

/ / JULY 2023

DESIGNING A
SYSTEMS-ORIENTED
STRATEGY TO UNLOCK
THE POTENTIAL OF
3D WOVEN DENIM

MASTER THESIS BY STERRE LIDWINE DE JAGER

KEYWORDS:
SYSTEMS-ORIENTED DESIGN - SYSTEMIC CHANGE -
FASHION SUSTAINABILITY - DENIM - 3D WEAVING - ZERO WASTE



Delft, July 2023

MASTER THESIS

Designing a systems-oriented strategy to unlock the potential of 3D woven denim

AUTHOR

Sterre Lidwine de Jager
MSc Strategic Product Design
Faculty of Industrial Design Engineering
Delft University of Technology

CHAIR

Dr. Holly McQuillan
Department of Sustainable Design Engineering

MENTOR

Dr. Ingrid Mulder
Department of Human Centered Design

DEFINITIONS & ABBREVIATIONS

SYSTEMS-ORIENTED DESIGN

Embraces various methods and tools in system thinking to comprehend the intricacies of a system, supporting designers in addressing and creating solutions for complex problems (Sevaldson, 2009).

3D WEAVING

A niche innovative design-manufacturing technique for garments, in which multi-layered structures are woven with integrated 'seams', allowing for an almost entirely whole garment upon cutting open and unfolding the structure. In normal pattern designs, 10-15% of the newly woven material is excess, sent to incineration or landfill (=pre-consumer waste). 3D weaving enables zero-waste pattern design and a shorter supply chain.

PRE- & POST-CONSUMER WASTE

Pre-consumer waste encompasses waste generated within the value chain before it reaches the consumer. It ranges from fibre loss to excess material, and from chemical wastewater to overstock in warehouses. Post-consumer waste occurs after the consumer has acquired the garment and discards the item, sometimes reaching reuse or recycling, but more often ending up in incineration or landfill.

TRACEABILITY

The ability to trace products, components and materials along each step of the supply chain, all the way back to fibre origin, including the environmental conditions at each step.

TRANSPARENCY

Enabling the accessibility, clarity, and comparability of information (such as product specifications, chemicals, fibre content, production, environmental effects) to all participants in the supply chain, including users.

ABSTRACT

Today's fashion industry is characterised by a continuous cycle of rapid production, early disposal, low-quality materials, and pre- and post-consumer waste, with consequential environmental damage and social injustice. The production of denim involves a resource-intensive and lengthy supply chain, in which a lack of evolution in design over the past 150 years is coupled with significant pre-consumer waste.

This highlights the need to reevaluate the design and manufacturing process. Conventional pattern designs result in a significant portion of newly woven material, sent to incineration and landfill. 3D weaving presents an innovative niche design-manufacturing technique, allowing for the creation of multi-layered structures with interwoven 'seams'. This enables the production of nearly complete garments, while aiming for zero waste and reducing labour-intensive steps at the cut and sew stage.

To unlock the potential of 3D woven denim and demonstrate how such niche techniques can be utilised to achieve systemic change, a Systems-Oriented design approach is adopted. The research project analyses the complex denim supply chain and delves into the meaning of current and 3D woven denim. Field research at a denim mill in Pakistan formed the basis of a general ecosystem map, addressing various layers of the system from the final lens of the Dutch denim market. This includes material flow, fashion brands, consumers, post-disposal stage, government influence, and certifications. Further collaboration with 3D weaving experts, denim mills, designers, and user research supported the multifaceted approach.

The project concludes with a Systems-Oriented strategy to establish a local Dutch eco-label for 3D woven denim, alongside traditional denim: New-Fashioned Denim Dimensions. By involving relevant stakeholders in the denim system, including major brands and suppliers, an initiative structure and implementation roadmap are developed. The roadmap outlines key actions, such as refining zero-waste patterns, developing equipment and training programmes, necessary to establish local, vertical 3D weaving supply chain behind the label. The ultimate aim is to create a cascading effect, inspiring denim brands to further explore future transitions towards local and sustainable models in the broader fashion industry, extending beyond the realm of 3D weaving.



BILD, 1972

ACKNOWLEDGEMENTS

Dear reader,

After 100 days of work, this thesis represents my final efforts toward the completion of my studies, marking an end to this phase of my life. Never would I have imagined the incredible opportunities given to me in these last 5 months, translating my thoughts and aspirations for contributing to the much-needed systemic transformation of fashion, into a gratifying end result. I hope to continue on this endeavour and inspire others to employ similar systemic approaches in this field – joining forces to collaboratively resolve the damage we have done, and ensuring a more hopeful future for generations to come.

To Holly and Ingrid, thank you for your willingness and enthusiasm in helping me approach fashion transformation in the holistic manner I wished to achieve and your guidance during the process.

Diamond Denim, words cannot express my gratitude for the opportunities you have given me to conduct research in Pakistan and weaving new trials to extend my user research. Maurizio, Farhan, Jay, Faisal, Salamat, Shahbaz and so many others, you've been incredibly valuable and I was amazed at how much I was able to learn in a mere week, thanks to your kindness. In your words a 'routine thing', in my experience truly the most special and helpful thing anyone could have done along this quest. And thank you to Urooj, for exploring Lahore and its history with me, and designing a tailor-made denim outfit for my graduation ceremony. Now that will be an item I will cherish and wear for a very long time.

Mohsin, thank you for taking me along with you in London to the Japanese denim stores and Blackhorse Lane Atelier, as well as sharing your thoughts and expertise. Graysha, thank you for making time to answer all of my detailed questions.

Barbara, thank you for all of the hours you have invested in helping me with this project through your beautiful 3D woven denim jackets, as well as your support as a friend.

Participants, I know I asked a lot from you in the mode of user research chosen. Thank you for your time and effort.

To Ingo, thank you for always believing in me and being (quite literally) constantly by my side. I promise I will return the favour in the next semester.

Finally, to my parents, sister and dear friends, your incredible support and the time you've taken in listening to my personal thoughts is appreciated beyond comprehension. You all kept me going.

Enjoy the read,

Sterre

TABLE OF CONTENTS

INTRODUCTION		
C1 // BACKGROUND		01
PROBLEM CONTEXT	1.1	03
FURTHER LITERARY BACKGROUND	1.2	07
FAST FASHION	1.2.1	08
IMPLEMENTING NEW MODELS	1.2.2	10
TAKE-AWAYS		13
C2 // RELATED WORK		15
TOWARDS A CIRCULAR ECONOMY	2.1	17
EMERGING OPPORTUNITIES	2.2	21
NEW DEMANDS	2.2.1	22
ON-DEMAND PRODUCTION	2.2.2	29
THE RELEVANCE OF 3D WEAVING	2.2.3	33
ATTEMPTS AT UNDERSTANDING COMPLEXITY	2.3	41
TAKE-AWAYS		47
C3 // PROBLEM DEFINITION		49
RESEARCH AIM	3.1	51
OVERALL FRAMING	3.1.1	52
RESEARCH QUESTION	3.1.2	54

TABLE OF CONTENTS

55	3.2	STAKEHOLDERS // COLLABORATION PARTNERS
57	3.3	METHODOLOGY
58	3.3.1	METHODOLOGY DESCRIPTION
61	3.3.2	RESEARCH ACTIONS
65		TAKE-AWAYS
		STUDY PRESENT TO PARADIGM SHIFT // C4
67		
69	A	THE PRESENT
71	4.1	MAPPING THE CURRENT DENIM SYSTEM
72	4.1.1	METHODOLOGY
73	4.1.2	ECOSYSTEM MAP // RESULT
75	4.1.3	ZOOMING IN // DISCUSSION
83		TAKE-AWAYS
85	B	TOWARD A PARADIGM SHIFT
87	4.2	UNDERSTANDING THE CONSUMER MINDSET
88	4.2.1	METHODOLOGY
93	4.2.2	USER RESEARCH ROUND 1 // RESULTS
101	4.2.3	USER RESEARCH ROUND 2 // RESULTS
106	4.2.4	USER RESEARCH // DISCUSSION
109		TAKE-AWAYS

TABLE OF CONTENTS

IMPLEMENTING NEW MODELS	4.3	111
METHODOLOGY	4.3.1	112
KEY COMPONENTS // RESULTS	4.3.2	114
INDUSTRY-LED CHANGE // DISCUSSION	4.3.3	115
RELOCALISATION // DISCUSSION	4.3.4	116
REIMAGINING DENIM DESIGN ROLES // DISCUSSION	4.3.5	118
CONSUMER COMMUNICATION // DISCUSSION	4.3.6	120
TAKE-AWAYS		123
GENERAL DISCUSSION // ADOPTION MOTIVATIONS & BARRIERS	4.4	125
MOTIVATIONS	4.4.1	127
BARRIERS	4.4.2	129
GENERAL DISCUSSION // 3D WEAVING-SPECIFIC BARRIERS	4.5	131
TAKE-AWAYS		133
C5 // FINAL DESIGN NEW-FASHIONED DENIM DIMENSIONS		135
NEW MODELS FOR FASHION	5.1	137
IDENTIFYING LEVERAGE POINTS	5.1.1	138
DESIGN DIRECTION	5.1.2	141
CO-CREATION OF A CONCEPT	5.1.3	145

TABLE OF CONTENTS

155	5.2	INTRODUCING A LABEL: NEW-FASHIONED DENIM DIMENSIONS
157	5.2.1	THE INITIATIVE
165	5.2.2	THE LABEL
171	5.2.3	TRAINING PROGRAMME
173	5.2.4	IMPLEMENTATION ROADMAP
175	5.3	CONCEPT EVALUATION RESULTS
176	5.3.1	USER VALIDATION
179	5.3.2	EXPERT VALIDATION MARKETING
180	5.3.3	EXPERT VALIDATION STRATEGY
185	5.3.4	ROADMAP ITERATION // TACTICAL
187	5.4	CONCEPT DISCUSSION
193		TAKE-AWAYS
195		CONCLUSION // C6
197	6.1	CONCLUSION
201	6.2	DISCUSSION
207	6.3	RECOMMENDATIONS FOR FUTURE RESEARCH
211	6.4	REFLECTION
217		REFERENCES
233		APPENDIX

INTRODUCTION

INTRODUCTION

The choice to wear clothes already present in one's closet may possess the greatest degree of sustainability. Yet, in a society driven by consumerism, it is often tempting to be attracted to the affordability of inexpensive clothing, with long-term repercussions on our environment. With brands driving mass produced, trending and seasonal fashion, a constant cycle of fast fashion is perpetuated, where clothing is rapidly produced and disposed of. Most garments, crafted from low-quality material, often petrol-based and designed for short lifespans, lack durability and fail to establish strong emotional attachments. As a result, many are discarded and end up in landfills before reaching their full potential.

In the domain of denim, fashion brands have sought to reduce market risks and enhance profitability by shifting their apparel manufacturing to lower income countries (Martino et al., 2017). This strategic move allows them to optimise costs while turning a blind eye to the resource-intensive, complex and geographically dispersed supply chain involved in denim production, and the accompanying significant social and environmental implications (Egels-Zandén et al., 2015).

In the context of the circular economy, there have been attempts to address concerns in sustainability of denim by implementing measures such as designing for disassembly, incorporating recycled fibre contents and rejecting chemical treatments. However, the fundamental design of denim itself raises a crucial question, as its aesthetic form has remained largely unchanged over the past 150 years. The conventional drawing of patterns inherently generates significant pre-consumer waste, with estimates suggesting 10-15% of fabric is discarded during this design process (Enes & Kipöz, 2019). The cut and sew stage accounts for 15.6% of a garment's overall environmental impact throughout its lifecycle (Wennberg & Östlund, 2019), where this pre-consumer waste is often immediately sent to incineration or landfills (Enes & Kipöz, 2019). The persistence of such practices can be viewed as a design flaw, where the significance of introducing changes from the design stage is reinforced by the fact that approximately 80% of a garment's environmental footprint is solely determined during this stage (Östlund et al., 2020).

This emphasises the need to reassess the design and manufacturing processes associated with this longstanding fashion staple. This can lead to alternative approaches such as zero-waste pattern design, which highlights the potential of 3D weaving. This innovative technique enables the creation of multi-layered structures in a single step. By incorporating woven seams into the structure, cutting open specific layers can generate larger fabric pieces that would typically

require the joining of multiple separate panels. As a result, the garment's function is integrated into its design, reducing the need for machining, minimising material wastage, and streamlining the lay-up process (Perera et al., 2021) (McQuillan, 2020). Furthermore, as on-demand, micro-manufacturing and localised supply chains gain importance, 3D weaving presents an opportunity for an innovative and holistic approach to the aforementioned problems, while also drastically changing the denim's aesthetic form.

The pivotal question lies in effectively showcasing its potential capacity to drive systemic change, from the lens of the Dutch denim market as the ultimate focal point in this case. Thus, this research project employs a Systems-Oriented design approach, in recognition of the interdependencies among complex components of the fashion system.

The research is initiated through analysing the complex denim supply chain, addressing challenges in transparency, traceability and environmental concerns, as well as understanding the meaning of textiles. Field research in Pakistan further provided insight into Diamond Denim by Sapphire's supply chain, forming the basis of an entire ecosystem map. This incorporates additional information on material flow, fashion brands, the consumer stage, post-disposal stage, governmental influence and certifications. Research with a 3D weaving expert, a UK-based denim mill, denim designers and consumers further identified the need for a multi-faceted, collaborative approach to showcase 3D woven denim's potential and enhance supply chain understanding, and which elements are crucial in order for alternative models to be implemented.

The project concludes with a Systems-Oriented strategy toward the establishment of a local eco-label for 3D woven denim, alongside traditional denim. By leveraging the collaborative nature of the denim industry and involving various relevant actors in the Dutch field, as well as major brands catering to the Dutch market and their suppliers, an initiative structure and implementation roadmap were created. The roadmap outlines the steps towards a local, physical 3D weaving supply chain behind the label, including key actions such as the refining of zero-waste patterns, the development of equipment and training programmes, and exploring traceability schemes. The ultimate aim of the New-Fashioned Denim Dimensions label is to create a cascading effect, inspiring denim brands to further explore future transitions towards local and sustainable models in the broader fashion industry, extending beyond the realm of 3D weaving.

BACKGROUND

CHAPTER 1

- 1.1 **PROBLEM CONTEXT**
- 1.2 **FURTHER LITERARY BACKGROUND**
 - 1.2.1 FAST FASHION
 - 1.2.2 IMPLEMENTING NEW MODELS
- TAKE-AWAYS**

This chapter introduces the context of denim in which the project is situated, covering aspects such as materials, production, social and environmental implications, pre-consumer waste, post-consumer waste, consumer behaviour, cultural importance, and form perception (1.1). Additional literary background is provided to further support the research approach, delving into the concept of fast fashion and underscoring the need for urgent implementation of new models in the current, longstanding but ultimately unsustainable denim system (1.2).

