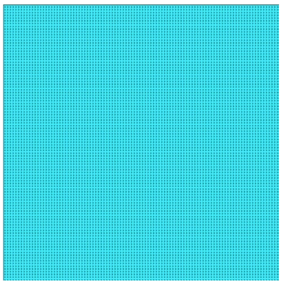
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Double Maglia Spiga

Front (in %)		Back (in %)	
Stitches:	25	Stitches:	25
Tucks:	25	Tucks:	25
Floats	0		



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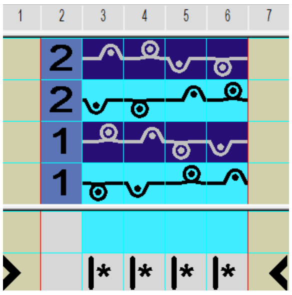


Li_1_MS_M32_1.mdv

Purpose

This knit structure appeared in a paper about breathability of different knit structures, so I was curious what it would look and feel like. Additionally, it is curious how tucks might influence the 100x100 sample,

Expectation

Similar to the Pique but wider and smaller, because there are more tucks.

Result

Observations

Similar to the Full Cardigan, it is very wide, soft, and stretchy.

When washed, the swatch looses its stretch and shrinks significantly.

Comments

Space for additional comments

Dimensions

Regular

Wale:	240 mm	Course:	60 mm	Ratio:	4	Height:	-

Washed

Wale:	160 mm	Course:	45 mm	Ratio:	3.56	Height:	-

Li_1_LK_M32_1

Library_1_Lockknit_Merino1/32_1

24-01-2024

Specifications

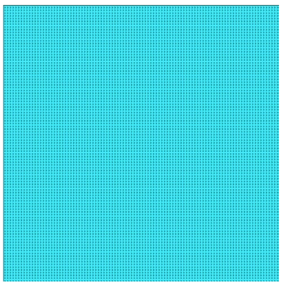
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Double Lockknit

Front (in %)		Back (in %)	
Stitches:	37.5	Stitches:	37.5
Tucks:	0	Tucks:	0
Floats	25		



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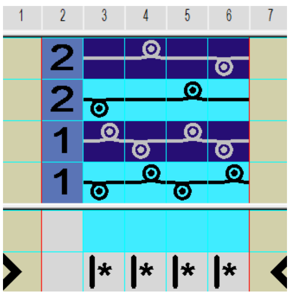


Li_1_LK_M32_1.mdv

Purpose

This knit structure appeared in a paper about breathability of different knit structures, so I was curious what it would look and feel like. It also has a different ratio of floats to stitches compared to some other samples.

Expectation

I expect an interlock-feeling swatch that is slightly smaller because of the floats every other row.

Result

Observations

Similar to an Interlock, but it creates a vertical rib texture. Very stretchy, but also quite stable.

When washed the rib texture disappears. Shrinks more in height than in length.

Comments

Space for additional comments

Dimensions

Regular

Wale:	130 mm	Course:	105 mm	Ratio:	1.24	Height:	-

Washed

Wale:	110 mm	Course:	75 mm	Ratio:	1.47	Height:	

Li_1_FL_M32_1

Library_1_Float_Merino1/32_1

24-01-2024

Specifications

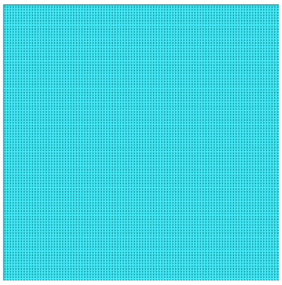
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

1/2 Density Double Jersey w/ 7 needle-length floats.

Front (in %)		Back (in %)	
Stitches:	25	Stitches:	25
Tucks:	0	Tucks:	0
Floats	50		



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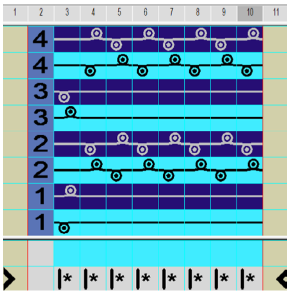


Li_1_FL_M32_1.mdv

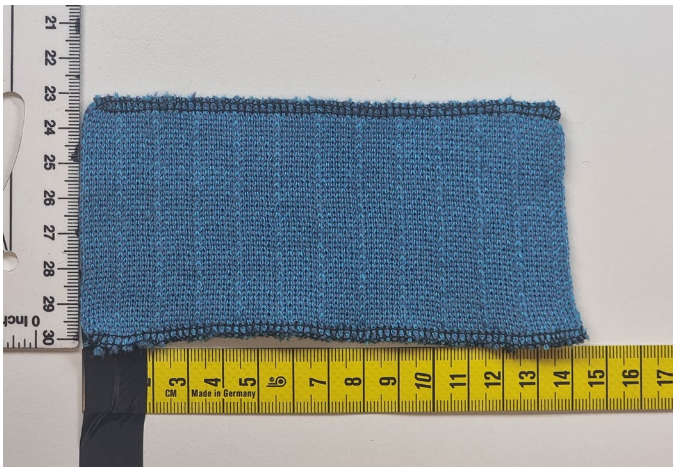
Purpose

The same ratio of floats and stitches as Double Jersey 25. However, every other row has very long floats. When shrinking, these floats hopefully are more free to react and shrink compared to the DJ25.

Expectation

Should be identical to the DJ25 from the outside, before washing. After washing, I expect the swatch to shrink more than the DJ25

Result



Observations

The structure creates a very noticably vertical rib texture. Not stretchy in wale direciton. Stretchy in couurse direciton. Both because of the long floats. Dimensions are similar to DJ25.

When washed, it shrinks more in the float direction. The rib texture disappears, but visually remains. The floats create a relatively large shrinkage in the wale direction.

Comments

Space for additional comments

Dimensions

Regular

Wale:	140 mm	Course:	70 mm	Ratio:	2.15	Height:	-

Washed

Wale:	90 mm	Course:	55 mm	Ratio:	1.64	Height:	

Li_1_SL_M32_1

Library_1_Sewlike_Merino1/32_1

24-01-2024

Specifications

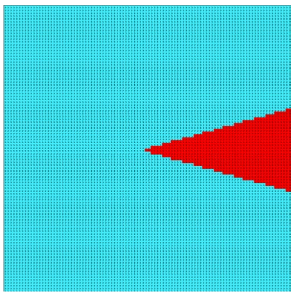
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Sew-like stacked floats dart & Double Jersey

Front (in %)		Back (in %)	
Stitches:	31.25	Stitches:	31.25
Tucks:	0	Tucks:	0
Floats	37.5		



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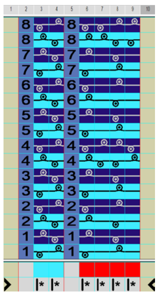


Li_1_SL_M32_1.mdv

Purpose

Based on a paper by the ITA research group, the red area has multiple floats stacked on top of eachother. This kind of acts like needle parking, so it should pinch the material.

Expectation

I expect a significant reduction in material in the red area, so the swatch should appear to have a dart.

Result

Observations

The dart works, but only slightly. It does not remove all the material that is presesnt within the red area. The stitches in the dart are also a lot looser than the surrounding stitches.

Washed, the colour of the swatch becomes uniform and the entire swatch shrinks. However, the dart appears to shrink less than its surroundings.

Comments

Space for additional comments

Dimensions

Regular

Wale:	150 mm	Course:	130 mm	Ratio:	1.15	Height:	-

Washed

Wale:	130 mm	Course:	95 mm	Ratio:	1.37	Height:	-

Li_1_SL_M32_2

Library_1_Sewlike_Merino1/32_2

24-01-2024

Specifications

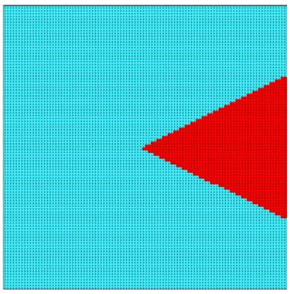
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Sew-like stacked floats dart & Double Jersey

Front (in %)		Back (in %)	
Stitches:	13.5	Stitches:	13.5
Tucks:	0	Tucks:	0
Floats	73		



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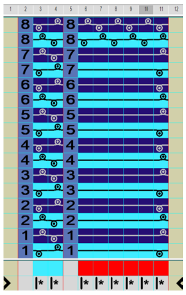


Li_1_SL_M32_2.mdv

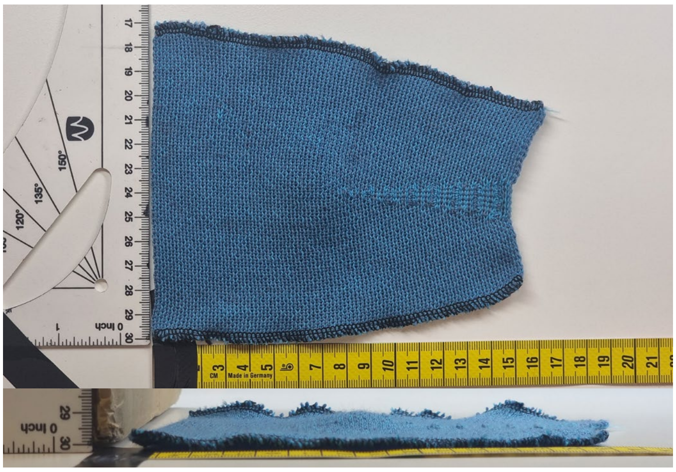
Purpose

Based on a paper by the ITA research group, the red area has multiple floats stacked on top of eachother. This kind of acts like needle parking, so it should pinch the material. The first Sew-Like did not do much. Therefore the size of the dart and the amount of stacked floats is increased.

Expectation

Similar to the first dart attempt, but with a larger reduction of material, since both the red area and the ratio of floats is increased.

Result



Observations

The effect of the dart is more noticable. There is also a vertical rib texture that feels hard and stiff in the dart. There is no wale-direction stretch or course-direction stretch.

When washed, the dart does not shrink as much as the surrounding interlock and the texture also remains.

Comments

Space for additional comments

Dimensions

Regular

Wale:	150 mm	Course:	130 mm	Ratio:	1.15	Height:	-

Washed

Wale:	120 mm	Course:	85 mm	Ratio:	1.41	Height:	

Li_1_SL_M32_3

Library_1_Sewlike_Merino1/32_3

24-01-2024

Specifications

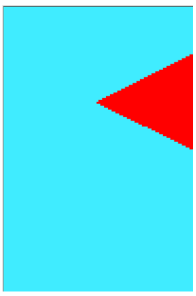
Wale Count (needles):	100
Course Count per yarn (rows):	150
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Sew-like stacked floats dart & Double Jersey

Front (in %)		Back (in %)	
Stitches:	6.25	Stitches:	6.25
Tucks:	0	Tucks:	0
Floats	87.5		



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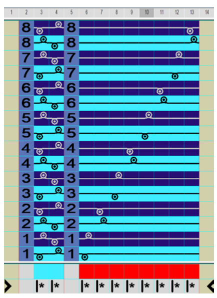


Li_1_SL_M32_3.mdv

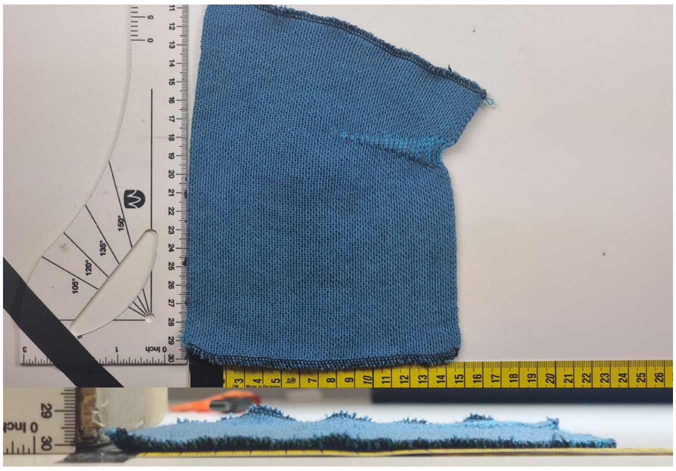
Purpose

Iterating on the second sample, the amount of stacked floats is increased to 7. There is also more knitted material before the dart so the auxiliry take-down provides better distributed tension.

Expectation

I expect a more significant dart in the red area. Additionally I hope the loops/ needles can hold the yarn for enough rows.

Result



Observations

Similar to the first results, however the dart takes in more material and the swatch is noticably not rectangular.

The dart also appears to shrink more consistently with the surrounding knit.

Comments

Space for additional comments

Dimensions

Regular

Wale:	150 mm	Course:	200 mm	Ratio:	1.13	Height:	-

Washed

Wale:	130 mm	Course:	140 mm	Ratio:	1.35	Height:	-

Li_1_SL_M32_4

Library_1_Sewlike_Merino1/32_4

24-01-2024

Specifications

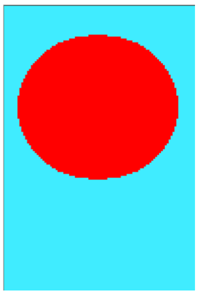
Wale Count (needles):	100
Course Count per yarn (rows):	150
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Sew-like stacked floats dart & Double Jersey

Front (in %)		Back (in %)	
Stitches:	6.25	Stitches:	6.25
Tucks:	0	Tucks:	0
Floats	87.5		



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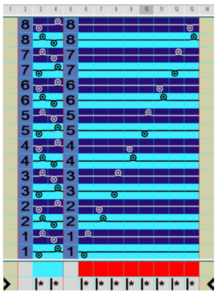


Li_1_SL_M32_4.mdv

Purpose

This sample has the same float density structure, but now in the shape of a circle to investigate how different 'dart' geometries behave.

Expectation

I expect that the swatch will be shortest in the middle, since there is larger reduction of material. The rest is a surprise.

Result

Observations

The reduced middle when flat pulls up the edges a lot. When folded through the middle, it lays flat with a curved fold line. This is perfect for armpit panels. Material is mostly reduced in the course direction.

When washed the behaviour is similar, but the reduced element becomes very thick.

Comments

Space for additional comments

Dimensions

Regular							
Wale:	150 mm	Course:	125 mm	Ratio:	1.2	Height:	-
Washed							
Wale:	115 mm	Course:	80 mm	Ratio:	1.44	Height:	

Li_1_SL_M32_5

Library_1_Sewlike_Merino1/32_5

24-01-2024

Specifications

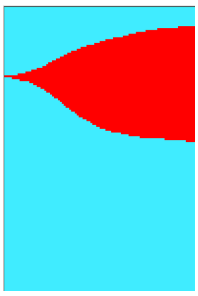
Wale Count (needles):	100
Course Count per yarn (rows):	150
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Sew-like stacked floats dart & Double Jersey

Front (in %)		Back (in %)	
Stitches:	6.25	Stitches:	6.25
Tucks:	0	Tucks:	0
Floats	87.5		



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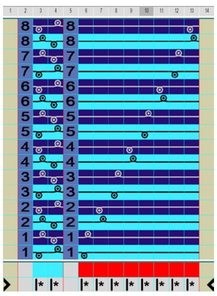


Li_1_SL_M32_5.mdv

Purpose

This sample has the same float density structure, but now in the shape of a curved dart to investigate how different 'dart' geometries behave.

Expectation

ISimilar to Sew-Like 3, but different geometry to see if the pinching can be curved.

Result

Observations

This variation of a dart creates more curvature in its material reduction. The tubular effect with each yarn on one side is also cool. The reduced area also has no stretch.

When washed the red area become very uniform and thick. The rest of the swatch behaves like the other swatches.

Comments

Space for additional comments

Dimensions

Regular							
Wale:	150 mm	Course:	170 mm	Ratio:	1.36	Height:	-
Washed							
Wale:	115 mm	Course:	120 mm	Ratio:	1.44	Height:	-

Li_1_SL_M32_6

Library_1_Sewlike_Merino1/32_6

24-01-2024

Specifications

Wale Count (needles):	100
Course Count per yarn (rows):	350
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5
Yarn Material(s):	Merino wool 1/32 Nm

Structure

Several sew-like stacked floats dart & Double Jersey. 7 variations with different ratios of floats to stitches.