1.1.

PROBLEM CONTEXT

This section introduces an overview of the research context, highlighting the inherent challenges associated with current denim production. It briefly addresses various aspects including materials, production and labour conditions, emissions, pre-consumer waste, consumer behaviour in the fast fashion era, and closes off with cultural significance and perceptions of form. Through the identification of these key issues, it becomes clear that the conventional methods of manufacturing denim, which have maintained a consistent aesthetic form for many years, are ultimately unsustainable. However, this recognition of deeply engrained values and interconnected problems also unveils the unique complexity involved in undergoing any transformation in the denim industry specifically.

Over the past 150 years, denim form has remained largely unchanged in terms of aesthetics, however, the methods used to create denim garments have undergone significant transformations. The production of denim currently necessitates a resource-intensive supply chain that is predominantly global and lengthy, involving complex decentralised business processes (Egels-Zandén et al., 2015). This is accompanied with substantial ethical, ecological and social consequences at every stage in a garment's life cycle, referring to its construction, use and disposal (Asmi et al., 2022).

The scope of associated problems is extensive, firstly revealing heavy water reliance in the cultivation of cotton, the most commonly used fibre in denim, and in finishing processes in later stages of the supply chain. As for material choice, the current blending of petrol-based fibre with cotton, leads to further emissions and fossil fuel depletion. Moreover, harmful substances are employed across the complete denim manufacturing process, including fertilisers, pesticides and synthetic indigo dyes, resulting in resource depletion, environmental damage and health hazardous labour conditions. A lack of formal regulation contributes to improper disposal of chemical waste, contaminating irrigation systems and food sources (Choudhury, 2017). Additionally, a significant amount of fabric is wasted during the pattern cutting process, estimated between 10-15%, mostly finding its way to incineration or landfills (Enes & Kipöz, 2019). Considering the aforementioned problems, it is crucial to maximise resource utilisation for functional purposes and minimise excess denim fabric production where possible.

The increasing demand for affordable garments exacerbates the impact of pre-consumer waste in the denim industry, perpetuating a cycle where quantitative practices prioritise quantity over the production of high-quality products (Niinimäki et al., 2020). The rise of the phenomena referred to as 'fast fashion', accompanied by offshore outsourcing practices, encourages frequent product replacement, impulse buying and continuous trend-driven design (Luján-Ornelas et al., 2020). These practices allow fashion brands to overlook ethical concerns, creating a

disconnect between consumers and the environmental impact of their choices (Gereffi & Frederick, 2010). The continuous cycle of acquiring and prematurely discarding clothes diminishes emotional attachment and leads to garments being disposed of in landfills before reaching their full lifespan (Ruiz, 2023). Even recycling attempts at disposal stages often result in a loss of textile value through downcycling. As supply chains expand and processes become increasingly energy- and emission-intensive, it becomes crucial to address the negative consequences of the current fashion system and explore alternative models that prioritise sustainability.

The complexities within the denim industry are deeply intertwined with economic and social factors however, resulting in complex wicked problems within many layers of the system. Clothing generally transcends its utilitarian purpose and is intricately tied to social behaviour (Niinimäki, 2014; McCracken & Roth, 1989). Denim, viewed from both contemporary and historical perspectives, has attained a distinct status in the world of fashion: a symbol of exceptional quality, originality, craftsmanship, cotton fibre and an aesthetic connection to the past (Fischer, 2015). The success of "Dutch Denim" in particular can be attributed to its integration into the specific cultural context of the Netherlands, where shared values and cultural encounters have facilitated its adoption and subsequent prosperity as a clothing category (Smelik & Feitsma, 2016). However, in the light of achieving high production efficiency and speed, this desire for the aged and distressed denim look has led to the emergence of specific adverse practices. These include chemical stone washes, bleaching, hand scraping and sand-blasting, artificially achieving the desired appearance - unknowing to the consumer. The juxtaposition of authentic value and artificial execution highlights the necessity to consider alternative aesthetic expressions of denim that do not perpetuate the negative impacts and wastefulness of the pre-consumer stage.

The existing practices of denim production are fundamentally unsustainable and while the aforementioned issues underscore the need for a paradigm shift, it becomes apparent that achieving this in the case of denim may be challenging.

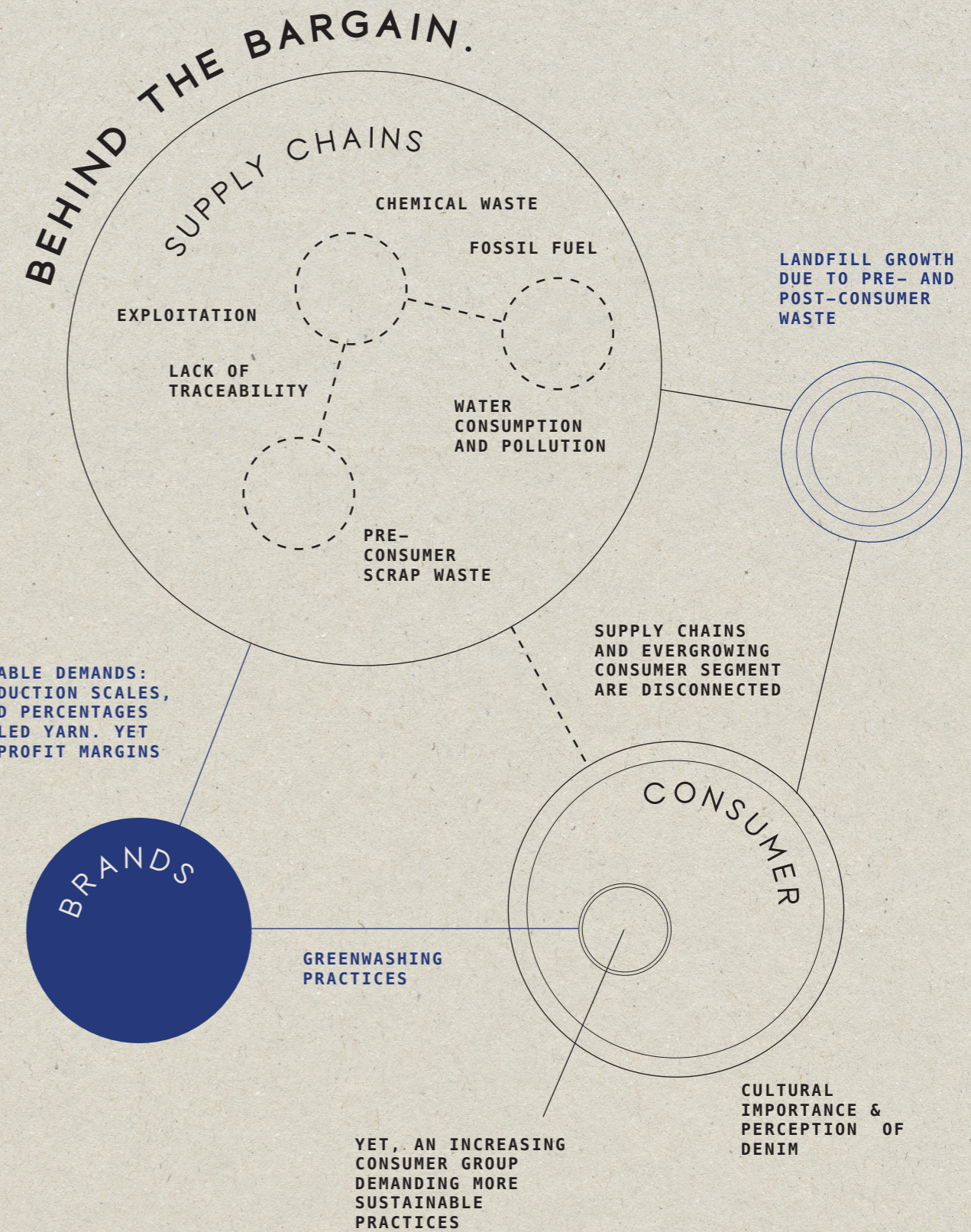


Figure 01
SIMPLIFIED OVERVIEW OF PROBLEMS IN THE CURRENT DENIM INDUSTRY

1.2.

FURTHER LITERARY BACKGROUND

This section provides additional background information to support the research approach as will be explained in Chapter 3 Problem Definition, drawing on a comprehensive literature review. It begins by delving into the concept of fast fashion and emphasises the urgency of implementing new models in the current, ultimately unsustainable system. The limitations of top-down strategies commonly used to introduce these models are also highlighted, emphasising the need for industry-led, collaborative efforts. Additionally, the section points out the significance of effective communication strategies targeted at consumers, which often goes overlooked despite its pivotal role in promoting the acceptance and adoption of new sustainable and circular models. These key aspects serve as primary considerations in addressing the challenges associated with the prevailing linear model and the necessary shift towards more sustainable alternatives.

1 . 2 . 1

FAST FASHION

The widespread phenomenon of fast fashion is characterised by the practice of clothing producers offering inexpensive apparel at the expense of environmental sustainability and ethical standards, whether knowingly or unknowingly, in response to an extremely high consumer demand (Niinimäki et al., 2020). How did the concept of fast fashion manage to achieve such remarkable growth?

CURRENT CONSUMPTION PATTERNS & THE INFLUENCE OF SOCIAL DIMENSIONS

Given the labour-intensive nature of apparel production, fashion brands have increasingly outsourced these phases to manufacturers and subcontractors located in low-income countries such as Pakistan, China, India, Vietnam and Bangladesh, among others. This strategic move aims to mitigate market volatility risks and amplify profit margins, as they seek to optimise cost-efficiency in their operations (Martino et al., 2017).

As mentioned in the previous section, cultural norms and socialisation processes play a crucial role in the acceptance of types of fashion (consult Appendix A for additional information regarding the role of cultural significance and form perception in shaping denim as a distinctive fashion category). Thus, taking this into account in understanding the rapid growth of fast fashion over the last decades, is more important than might initially be perceived. Normally, the effects of social influence may not be noticeable instantly, as changes resulting from such influence can grow on individuals over time. The

socialisation process is dynamic, complex, and involves reciprocal interactions among multiple sources and targets (Mason et al., 2007). Yet, the outsourcing of production, gaining prominence since the 1960s, has enabled fashion to become so vastly and rapidly adopted by consumers across the globe due to what is often referred to as 'democratisation'. This terminology is not entirely accurate when describing the expansion of fashion to broader consumer segments throughout history (Atik et al., 2022). However, never before was fashion as accessible to such a broad range of individuals in human history, regardless of socio-economic background, allowing them to experience the hedonistic and psychological aspects associated with fashion (Hirschman & Holbrook, 1982). Furthermore, in the past decade, the influence and benefits of the topic have been amplified through the pervasive impact of social media, further contributing to socialisation processes (Ahmad et al., 2015).

EVER-GROWING CONSEQUENCES

Fast fashion has undergone exponential growth, with a current consumer demand being approximately five times the amount of garments as opposed to 1980 (One Planet Life, 2023). Out of the staggering 100 billion garments manufactured annually, 92 million tonnes find their unfortunate fate in landfills (Igini, 2022). In the absence of measures addressing the issue of pre- and post-consumer waste, it is projected that

the fashion industry's worldwide emissions will double by the end of the decade (Igini, 2022). With 66% of online fashion retail categorised under fast fashion (as opposed to mid, premium, and luxury brands), the magnitude of the matter is underlined (Gilliland, 2019). As for the Dutch market, consumers exhibit a higher percentage of clothing purchases every six months or a few times a year. In comparison to Sweden, the UK, the US and Germany, Dutch individuals consume approximately 46 fashion items annually. The average Dutch wardrobe consists of 173 garments, out of which 123 are actively used, indicating that around 28% of the wardrobe remains unused (Leinenga, 2019).

In order to fulfil the persistent emotional desires of their customers, fast fashion brands have adopted an efficient approach, encompassing design, production and distribution within a mere twenty-day timeframe. In combination with the development of digital technology, this rapid system enables retailers to introduce new fashion collections as frequently as every two weeks, creating a constant cycle of novelty on the consumer-end. What exacerbates the issue further is that the sector operates on a model that ignores precise demand, instead relying on projected sales to justify overproduction (Amed et al., 2019).

The constant cycle of acquiring and discarding garments significantly reduces the sentimental value that consumers attach to their clothing. Clothes become

mere objects, lacking meaning and emotional significance, despite fulfilling psychological needs. This concatenation of events highlights the pressing need for an immediate shift towards slow fashion, aiming to minimise and alleviate the detrimental environmental consequences (Niinimäki et al., 2020).

**“FAST FASHION SWEEP
AWAY A CERTAIN KIND OF
COMMON SENSE KNOW-HOW
AND RESPECT SURROUNDING
OUR CLOTHING, FROM HOW
TO RECOGNISE A GOOD BUY
AND SHOP FOR QUALITY
TO HOW TO SEW ON A
BUTTON AND MEND A HOLE
IN A FAVOURITE PAIR OF
JEANS.”**

FROM FASHIONOPOLIS – THE
SECRETS BEHIND THE CLOTHES
WE WEAR BY DANA THOMAS (2022)

1 . 2 . 2

IMPLEMENTING NEW MODELS

**THE NEED FOR INDUSTRY-LED,
COLLABORATIVE MEASURES**

According to Fletcher and Tham (2019), a reduction of at least 75% in resource use is necessary to prevent total exhaustion of the essential ones, meaning change is imperative. Recently, consumer interest in transitioning towards a circular economy has grown, with increased attention towards value chain transparency and the promotion of second-hand and vintage trends (Dissanayake & Weerasinghe, 2022; Notten, 2020). However, there remains a large group of consumers who are unaware of sustainability issues altogether, lacking sufficient knowledge about the environmental impact of their clothing (Goworek et al., 2012). This underlines the need for addressing gaps in consumer awareness.

While acknowledging that some people rely on the fast fashion paradigm to afford human needs, the current model is in desperate need of reformation. Particularly, overconsumption and short textile life-spans need to be intercepted. Common ways of trying to achieve this include gaining consumer support for clothing subscription- and rental services, sharing platforms and clothing exchanges (Zibell et al., 2021). Furthermore, educational strategies towards consumers, in an effort to transform consumer behaviour, are perceived as vital (White et al., 2019). Additionally, discounts or refunds are opted to be implemented

by fashion brands to encourage sustainable purchases, which could be supported in the form of governmental tax reductions (Mizrachi & Tal, 2022). For consumers, facilitating low-threshold accessibility to sustainable options is argued to be the most crucial (Notten, 2020). Overall, consumers must recognise fashion as a practical and meaningful necessity rather than objects of short-lived pleasure. Embracing the idea of investing in environmentally-conscious, higher-priced products is becoming increasingly inevitable (Niinimäki et al., 2020).