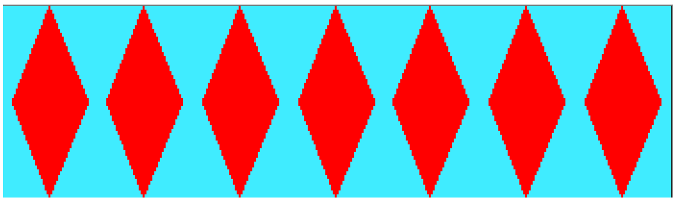


Image is rotated 90 degrees.

Li_1_SL_M32_6.mdv

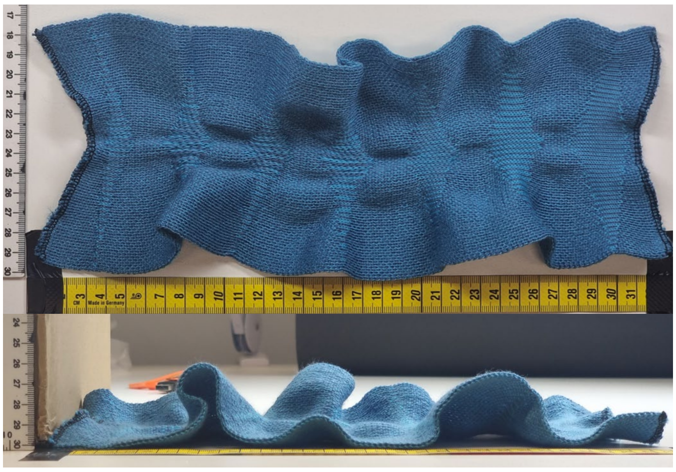
Purpose

A sequence of 7 darts, each with a different float density. It starts with one stacked floats and builds up to 7 stacked floats.

Expectation

A gradient of structure that scale up the amount of material deformation around each dart.

Result



Observations

The multiple darts create a nice flowy swatch edge. The different dart densities is observable, especially in how tight the stichtes are knit, since the darts are a tubular knit, so the initial dart is very tight.

When washed, the dart with the least floats feels identical to its surrounding knit, but the more floats in a dart the thicker is becomes. It also looses its stretch.

Comments

Space for additional comments

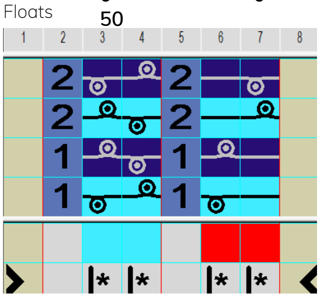
Dimensions

	Wale:		Course:		Ratio:		Height:	
Regular	Wale:	130 mm	Course:	280 mm	Ratio:	1.63	Height:	-
Washed	Wale:	95 mm	Course:	185 mm	Ratio:	1.80	Height:	-

Structure

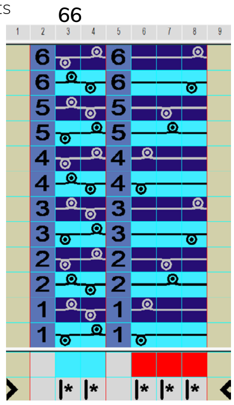
Sew-like 2

Front (in %)		Back (in %)	
Stitches:	25	Stitches:	25
Tucks:	0	Tucks:	0
Floats	50		



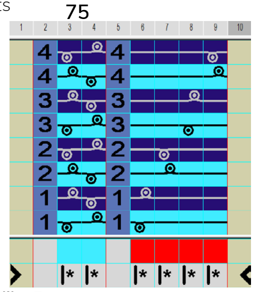
Sew-like 3

Front (in %)		Back (in %)	
Stitches:	16.6	Stitches:	16.6
Tucks:	0	Tucks:	0
Floats	66		



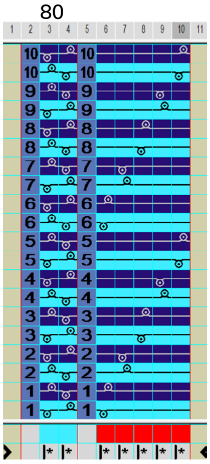
Sew-like 4

Front (in %)		Back (in %)	
Stitches:	12.5	Stitches:	12.5
Tucks:	0	Tucks:	0
Floats	75		



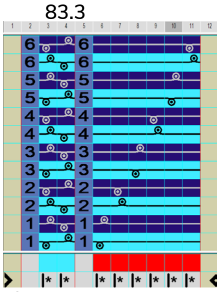
Sew-like 5

Front (in %)		Back (in %)	
Stitches:	10	Stitches:	10
Tucks:	0	Tucks:	0
Floats	80		



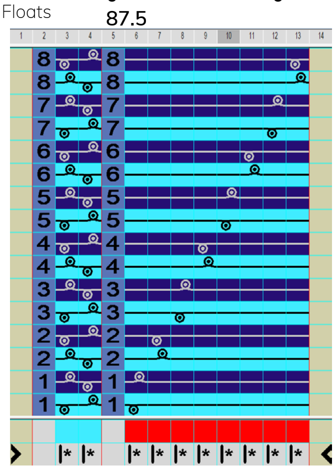
Sew-like 6

Front (in %)		Back (in %)	
Stitches:	8.3	Stitches:	8.3
Tucks:	0	Tucks:	0
Floats	83.3		



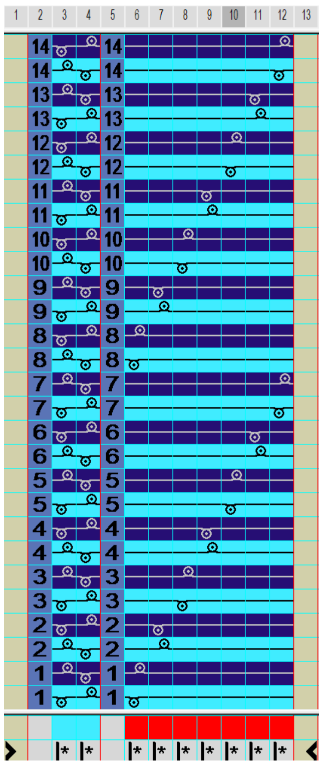
Sew-like 8

Front (in %)		Back (in %)	
Stitches:	6.75	Stitches:	6.75
Tucks:	0	Tucks:	0
Floats	87.5		



Sew-like 7

Front (in %)		Back (in %)	
Stitches:	7.15	Stitches:	7.15
Tucks:	0	Tucks:	0
Floats	85.7		



Li_1_SL_M32_7

Library_1_Sewlike_Merino1/32_7

24-01-2024

Specifications

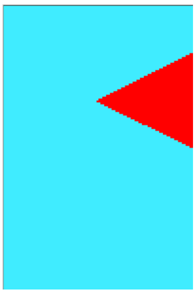
Wale Count (needles):	100
Course Count per yarn (rows):	150
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Sew-like stacked floats dart & Double Jersey

Front (in %)		Back (in %)	
Stitches:	7.15	Stitches:	7.15
Tucks:	0	Tucks:	0
Floats	85.7		



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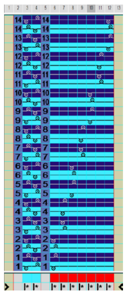


Li_1_SL_M32_7.mdv

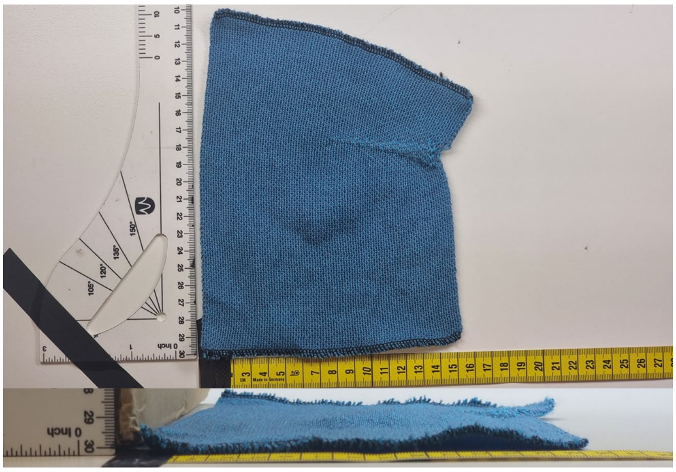
Purpose

Finally, this dart module is to investigate how many stacked floats are possible without the knit breaking. For this version, there are 12 stacked floats.

Expectation

If it doesnt break it will be a tighter, more effecient version of the dart from Sew-Like 3.

Result



Observations

Very effective dart that takes in a lot of material. The dart itself is also not much denser than other less harsh darts.

When washed, the swatch shrinks very similar to the other dart swatches.

Comments

Space for additional comments

Dimensions

Regular							
Wale:	150 mm	Course:	200 mm	Ratio:	1.12	Height:	-
Washed							
Wale:	115 mm	Course:	135 mm	Ratio:	1.35	Height:	-

Li_2_DS2_M32_1

Library_2_DartStructure2_Merino1/32_1

30-01-2024

Specifications

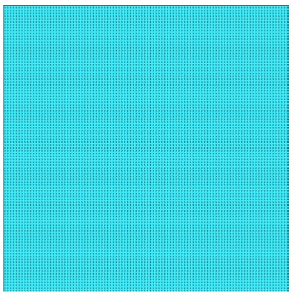
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Structure for dart applications, contains 2 stacks of floats.

Front (in %)		Back (in %)	
Stitches:	16.7	Stitches:	16.7
Tucks:		Tucks:	
Floats	66.6		



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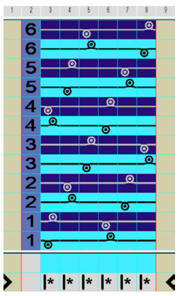


Li_2_DS2_M32_1.mdv

Purpose

Quantifying how many floats can be stacked in a dart structure like the sew-like samples and to figure out how much size is reduced.

Expectation

I expect the course length (height) to be 1/3 of the interlock (baseline) structure. The wale length (width) will be similar. It will also be a bit thicker.

Result

Observations

Stable and soft structure that is a lot wider than tall, just as expected. The thickness is not very noticable.

Washed is still uniform but slightly smaller in both directions.

Comments

Space for additional comments

Dimensions

Regular							
Wale:	115 mm	Course:	50 mm	Ratio:	-	Height:	-
Washed							
Wale:	105 mm	Course:	35 mm	Ratio:	-	Height:	-

Li_2_DS4_M32_1

Library_2_DartStructure4_Merino1/32_1

30-01-2024

Specifications

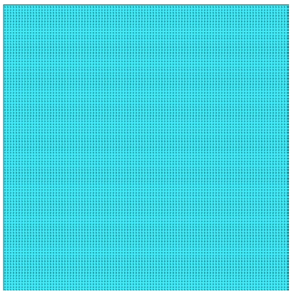
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Structure for dart applications, contains 4 stacks of floats.

Front (in %)		Back (in %)	
Stitches:	10	Stitches:	10
Tucks:		Tucks:	
Floats	80		



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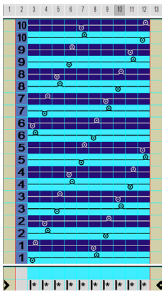


Li_2_DS4_M32_1.mdv

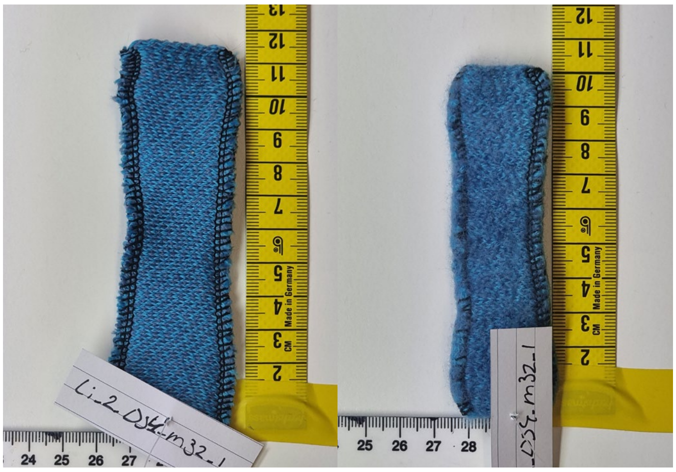
Purpose

Quantifying how many floats can be stacked in a dart structure like the sew-like samples and to figure out how much size is reduced.

Expectation

I expect the course length (height) to be 1/5 of the interlock (baseline) structure. The wale length (width) will be similar. It will also be a bit thicker.

Result



Observations

DS4 is shorter than DS2, which makes sense since there are more floats. Moldable in the course direction and slightly thicker.

Comments

Space for additional comments

Dimensions

Regular							
Wale:	115 mm	Course:	35 mm	Ratio:	-	Height:	-
Washed							
Wale:	100 mm	Course:	25 mm	Ratio:	-	Height:	-

Li_2_DS6_M32_1

Library_2_DartStructure6_Merino1/32_1

30-01-2024

Specifications

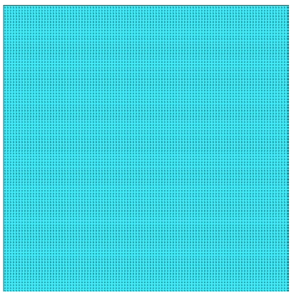
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Structure for dart applications, contains 6 stacks of floats.

Front (in %)		Back (in %)	
Stitches:	7.14	Stitches:	7.14
Tucks:		Tucks:	
Floats	85.7		



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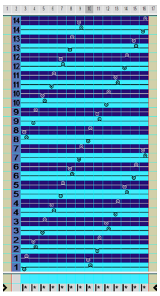


Li_2_DS6_M32_1.mdv

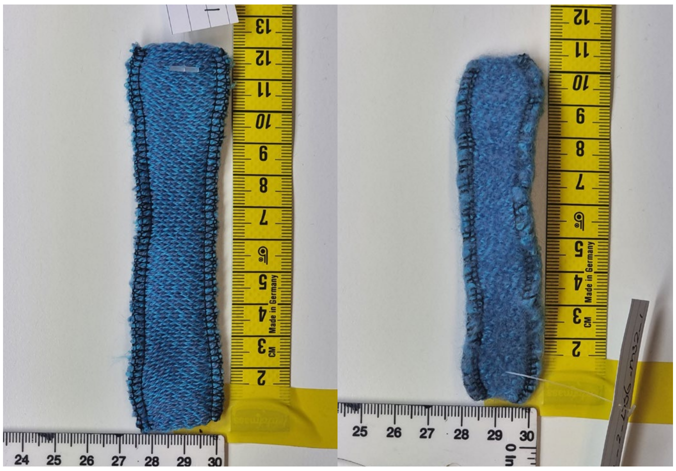
Purpose

Quantifying how many floats can be stacked in a dart structure like the sew-like samples and to figure out how much size is reduced. This structure reaches the maximum float length limit for one row.

Expectation

I expect the course length (height) to be 1/7 of the interlock (baseline) structure. The wale length (width) will be similar. It will also be a bit thicker.

Result



Observations

Even shorter than DS4, this structure is again a bit thicker, moldable and stable.

Washed, there is very little stretch and it is no longer moldable.

Comments

Space for additional comments

Dimensions

Regular							
Wale:	115 mm	Course:	25 mm	Ratio:	-	Height:	-
Washed							
Wale:	105 mm	Course:	20 mm	Ratio:	-	Height:	-

Li_2_DS8_M32_1

Library_2_DartStructure8_Merino1/32_1

30-01-2024

Specifications

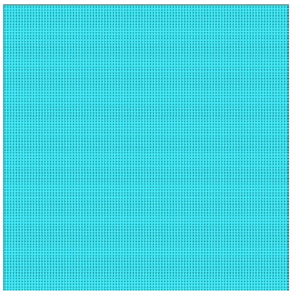
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Structure for dart applications, contains 8 stacks of floats.