However, relying solely on changing consumer behaviour through sustainability narratives in an effort to disrupt the fast fashion system may not be sufficient. An example of this is the prevalence of unverified sustainability claims by many brands, which has resulted in greenwashing practices and subsequently, consumer scepticism (Marrucci et al., 2021). As seen in literature, one other simple reason for insufficiency in this approach is that price often takes precedence, regardless of whether individuals are environmentally conscious or not (West et al., 2021; McDonald et al., 2012). Consumers vary in their response to social norms and base purchase decisions on numerous values. Even individuals with the strongest ethical values participate in “grey” consumption and are vulnerable for the intentional obsolescence inherent in fashion trends (McDonald et al., 2012). Therefore, responsibility for achieving a circular or more sustainable fashion industry does not rest solely with consumers.

CHAPTER TAKE-AWAYS // *BACKGROUND*

OVERALL CONCLUSION

This chapter emphasises the urgent need for a paradigm shift in the denim industry to address the pressing challenges and unsustainability of current production practices. The analysis of the contemporary denim system reveals a range of environmental and social issues, such as resource-intensive production processes, chemical pollution, and pre- and post-consumer waste. Additionally, through an examination of fast fashion and consumer behaviour, it becomes evident that traditional denim production methods and fashion-to-consumer models, maintaining a consistent aesthetic form and make-take-waste mindset, are ultimately unsustainable and will keep contributing to the cycle of overconsumption and excess material usage. The exploration of novel aesthetics and industry-led change is necessary, as relying solely on changing consumer behaviour through sustainability narratives may not be sufficient. To effectively transition the system, it is essential to depart from existing production practices and undertake a comprehensive redesign of interconnected facets within the industry. This includes redistributing power dynamics, accounting for the true costs of production, and redefining societal perceptions of what is considered 'fashionable'.



RELATED WORK

CHAPTER 2

- 2.1 **TOWARDS A CIRCULAR ECONOMY**
- 2.2 **EMERGING OPPORTUNITIES**
 - 2.2.1 NEW DEMANDS
 - 2.2.2 ON-DEMAND PRODUCTION
 - 2.2.3 THE RELEVANCE OF 3D WEAVING
- 2.3 **ATTEMPTS AT UNDERSTANDING COMPLEXITY**
- TAKE-AWAYS**

The previous chapter highlighted the ultimately unsustainable nature of current methods in denim and fashion production, emphasising the need for systemic change. This chapter aims to provide insight into the opportunities associated with alternative manufacturing methods through exploring existing relevant contributions, situated in various layers of the intricate system. To start, the chapter examines work in the denim industry within the context of transitioning to a circular economy, indicating the importance of moving away from the linear system towards a closed-loop model (2.1). Additionally, emerging opportunities (2.2) are discussed, related to currently shifting demands in the industry and how different actors are responding to these changes. This is followed by the notion of on-demand production and its accompanied opportunities for shifting design roles and relocalising supply chains to local contexts. This is where the relevance of 3D weaving as an innovative production technique example is revealed. Furthermore, attempts at understanding systemic complexity are illustrated (2.3). The chapter ends with the subsequent identification of a research gap, paving the way for further investigation and continuation of this research.

2.1

TOWARDS A CIRCULAR ECONOMY

It has become evident that the linear economic model in the fashion industry, characterised by high resource consumption and significant pre- and post-consumer waste, is ultimately unsustainable. To address the issues embedded in the 'make-take-waste' system, the concept of a circular economy has gained significant attention. This aims to close energy and material loops, thereby eliminating waste and pollution. This section showcases related work in the denim industry that addresses circular economy principles from the initial, impactful design stage. However, it often overlooks a crucial aspect in the textile context for achieving circular economy goals: the generation of pre-consumer waste during the cut and sew process.

The concept of material cycles has been recognised since the early days of industrialisation, but its significance has been amplified by current discussions on decoupling economic growth from resource consumption (Dissanayake & Weerasinghe, 2021). Rather than merely focusing on recycling, there is a growing emphasis on transitioning to regenerative growth models that promote circular material usage and reduce overall consumption (Ellen MacArthur Foundation, 2017).

Circular economy (CE) can be understood as an economic system that aims to optimise the use of materials and energy by adopting circular flows, renewable resources and efficient energy cascades within the interconnected loops of nature, society, and pre- and post-consumption (Korhonen et al., 2018). Overall, CE is often typified by the so-called "Rs", a hierarchy of value retention options. Reike et al. (2018) provide an overview of ten options within the circular economy model, starting with 'R0: Refuse', which emphasises the importance of rejecting new acquisitions and recognising that the most sustainable garment is the one already present in your closet. The overview gives insights into how loops can be closed in a circular economy model, extending beyond the widely recognised 'recycling' practice:

R0: REFUSE	R5: REMANUFACTURE
R1: REDUCE	R6: REPURPOSE
R2: REUSE	R7: RECYCLE
R3: REPAIR	R8: RECOVER
R4: REFURBISH	R9: REMINE

Jia et al. (2020) highlight that circularity necessitates a transformative shift, commencing from the design phase and extending throughout the entire lifecycle of a product. At its core, circularity emphasises the importance of designing products with waste generation in mind at every step of the product's lifecycle: considering its manufacturing, the durability of the materials used and construction of the product. Working towards circular economy at the design stage refers to addressing whether the material value can be recaptured at end-of-life through reuse, repair, refurbishment, cascading or upgrading of the entire product, its components or materials (Korhonen et al., 2018). Concentrating efforts on the design stage is crucial as it accounts for approximately 80% of the environmental impact of textiles throughout their lifecycle (Östlund et al., 2020), making it a key area to focus on for maximising impact.

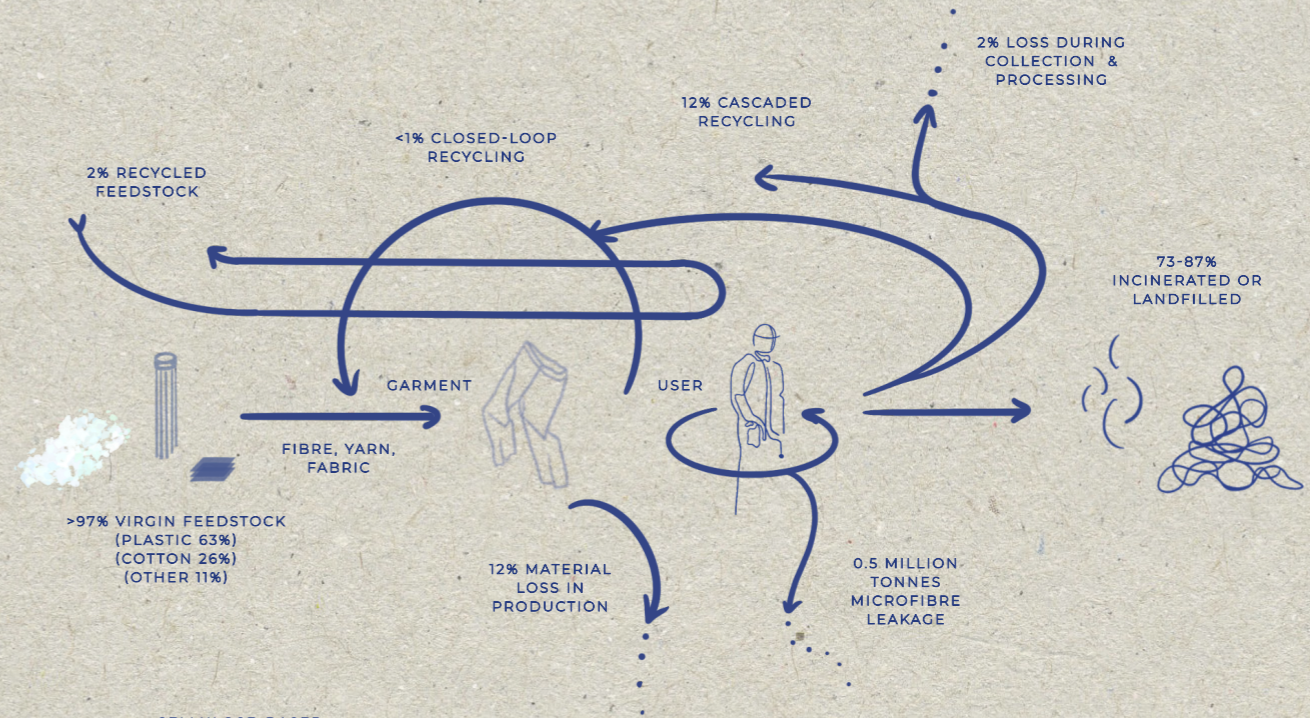
THE JEANS REDESIGN

In 2021, the Ellen MacArthur Foundation published a report that synthesised two years of insights gathered through collaboration with various denim brands. The report aimed to establish a set of guidelines for redesigning jeans, acting as a starting point for the industry to design and produce products in alignment with the principles of a circular economy. Specific design requirements are outlined which need to be met in order to achieve objectives of durability, material, labour and ecosystem health, user empowerment through repair knowledge and service, recyclability, and traceability. Figure 03 shows an overview of The Jeans Redesign guidelines on a simplified circular economy model for textiles.

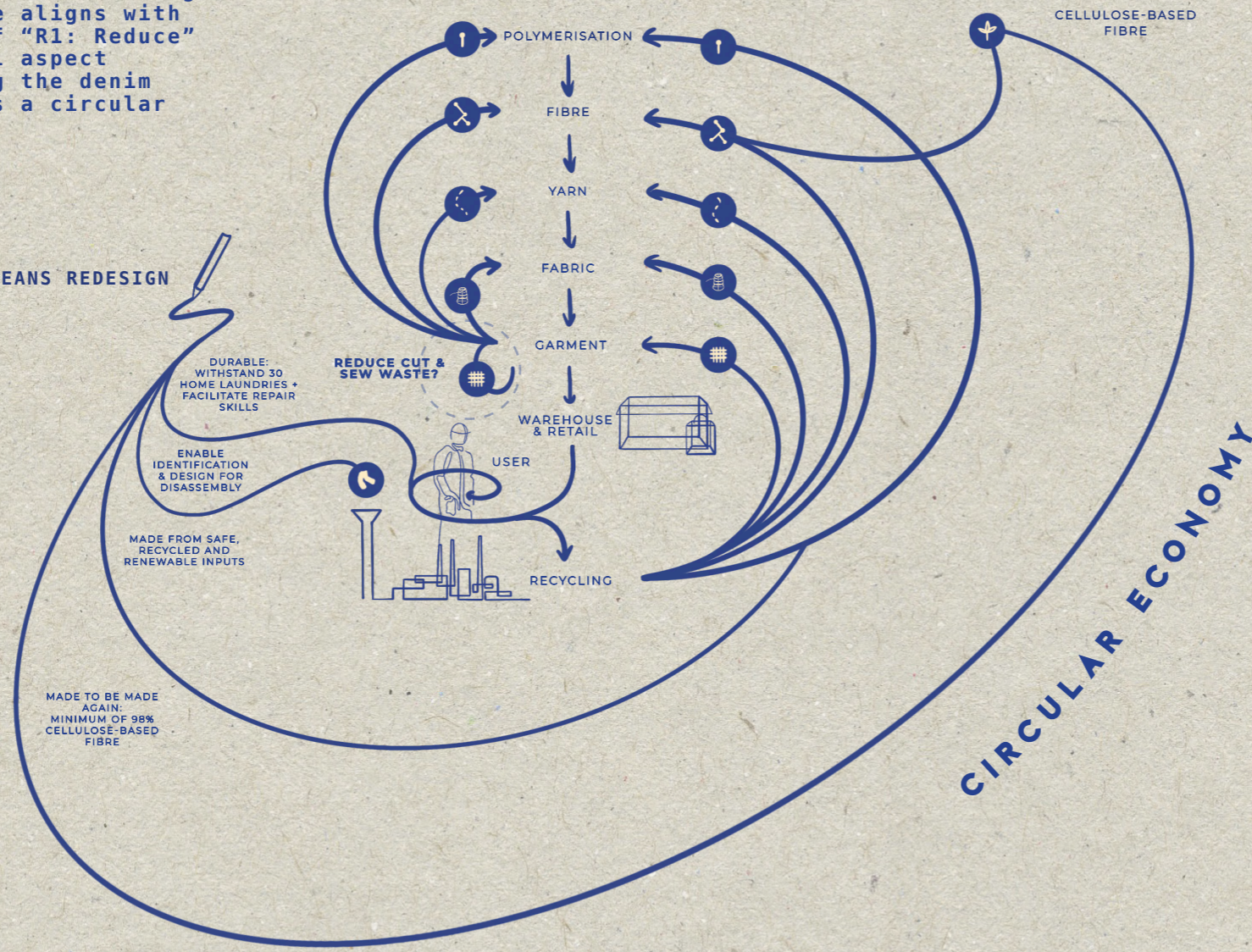
TAKE-AWAY

Although circular economy approaches often prioritise closing loops in end-of-life stages, it is important not to overlook the significant amount of pre-consumer waste generated in the design and cutting processes of denim patterns. This excess material, often sent immediately to incineration or landfill, is estimated at 10-15% per pattern average (Enes & Kipöz, 2019). Focusing on reducing this waste during the design stage aligns with the principle of "R1: Reduce" and is a crucial aspect of transitioning the denim industry towards a circular economy.

CURRENT LINEAR ECONOMY



THE JEANS REDESIGN



CARBON FOOTPRINT GARMENT

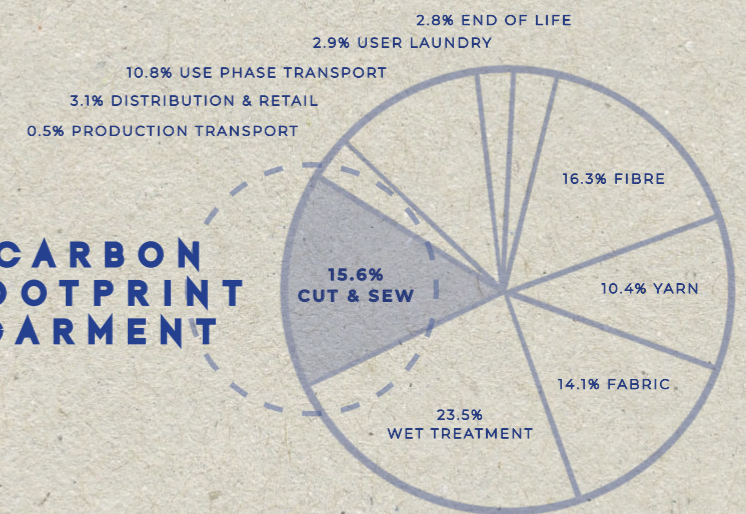


Figure 03

AN OVERVIEW OF THE CURRENT LINEAR TEXTILE SYSTEM VERSUS THE CIRCULAR ECONOMY, WITH RELATED WORK OF THE JEANS REDESIGN INTEGRATED (ELLEN MACARTHUR FOUNDATION, 2017; 2021; RUIZ, 2023; WENNBERG & ÖSTLUND, 2019)

2.2

EMERGING OPPORTUNITIES

In the context of the unsustainable nature of the current fashion system and the growing discourse around transitioning to a circular economy, an increasing number of eco-conscious consumers is emerging. This consumer group is driving new demands and exerting pressure on governments, industry, and brands to adopt sustainable practices. However, it is important to note that these consumers represent only a fraction of the larger population, many of whom may not yet have a strong awareness of sustainability issues, meaning ultimate systemic transformation can't be expected to unfold by action of this group alone. Furthermore, categorising consumers in this context can be challenging due to the presence of grey areas in consumerism and varying levels of engagement. Nonetheless, significant policies and regulations are being implemented at the EU and Dutch national levels, with the ambitious goal of achieving a fully circular and net-zero economy by 2050. These policy changes, along with the growing demands from consumers, provide opportunities for alternative models for fashion to develop. The emergence of other technological advancements, particularly in the realm of on-demand production, highlights the significance of 3D weaving. 3D weaving not only offers possibilities for creating zero-waste pattern designs but also caters to smaller manufacturing contexts, allowing for tailored production to meet customer demands and measurements in a local setting. Therefore, 3D weaving serves as an intriguing case to demonstrate how this innovative design and manufacturing technique can be utilised to achieve alternative sustainable models that align with the emerging opportunities discussed in this section.

2.2.1

NEW DEMANDS

AN EMERGING GROUP OF ECO-CONSCIOUS CONSUMERS

Across the globe, there is an increasing group of consumers seeking better quality, greater availability of sustainable products, traceability in the supply chain and overall transparency regarding human rights, health and environmental concerns (Brun et al., 2020). The impact of the recent COVID-19 pandemic has further strengthened this demand (Rinaldi et al., 2022). Although the total amount of sustainable fashion products is still relatively small, there has been a five-fold increase in such products between 2017 and 2019 (Berg et al., 2019). The number of Dutch consumers holding a favourable attitude towards sustainability is on the rise as well, experiencing an almost 10% growth from 2016 to 2017, reaching 59% (Leinenga, 2019). There exists a distinct group of Dutch consumers, comprising 6%, known as early adopters. Although small, this particular group demonstrates a heightened concern for environmental issues. This group is characterised by higher education levels and income, possesses more extensive knowledge about eco-fashion and exhibits greater openness towards sharing models (Van der Wijst, 2016).

Fashion brands and retailers face the risk of falling behind if they do not promptly adapt to the evolving demands of customers. Meeting these changing customer expectations is argued to potentially be the most crucial driving force for initiating

meaningful change within the industry. Moreover, the growing inclination of consumers to make purchasing choices that align with their ethical values has put pressure on policymakers to take action. A notable example of this is the recent establishment of a global alliance by the United Nations, which aims to tackle the critical environmental and social challenges faced by the fashion industry (Cueye, 2021). For several denim manufacturers, sustainability has emerged as a distinctive selling point. Energy conservation and environmental protection have become foundational criteria within certain mills, in response to the growing societal concern for the environment and finite resources (Periyasamy & Periyasami, 2023).

THE VALUE-ACTION GAP

Granskog et al. (2020) suggest that by making simple behavioural adjustments to stimulate conscious consumption choices, significant results can be obtained. However, studies have uncovered the complex nature of sustainable consumption decisions among fashion consumers (Niinimäki, 2010). As mentioned in the previous chapter and in Appendix A discussing the cultural significance and form perception of denim, clothing serves as a visually prominent means for individuals to express social status, values and personal or collective identity, influenced by societal norms and cultural conditioning (Blázquez et al., 2020).

This may lead to persistent acceptance of fast fashion consumption. As noted by Niinimäki (2010), despite having a positive attitude towards environmental protection, fashion consumers show a lower inclination to purchase eco-fashion, revealing the presence of a **value-action gap**.

AVOIDING SIMPLISTIC CATEGORISATION

Individuals cannot be simply categorised as either being “green” (those who actively participate in ecologically conscious decision-making) or “non-green”. The reality is more nuanced, as individuals who engage in ecologically sound behaviour do not form a homogeneous group (McDonald et al., 2012). In literature, they are identified as translators, exceptors or selectors. Translators often lack a comprehensive approach, attempting to make responsible choices by passively absorbing information regarding potential lifestyle changes. Exceptors are anti-consumerist, actively seeking alternative media sources for advice on ethical consumption. While they generally demonstrate commendable pro-environmental behaviour, they do make exceptions for the acquisition of products they have a strong affinity for. Lastly, selectors constitute the largest group of environmental advocates, who focus on a specific area, overlooking other topics of issue (McDonald et al., 2012). Therefore, even in the face of emerging demands from

specific consumer segments, it is crucial to recognize that these individuals still possess varying perspectives and behaviours.

Furthermore, amidst the shifting of demands, it is important to acknowledge the existence of a larger group that still lacks sustainability awareness. For instance, the awareness level among Dutch consumers stands at a mere 46%, evident through their limited capacity to provide examples of sustainable practices implemented by businesses (Leinenga, 2019).

TAKE-AWAY

Thus, it is necessary to explore strategies for expanding the group of eco-conscious fashion consumers, while also implementing mechanisms that foster a stronger identification with sustainable clothing choices to effectively bridge the value-action gap.



Figure 04
IMPORTANT CONSIDERATIONS IN CURRENTLY RISING DEMANDS AMONG ECO-CONSCIOUS CONSUMERS

UPCOMING LEGISLATION

New legislation is being developed at national and EU level to promote a future circular economic model in the textile industry.

DUTCH GOVERNMENT

The Dutch Government has established an objective of achieving a circular economy by 2050 in their Dutch Mission-oriented Innovation System (MIS), which entails maximising the reuse of materials and resources in various capacities (Hekkert et al., 2021). Specifically, in the realm of textiles, the target is for textiles produced in 2030 to incorporate a minimum of 30% recycled fibres. Presently, however, only a mere 1-4% of textiles meet this criterion (National Institute for Public Health and the Environment, 2023).

To reach the latter goal, efforts will need to be intensified to enhance textile recycling processes and encourage greater participation from brands and consumers to ensure a higher proportion of clothing is recycled.

DUTCH DENIM DEAL

The Dutch Denim Deal, a coalition launched by the Dutch government and House of Denim in 2020, is now reflecting on its

progress two years after its establishment. The Denim Deal started off with uniting parties in the PCR value chain and stimulates them to work together to achieve a more sustainable future in denim, including brands, collectors and weavers. Aligned with the European Green Deal and Circular Action Plan, the project aims to establish a reverse value chain that facilitates the collection, sorting and recycling of textile garments for use as fibre input.

Although progress has been minimal, over 464,000 pieces were produced in accordance with the specified standards by the start of 2022, including the utilisation of at least 5% PCR material. This marked an 18% increase compared to 2020 (Pavarini, 2022).

Out of the 1.1 million jeans introduced to the Dutch market by the participating brands in 2021, 36% of them contained a minimum of 20% post-consumer recycled (PCR) cotton. While this proportion remains relatively small compared to the overall jeans supply in the country, there has been a significant increase from 8% in 2020 to 36% in 2021 in terms of volume (Pavarini, 2022).

However, it is important to acknowledge that there are still concerns regarding other stages in the supply chain, particularly in the laundry department. Although clothing entering the Netherlands already needs to comply with chemical limits to mitigate potential hazards, the jeans currently produced with PCR materials are still

subject to the aforementioned practices in the supply chain (National Institute for Public Health and the Environment, 2023). This highlights the need for continued attention and improvement in addressing all potential harmful aspects throughout the entire production process.

EXTENDED PRODUCER RESPONSIBILITY FOR TEXTILES

Starting from July 2023, a significant change will be implemented in the Netherlands regarding the management of textile waste: Extended Producer Responsibility (EPR). Textile manufacturers and importers will share co-responsibility for the waste generated from the products sold, regarding collection, recycling, reuse, and proper disposal of the products they introduce to the market. Additionally, manufacturers will be required to cover the logistics costs associated with implementing this waste management system (Bernal, 2023). Due to the swift implementation of this policy change, fashion brands are experiencing significant pressure to quickly adapt and comply with the new regulations. The implementation timeline is challenging and brands have expressed concerns about the feasibility of meeting the requirements before receiving potential repercussions for non-compliance.

EU POLICIES & REGULATION

Numerous policies and regulations have recently been developed by the European Union as part of the comprehensive framework known as the European Green Deal (EGD). Many are still in the proposal or implementation stage, yet aim to guide the continent towards achieving the ambitious objective of net zero emissions by 2050, in similar fashion to the Dutch government. The EGD serves as a roadmap for Europe's transition to a more sustainable and environmentally friendly future among multiple sectors.

Among the several significant EU regulations currently at different stages of proposal, implementation and enforcement, the most notable for the textile sector are:

THE CIRCULAR ECONOMY ACTION PLAN (CEAP)

Implemented in March 2020 under the EGD, the CEAP addresses the concept of Digital Product Passports and their potential implementation at a governmental level within the European Union (EU). These passports aim to ensure traceability and transparency throughout the lifecycle of products. Although still in the early stages of development, Digital Product Passports will become mandatory by 2030 according to the guidelines set forth in the CEAP in three sectors: textiles, batteries, and construction,

due to their high circularity potential, recyclability, and significant environmental impact. By implementing these passports, the EU aims to support informed-decision making for purchase and informing overall stakeholders with detailed and verified sustainability information.

EU STRATEGY FOR SUSTAINABLE AND CIRCULAR TEXTILES + ECODSIGN FOR SUSTAINABLE PRODUCTS REGULATION

Proposed in March 2022, this regulation aims to enhance product circularity and sustainability from the very first stage of product design. It sets guidelines on longevity and quality, reusability, enhancing ease of recyclability, resource efficiency and carbon footprints. In 2030, all brands are expected to implement these guidelines.

FIRST SET OF STANDARDS OF THE CORPORATE SUSTAINABILITY REPORTING DIRECTIVE (CSRD)

Introduced in late 2022, the CSRD's forthcoming entry into force is currently scheduled on January 1, 2024, bringing significant attention to the first set of standards. Textile companies affected by this directive must swiftly prepare to meet extensive criteria, in order to disclose the impact of their practices on human wellbeing and the environment.

GREEN CLAIM DIRECTIVE

The recently proposed Green Claim Directive (2023) is closely linked to CSRD. It empowers consumers to verify the environmental claims made by textile companies. After the official entry into force announcement, companies will have a 24-month timeframe to achieve full compliance. To prepare, companies should undertake a review and audit, ensure documentation and substantiation of claims, develop a communication strategy, and establish compliance monitoring procedures (SER, 2023).

DIRECTIVE ON PACKAGING AND PACKAGING WASTE

This directive focuses on reducing excess packaging, optimising transport space, increasing the use of recycled packaging material, and introducing new design criteria for recycling. It aims to promote sustainable packaging practices and waste reduction and its entry of force is scheduled for 2030.

(European Commission, 2022)
(European Commission, n.d.)

TAKE-AWAY

These measures serve as crucial factors of influence, affecting the strategy to be designed, aiming to explore alternative models for fashion. By aligning with these policies in further conceptualisation of this project, the strategy can effectively contribute to the larger goal of fostering systemic change in the Dutch denim market.



Figure 05

AN OVERVIEW OF RELEVANT UPCOMING NATIONAL AND EU-LEVEL POLICIES AND REGULATIONS IN THE TEXTILE SYSTEM

2 . 2 . 2

ON-DEMAND PRODUCTION**WHY ON-DEMAND?**

The fashion industry is witnessing the emergence of alternative models of on-demand production, aimed at replacing traditional approaches that rely on inaccurate estimations of consumer demand. This shift is made possible through the integration of new digital and manufacturing technologies. The importance of on-demand production of fashion lies in its ability to make the production process cleaner, more responsive and responsible, while also promoting sustainability. Overproduction, which accounts for approximately 35% of all apparel (Goldman, 2017), can be reduced through more accurate demand estimations, preventing inventory destruction and additional waste in landfills. The emerging digital technologies associated with this manner of production allows for quicker response to market trends and eliminates the need for excessive inventory which responds too late to trends. While eliminating excess waste, on-demand production fosters a greater range of product differentiation, fostering immediate expression of identity, customisation and personalisation. This approach, bringing the user to the origin of their garment, aligns more closely with consumer preferences, potentially leading to higher levels of satisfaction and material attachment due to higher perception of authenticity (Newman & Dhar, 2014). Arguably, the subsequent more efficient resource allocation in on-demand production

contributes to enhanced profitability for brands and manufacturers. In essence, on-demand production reduces supply chain complexities and fragmentation, and allows for better oversight in waste management, labour, transport and material choice (Rainey, 2021).

MICRO-MANUFACTURING

Transitioning from a conventional supply chain to an on-demand business model at a large scale within outsourced supply chains overseas can be challenging. On-demand production is better suited for micro-manufacturing contexts, where quick and agile demand-driven production, situated in local regions, is enabled (McQuillan, 2019a).

RELOCALISATION

This aligns with the concept of future supply chain relocalisation. Research conducted on the topic of local Italian fashion districts, indicates that among these districts, the ones with limited capabilities face greater risks in non-outsourcing manufacturing activities to a global value chain, while innovative districts can strategically relocate activities and attract local investments (Sammorra, & Belussi, 2006). This highlights the importance of establishing innovative, localised centres to meet the demand for reshoring initiatives, which also matches previous work in reshoring textile activities

in the UK (Postlethwaite et al., 2022). Relocalisation becomes even more crucial due to various factors such as rising geopolitical uncertainty, uneven economic recoveries, the impact of the COVID-19 pandemic and intensified competition in the digital market. As highlighted by (Amed et al., 2022), brands need to reassess their growth priorities and refine their strategies to align with specific geographical contexts.

Localisation involves a deep understanding of local culture and values. It should encompass the use of local materials, colours and patterns in designs, as well as the creation of tailored advertising and promotional materials. The significance of bottom-up solutions in enabling slow fashion also becomes evident in this context, through solutions such as user-making stations, social marketing, wardrobe audits and education (West et al., 2021). Moreover, local material opportunities can be explored. By bringing users, makers, and the production process closer together while aligning with their values, a stronger symbolic bond can be formed between garments and consumers, potentially leading to a desirable shift in consumer behaviour, such as extended garment use (McQuillan et al., 2018).

SHIFTING DENIM DESIGN ROLES

According to Faerm (2017), the increased search for meaning and self-expression among consumers has fundamentally

transformed their perspective on design. Coupled with a growing knowledge-driven economy and market oversaturation, fashion designers have become required to contextualise their work in unique ways in order to attract consumers. The previous emphasis on merely crafting objects has transitioned into the crafting of intricate narratives that generate novel perceptions of emotional value.