Front (in %)		Back (in %)	
Stitches:	10	Stitches:	10
Tucks:		Tucks:	
Floats	80		



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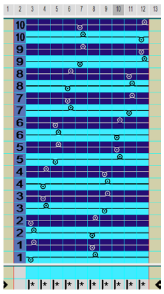


Li_2_DS8_M32_1.mdv

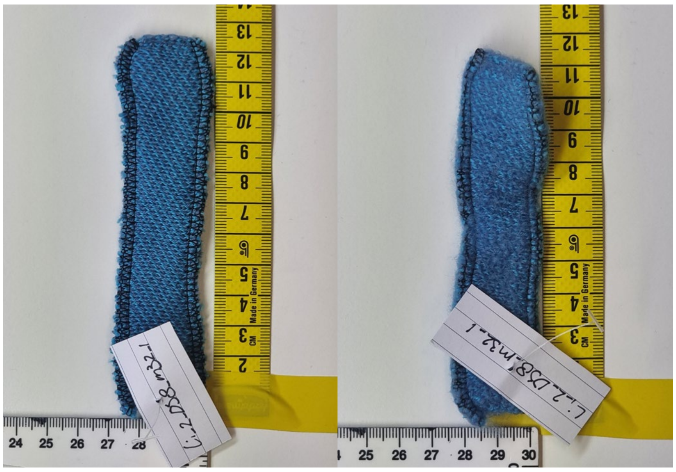
Purpose

Quantifying how many floats can be stacked in a dart structure like the sew-like samples and to figure out how much size is reduced. Stacking 2 stitches allows for a stack of 8 float with an even repeat.

Expectation

I expect the course length (height) to be 1/5 of the interlock (baseline) structure, since for every 10 rows, there will be two knitted rows even though 8 rows are pinched with floats. The wale length (width) will be similar. It will also be a bit thicker.

Result



Observations

Seems to be thicker than DS6, but it is also a bit taller, so less effective as material reduction. Otherwise very similar to the other Dart Structures.

Washed also similar to the others, not stretchy and a bit smaller than the normal version.

Comments

Space for additional comments

Dimensions

Regular							
Wale:	120 mm	Course:	25 mm	Ratio:	-	Height:	-
Washed							
Wale:	110 mm	Course:	25 mm	Ratio:	-	Height:	-

Li_2_DS10_M32_1

Library_2_DartStructure10_Merino1/32_1

30-01-2024

Specifications

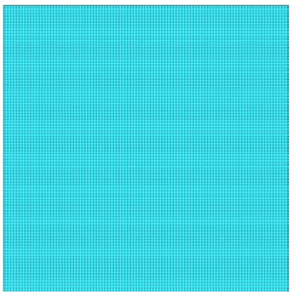
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Structure for dart applications, contains 10 stacks of floats.

Front (in %)		Back (in %)	
Stitches:	8.3	Stitches:	8.3
Tucks:		Tucks:	
Floats	83.4		



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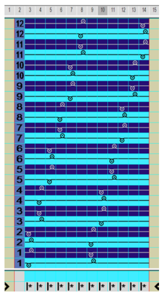


Li_2_DS10_M32_1.mdv

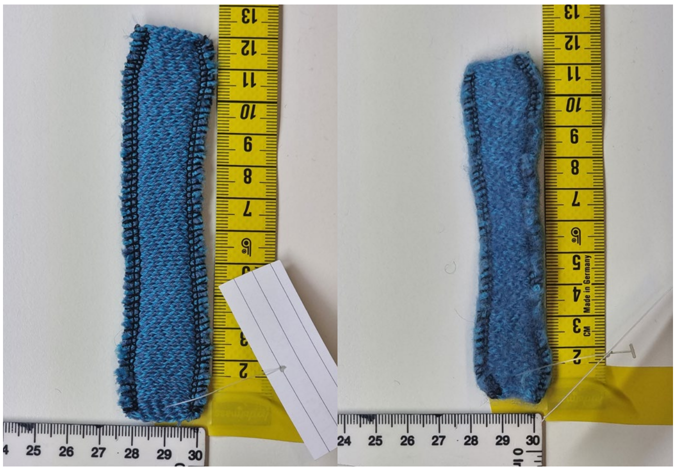
Purpose

Quantifying how many floats can be stacked in a dart structure like the sew-like samples and to figure out how much size is reduced. Stacking 2 stitches allows for a stack of 10 float with an even repeat.

Expectation

I expect the course length (height) to be 1/6 of the interlock (baseline) structure, since for every 12 rows, there will be two knitted rows even though 10 rows are pinched with floats. The wale length (width) will be similar. It will also be a bit thicker.

Result



Observations

In size very similar to DS6, perhaps a little bit thicker and very moldable vertically. Stability is hard to determine because the sample is small.

Washing has the same effect as on the other Dart Structure samples.

Comments

Space for additional comments

Dimensions

Regular							
Wale:	120 mm	Course:	25 mm	Ratio:	-	Height:	-
Washed							
Wale:	100 mm	Course:	20 mm	Ratio:	-	Height:	-

Li_2_DS12_M32_1

Library_2_DartStructure12_Merino1/32_1

30-01-2024

Specifications

Wale Count (needles): 100
Course Count per yarn (rows): 100
Number of Yarns: 2

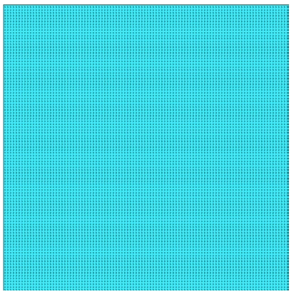
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Structure for dart applications, contains 12 stacks of floats.

	Front (in %)		Back (in %)
Stitches:	7.15	Stitches:	7.15
Tucks:		Tucks:	
Floats	86.7		



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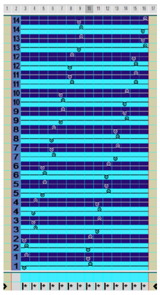


Li_2_DS12_M32_1.mdv

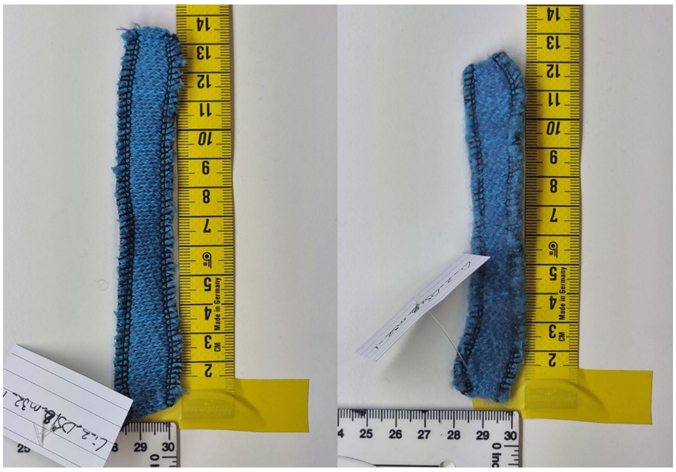
Purpose

Quantifying how many floats can be stacked in a dart structure like the sew-like samples and to figure out how much size is reduced. Stacking 2 stitches allows for a stack of 12 float with an even repeat.

Expectation

I expect the course length (height) to be 1/7 of the interlock (baseline) structure, since for every 14 rows, there will be two knitted rows even though 12 rows are pinched with floats. The wale length (width) will be similar. It will also be a bit thicker. It will be the shortest and thickest.

Result



Observations

Structure with the shortest Course Length. Is a bit thick, but not a lot thicker than the other samples. Also moldable vertically and not very stretchy horizontally.

After washing no stretch or moldabilty, hard to lay down flat. Probably because it is so think.

Comments

Space for additional comments

Dimensions

	Wale:	Course:	Ratio:	Height:
Regular	130 mm	20 mm	-	-
Washed	115 mm	15 mm	-	-

Li_2_FL1_M32_1

Library_2_Floater1_Merino1/32_1

01-02-2024

Specifications

Wale Count (needles): 100
Course Count per yarn (rows): 100
Number of Yarns: 2

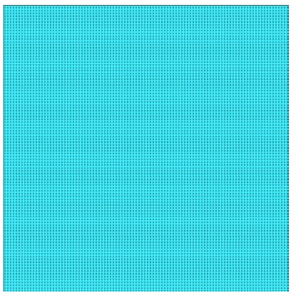
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Structure for shrink manipulation. Inserting long floats with shorter floats.

	Front (in %)		Back (in %)
Stitches:	25	Stitches:	25
Tucks:		Tucks:	
Floats	50		



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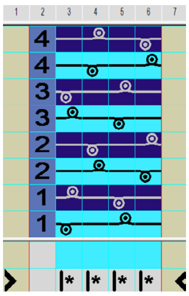


Li_2_FL1_M32_1.mdv

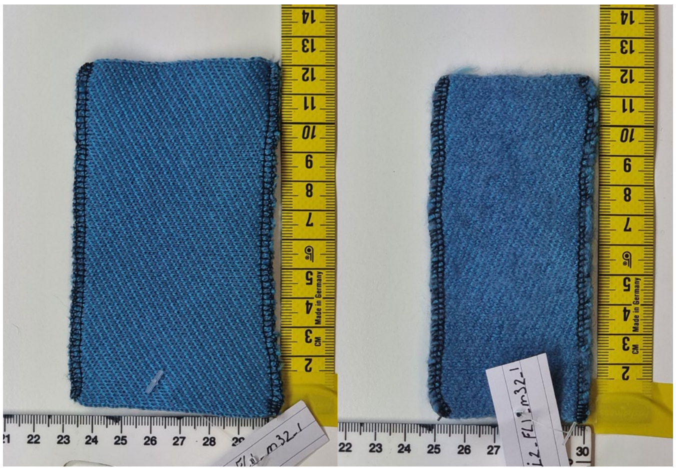
Purpose

To quantify how much effect different floatlength have on the felting/shrinking behaviour of a knit structure. The ratio and stackheight of floats and stitches is kept identical.

Expectation

All floater samples should have the same dimensions after knitting and change relatively after washing. I expect this sample to shrink very similar to previous samples, since there are no large changes to the float length.

Result



Observations

Stable and stretchy structure with uniform pattern. Similar dimensions to DJ25, which has the same amount of floats and stitches. No ribbed texture.

Washing influences the height more than the width.

Comments

Space for additional comments

Dimensions

	Wale:	Course:	Ratio:	Height:
Regular	120 mm	65 mm	-	-
Washed	120 mm	55 mm	-	-

Li_2_FL3_M32_1

Library_2_Floater3_Merino1/32_1

01-02-2024

Specifications

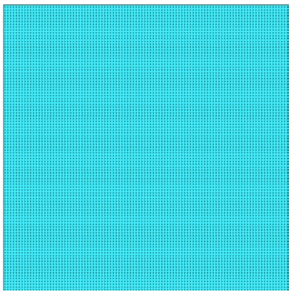
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): Merino wool 1/32 Nm

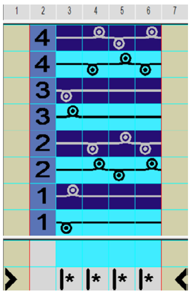
Structure

Structure for shrink manipulation. Inserting long floats with shorter floats.

Front (in %)		Back (in %)	
Stitches:	25	Stitches:	25
Tucks:		Tucks:	
Floats	50		



-



Li_2_FL3_M32_1.mdv

Purpose

To quantify how much effect different floatlength have on the felting/shrinking behaviour of a knit structure. The ratio and stackheight of floats and stitches is kept identical.

Expectation

All floater samples should have the same dimensions after knitting and change relatively after washing. This sample should shrink more than the Floater 1 structure, but less than the other longer float structures.

Result

Observations

There is a slight rib texture every fourth stitch, and a bit wider than Floater 1. A little less stretchy and still stable.

Washing shrinks the width more and also the final dimensions are similar to Floater 1.

Comments

Space for additional comments

Dimensions

Regular

Wale:	125 mm	Course:	70 mm	Ratio:	-	Height:	-

Washed

Wale:	110 mm	Course:	60 mm	Ratio:	-	Height:	-

Li_2_FL5_M32_1

Library_2_Floater5_Merino1/32_1

01-02-2024

Specifications

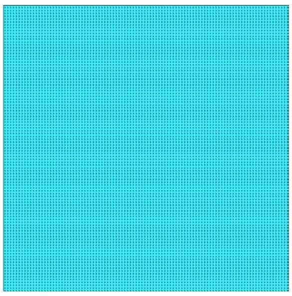
Wale Count (needles):	100
Course Count per yarn (rows):	100
Number of Yarns:	2
Stitch Length Front Bed:	10.5
Stitch Length Back Bed:	10.5

Yarn Material(s): Merino wool 1/32 Nm

Structure

Structure for shrink manipulation. Inserting long floats with shorter floats.

Front (in %)		Back (in %)	
Stitches:	25	Stitches:	25
Tucks:		Tucks:	
Floats	50		



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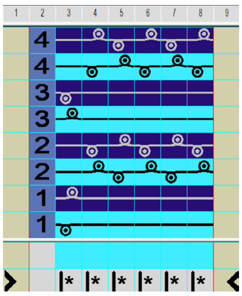


Li_2_FL5_M32_1.mdv

Purpose

To quantify how much effect different floatlength have on the felting/shrinking behaviour of a knit structure. The ratio and stackheight of floats and stitches is kept identical.

Expectation

All floater samples should have the same dimensions after knitting and change relatively after washing. This sample should shrink more than Floater 1 and 3 structure, but less than Floater 7.

Result

Observations

More ribbing than with Floater 3, also a bit wider and less stretchy.

Washed it becomes the same size as the other two Floater structures.

Comments

Space for additional comments

Dimensions

Regular

Wale:	135 mm	Course:	70 mm	Ratio:	-	Height:	-

Washed

Wale:	110 mm	Course:	60 mm	Ratio:	-	Height:	-

Li_2_FL7_M32_1

Library_2_Floater7_Merino1/32_1

01-02-2024

Specifications

Wale Count (needles): 100
Course Count per yarn (rows): 100
Number of Yarns: 2

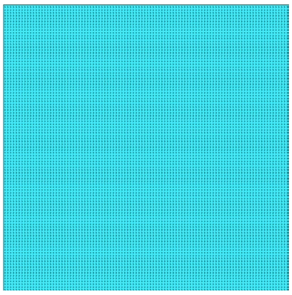
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

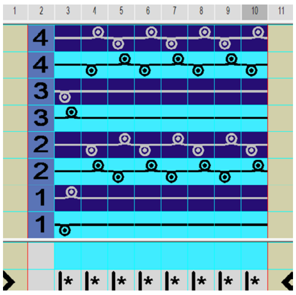
Structure

Structure for shrink manipulation. Inserting long floats with shorter floats.

Front (in %)		Back (in %)	
Stitches:	25	Stitches:	25
Tucks:		Tucks:	
Floats	50		



-



Li_2_FL7_M32_1.mdv

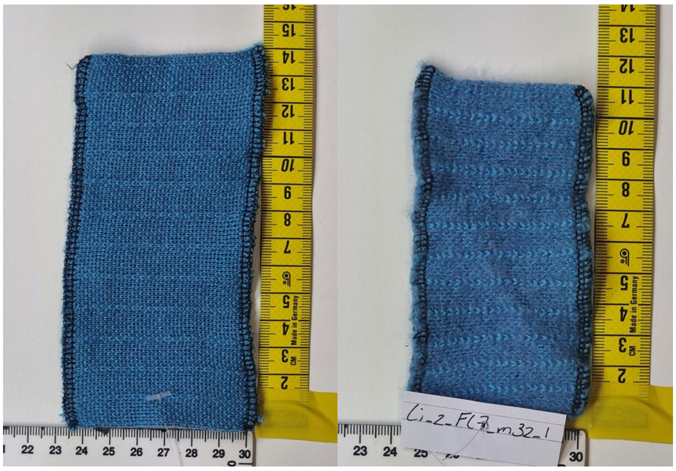
Purpose

To quantify how much effect different floatlength have on the felting/shrinking behaviour of a knit structure. The ratio and stackheight of floats and stitches is kept identical.

Expectation

All floater samples should have the same dimensions after knitting and change relatively after washing. This sample should shrink more than the other Floater structures.

Result



Observations

Also ribbed, but more spread apart, which makes sense. Less stretchy again and wider that the others.

Washed again has the same dimensions as the other structures. Thus the longer floats shrinks more relative to its original size but not more than other structures.

Comments

Space for additional comments

Dimensions

	Wale:		Course:		Ratio:		Height:
Regular							
Wale:	140 mm	Course:	70 mm	Ratio:	-	Height:	-
Washed							
Wale:	110 mm	Course:	60mm	Ratio:	-	Height:	-

Li_2_Sphere_M32_1

Library_2_Sphere_Merino1/32_1

01-02-2024

Specifications

Wale Count (needles): 100
Course Count per yarn (rows): 232
Number of Yarns: 2

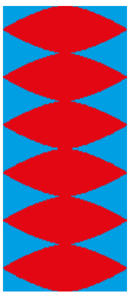
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

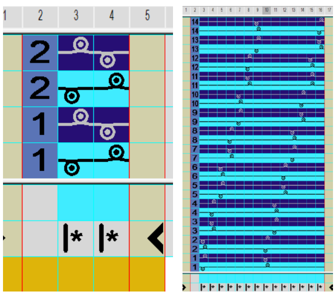
Structure

A combination of Floater 12 and Interlock structures.

Front (in %)		Back (in %)	
Stitches:	-	Stitches:	-
Tucks:		Tucks:	
Floats			



Sphere-Pattern.tiff



Li_2_Sphere_M32_1.mdv

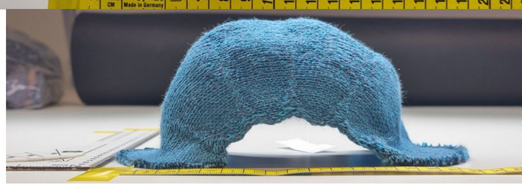
Purpose

The first research paper by the ITA group made a semi-sphere. The goal is to recreate it with quantified structures.
Simonis, K., Gloy, Y., & Gries, T. (2017). 3D knitting using large circular knitting machines. IOP Conference Series: Materials Science and Engineering, 254(9), 092004.

Expectation

I expect the sphere to hold a decent curve, but since the Floater 12 structure does not completely eliminate unwanted areas it will not be a perfect sphere.

Result



Observations

Very shaped result, not close to a sphere but with more elements it would be closable. Lesser versions of this idea can function well in the elbows and shoulders as well as a hood. Basically around all ball-shaped geometries.

Washed the dart structures become tighter so the shape is even more evident.

Comments

Space for additional comments

Dimensions

Regular							
Wale:	120 mm	Course:	190 mm	Ratio:	-	Height:	65 mm
Washed							
Wale:	105 mm	Course:	150 mm	Ratio:	-	Height:	55 mm

JD_1_IL_M32_1

JacketDanielle_1_Interlock_M32_1

26-02-2024

Specifications

Wale Count (needles): 200
Course Count per yarn (rows): 150
Number of Yarns: 2

Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

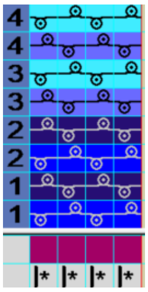
Yarn Material(s): **Merino wool 1/32 Nm**

Structure

Interlock structure with 4 yarns, but programmed as 2.

Front (in %)		Back (in %)	
Stitches:	50	Stitches:	50
Tucks:		Tucks:	
Floats			

Universal-Swatch-for_Jacket-Danielle.tiff



JD_1_Swatch_M32_1

Purpose

As one of the selected structure for the compound structure jacket, this sample verifies earlier measurements for this structure, so that the artwork can be scaled up correctly.

Expectation

I expect that the measurements of this knit structure, corrected for the amount of needles and rows, is identical to the earlier sample Li_1_IL_M32_1.

Result

Observations

Knits will always have some inconsistencies, since its an elastic fabric. However, this samples is only 4 mm off from the original swatch and 5 mm when washed. Compared to the difference between structures, this difference is small and can be explained by the larger scale and thus more accurate measurement.

Comments

Space for additional comments

Dimensions

Regular

Wale:	293 mm	Course:	201 mm	Ratio:	-	Height:	-

Washed

Wale:	248 mm	Course:	141 mm	Ratio:	-	Height:	-

JD_1_DJ33_M32_1

JacketDanielle_1_DoubleJersey0.33_M32_1

26-02-2024

Specifications

Wale Count (needles): 200
Course Count per yarn (rows): 150
Number of Yarns: 2

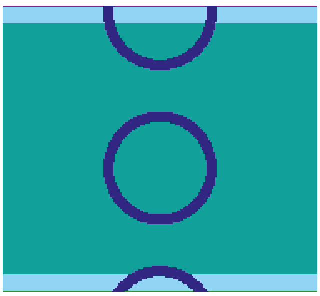
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

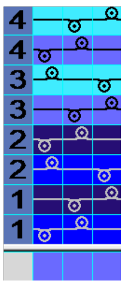
Structure

Interlock structure with 4 yarns, but programmed as 2.

Front (in %)		Back (in %)	
Stitches:	33	Stitches:	33
Tucks:		Tucks:	
Floats	33		



Universal-Swatch-for_Jacket-Danielle.tiff



JD_1_Swatch_M32_1

Purpose

As one of the selected structure for the compound structure jacket, this sample verifies earlier measurements for this structure, so that the artwork can be scaled up correctly.

Expectation

I expect that the measurements of this knit structure, corrected for the amount of needles and rows, is identical to the earlier sample Li_1_DJ33_M32_1.

Result

Observations

Knits will always have some inconsistencies, since its an elastic fabric. However, this samples is only 5-8 mm off from the original swatch and 1-4 mm when washed. Compared to the difference between structures, this difference is small and can be explained by the larger scale and thus more accurate measurement.

Comments

Space for additional comments

Dimensions

Regular

Wale:	250 mm	Course:	140 mm	Ratio:	-	Height:	-

Washed

Wale:	227 mm	Course:	101 mm	Ratio:	-	Height:	-

JD_1_HC_M32_1

JacketDanielle_1_HalfCardigan_M32_1

26-02-2024

Specifications

Wale Count (needles): 200
Course Count per yarn (rows): 150
Number of Yarns: 2

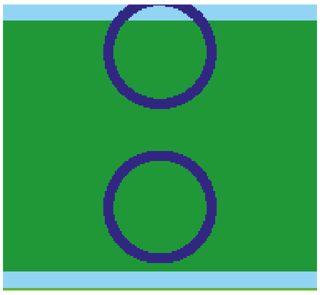
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

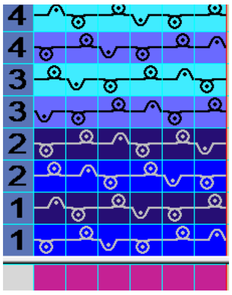
Structure

Interlock structure with 4 yarns, but programmed as 2.

Front (in %)		Back (in %)	
Stitches:	33	Stitches:	33
Tucks:	33	Tucks:	
Floats			



Universal-Swatch-for_Jacket-Danielle.tiff



JD_1_Swatch_M32_1

Purpose

I need something that adds width like the full cardigan, but has the same height as Double Jersey 33, not Double Jersey 25.

Expectation

Since it has the same amount of stitches as Double Jersey 33, I expect the height to be similar and since it has tucks, I expect the width to be more.

Result

Observations

It works, the wale length is increased, similar to a full cardigan, and the course length is identical to that of double jersey 33. This is only valid when felted. Unwashed the half cardigan is slightly shorter.

Comments

Space for additional comments

Dimensions

	Wale:		Course:		Ratio:		Height:	
Regular	Wale:	348 mm	Course:	128 mm	Ratio:	-	Height:	-
Washed	Wale:	298 mm	Course:	102 mm	Ratio:	-	Height:	-

JD_1_DJ25_M32_1

JacketDanielle_1_Interlock_M32_1

26-02-2024

Specifications

Wale Count (needles): 200
Course Count per yarn (rows): 150
Number of Yarns: 2

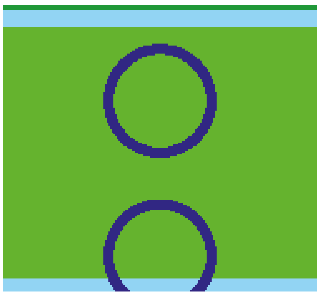
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

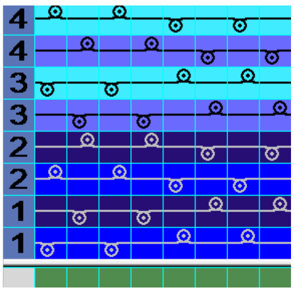
Structure

Interlock structure with 4 yarns, but programmed as 2.

Front (in %)		Back (in %)	
Stitches:	25	Stitches:	25
Tucks:		Tucks:	
Floats	50		



Universal-Swatch-for_Jacket-Danielle.tiff



JD_1_Swatch_M32_1

Purpose

As one of the selected structure for the compound structure jacket, this sample verifies earlier measurements for this structure, so that the artwork can be scaled up correctly.

Expectation

I expect that the measurements of this knit structure, corrected for the amount of needles and rows, is identical to the earlier sample Li_1_DJ25_M32_1.

Result

Observations

Knits will always have some inconsistencies, since its an elastic fabric. However, this samples is only 4 mm off from the original swatch and 5 mm when washed. Compared to the difference between structures, this difference is small and can be explained by the larger scale and thus more accurate measurement.

Comments

Space for additional comments

Dimensions

	Wale:		Course:		Ratio:		Height:	
Regular	Wale:	240 mm	Course:	100 mm	Ratio:	-	Height:	-
Washed	Wale:	200 mm	Course:	74 mm	Ratio:	-	Height:	-

JD_1_DS2_M32_1

JacketDanielle_1_Dartstructure2_M32_1

26-02-2024

Specifications

Wale Count (needles): 200
Course Count per yarn (rows): 150
Number of Yarns: 2

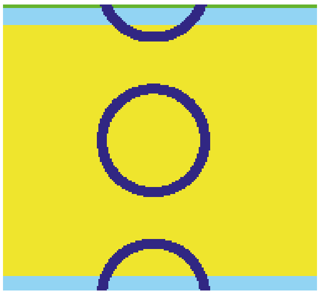
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): Merino wool 1/32 Nm

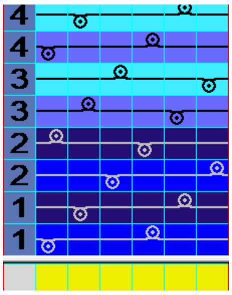
Structure

Interlock structure with 4 yarns, but programmed as 2.

Front (in %)		Back (in %)	
Stitches:	16.7	Stitches:	16.7
Tucks:		Tucks:	
Floats	66		



Universal-Swatch-for_Jacket-Danielle.tiff



JD_1_Swatch_M32_1

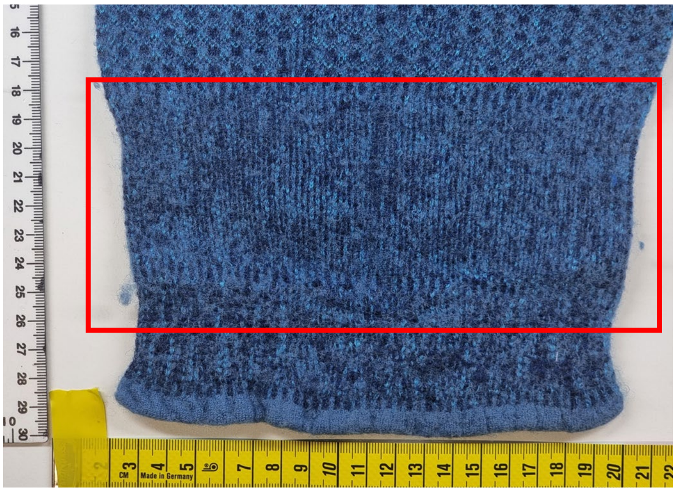
Purpose

As one of the selected structure for the compound structure jacket, this sample verifies earlier measurements for this structure, so that the artwork can be scaled up correctly.

Expectation

I expect that the measurements of this knit structure, corrected for the amount of needles and rows, is identical to the earlier sample Li_1_DS2_M32_1.

Result



Observations

Knits will always have some inconsistencies, since its an elastic fabric. However, this samples is only 3 mm off from the original swatch and 8 mm when washed. Compared to the difference between structures, this difference is small and can be explained by the larger scale and thus more accurate measurement.

Comments

Space for additional comments

Dimensions

	Wale:		Course:		Ratio:	Height:
Regular	Wale:	220 mm	Course:	76 mm	Ratio: -	Height: -
Washed	Wale:	178 mm	Course:	64 mm	Ratio: -	Height: -

JD_1_DS4_M32_1

JacketDanielle_1_Dartstructure4_M32_1

26-02-2024

Specifications

Wale Count (needles): 200
Course Count per yarn (rows): 150
Number of Yarns: 2

Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

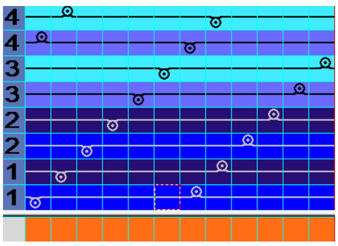
Yarn Material(s): Merino wool 1/32 Nm

Structure

Interlock structure with 4 yarns, but programmed as 2.

Front (in %)		Back (in %)	
Stitches:	8.3	Stitches:	8.3
Tucks:		Tucks:	
Floats	83.3		

Universal-Swatch-for_Jacket-Danielle.tiff



JD_1_Swatch_M32_1

Purpose

As one of the selected structure for the compound structure jacket, this sample verifies earlier measurements for this structure, so that the artwork can be scaled up correctly.

Expectation

I expect that the measurements of this knit structure, corrected for the amount of needles and rows, is identical to the earlier sample Li_1_DS4_M32_1.

Result

Observations

Knits will always have some inconsistencies, since its an elastic fabric. However, this samples is only 3 mm off from the original swatch and 15 mm when washed. Compared to the difference between structures, this difference is small and can be explained by the larger scale and thus more accurate measurement.

Comments

Space for additional comments

Dimensions

	Wale:		Course:		Ratio:	Height:
Regular	Wale:	224 mm	Course:	46 mm	Ratio: -	Height: -
Washed	Wale:	162 mm	Course:	36 mm	Ratio: -	Height: -

SJ_1_SJ_M32_1

SingleJersey_1_SingleJersey_M32_1

19-04-2024

Specifications

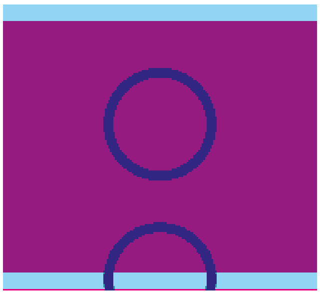
Wale Count (needles): 200
Course Count per yarn (rows): 150
Number of Yarns: 2

Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5
Yarn Material(s): **Merino wool 1/32 Nm**

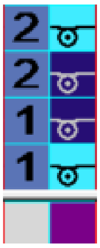
Structure

Single Jersey structure with 2 yarns

Front (in %)		Back (in %)	
Stitches:	100	Stitches:	
Tucks:		Tucks:	
Floats			



Universal-Swatch.tiff



SJ_1_Swatch_M32_1

Purpose

Does knitting on one bed affect the way knit structures behave? To find out, the structures from the universal swatch have been converted to single bed.

Expectation

For single jersey, I expect this one to be the biggest, like the Interlock is in the double bed version.

Result

Observations

Single jersey, similar to the earlier tubular samples (double sides single jersey), knits very tight. The loops are quite small. Also the physical size is not reasonably bigger than the other structures, unlike interlock which does. It is bigger than the others, but not in the way I expected. I believe this is because of the consistent stitchlength and how that interacts with only one bed.