While this change in roles has already become evident in other fashion design categories, the realm of denim design has remained relatively stagnant, with minimal changes occurring over the past 150 years (Gleason, 2023). Denim has evolved in distinctive characteristics throughout the years, with designers modifying garments to exhibit personal taste and style, but the fundamental tools and processes involved in creating basic denim garments have hardly changed. However, this is not to imply that a shift in roles is unnecessary within this particular category. The problems within the denim industry (pointed out in the previous chapter and in Chapter 4.1 Mapping The Current Denim System) and emerging new demands across the system imply that the current way of designing denim will not withstand. Striving for circularity or greater sustainability in garment production necessitates the integration of entire lifecycle considerations right from the very beginning (Jia et al., 2020).

On-demand and relocalised production further necessitate a shift in the design role,

reuniting designers with the manufacturing process - currently decoupled. Designers must embrace new innovative tools that bridge these two phases, enabling a more creative and holistic approach to eliminate the inherent flaws in current production processes (Postlethwaite, 2022).

RELATED CONTRIBUTIONS TO ON-DEMAND PRODUCTION

There are many recent textile examples which address the previously mentioned principles in the light of on-demand production.

FASHTECH INNOVATION CENTER

Kornit, Zund, and Fashion Enter have joined forces to create an on-demand micro-factory concept. This concept integrates **fabric printing, digital cutting, and sewing processes** to empower sustainable manufacturing in the fashion industry in local contexts, through automated streamlining of the entire production process (Douglass, 2022; see figure 06).

CARESTE

Careste and The Yes aim to bring a digital, zero-inventory model to the luxury market, providing demand platforms and a comprehensive digital measuring process. The manufacturing process is semi-

localised, as the garments are sourced from reputable Italian mills (Cernansky, 2021).

STAMP JEANS

In 2019, the Fabric Tokyo group introduced their STAMP jeans collection, pioneering the on-demand fashion model with a made-to-order approach (Digitally Empowering Fashion, 2021).

UNSPUN

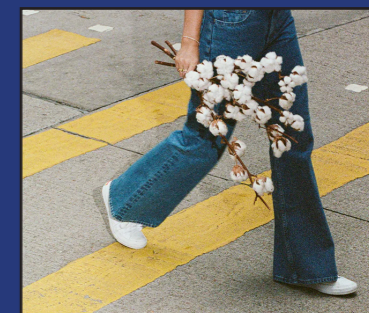
Unspun is known for its made-to-order jeans and showcases the adoption of digital body scanning technology in the fashion industry, allowing customers to receive made-to-measure and on-demand production. Recently, Unspun has also released their work on creating further design-manufacturing innovation, which will be explained in more detail in the next subsection (The Relevance of 3D Weaving), further implying how unconventional technology plays a pivotal role in embracing on-demand models (Unspun, 2023; figure 07 and 08).

ATALYÉ

Atalyé is an Amsterdam-based studio, only producing on-demand and made-to-measure clothing within the Netherlands. They utilise automated pattern-making and 3D scanning technology, and only implement fabrics from European deadstock, thus creating unique garment options through limited availability in material (DDW, 2022; figure 09).

TAKE-AWAY

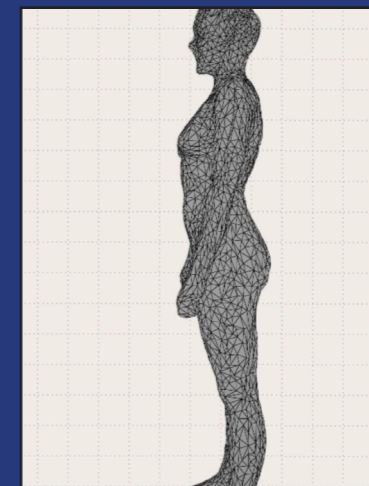
On-demand production can enable tailor-made experiences through customisation and made-to-measure opportunities, reflecting both consumer needs in unique identity-crafting and sustainability. On-demand caters to the today's fast-paced, digitally-driven economy, through a micro-factoring model and proximity production approaches eliminating logistical emissions. However, this also raises concern in potentially contributing to the perpetuation of fast fashion and the constant need for new clothing, without necessarily fostering a stronger emotional connection to garments, as it operates within the existing capitalist framework.



UNSPUN MADE-TO-MEASURE JEANS (2021; 2023) | FIG 07 08



FASHTECH INNOVATION CENTER ON-DEMAND (FASHION TECHNOLOGY ACADEMY, 2022) | FIG 06



ATALYÉ O(W)N-DEMAND (DDW, 2022) | FIG 09

2 . 2 . 3

THE RELEVANCE OF 3D WEAVING

IMPORTANCE OF MATERIAL EFFICIENCY

As could be seen from the circular model of The Jeans Redesign, emphasis is given on waste regeneration and thus recapturing value from what would otherwise be lost. While designing with waste can help clearing all grounds from textile disposal in theory, the waste management hierarchy suggests that waste minimisation is the preferred approach (McDougall et al., 2001). Among pre-consumer waste types, **cut-and-sew waste is particularly significant** as fabric constitutes for nearly half of the garment cost (Enes & Kipöz, 2020). Yet, the choice of minimisation options depends on factors such as waste quantity, composition, and existing waste infrastructure (McDougall, 2001; McDougall et al., 2001).

The denim industry has faced challenges due to the recently escalating costs of raw materials and logistics. To mitigate rising prices, denim manufacturers have implemented strategies at various levels, such as reducing fabric weight, optimising production lines, exploring alternative dye combinations and lighter shades and incorporating blends of cotton and synthetic fibres such as polyester. Additionally, there has been an increase in automation to save energy and water (Crouth, 2022).

The significance of resource efficiency in the denim industry cannot be overstated. Unfortunately, there is often a misconception that the circular economy solely focuses

on waste management (Dissanayake & Weerasinghe, 2021). Moreover, even when this concern is addressed, waste minimisation is often perceived to be the preferred solution for solving cut and sew waste, while the elimination method could be more favourable - preventing any excess fabric that is unnecessary from the outset (McDougall et al., 2001).

ZERO-WASTE DESIGN

Zero-waste pattern making is an example of waste elimination, challenging designers to consider both the form aesthetics and functional use of fabric. It is especially relevant because it tackles the problem of waste at its root: in the design phase, which is where 80% of a garment's footprint is already set in stone (Östlund et al., 2020). Various designers and academics, such as Issey Miyake, Mark Liu and Timo Rissanen, have focused on zero-waste pattern design, whose related work is shown in Appendix C. While some examples show effective reduction of material, others still utilise large quantities of fabric, as seen with Julian Roberts for instance. This raises the question whether shape-changing or draping textile forms may still result in excess fabric being used in the garment under the disguise of zero cutting, which could have potentially been utilised for other product creation.

3D WEAVING

One particular method which is suitable for creating zero-waste pattern design for denim could be 3D weaving. Weaving in this manner offers a unique capability to have two-dimensional textiles exist in a three-dimensional form only through the weaving process itself, utilising a multi-layer woven textile construction (McQuillan, 2020). By creating certain divisions of the warp in the weave structure and strategically interlacing these warp yarns of the multiple layers in some places, 'bindings' are created. When the 2D structure is subsequently cut in several places and unfolded into a 3D textile form, these bindings resemble what we know as seams. However, the difference lies in the fact that post-weaving sewing steps have become hardly necessary, while also eliminating the 10-15% excess fabric waste (Enes & Kipöz, 2019) which would be occurring in current methods of pattern design. With the achievement of an almost or complete whole garment (referred to as Woven Textile-Form) through this weaving method, the need for marker laying and cutting and sewing separate flat panels is eliminated, resulting in a significant reduction in the number of supply chain steps involved - thus removing the need for transport in between supply chain steps as well (McQuillan, 2020).

In other words: **the 3D woven garment's three-dimensional function is interwoven in its design.**

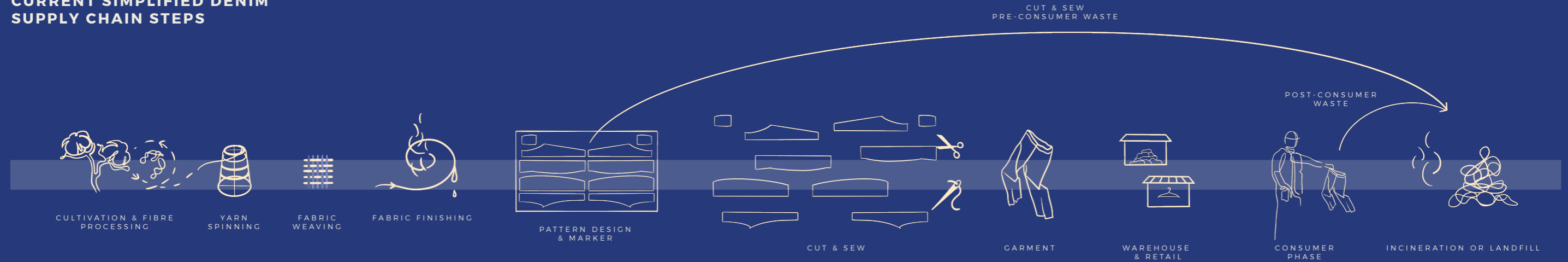
3D-2D-3D WORKFLOW

Exploring alternative tools is essential for working with this integrated design-manufacturing approach. A first example is the use of Clo3D, a CAD program that enables the visualisation of 3D textile forms on a digital embodiment of a model. This helps in understanding how to construct a subsequent 'Map of Bindings', transitioning from a 3D to 2D representation. The Map of Bindings can be visualised using Adobe Illustrator, followed by the creation of weave cards through ScottWeave, NedGraphics or AdaCad. These serve as the translation of the map into an actual weave pattern, facilitating the weaving of the multi-layer structure (McQuillan, 2020). Unlike conventional shaft looms used in the denim industry, jacquard looms are necessary for 3D weaving. Usually, these existing looms are merely present in small amounts for specific visual decorative weaving patterns through more creative freedom with the warp. This ability enables the weaving of multiple layers as well, although desired design freedom desired design freedom is dependent on the specific width and repeat of the loom at hand. The latter dependency points to the notion that an ideal jacquard loom specifically for creating zero-waste patterns through 3D weaving, is yet to be introduced.

In short, the workflow associated with 3D weaving through these tools is typified by transition from **3D to 2D and back to a 3D textile form.**

Figure 10 shows a complete overview of the current weaving process versus the 3D weaving steps

CURRENT SIMPLIFIED DENIM SUPPLY CHAIN STEPS



3D WEAVING SIMPLIFIED SUPPLY CHAIN STEPS

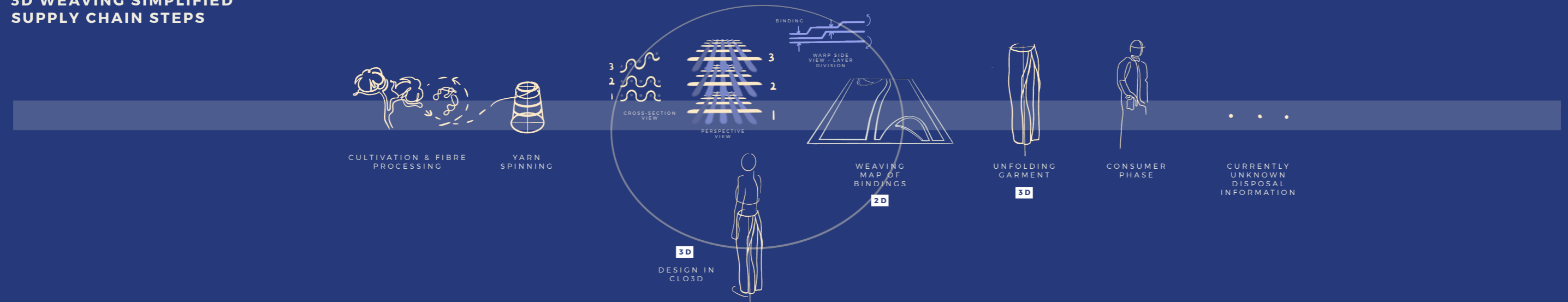


Figure 10
SIMPLIFIED OVERVIEW OF SUPPLY CHAIN STEPS IN THE CURRENT DENIM INDUSTRY VERSUS SUPPLY CHAIN STEPS ASSOCIATED WITH 3D WEAVING (MOB AND 3D WOVEN TROUSERS DRAWINGS ADAPTED FROM MCQUILLAN, 2020)

**RELATED WORK
IN 3D WEAVING**

The interest in exploring 3D weaving, particularly through material-driven design, is growing among scholars and professionals in the business field.

Holly McQuillan, for instance, has conducted various experiments using weaving techniques to create garments with zero waste. One notable example is the development of a T-shirt through multi-layer 3D garment weaving (McQuillan, 2020; figure 11). A collaboration with Milou Voorwinden resulted in the creation of a zero-waste Woven Textile Form of a trouser (McQuillan, 2020). Barbara Vroom (2022; figure 12) designed 3D woven denim jackets using jacquard machinery from Diamond Denim by Sapphire. The project showed potential in achieving a more holistic approach to sustainable denim design, although the limited repeat and width of the loom at hand hindered the jackets from fully realising the zero-waste objective at this early stage of research. Weffan (2022; figure 13) aims to establish a consultancy for 3D woven garments. Starting off with denim pant trials, the textile forms are currently further explored to develop a fully efficient general zero-waste design-manufacturing technique. Unspun (2023; figure 14 and 15) is developing a specialised loom for automating 3D weaving, aiming to integrate it into the fashion industry on a broader scale facilitating automation and on-demand.

These examples reveal that the aesthetics of garments created through zero-waste pattern making are significantly different from conventionally recognised garment forms. Barbara Vroom's (2022) work in creating denim garments that closely resemble a traditional trucker jacket, still exhibits a distinct aesthetic outcome. This raises the question of whether embracing this alternative aesthetic is worth exploring in the context of sustainable fashion, and whether consumers would be receptive to such new textile forms. Furthermore, the case of denim, a well-established garment category, prompts us to consider whether the ultimate intention of 3D woven denim forms should be to dominate the entire industry or rather: coexist as a distinctively understood category of 3D woven products.

TAKE-AWAY

Due to its more streamlined supply chain and integrated design-manufacturing process, 3D weaving is well-suited for small-scale manufacturing. This makes it compatible with micro-manufacturing and on-demand approaches, as discussed earlier. Additionally, this could fit in the context of relocalisation, mentioned in the previous chapter. By combining the principles of zero-waste production and alternative aesthetics, 3D weaving presents an opportunity for creating new sustainable design-to-consumer models through a more holistic approach.



WOVEN TEXTILE-FORM OF A SHIRT
MCQUILLAN (2020) | FIG 11



3D WOVEN DENIM BY WEFFAN (2022)
| FIG 13



3D WOVEN DENIM JACKET BY BARBARA
VROOM (2022) | FIG 12



3D WEAVING BY VEGA™, UNSPUN (2023)
| FIG 14



3D WEAVING BY VEGA™, UNSPUN (2023)
| FIG 15

2.3

ATTEMPTS AT UNDERSTANDING COMPLEXITY

This section aims to address the importance of adopting a systemic perspective when exploring zero-waste pattern design and innovative design-manufacturing approaches like 3D weaving. The textile system is inherently complex, requiring a holistic understanding to address its challenges effectively. Systemic design offers a potential solution by examining how it has been applied in different ways to the textile system. Through analysing these approaches, a research gap is identified that will be further explored in this work.

INTERCONNECTIVITY AND COMPLEXITY IN THE TEXTILE SYSTEM

In the context of pre-consumer waste, the focus has been on minimising disposal rather than eliminating resource use. However, it is important to recognise that zero-waste design alone is not sufficient. Many hope that recycling or zero-waste fashion design will provide a quick solution to the industry's problems, allowing it to continue with its current economic model (Rissanen, 2013). Unfortunately, material optimisation and increased production efficiency obtained through innovative design-manufacturing techniques which facilitate things such as zero-waste design, could lead to counterproductive outcomes. Think of increased consumption and remaining manufacturing of new textiles. This is exactly the opposite of what should be obtained in utilising new innovative design-manufacturing techniques and a more holistic outlook is necessary to multiple related facets. For instance, instead of 'simply' reverting to former textile infrastructures or seeking quick fixes within the current supply chains with new technology, a mediator is needed to understand the interconnected nature of the issue. 3D weaving could potentially offer such an approach by combining high-tech and micro-manufacturing opportunities (McQuillan, 2019a; b).

To effectively utilise zero-waste pattern designing and innovative manufacturing

techniques, the textile system and its multiple layers should be understood thoroughly first. The fashion system is understood as intrinsically complex. This complexity gives rise to interconnected, interdependent and disorganised phenomena, forming what is known as 'wicked problems'. Understanding the true nature of these problems involves acknowledging that they are not standalone issues but rather recurring patterns of behaviour that arise from the intricate interplay and connections between various actors and phenomena within the system (Murphy, 2022). The system exists of networks of individual actors, (sub-)organisations, material input, fragmented manufacturing sequences, rules and regulations on national and international levels, brand demand, consumers and material output, among many other aspects. Hence, pre-consumer waste represents only a fraction of the complexity inherent in this system, and addressing individual components in isolation is unlikely to yield effective solutions.

RELATED WORK IN ADDRESSING COMPLEXITY

Systemic design can help with the need to address the entire system to undergo any transformation (Murphy, 2022). Systemic design is fundamentally an interdisciplinary approach to creating positive change in complex systems through applying various theories and tools (Jones, 2014).

There are variations in how systemic design is applied in understanding complexity in the textile system.

MULTIMORPHIC-THINKING

McQuillan (2020) introduces the concept of multimorphic thinking, which is a design approach for zero-waste textile forms which looks holistically at surrounding system layers, actor perspectives and interrelated problems. Within this approach, the designer does not merely design a pattern, but adopts a multidisciplinary mindset, encompassing roles in design, manufacturing and material science. One element at a time is addressed, whilst keeping track of actively mapped interactions and aspects of importance in the broader system.

THINKING IN SYSTEMS

Donella Meadows (2008) approach to 'Thinking in Systems' approach underlines the identification of problem root causes, uncovering new possibilities, informed and iterative decision-making, while navigating through complex dynamic environments. Meadows further explains the significance of finding "leverage points" within systems, where small interventions can yield substantial results (Meadows, 2008). An example of her work applied in the textile context, is Tamborrini et al.'s (2018) use of big data, reflecting user behaviour, upstream processes and interrelations to generate more effective sustainable value within

the fashion system. Through mapping the current system, both information gaps and four main interdependent levels were identified to create leverage from: research, service, product and organisation.

FLOURISHING LOCAL FASHION SYSTEMS

Three systemic design tools are presented by Real and Lizarralde (2017) to help designers in mapping transformative opportunities, situated in arising local communities focused on circular fashion. The tools entail 1) visual representation for systemic challenge ideation, 2) a prospective actions framework and 3) business model comparison.

SYSTEMS-ORIENTED DESIGN

Systems-Oriented Design aims to help designers to deal with complex real-world problems in the modern, rapidly changing society (Sevaldson, 2009). It is an approach that sits closer to design-oriented approaches in the field of systemic design. The process entails giga-mapping, in which ecosystems are mapped out with multiple layers of relevance and interconnected relations, as well as consequential effects and points of friction. This approach has been used in the context of the denim industry before by Lieke van Raan (2019), but through the scope of introducing closed-loop systems at end-of-life and back-feeding post-consumer recycled cotton in the chain.

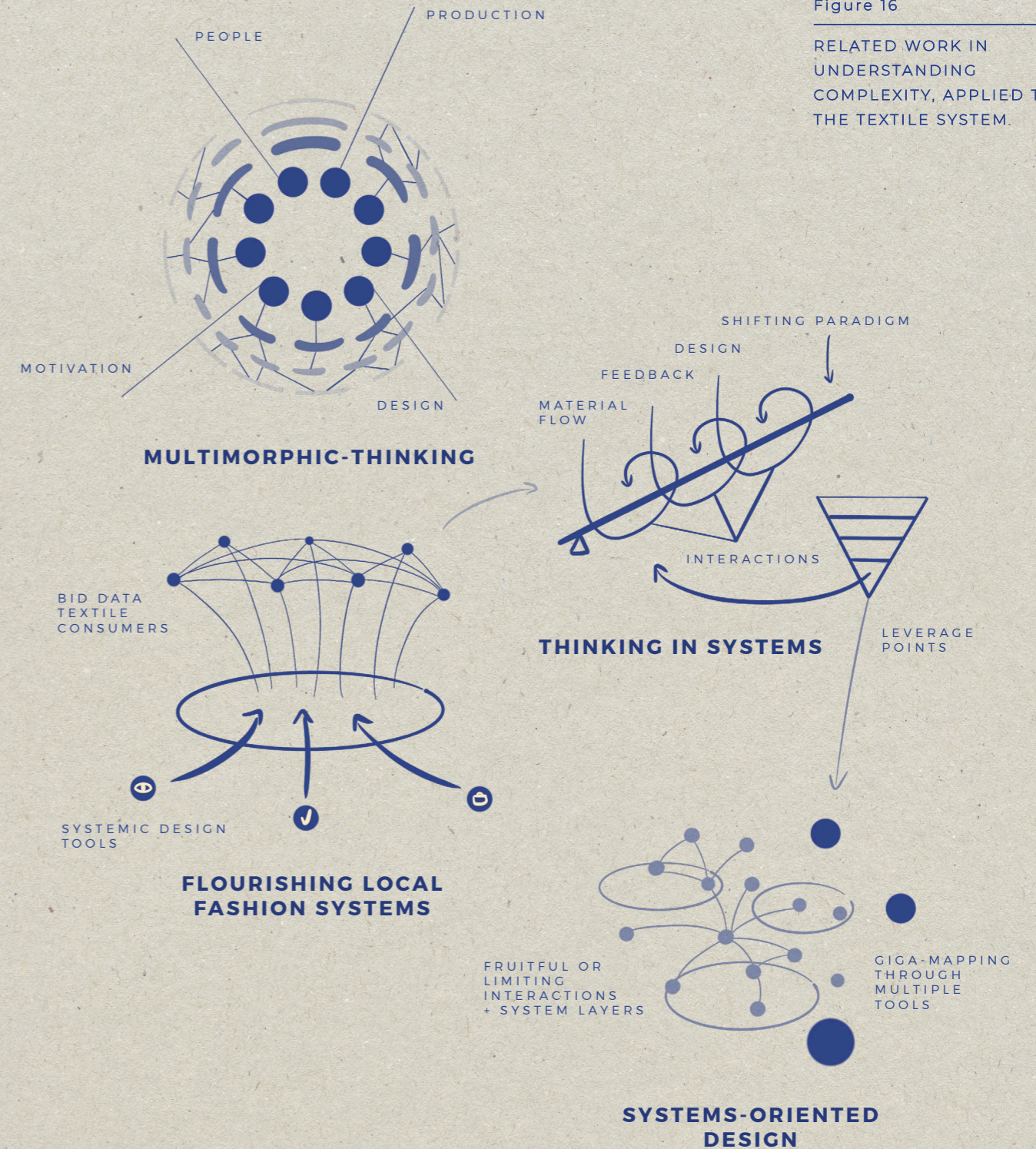


Figure 16
RELATED WORK IN UNDERSTANDING COMPLEXITY, APPLIED TO THE TEXTILE SYSTEM.

THE GAP

A “window of opportunity” is illustrated by Geels (2002), where various factors, including innovative niches, socio-technical landscapes, and policymakers, align to initiate systemic change. This convergence is crucial for driving significant and sustainable transformation within a system (figure 17).

All aforementioned related work exemplifies elements of importance in moving towards a more sustainable fashion system: either through **a)** addressing circular economy approaches focused at closing loops in later stages, **b)** designing zero-waste patterns through innovative techniques, with in some cases pointing out important interrelated facets providing insights of opportunities to be further explored, and **c)** approaches of systemic design in general aspects of the textile system.

However, specifically investigating how all these different approaches tie in together, and how interconnected system elements can be leveraged on to exhibit the potential of niche innovative design-manufacturing methods like 3D weaving towards reaching this **window of opportunity**, has not been exemplified yet. Thereby, identifying which steps are necessary to do so is a gap to be filled. Especially in the light of the denim system, a particularly rigid and long established industry, with limits to achieving complete systemic change in eliminating all harmful aspects, this gap can be interesting to explore.

THE GAP

Investigating how interconnected system elements can be leveraged on to exhibit the potential of niche innovative design-manufacturing methods towards reaching the window of opportunity, in the case of 3D weaving denim.

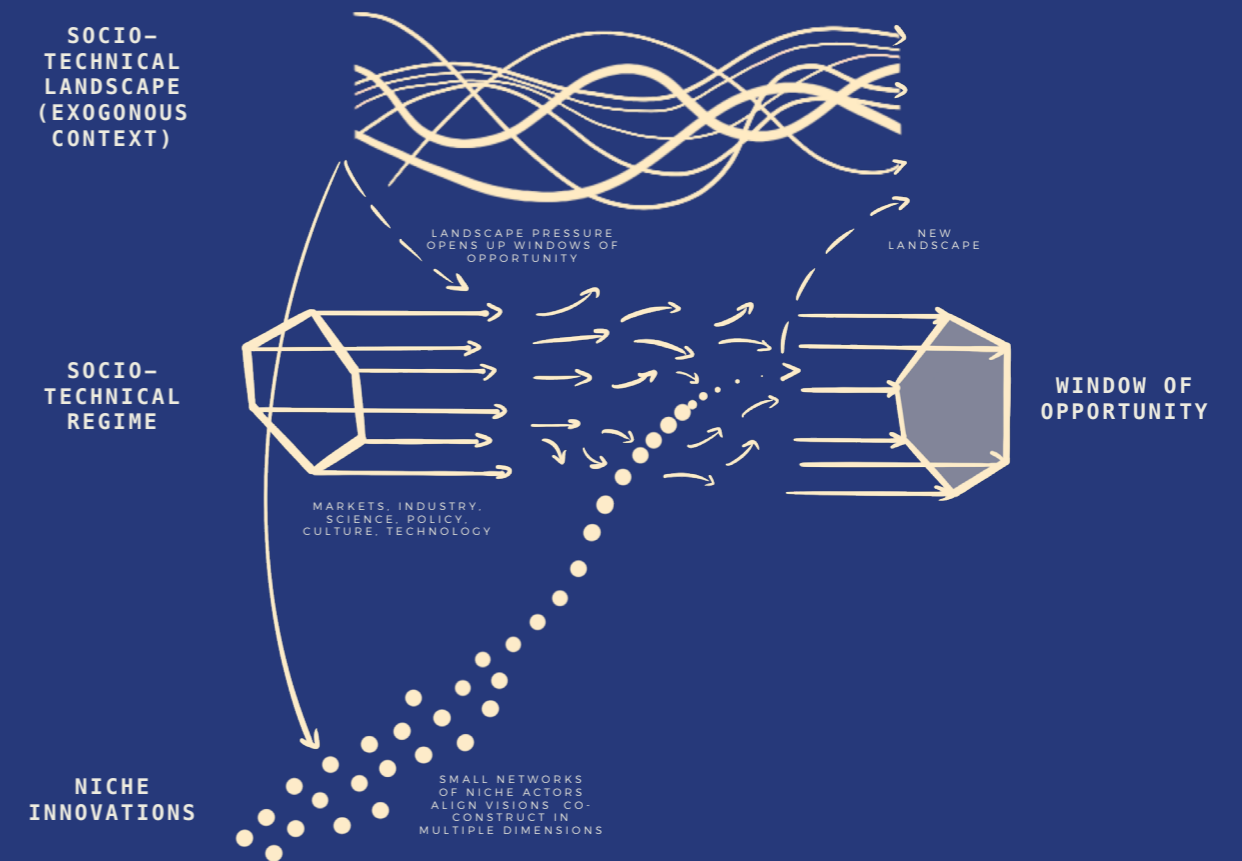


Figure 17
MULTI-LEVEL PERSPECTIVE ON TRANSITIONS, ADAPTED FROM GEELS (2002)

CHAPTER TAKE-AWAYS // RELATED WORK

OVERALL CONCLUSION

The diverse range of related work in sustainable fashion highlights important aspects such as circular economy practices, zero-waste pattern design and systemic design approaches. However, there is a need for further exploration to understand the interconnections between these approaches and how they can be leveraged to unlock the potential of innovative design-manufacturing methods like 3D weaving. Specifically, in the context of the long-established denim industry, which presents unique challenges, there is an opportunity to explore how the case of 3D weaving and its potential could be exhibited through a multi-layer systemic perspective.

TOWARD A CIRCULAR ECONOMY

Although circular economy approaches in denim often prioritise closing loops in end-of-life stages, it is important not to overlook the significant amount of pre-consumer waste generated in the design and cutting processes of denim patterns. This excess material, often sent immediately to incineration or landfill, is estimated at 10-15% per pattern average (Enes & Kipöz, 2019). Focusing on reducing this waste during the design stage aligns with the principle of 'R1: Reduce' and is a crucial aspect of transitioning the denim industry towards a circular economy.

NEW DEMANDS

It is necessary to explore strategies for expanding the group of eco-conscious fashion consumers, while also implementing mechanisms that foster a stronger identification with sustainable clothing choices to effectively bridge the value-action gap. Additional policy and regulation measures on EU and national level, quickly coming into effect, serve as crucial factors of influence - affecting the strategy to be designed, aiming to explore alternative models for fashion. By aligning with these policies in further conceptualisation of this project, the strategy can effectively contribute to the goal of fostering systemic change in the Dutch denim market.