Comments

The circles indicate clearly that the ratio for single jersey is different to double jersey, where the circles were elongated in the other direction.
Note the 90 degrees rotation in the picture. The swatch is knitted in the horizontal direction, thus width and height are switched.

Dimensions

Regular
Wale: **260 mm** Course: **240 mm** Ratio: - Height: -
Washed
Wale: **mm** Course: **mm** Ratio: - Height: -

SJ_1_HC_M32_1

SingleJersey_1_HalfCardigan_M32_1

19-04-2024

Specifications

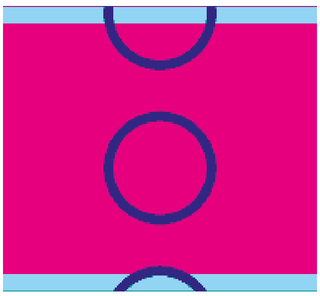
Wale Count (needles): 200
Course Count per yarn (rows): 150
Number of Yarns: 2

Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5
Yarn Material(s): **Merino wool 1/32 Nm**

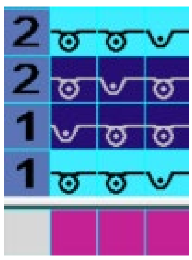
Structure

Single Jersey structure with 2 yarns

Front (in %)		Back (in %)	
Stitches:	66	Stitches:	
Tucks:	33	Tucks:	
Floats			



Universal-Swatch.tiff



SJ_1_Swatch_M32_1

Purpose

Does knitting on one bed affect the way knit structures behave? To find out, the structures from the universal swatch have been converted to single bed.

Expectation

For single half cardigan, I expect this one to be wider and the same height as SJ33, comparable to the double bed versions.

Result

Observations

The single jersey version of the half cardigan behaves like I expected. It is wider than the other structures, whilst it has the same height as the single jersey 33.

Comments

Note the 90 degrees rotation in the picture. The swatch is knitted in the horizontal direction, thus width and height are switched.

Dimensions

Regular
Wale: **mm** Course: **mm** Ratio: - Height: -
Washed
Wale: **mm** Course: **mm** Ratio: - Height: -

SJ_1_SJ33_M32_1

SingleJersey_1_SingleJersey33_M32_1

19-04-2024

Specifications

Wale Count (needles): 200
Course Count per yarn (rows): 150
Number of Yarns: 2

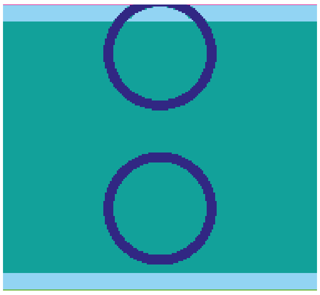
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

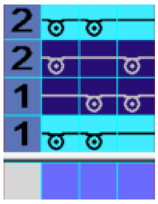
Structure

Single Jersey structure with 2 yarns

Front (in %)		Back (in %)
Stitches:	66	Stitches:
Tucks:		Tucks:
Floats	33	



Universal-Swatch.tiff



SJ_1_Swatch_M32_1

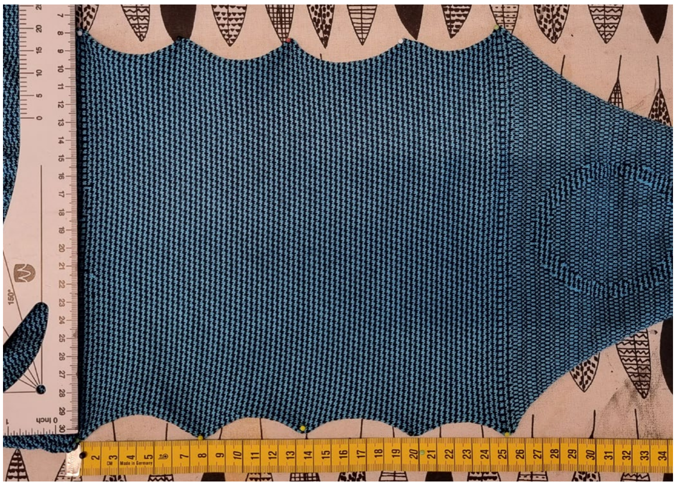
Purpose

Does knitting on one bed affect the way knit structures behave? To find out, the structures from the universal swatch have been converted to single bed.

Expectation

For single jersey 33, I expect this one to be a good base structure and the same height as single half cardigan, comparable to the double bed versions.

Result



Observations

Single Jersey 33 behaves as expected with a height and width that sits nicely in the middle of the other structures, so very good for a base structure. Interestingly, in single bed knitting, the different stitch module for the circles blends perfectly with this structure.

Comments

Note the 90 degrees rotation in the picture. The swatch is knitted in the horizontal direction, thus width and height are switched.

Dimensions

Regular							
Wale:	230 mm	Course:	260 mm	Ratio:	-	Height:	-
Washed							
Wale:	mm	Course:	mm	Ratio:	-	Height:	-

SJ_1_SJ25_M32_1

SingleJersey_1_SingleJersey25_M32_1

19-04-2024

Specifications

Wale Count (needles): 200
Course Count per yarn (rows): 150
Number of Yarns: 2

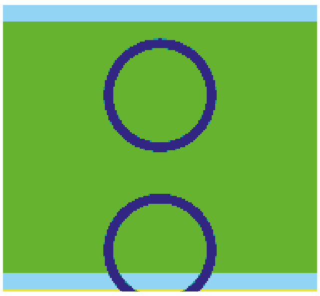
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

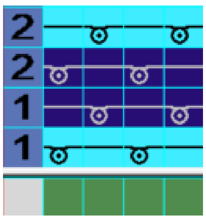
Structure

Single Jersey structure with 2 yarns

Front (in %)		Back (in %)
Stitches:	50	Stitches:
Tucks:		Tucks:
Floats	50	



Universal-Swatch.tiff



SJ_1_Swatch_M32_1

Purpose

Does knitting on one bed affect the way knit structures behave? To find out, the structures from the universal swatch have been converted to single bed.

Expectation

For single jersey 25, I expect this one to be a good base structure, comparable to the double bed versions.

Result

Observations

Compared to Single Jersey 33, it is very similar in widht (wale length) and a bit shorter in height. This was expected, since it has more floats. I believe the smaller differences between structures is in part because of the measuring method. The material is quite unstable and stretchy, so getting consistent measurements without a different setup will be hard.

Comments

Note the 90 degrees rotation in the picture. The swatch is knitted in the horizontal direction, thus width and height are switched.

Dimensions

Regular							
Wale:	225 mm	Course:	210 mm	Ratio:	-	Height:	-
Washed							
Wale:	mm	Course:	mm	Ratio:	-	Height:	-

SJ_1_DS2_M32_1

SingleJersey_1_DartStructure2_M32_1

19-04-2024

Specifications

Wale Count (needles): 200
Course Count per yarn (rows): 150
Number of Yarns: 2

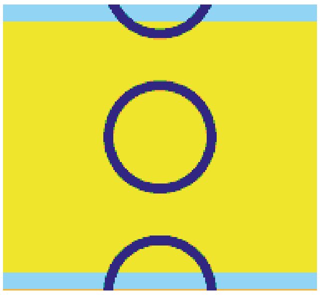
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

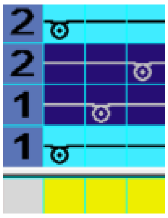
Structure

Single Jersey structure with 2 yarns

	Front (in %)	Back (in %)
Stitches:	33	
Tucks:		
Floats	66	



Universal-Swatch.tiff



SJ_1_Swatch_M32_1

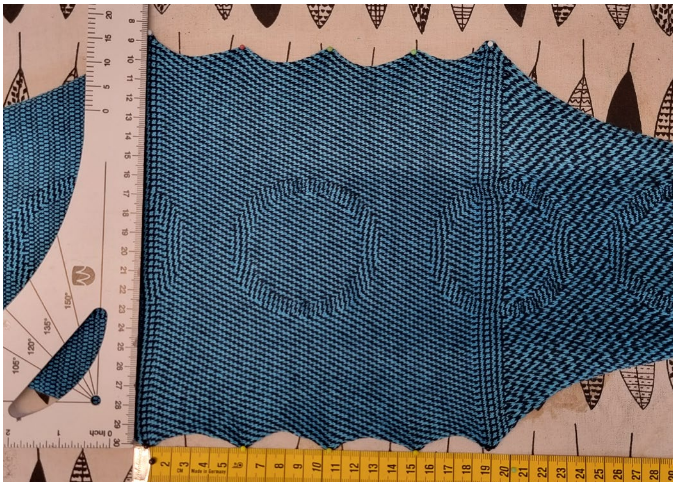
Purpose

Does knitting on one bed affect the way knit structures behave? To find out, the structures from the universal swatch have been converted to single bed.

Expectation

For single dart structure 2, I expect this one to be a smaller structure, comparable to the double bed versions.

Result



Observations

Sitting between SJ25 and DS4, DS2 behaves predictably as a smaller knit structure compared to the base structure.

Comments

Note the 90 degrees rotation in the picture. The swatch is knitted in the horizontal direction, thus width and height are switched.

Dimensions

Regular
Wale: **210 mm** Course: **190 mm** Ratio: - Height: -
Washed
Wale: **mm** Course: **mm** Ratio: - Height: -

SJ_1_DS4_M32_1

SingleJersey_1_DartStructure4_M32_1

19-04-2024

Specifications

Wale Count (needles): 200
Course Count per yarn (rows): 150
Number of Yarns: 2

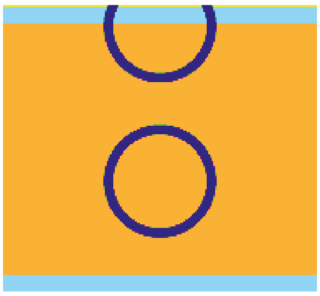
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

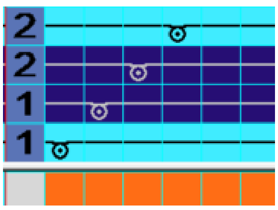
Structure

Single Jersey structure with 2 yarns

	Front (in %)	Back (in %)
Stitches:	16.7	
Tucks:		
Floats	83.3	



Universal-Swatch.tiff



SJ_1_Swatch_M32_1

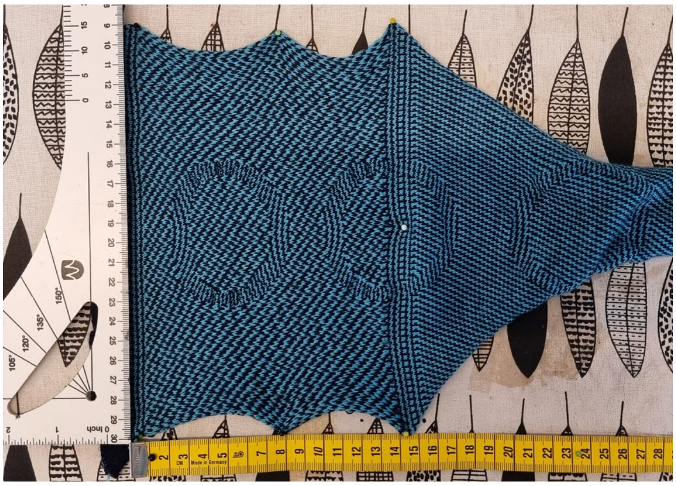
Purpose

Does knitting on one bed affect the way knit structures behave? To find out, the structures from the universal swatch have been converted to single bed.

Expectation

For single dart structure 4, I expect this one to be the smallest structure, comparable to the double bed versions.

Result



Observations

Dart Structure 4 is the smallest structure of the swatch, which was expected. Especially in height is it a lot smaller. However, compared to double bed the difference is smaller by about half. This can be explained by that with double bed, on one bed there are 10% stitches, and on single bed, there are 16.7% stitches. However, single and double bed should not be directly compared.

Comments

Note the 90 degrees rotation in the picture. The swatch is knitted in the horizontal direction, thus width and height are switched.

Dimensions

Regular
Wale: **200 mm** Course: **150 mm** Ratio: - Height: -
Washed
Wale: **mm** Course: **mm** Ratio: - Height: -

GR_1_Baseline_M32_1

Gradient_2_Baseline_Merino1/32_1

19-04-2024

Specifications

Wale Count (needles): **200**
Course Count per yarn (rows): **464**
Number of Yarns: 2

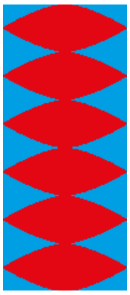
Stitch Length Front Bed: **10.5**
Stitch Length Back Bed: **10.5**

Yarn Material(s): **Merino wool 1/32 Nm**

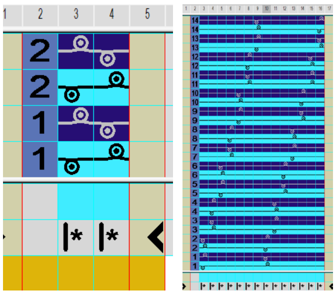
Structure

A combination of DS12 and Interlock structures.

Front (in %)	Back (in %)
Stitches: -	Stitches: -
Tucks:	Tucks:
Floats	



Sphere-Pattern-Baseline.tif



GR_1_Baseline_M32_1.mdv

Purpose

To see how a gradient behaves in its size compared to a pattern with hard edges, I need to establish the shape of a baseline sample. The semisphere has a very noticeable changed geometry, so a scaled up version gives a clear visual impression of the geometric behaviour.

Expectation

I expect the sphere to be an oversized version of a previous sample, Li_2_Sphere_M32_1.

Result

Observations

Very shaped result, very much like the previous sample. Colour is different because of a different shade of blue for the yarn. Folds flat in half as semi-donut, where the outer distance is the height of the interlock structure for the amount of knitted rows and the inner distance is the height of the dart structure. The larger the difference between the two, the more it will approach a circle.

Comments

Would work great for a weird shoulder or hood pattern without the assembly steps usually required for a the darts.

Dimensions

Regular
Wale: -mm Course: - mm Ratio: - Height: - mm
Washed
Wale: - mm Course: -mm Ratio: - Height: - mm

GR_1_Baseline4x_M32_1

Gradient_2_Baseline4x_Merino1/32_1

19-04-2024

Specifications

Wale Count (needles): **200**
Course Count per yarn (rows): **464**
Number of Yarns: 2

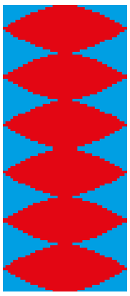
Stitch Length Front Bed: **10.5**
Stitch Length Back Bed: **10.5**

Yarn Material(s): **Merino wool 1/32 Nm**

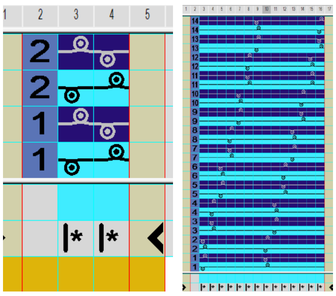
Structure

A combination of DS12 and Interlock structures.

Front (in %)	Back (in %)
Stitches: -	Stitches: -
Tucks:	Tucks:
Floats	



Sphere-Pattern-Baseline4x.tif



GR_1_Baseline4x_M32_1.mdv

Purpose

Compared to the regular baseline, how does a pixelated version behave? Here every pixel represents four needles and four rows. The idea is that this allows each module to better represent itself.

Expectation

I expect the sphere to be an oversized version of a previous sample, Li_2_Sphere_M32_, and that it is very comparable to the normal baseline sphere.

Result

Observations

Looks almost identical to the normal baseline. There is a slight jagger visible where the two structures border each other. In global behaviour there is no observable difference in geometry between this one and the baseline. Just like the normal baseline, the transition between the two structures is sharp and thus creates noticeable texture/ridge in the material.

Comments

Would work great for a weird shoulder or hood pattern without the assembly steps usually required for a the darts.