On-demand production can enable tailor-made experiences through customisation and made-to-measure opportunities, reflecting both consumer needs in unique identity-crafting and sustainability. On-demand caters to the today's fast-paced, digitally-driven economy, through a micro-factoring model and proximity production approaches eliminating logistical emissions. However, this also raises concern in potentially contributing to the perpetuation of fast fashion and the constant need for new clothing, without necessarily fostering a stronger emotional connection to garments, as it operates within the existing capitalist framework.

3D weaving of garments is a design-manufacturing technique that creates multi-layered structures and integrated seams in a single step, obtaining an almost complete garment form when unfolding the structure without cut and sew waste (Map of Bindings // binding pattern). Due to its shorter supply chain and integrated design-manufacturing process, 3D weaving is well-suited for small-scale manufacturing. This makes it compatible with micro-manufacturing and on-demand approaches. Additionally, this could fit in the context of relocalisation, mentioned in the previous chapter. By combining the principles of zero-waste production and alternative aesthetics, 3D weaving presents an opportunity for creating new sustainable design-to-consumer models through a more holistic approach.

Investigating how interconnected system elements can be leveraged on to exhibit the potential of niche innovative design-manufacturing methods towards reaching the window of opportunity, in the case of 3D weaving denim.

ON-DEMAND

3D WEAVING

THE GAP

PROBLEM DEFINITION

CHAPTER 3

3.1	RESEARCH AIM
3.1.1	OVERALL FRAMING
3.1.2	RESEARCH QUESTION
3.2	STAKEHOLDERS // COLLABORATION PARTNERS
3.3	METHODOLOGY
3.3.1	METHODOLOGY DESCRIPTION
3.3.2	RESEARCH ACTIONS
	TAKE-AWAYS

Building upon the identified research gap from the previous chapter, this chapter introduces the purpose and contribution of the present research in addressing that gap. The aim is defined as ‘exemplifying how the emerging fashion design-manufacturing technique of 3D weaving can be employed for changing into more sustainable design-to-consumer models through a holistic strategy.’ The overall framing of the project is illustrated, followed by the introduction of the main research question: ‘How can the technique of 3D weaving garments be utilised to drive systemic change within the Dutch denim market?’ This question is further supported by sub-research questions (3.1). Next, the stakeholders involved in this project are introduced (3.2). The chapter concludes by outlining a higher level description of the methodology employed in this project, as well as the research actions, methods and tools utilised to address the research questions and achieve the overall research aim (3.3).

3.1 RESEARCH AIM

The contribution of this research is to **exemplify how the emerging fashion design-manufacturing technique of 3D weaving can be employed for changing into more sustainable design-to-consumer models through a holistic strategy.** This research aims to fill the gap as concluded in the previous chapter, in the context of the rigid denim industry and Dutch denim market as scope, through mapping interrelated system elements, identifying leverage points and aligning actors in such a way that they self-initiate transformative action. In this research, 3D weaving is used as an exemplary case to illustrate how the potential of methods alike can be effectively employed to create systemic change, aiming to instigate a cascading effect toward the effective implementation of other techniques through systems-oriented design approaches.

3.1.1 OVERALL FRAMING

Figure 18 gives an overview of the scope of the problem, thus pointing to relevant research areas to be explored.

On the next page, the main research actions are framed through four phases of the Double-Diamond model (van Boeijen et al., 2020). This is followed by the definition of the research questions and sub-questions.

- < **DISCOVER** ...the context of problem to be defined, through conducting research through literature review and other research methods.
- > **DEFINE** ...limited boundaries in which the problem can be solved.
- < **DEVELOP** ...ideas which provide a solution to the problem.
- > **DELIVER** ...a validated design concept.

Within these main phases, adaptability to timing and emerging possibilities is applied, pointing to an iterative approach, rather than a mere linear approach of convergence-divergence-convergence-divergence.



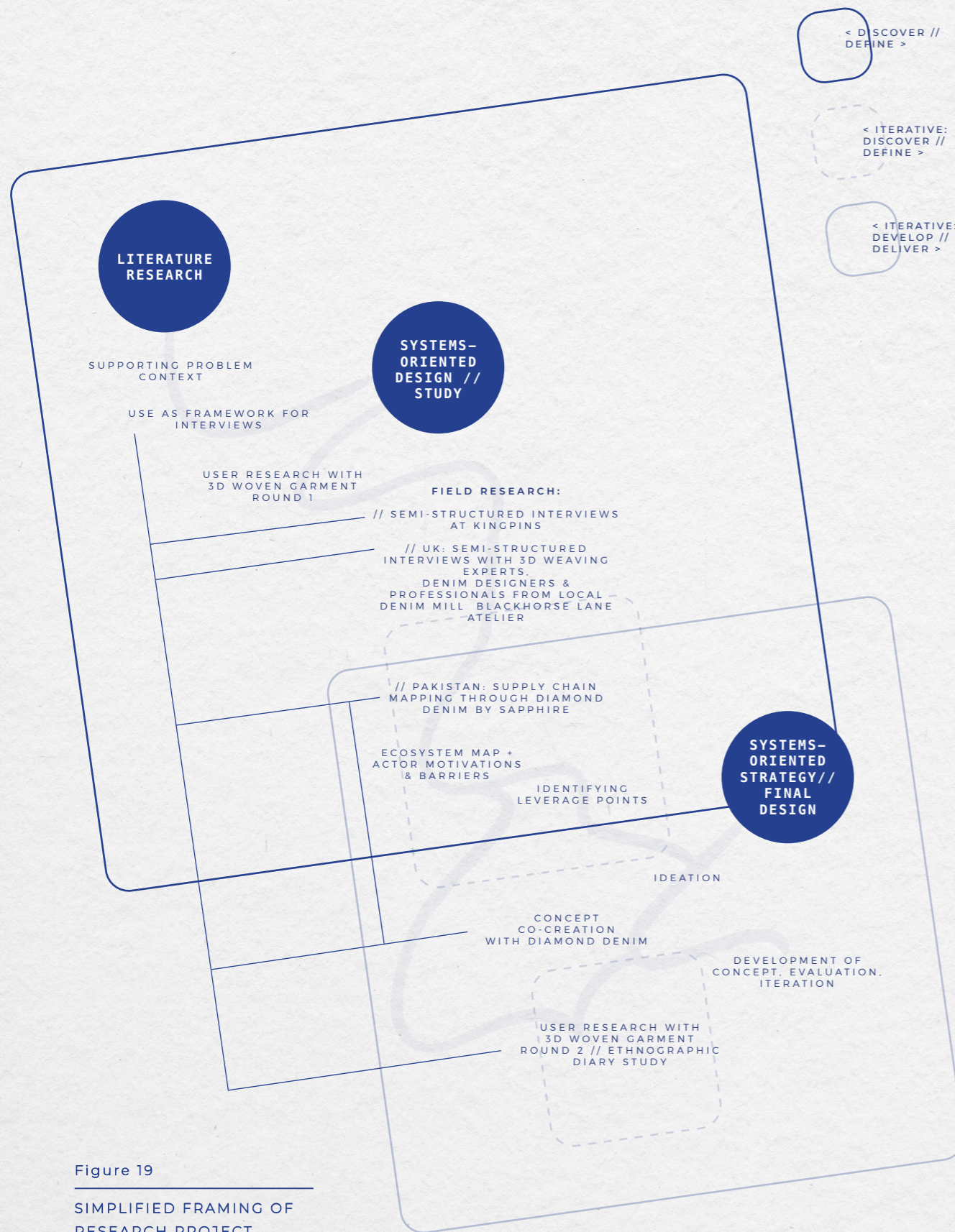


Figure 19
SIMPLIFIED FRAMING OF RESEARCH PROJECT

3.1.2

RESEARCH QUESTION

As explained before, exhibiting the potential use of 3D weaving in the denim industry is a complex systemic challenge. Addressing this challenge requires a holistic approach, in which the interconnectedness between stakeholders and problems needs to be thoroughly understood. Through the utilisation of a Systems-Oriented Design approach (Sevaldson, 2009), the following main question will be researched:

RQ0 // HOW CAN THE TECHNIQUE OF 3D WEAVING GARMENTS BE USED TO ACHIEVE SYSTEMIC CHANGE WITHIN THE DUTCH DENIM MARKET?

Consult section 3.3 Methodology for a further explanation behind the approach.

With the following sub-questions:

- RQ1 // What are consumer's perceptions of 3D woven denim forms?
- RQ2 // How do the different layers of the denim supply chain and overall system interact and influence each other?
- RQ3 // What are motivations and barriers for identified system-actors toward the implementation of alternative sustainable models?
- RQ4 // What are 3D weaving-specific barriers toward the implementation of alternative sustainable models?
- RQ5 // What are potential leverage points for 3D weaving-related interventions in the current denim system?
- RQ6 // How might the outcomes of the aforementioned subquestions translate into a strategy to unlock the potential of 3D woven denim, parallel to current denim?

3.2

STAKEHOLDERS// COLLABORATION PARTNERS

This graduation project has been organised with the active involvement of multiple collaboration entities, primarily during the research phase. One significant collaboration was established with denim designer and historian Mohsin Sajid, who not only served as an expert, but also as a networking mentor, to various denim field experts. Other networking opportunities arose at events such as Kingpins Show and a Blackhorse Lane Atelier party. Weffan by Graysha Audren, a 3D weaving garment company, provided valuable insights from an expert perspective.

To gain a comprehensive understanding of the denim value chain and conduct user research with 3D woven prototypes, a crucial collaboration was established with Diamond Denim by Sapphire. Barbara Vroom (2022), an industrial fashion designer, has designed 3D woven denim jackets during her own graduation project. This project is in part an extension of her research, in which she previously has worked with Diamond Denim as well. By working with both Barbara and Diamond Denim, we were able to reweave new trials of the jackets, facilitating thorough user research as described in the next subsection.

No commercial entity was engaged as a client, due to anticipated limitations on the freedom of exploratory research with 3D woven samples and the project's focus on understanding user perception and driving systemic change rather than seeking a commercial outcome.

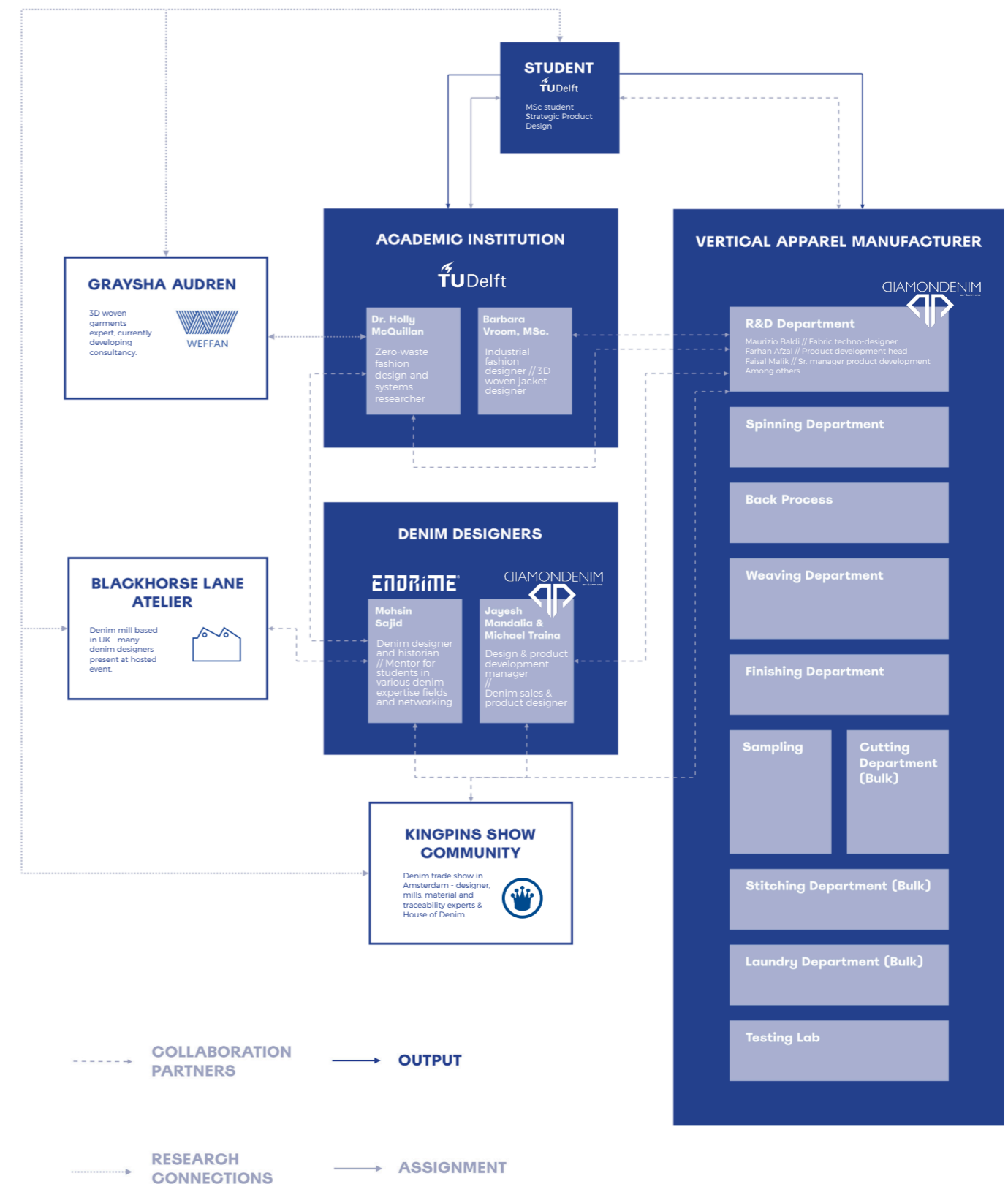


Figure 20
OVERVIEW OF PROJECT
COLLABORATION PARTNERS AND
THEIR RELATIONS

3.3.

RESEARCH METHODOLOGY

This subsection presents an overview of the methodology employed in this project. The Systems-Oriented Design approach was selected as a comprehensive and suitable methodology, encompassing various elements derived from the relevant literature on understanding complexities in the textile industry. Of particular significance is the inclusion of a consumer-focused component, involving user research with 3D woven denim samples. This aspect was deemed essential due to the recognition that implementing new models and driving paradigm shifts necessitates a thorough understanding of user needs, values and perceptions of sustainable innovations, especially within the established denim industry. It is crucial to identify the bottlenecks associated with embracing a new aesthetic and sustainable form of denim, and consider them within the broader strategy to be designed to ensure effectiveness. Additionally, the subsection outlines further research actions and considerations in detail.