Dimensions

Regular
Wale: -mm Course: - mm Ratio: - Height: - mm
Washed
Wale: - mm Course: -mm Ratio: - Height: - mm

GR_1_Gradient_M32_1

Gradient_2_Gradient_Merino1/32_1

19-04-2024

Specifications

Wale Count (needles): 200
Course Count per yarn (rows): 464
Number of Yarns: 2

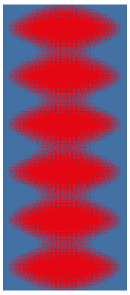
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

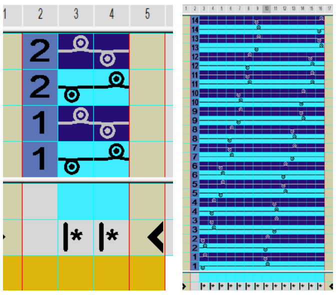
Structure

A combination of DS12 and Interlock structures.

Front (in %)		Back (in %)	
Stitches:	-	Stitches:	-
Tucks:		Tucks:	
Floats			



Sphere-Pattern-Base-Gradient.tif



GR_1_Gradient_M32_1.mdv

Purpose

Compared to the regular baseline, how does a blurred gradient behave geometrically. Does it still create a sphere like object or not at all?

Expectation

I expect the sample to be sphere-like and comparable to the baseline samples. I also expect that I will not be the exact same dimensions, because in the boundary layer, single pixel module will not be able to translate the properties of that structure fully.

Result

Observations

The sample is very comparable to the baseline. However overlaying them, this sample is actually smaller instead of larger. This makes sense because every single-pixel structure is either 100% stitch or 100% float and not somewhere in between, like what the baseline can demonstrate. This can however not be simulated before hand. That would require stitch-level computing.

Comments

The resulting graphic from this structure map looks really interesting and is a great example of form follows function. Also the texture of the knit is a lot smoother, so the gradient smooths out the border between structures.

Dimensions

	Wale:		Course:		Ratio:		Height:	
Regular	Wale:	-mm	Course:	- mm	Ratio:	-	Height:	- mm
Washed	Wale:	- mm	Course:	-mm	Ratio:	-	Height:	- mm

GR_1_Gradient4x_M32_1

Gradient_2_Gradient4x_Merino1/32_1

19-04-2024

Specifications

Wale Count (needles): 200
Course Count per yarn (rows): 464
Number of Yarns: 2

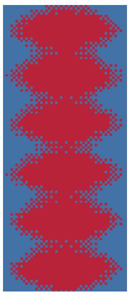
Stitch Length Front Bed: 10.5
Stitch Length Back Bed: 10.5

Yarn Material(s): **Merino wool 1/32 Nm**

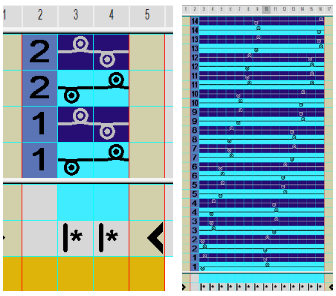
Structure

A combination of DS12 and Interlock structures.

Front (in %)		Back (in %)	
Stitches:	-	Stitches:	-
Tucks:		Tucks:	
Floats			



Sphere-Pattern-Base-Gradient4x.tif



GR_1_Gradient4x_M32_1.mdv

Purpose

Similar to the pixelated baseline, does the behaviour of the knit change if the pixels are larger, thus allowing each module to better represent itself?

Expectation

I expect the sample to be in between the gradient and baseline samples. I expect it will look similar to the gradient sample with a smooth transition between structures.

Result

Observations

The sample looks and feel a lot like the baseline samples, but with a slight glitch patternn. The transition is smoother but the visual distinction is a lot less because the yarn is able to switch between back and front more evenly since the module have more room to represent themselves.

Comments

Dimensions

	Wale:		Course:		Ratio:		Height:	
Regular	Wale:	-mm	Course:	- mm	Ratio:	-	Height:	- mm
Washed	Wale:	- mm	Course:	-mm	Ratio:	-	Height:	- mm

Appendix F Controlled Material Morphing

Introduction

This research experiment aimed to explore the felting of wool as a means of inducing shape change in textiles, drawing inspiration from the innovative approaches described in Chapter 2.3. Arts [4] demonstrated the potential of wool as an active fibre for shape transformation, leveraging felting processes induced by washing to manipulate textile structures. The degree of felting-induced shrinkage is linked to the yarn's freedom within the textile, with fewer bindings in woven samples correlating to greater shrinkage.

Method

Two primary methods for achieving felting-induced shape change in knitted textiles are proposed. The first method draws inspiration from Arts' experiments, wherein longer floats are knitted on one side of the fabric. Upon felting, these floats are expected to tighten, exerting localised tension and inducing shape change in the textile. Similar floats can also be achieved in knitting, although only in the course direction, by floating on multiple adjacent needles. The length of these floats is constrained by the capabilities of the knitting machine, typically limited to approximately 1 inch (Knitwearlab, personal communication, October 2023), or 7 needles for the Stoll CMS 530. The potential influence of floats was tested with four samples, varying the float length from 1 to 7 needles. All other variables are kept identical to the previous experiments.

Each variation was produced four times, one baseline and three were washed to validate the consistency of the felting process. These samples were then quantified like the samples from research 1 (page 55). The second method is felting the previously established structure library (page 56) to explore the form-creation potential of different knit structures. Therefore, duplicates were produced, felted, and quantified to compare the size profiles of the non-felted samples. The shrinkage relative to the knit tightness was tested by comparing the size profiles to the shrinkage of each sample.

The process of felting for this research was simplified to washing the samples at consistent settings, which were proven effective by (ref) and initial tests. These settings are a cotton treatment at 60 degrees, 1400 rpm, with a duration of 2.5 hours and a small addition of normal laundry detergent. The samples were post-processed by air-drying, then ironing them flat, in order to ensure the quality of measurements.

Results

The four float variations are mapped for their unfelted and felted size profile in Figure 85. The measurements for the non-felted samples demonstrate that at a consistent stitch length, larger floats create a greater course length. The felted samples have identical size profiles. The difference in measured wale length can be explained by the measurement accuracy of 5 mm, the same increment as the vertical axis.

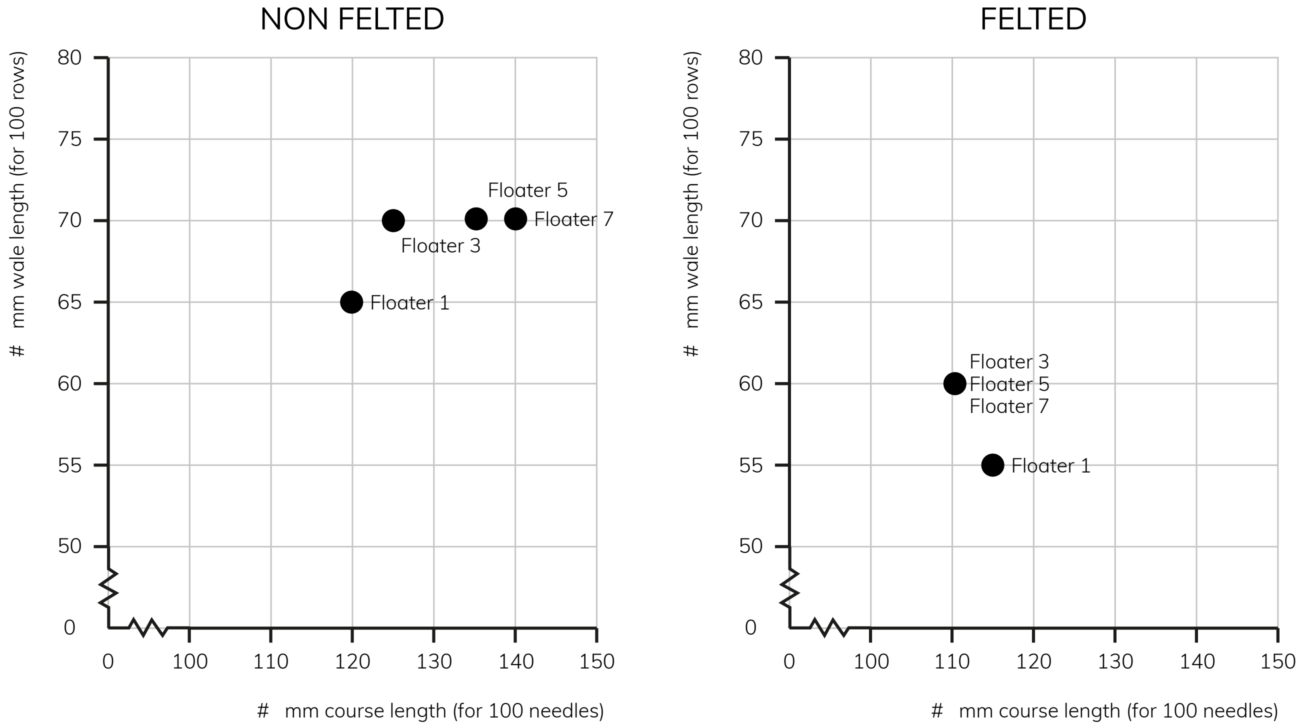


Figure 85, Graph for the size profile of the floater samples unfelted (left) and felted (right).

The size profile for each of the structures from the previous research is mapped in Figure 86. The data showcases the same clustering as the non-felted samples, however the shape of the cluster is shifted. The difference between structures is also less compared to the non-felted structure (Figure 34). Double jersey also falls outside of the cluster, shrinking more than expected in the course direction.

The results presented in Figure 87 and 88 show the relationship between course or wale length of each structure and its relative size compared to the non-felted version, focusing on the course length and wale length respectively. Figure 87specifically highlights that the presence of tucks in the knit structure correlates with increased fabric shrinkage.

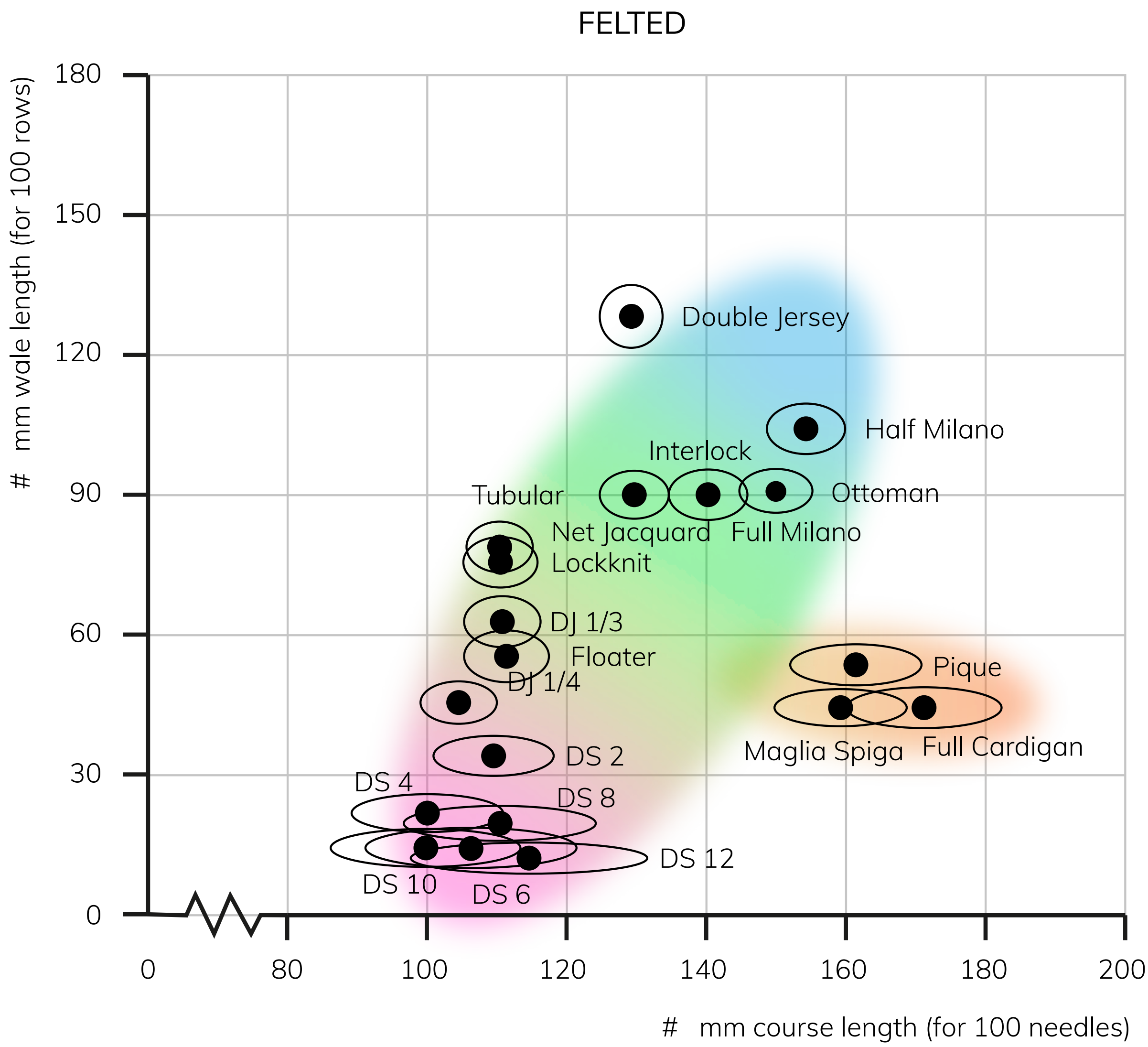


Figure 86, Size graph of 20 tested structures. The percentage of the type of stitch for each sample is illustrated by the coloured areas. Green represents stitches, blue represents double stitches, orange represents tucks, and pink represents floats. Additionally, an ellipse illustrates for each structure what the ratio between its course and wale length. Note, these ellipses only indicate length/width ratio and are not to scale.

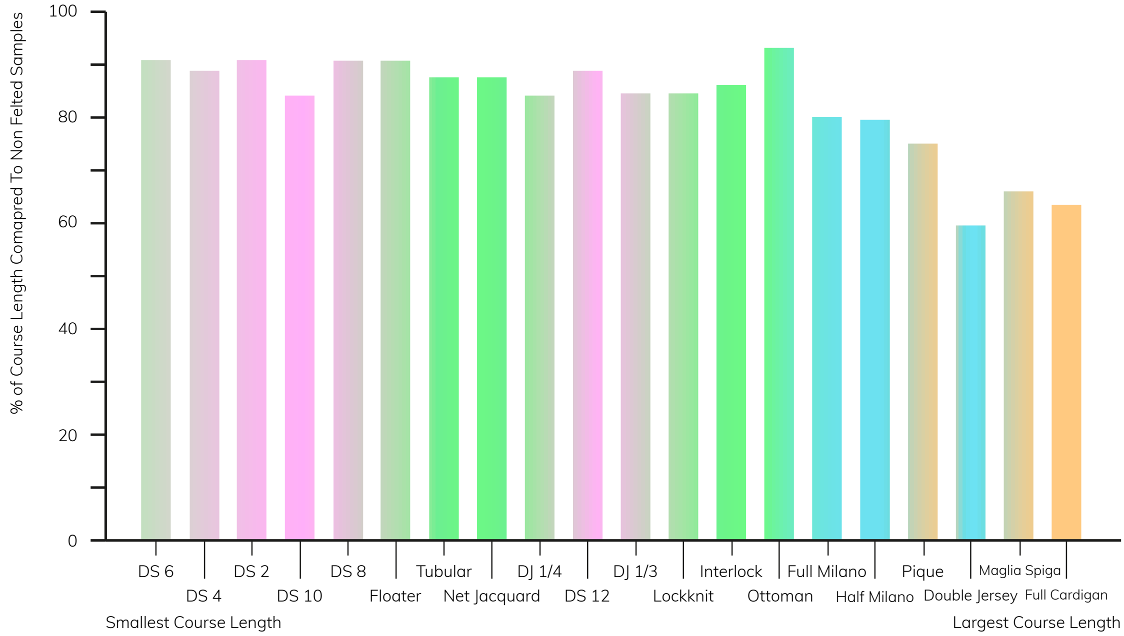


Figure 87, Graph of the shrinkage in course length of each tested structure, arranged from smallest (left) to largest course length (right). The colouration in the figures signifies the ratio of stitch types within each structure, comparable to the representation of clusters in previous visuals.

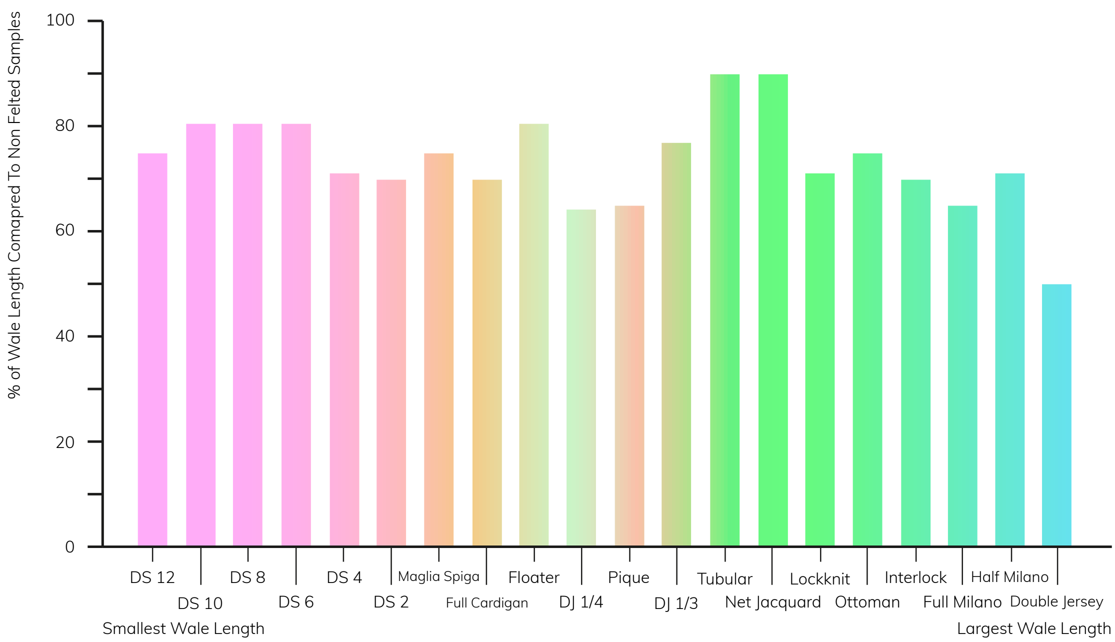
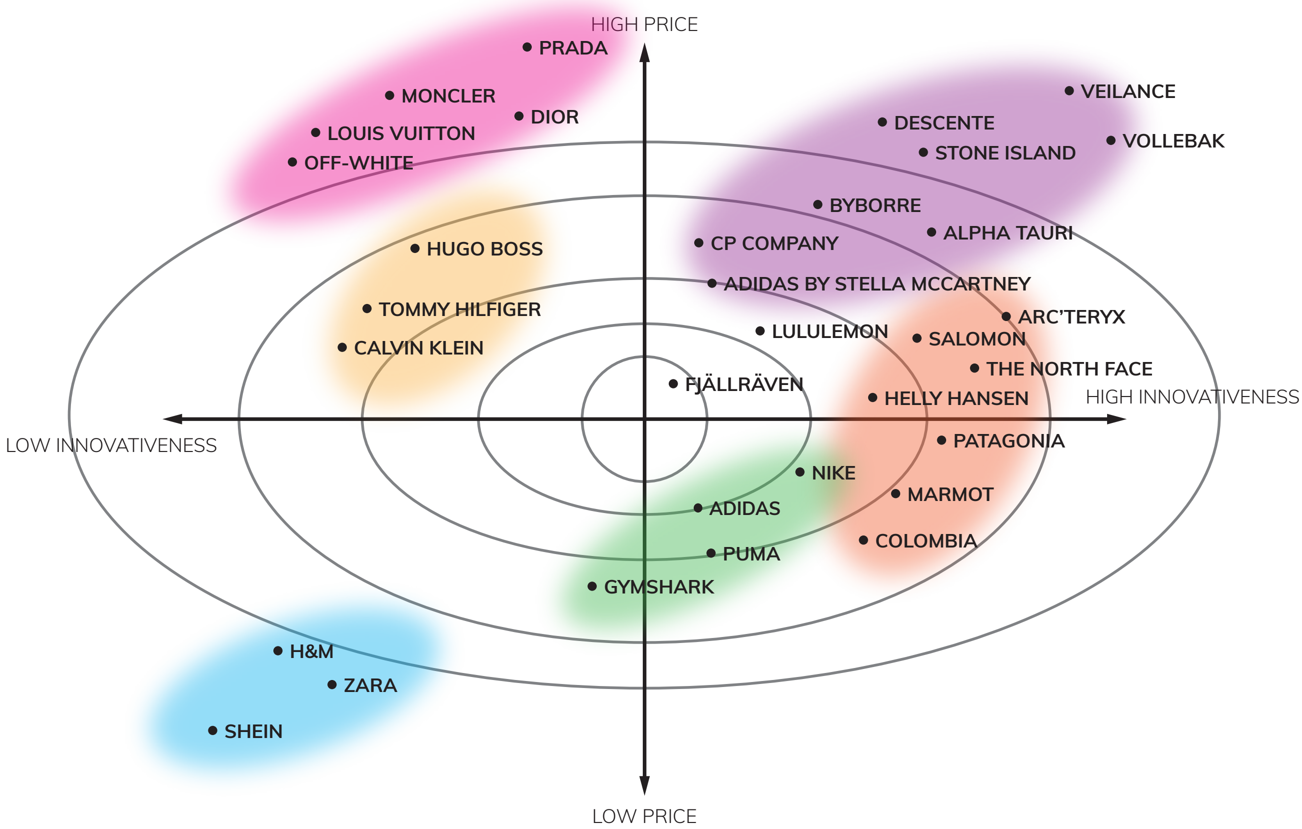
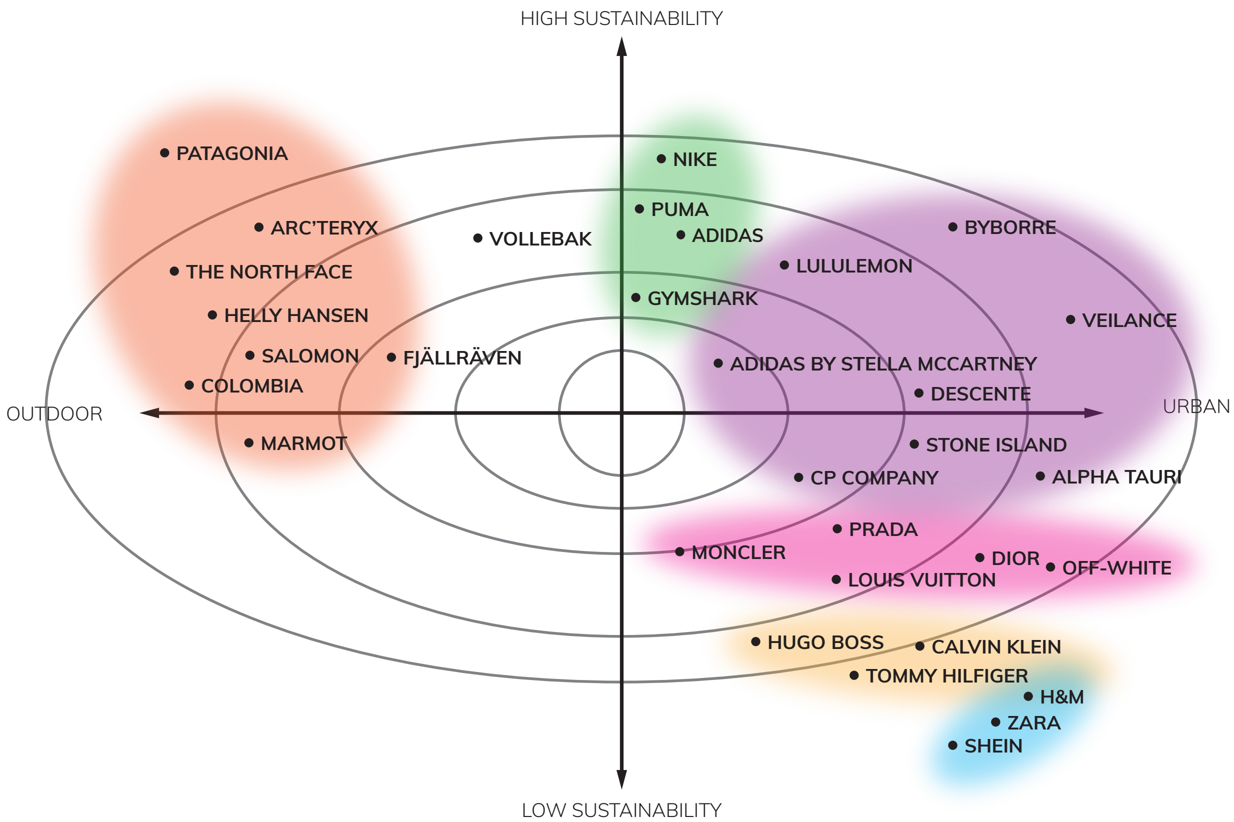


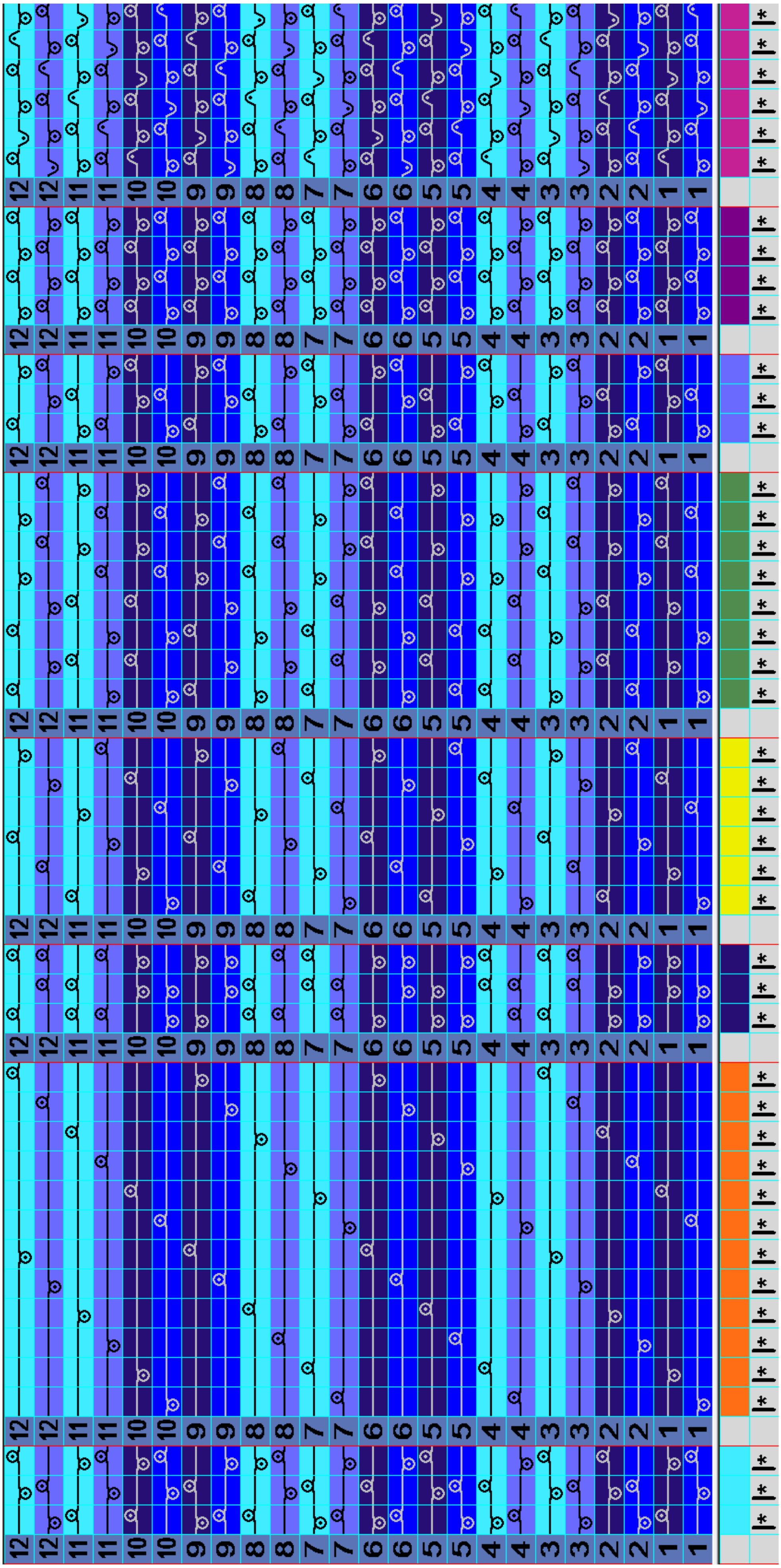
Figure 88, Graph of the shrinkage in wale length of each tested structure, arranged from smallest (left) to largest wale length (right). The colouration in the figures signifies the ratio of stitch types within each structure, comparable to the representation of clusters in previous visuals.

Appendix G Brands Analysis

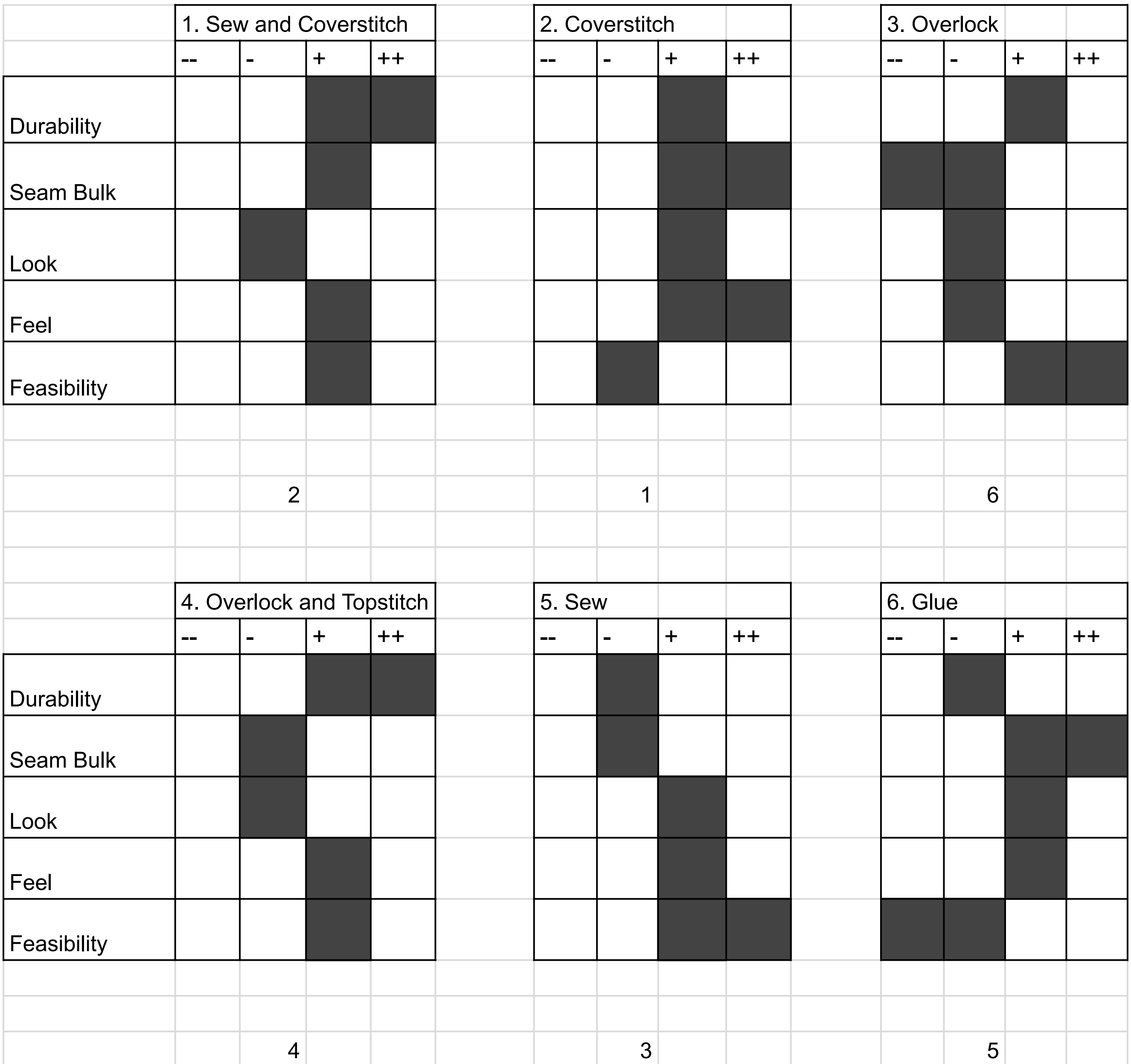




Appendix H Jacket Swatch Colour Module



Appendix I Sewing Evaluation (Harris profile)



Appendix J Phase 2 Interview questions.

Questions:

Part 1

Jackets on hangers, observe visually and tactically

Q1: What are your first impressions of both jackets?

Q2: What differences can you identify between the two jackets?

User tries on baseline jacket

Q3: How does the jacket feel when worn?

Q4: Can you move freely in the jacket?

User tries on compound jacket

Q5: How does the jacket feel when wearing?

Q6: How does this jacket compare to the previous one in terms of comfort and can you point out where the differences are, if any?

Q7: Which jacket do you prefer?

Hang back both jackets

Part 2

Explain the difference between the two jackets

Q8: What differences can you now identify between the two jackets?

Q9: What do you think of these differences?

Q10: Do you prefer a garment with or without any of those local structures visually?

Try on both jackets again

Q11: Which jacket do you prefer now?

Q12: Do you have any other comments?

Appendix K Phase 2 Participant Interviews

	Particpant 1	Participant 2
Age	25	24
Gender (for sizing)	Female	Female
Normal Size	S / 36	S/M
Q1	Teddy feel, heavy, warm, woolly, rigid	They look very comfortable and warm. Styles nicely with a white sweater. I personally prefer a longer style. This feels like a denim jacket type style.
Q2	Collar of Jacket 2 is shorter. Jacket 2 is also stiffer. Jacket 1 feels softer. Jacket 2 has more volume in the arms. Jacket 2 also holds its shape better. Jacket 2 is a darker shade of blue And there is a pattern visible on the shoulders and back of Jacket 2.	Jacket 2 is thicker/stiffer. The colour is also different. The hem of Jacke 1 is thicker. Jacket 2 appears smaller. The shoulders of Jacket 2 have a differnt pattern.
Q3	The jackets appear heavier then they feel. There is a lot of mass under the armpits, especially when moving the arms. More flexible/stretchy than it looks.	It feels heavy. The sleeves have a big opening. Potentially wear it with the buttons closed, but usually open. It is really nice.
Q4	Yes, I can move freely. *waves with armes* The stretch is nice for the arms.	It bends at the elbow and then there's a lot of material and pressure. Arms forward and up works just fine. Just a really thick material.
Q5	Sleeve hems are nice, because they seal well. Sleeves are fuller (neutral observation). Feels like it is more fitted/shaped.	Jacket 2 feels stretchier. Wrists are also tighter. Although the seams rub a little. Collar is comfortable. I have a lot of room at the waist. Sleeves conform better when bending. Jacket is noticable at the shoulders. Rigid is actually quite nice.
Q6	Stiffer then Jacket 1, but not restricting. Sleeve hems seal better. Collar is tighter, which is a good thing.	They both fit well. A bit rigid, but I get used to it quickly.
Q7	Jacket 2, because of the sleeves.	Jacket 2, because the sleeves wear better. Except for the finishing.
Q8	The elbows also have a visible structure in Jacket 2.	*Identifies extra space on the back and shoulders*.
Q9		It doesn't draw attention, but when you know it's there, you do notice it.
Q10		The colour of Jacket 1 is nicer. Even texture is also preferred.
Q11		Jacket 2 still has the preference.
Q12		The coats are nice and they feel great.
Picture Consent	Yes, with blurred face	

Jacket 1 is the baseline jacket, Jacket 2 is the adjusted jacket.

Participant 3	Participant 4	Participant 5
24	24	24
Female	Female	Female
M/L	M/L (Tall)	34/36 S
It is sturdy. Makes me think of a very warm jacket for outside. A little stretchy.	They're a bit stiff. Look very warm. Look likes a summer jacket, but feels like a winter jacket.	Both are quite robust. Really nice to wear if it is not raining. They look good. Very heavy, but that makes them feel high quality.
Jacket 2 feels heavier, but I don't think it is. Jacket 2 is also a bit stiffer. The colour is different. Jacket 1 has thicker sleeve hems.	Colour of Jacket 2 is nicer. Not a huge fan of the stripes. The sleeves look different.	The sleeve is different. The hem of the sleeve of Jacket 1 is more official/traditional. The colour is obviously different.
I like it. It feels nice and the style is nice. It is also quite supple and fresh. Although it pinches a bit at my shoulderblades.	Sleeves are a bit short. Length and width ratio also is a bit off. Denim jacket vibes. I would have to get used to it. It is very heavy.	It is very bulky. A lot of material, especially at the shoulders. Nicely warming. Nice that the pockets are diagonal. Arms feel very wide.
Movement is good, although a bit tight when I raise my arms. Loose sleeves. Tight at the shoulders.	Enough room for movement, because it is not closed.	Arms move fine when the jacket is open. And also if it is closed. The material feels rigid, but doesn't interfere with movement.
It's fine, just like a normal jacket. I don't notice anything unusual. Weight is also fine when I'm wearing it.	Sleeves are again a bit short. This feels more elastic. The rest is quite similar.	Feels comparable. If I hug myself, there is a lot of material at the elbows.
This jacket is a bit more fitted at the waist. It fits better at the shoulders. Pinching in the back is also gone. The elbows are still tight, but the sleeves fit better and are more shaped, which I like.	Colour is different, but in terms of comfort they are very similar.	This jacket feels like I'm living in it. It is very formed and stays in its shape instead of follwoing the body. Feels high quality.
Jacket 2, because the sleeves, shoulders, and back fit better.	Jacket 1, because it feels bigger. (Both are too small)	Jacket 2, because of the colour. But Jacket 1 fits better.
The sleeves of Jacket 1 don't really fit with my arms. With Jacket 2, they felt more integrated.		Now I notice that the sleeve has some curvature. Jacket 1 also looks flatter, while Jacket 2 keeps its shape more
Visually, there aren't a lot of differences. Except for the colour I still don't see big differences, but it feels different when I wear them.	Now that I know, Jacket 2 has more shape. You can feel the difference in the shoulders. I don't fit the jacket very well so I'm not sure how well I can feel the difference. Jacket 1 looks more for men, whilst Jacket 2 looks for women because it is more tailored. I would get annoyed that the material texture is not regular throughout.	If the structures are a feature like when it is tailored, it would be cool. But for a normal jacket, a plain fabric is better. A stripe pattern or something would be harder to wear with other clothing items.
I would like the visibility of the different structures, if they had a big constract. If the differences are smaller I wouldn't like it as much. If everything is stripes, that would be fun.	Preference for no visible structures.	*Waves sleeves of Jacket 1* It's nice that the sleeves are big so I can fit my hands in there. It does feel too big and I feel like a dwarf. Jacket 2 seals better at the sleeves. But I prefer the looser fit. Jacket 1 feels more cosy. Jacket 2 feels more stylish and tailored.
Still Jacket 2, because it fits nicer.	Still Jacket 1, because they both don't fit and Jacket 1 feels bigger. (Jacket 1 is 4% bigger)	For fit still Jacket 1. Jacket 2 feels like it fits really well on someone else and that I am wearing someone else's jacket. There is definitely a differnce in shape. Jacket 2 also feels more thoughtful.
They look really nice, well done. The elbows could be even more bended into shape. And by shifting the shape you might create inpinchments elsewhere.	This would be a nice investment type garment, however I don't know what my style would be in 20 years. So it should be a timeless style.	

Appendix L Gradient Experiment

Introduction

This chapter delves into the experimentation and significance of implementing a gradient artwork to blend knit structures together. Addressing the feedback from user testing in Chapter 5.2, this method offers the potential to enhance visual storytelling in garments while addressing textural inconsistencies observed in previous designs. Moreover, it presents an opportunity to ease the yarn tension during the knitting process, particularly when dealing with large discrepancies in size profiles of adjacent knit structures.

However, implementing gradients raises questions regarding the predictability of physical size and their ability to be simulated digitally. The simulation method for structure mapping, as applied in Chapter 5.2, is not feasible for individual stitches, and therefore cannot be used to predict the shape and size of the material. Knit structures are composed of modules that necessitate a specific pixel size for accurate representation. When the pixel count falls below this threshold, only a portion of the module can be manifested. Thus, this research aimed to investigate the following three assumptions:

1. An artwork gradient produces a smoother tactile and visual transition between knit structures.
2. A gradient will influence the representability of knit structures, therefore changing the knitted results, compared to a colourblocked version.
3. The resolution of the artwork influences the representability of a knit structure, with a lower resolution allowing more room for accurate representation.

Method

To assess these assumptions, four samples were created, all derived from experiment Sphere_1 (page 64) and enlarged twofold. Two samples maintained the traditional colour-blocked structure mapping approach at resolutions of 1:1 and 1:4, where each pixel represents a square of 16 stitches for the 1:4 resolution. Conversely, the remaining two samples utilised gradient artwork generated with Gaussian blur overlays, which fades the blocks equally from the edge, also at 1:1 and 1:4 resolutions. The rest of the variables were identical to the experiments in Chapter 5.2, with interlock and DS8 as the chosen structures. Appendix E shows the artwork and structure module for each sample.

Results

The results of the baseline samples aligned with expectations, appearing as enlarged versions of Sphere_1, both maintaining identical sizes (Figure 89). The difference in size profile between the interlock and DS8 is evident in the inner and outer lengths, given the DS8's significantly shorter wale length, approximately 5.2 times less.

Observing the gradient samples, the 1:4 version closely resembled the baseline 1:4, matching in size. However, the transition between structures exhibited a smoother feel and visually blended the structures more seamlessly. Conversely, the 1:1 gradient sample displayed a distinct appearance compared to the other samples, manifesting a bright or dark hue dependent on the side at structure transitions and offering a consistently smooth texture. This sample appeared smaller than the others, as depicted in Figure 90, overlaid on the 1:1 baseline sample.

Figure 89, Baseline 1:4 (left) and 1:1 (right) sphere-like samples.

Figure 90, Gradient 1:4 (left) and 1:1 (right) sphere-like samples.

Discussion

Beginning with the initial assumption, the incorporation of a gradient artwork into the structure mapping technique does indeed result in a smoother tactile transition. However, the visual transition is notably influenced by the resolution of the gradient, with the 1:1 gradient unexpectedly producing a comparatively high-contrast pattern.

Moreover, the gradient does impact the size when compared to a strict colour-block. In this instance, the sample decreased in size as it was unable to knit the complete DS8 module in transitional areas, given the module's 8x8 stitch dimension. This issue could potentially be resolved by adjusting the resolution, as demonstrated by the 1:4 gradient producing results very similar to the baseline samples. Alternatively, enhancing the predictability of the sample could be achieved by maintaining solid vertical and horizontal colours in the gradient, allowing the main dimensions to be determined by a singular structure.

Additionally, it's worth noting that all samples fold perfectly flat into a circular shape, deviating from the original rectangular artwork. This characteristic may find applications in joint areas on garments, like the shoulder or elbow, facilitating articulation, or in other soft goods categories such as furniture.

Appendix M Phase 3 Interview Questions.

Questions:

Part 1

Jacket on hanger, observe visually and tactically

Q1: What are your first impressions of the jacket?

User tries on jacket

Q2: How does the jacket feel when worn?

Q3: Can you move freely in the jacket?

Hang back jacket

Part 2

Explain the technology behind the jacket

Q4: Can you identify areas that have integrated shaping?

Q5: What do you think of these areas?

Q6: Do you prefer a garment with or without any of those local structures visually?

Try on jacket again

Q7: Any final thoughts on the jacket?

Q8: Do you have any other comments?

Appendix N Phase 3 Participant Interviews

	Particpant 1	Participant 2
Age	24	25
Gender (for sizing)	Male	Male
Normal Size	L	L/XL
Q1	Feels like a blanket, heavy, warm, woolly, rigid.	It appears very comfortable and warm. Styles nicely with a shirt or suit. I like the length, although for smaller people it might be a bit long.
Q2	It is very bulky. A lot of material, especially at the shoulders. Nicely warming. Nice that the pockets are very big. Arms feel very wide, but not restrictive because it is stretchy.	I like it. It feels soft and the style is good It is also quite supple and fresh. Although it pinches a bit in the neck.
Q3	Movement is good, although a bit tight when I raise my arms. Pockets are a bit hard to reach, but once in it works.	*waves with armes* Not as tight as I expected. Sleeves are a bit short and the collar is far back, but feels comfortable.
Q4	Yes, the shoulders have a thicker texture. Sleeves also, mostly at the shoulder.	Jacket look uniform. Shoulders are a bit rougher.
Q5	The collar is cool, with the cut edge visible. . The shoulders are interessting. And I did not notice until you told me, so I think it is fine.	They're interesting, but I would not want it on my jacket. I do like the colour it creates.
Q6	I like prints and graphics on my clothes, so this would blend right in. Maybe even larger colour differences could be nice.	Even texture is preferred.
Q7	Sleeve hems are nice, because they seal well. Sleeves are quite full. Feels like it is more fitted/shaped, but looks a little weird on others.	It's just a normal jacket, just very heavy. I don't notice anything unusual. Weight is also fine when I'm wearing it.
Q8	The coat is nice and it feels great.	It looks great, good job! I guess the shoulder could use some work. I like how the edges are visible.

Participant 3	Participant 4
26	25
Male	Male
M/L	L
It is sturdy. Makes me think of a very warm jacket for outside. A little stretchy. Also quite chic.	It's a bit stiff. Looks very warm. Looks likes a summer jacket because of the colour, but feels like a winter jacket.
Sleeves are a bit short. Length and width ratio also is a bit off. Overcoat vibes, but not as sleek. I would have to get used to it. It is very heavy.	It feels heavy. The sleeves feel like tubes. Potentially wear it with the buttons closed, but usually open. It is really nice.
A bit tight in the back. It bends at the elbow and then there's a lot of material and pressure. Very thick fabric.	The material feels rigid, but doesn't interfere with movement. Arms move fine when the jacket is open. And also closed. Buttons are suprisingly easy to use.
There is a cool pattern on the shoulders and arms. Also feels differently, which is interesting.	I see some things on the collar and shoulders. The rest seems to be normal.
Effect is subtle. The colour is nice and the brown adds nice depth.	I like it. Gives a unique touch to the jacket.
I don't mind the texture, knowing what it does. Can be cool ,but maybe for a different style of jacket. This should be traditional.	Preference for no visible structures.
Thhe seams don't rub as much as expected. Collar is comfortable. I have a lot of room at the waist. Sleeves conform decently bending. Jacket is noticable at the shoulders. Rigid is actually quite nice.	The collar is very thick. Comfy to wear, but not very protective. It looks luxurious. Very heavy, but that adds to the quality.
This would be a nice investment type garment, however with the texture I don't know I still like it in a few years.	The seems are really cool, that it is so flat.

Appendix O Phase 3 Overcoat Colour Module