3 . 3 . 1

METHODOLOGY DESCRIPTION

SYSTEMS-ORIENTED DESIGN

In Chapter 2.3 (Attempts at Understanding Complexity), various categorisations of systemic design were explored, highlighting the diverse approaches that exist for understanding complexity. Considering the examples applied to the textile industry, led to the decision of adopting a qualitative, Systems-Oriented Design approach for this research project. Given the intricate nature of the denim industry, where a high variety of actors and factors, each representing unique needs and (inter)dependencies, influence the system on various layers. Systems-Oriented Design (SOD) proves suitable as it captures complexity and focuses on understanding interactions within the system, and is particularly argued to be useful for designers dealing with wicked societal problems. This aligns with Murphy's (2022) contention regarding the importance of acknowledging the interdependencies among components and their pertinence in strategic problem-solving and innovation. The approach encompasses a wide range of accessible tools and methods for designers, often intersecting with elements from other systemic design approaches. Consequently, the adoption of SOD is understood as the most comprehensive option for addressing the research question, aiming for a thoroughly grounded strategic design solution in unlocking the potential of 3D woven denim, towards systemic transformation. Figure 21 illustrates the SOD methodology applied to this research. Subsection 3.3.2 shows a more detailed

overview of all research actions undertaken within this overall approach, including the research sub-questions that are aimed to be answered through each action.

THE CONSUMER

According to Camacho-Otero, Boks, & Nilstad Pettersen (2019), one of the major criticalities encountered by radical innovations is the lack of consumer or user acceptance. This refers to the favourable inclination of an individual to adopt a product or utilise a new service. To address this challenge, user research plays a critical role in the development of any product, including denim. By gathering insights and feedback from users, it becomes possible to better understand their needs, preferences, and behaviours. In the case of 3D weaving denim, user research is particularly crucial due to the unique characteristics of denim fabric, known for its durability, comfort, and versatility. Given the adaptations required by the 3D weaving technique, impacting the garment form and aesthetics, it is essential to ensure that consumer needs and preferences would be adequately met in the case this garment category would enter the market through any alternative fashion model. Furthermore, the need for a paradigm shift in consumer behaviour has been recognised, while acknowledging that merely relying on top-down strategies yields limited impact, especially when the expectation is solely placed on consumers to initiate change. Therefore, incorporating a consumer-focused perspective becomes essential to address this aspect

comprehensively and foster a more effective and holistic design outcome.

Thus, two rounds of user research were conducted, which will be further discussed in Chapter 4 Study. The first was situated in the initial part of the process, in which 3D woven denim jacket samples from Barbara Vroom (2022) were utilised to conduct 20 semi-structured interviews with, aiming to answer Research Question 1 and 3. A semi-structured approach is preferred in social research due to its ability to yield deeper insights in addressing research questions. The method allows for the natural flow of conversation while maintaining flexibility based on the participant's responses. In-depth, semi-structured interviews involve verbal exchanges where an interviewer seeks to gather information through asking open-ended questions. This research methodology is particularly valuable when delving into intricate behaviour, opinions and emotions, while also capturing a wide range of diverse experiences. However, it should be acknowledged that ethical dilemmas may arise concerning power dynamics or in the researcher-participant relationship (Belina, 2023; Longhurst, 2009).

Although the initial semi-structured interviews were conducted thoroughly, with each lasting approximately an hour, the participants' responses were limited to their initial impressions of the 3D woven jackets. Recognising the need to assess the actual perception of the garments over a longer period, a second round of research was

implemented. In this phase, participants were provided with one of two jacket types, and were asked to wear them every day for a duration of a month. They were encouraged to report their experiences and insights on a daily basis through an ethnographic user diary (User Interviews, n.d.), derived from the discipline of anthropology. This approach allows for a more comprehensive understanding of the patterns, values, and barriers that influenced participants' daily lives, shaping their perception and utilisation of the garment. By accessing tacit values and gaining insights into their uncommunicative experiences and intuitive knowledge, the researcher could draw more accurate conclusions. Additionally, a deliberate effort was made to include participants from diverse cultural backgrounds and with varying opinions regarding current denim wear. This inclusion is important because these factors could potentially influence their perception of the textiles. Fashion meanings are continuously evolving as they engage with distinct sociohistorical, economic, and cultural contexts, making a diverse participant pool essential for a comprehensive analysis (Tse, 2016).

This user research round required the weaving of new trials of the 3D woven denim jackets with Diamond Denim. Due to time constraints, the production of these samples had to be scheduled for a later stage of the process. As a result, the findings from this user research were primarily used for validation and recommendation purposes after conceptualisation was almost completed.



Figure 21
SYSTEMS-ORIENTED
METHODOLOGY

3 . 3 . 2

RESEARCH ACTIONS

This subsection showcases an overview of the research actions undertaken during the project, in order to answer the research question and sub-questions, adhering to a Systems-Oriented Design approach. The actions are not entirely in chronological order, since some phases were subject to an iterative process (as seen in figure 19) due to the research opportunity with Diamond Denim in Pakistan occurring later in the process.

Research actions, tools & methods

RESEARCH AIM

Literature review (RQ2+3)

UNDERSTANDING THE BROADER CONTEXT

A comprehensive literature review was conducted to explore the problem background and answer Research Questions 2 and 3. This analysis further contributed to the framing of the remaining research questions and defining the research actions to be undertaken in subsequent phases of the project.

Literature review forming the basis for semi-structured interview guides for:

Framework - User research round 1 (RQ1+3; 20 participants)

User research round 2, ethnographic research diary (RQ1+3+4+6; 10 participants)

UNDERSTANDING THE ECOSYSTEM & FUTURE PARADIGM FACTORS

Literature review served as the foundation for developing a framework to create a semi-structured interview guide. This approach ensured that the initial round of user research was grounded and comprehensive, with the primary aim of addressing Research Questions 1 and 3, as a more extensive second round of user research would only be able to be conducted at a later stage of the process. Consequently, the outcomes of the latter user research round were primarily used to validate the final concept, and integrated into an iteration of a roadmap, as well as providing valuable recommendations for future research.

To initiate the process, a total of 14 industry experts in the field of denim were interviewed at the Denim Trade Show Kingpins in Amsterdam. These interviews were conducted using a semi-structured approach, encompassing various pertinent subjects such as materials, sustainable manufacturing, the Dutch denim market, certification, and traceability. The objective was to address Research Questions 2 and 3.

Expert interviews at Kingpins with denim designers, mills, material and traceability experts & House of Denim (RQ2+3; 14 participants)

In the UK, an unstructured interview approach was employed with a denim designer and historian, spanning an entire day. This individual possessed prior knowledge of 3D weaving in the context of denim. The purpose of this interview was to address Research Questions 1, 2, 3, and 4. Additionally, two Japanese denim experts were interviewed for a shorter duration of approximately 20 minutes each, focusing on Research Questions 2 and 3.

Unstructured interviews:

Expert interviews in UK - Denim designer and historian from Endrime, Japanese denim experts, designers and field experts at Blackhorse Lane Atelier, & UK trendwatchers/design consultants for Diamond Denim (RQ 2+3+4+5+6)

At the Blackhorse Lane Atelier, unstructured interviews were conducted with 18 individuals over a time frame of approximately four hours. These participants included denim designers, experts in denim education, and ozone-finishing experts from Tonello. The aim of these interviews was to explore Research Questions 3, 4 and 5.

Lastly, unstructured interviews were held with two UK-based denim consultants associated with Diamond Denim. These consultants closely monitor trends and have a direct connection with final retailers. Some time was spent with them during the delivery of samples to Asos. The objective here was to gain specific insights into the power dynamics and communication between final fashion brands and overseas denim mills, adhering to Research Question 2. A rapid giga-mapping process followed the previous research actions.

Rapid giga-mapping based on previous research actions:

Actor mapping (RQ2+5)

Preliminary ecosystem mapping (RQ2+5)

Interconnected problem networks (RQ5)

Field research in Pakistan:

Semi-structured interviews and tours with all heads of departments at Diamond Denim (RQ2+4; 8 participants)

Supply chain mapping (RQ2)

Ecosystem mapping (RQ2+3+4+5+6)

Discussion of identified barriers & motivations toward new model and 3D weaving acceptance among different system actors (RQ2+3+4)

Unstructured interview:

3D weaving expert Weffan (RQ3+4)

Using theory of Meadows (2008) and model of Kanial et al. (2018) (RQ5)

Through field research conducted in Lahore, Pakistan, a valuable opportunity arose to delve into the intricacies of supply chains by visiting the denim mill, Diamond Denim. Semi-structured interviews were conducted with the aim of comprehending their internal supply chain operations, as well as gaining insights into the interdependencies among different system layers (Research Question 2). The other objective was to explore the motivations and obstacles associated with implementing alternative sustainable techniques (Research Question 4). The overarching goal was to gain a holistic understanding of the broader supply chain dynamics within the denim industry. A general denim supply chain map was created subsequently (access Appendix F), forming the basis for a final ecosystem map in combination with research insights from earlier actions.

The outcomes of the previous research actions were discussed through interconnected factor tables, in which identified barriers & motivations toward new model and 3D weaving acceptance among different system actors were showcased.

To address Research Questions 3 and 4, a semi-structured interview was conducted with an expert in 3D weaving.

CONCEPT DEVELOPMENT OF FEASIBLE SYSTEMS-ORIENTED STRATEGY

To go from research in the present to design for the future, the theory of Meadows (2008) and model Kanial et al. (2018) were applied. The aim was to identify leverage points where an intervention with 3D weaving could yield the highest systemic impact, through the lens of the Dutch Denim market, relating to Research Question 5.

Co-creative sessions took place at Diamond Denim, involving multiple groups of experts and department heads. The objective was to collaboratively refine and develop previously determined key components of a final strategy. These sessions aimed to assess the suitability of the identified leverage points and evaluate the feasibility and desirability of the proposed design direction from the perspective of supply chain experts, supporting Research Question 6.

To conclude, the designed strategy was validated through multiple methods. Firstly, the second round of user research included a section in the ethnographic booklet where the concept was implemented. The aim was to evaluate whether this group of users of 3D woven denim jackets perceives the visual component of the strategy, referring to a label, as a feasible and positive contribution to the new woven form. Further outcomes of this round of user research were implemented in an iterated roadmap, as well as future recommendations.

Furthermore, unstructured interviews took place with people who did not have prior knowledge of 3D woven denim forms, to test whether they understand the entire strategy and, again, perceive the visual component of the label as a feasible and positive contribution.

The strategy was further validated by conducting a semi-structured interview with an expert in supply chain traceability and product passports. This validation process was essential because the feasibility of the strategy is influenced by impending policy changes at both national and EU level. The insights provided by the expert helped ensure that the strategy aligned with the anticipated regulatory landscape in the near future.

Finally, the marketing aspect of the strategy underwent evaluation by a denim consultant/trendwatcher. This resulted in practical recommendations and insights to further enhance and refine this particular element in a well-informed manner.

Co-creative sessions with multiple groups of experts at Diamond Denim, Pakistan (RQ6)

Validation (RQ6):

User research round 2, last week of ethnographic diary = concept evaluation

Consumer evaluation, unstructured interviews first-time viewers

Roadmap evaluation and iteration through semi-structured interview with supply chain traceability expert

Branding and marketing element evaluation with denim trendwatcher

CHAPTER TAKE-AWAYS // *PROBLEM DEFINITION*

RESEARCH AIM

This research project aims to exemplify how the emerging fashion design-manufacturing technique of 3D weaving can be employed for changing into more sustainable design-to-consumer models through a holistic strategy. The previous chapter highlighted the challenges and unsustainability of current denim production practices, setting the context for this research.

METHODOLOGY

To address the research questions and develop a strategic design solution, a Systems-Oriented Design (SOD) approach is adopted. SOD is well-suited to tackle the complexity and interdependencies within the denim industry, providing a thorough understanding of the system and its interactions. This approach aligns with the acknowledgement of interdependencies among components toward strategic problem-solving and innovation.

Consumer acceptance is crucial for the success of radical innovations like 3D weaving. User research plays a vital role in understanding consumer needs, preferences, and behaviours. In the case of 3D woven denim, user research becomes even more significant due to the unique characteristics and potential impact on garment form and aesthetics.

Through specific research actions, including mapping interrelated system elements, finding crucial factors of influence in shifting to alternative models for fashion, and further identification leverage points, this study seeks to unlock the transformative potential of 3D woven denim.



A

THE PRESENT

4.1

MAPPING THE CURRENT DENIM SYSTEM

4.1.1 METHODOLOGY

4.1.2 ECOSYSTEM MAP // RESULT

4.1.3 ZOOMING IN // DISCUSSION

SECTION TAKE-AWAYS

B

TOWARD A PARADIGM SHIFT

4.2

UNDERSTANDING THE CONSUMER MINDSET

4.2.1 METHODOLOGY

4.2.2 USER RESEARCH ROUND 1 // RESULTS

4.2.3 USER RESEARCH ROUND 2 // RESULTS

4.2.4 USER RESEARCH // DISCUSSION

SECTION TAKE-AWAYS

4.3

IMPLEMENTING NEW MODELS

4.3.1 METHODOLOGY

4.3.2 KEY COMPONENTS // RESULTS

4.3.3 INDUSTRY-LED CHANGE // DISCUSSION

4.3.4 RELOCALISATION // DISCUSSION

4.3.5 REIMAGINED DENIM DESIGN ROLES // DISCUSSION

4.3.6 CONSUMER COMMUNICATION // DISCUSSION

SECTION TAKE-AWAYS

4.4

GENERAL DISCUSSION // ADOPTION MOTIVATIONS & BARRIERS

4.4.1 MOTIVATIONS // DISCUSSION

4.4.2 BARRIERS // DISCUSSION

GENERAL DISCUSSION // 3D WEAVING-SPECIFIC BARRIERS

CHAPTER TAKE-AWAYS

STUDY: PRESENT TO PARADIGM SHIFT

UNDERSTANDING THE CURRENT
DENIM ECOSYSTEM, THE
CONSUMER MINDSET BEFORE
SHIFTING PARADIGMS AND
CRUCIAL FACTORS TOWARD
NEW MODEL IMPLEMENTATION

CHAPTER 4

This chapter offers a detailed overview of the studies conducted within the project. Firstly, to gain an understanding of the present state of denim (A), the current denim system is analysed and an ecosystem map is created, followed by an in-depth discussion of its elements (4.1). Furthermore, the chapter delves into the studies conducted toward driving a paradigm shift (B). Two rounds of user research, utilising 3D woven denim garments, are presented. Although different set-ups and implementations were employed across these studies, both rounds yield similar outcomes, which are subsequently discussed (4.2). The third study is specifically focused on identifying key factors in the adoption of alternative design-to-consumer models in the fashion system, both within the context of 3D weaving and the broader denim industry. The crucial factors identified are extensively examined (4.3). After all the studies are completed, a comprehensive discussion ensues to conclude the chapter (4.4). This discussion highlights the interconnections among relevant actors in the system, explores their motivations and barriers towards implementing new models, and specifically addresses the implications for 3D weaving.

THE PRESENT //A

4.1

MAPPING THE CURRENT DENIM SYSTEM

In this section, an overview of the current denim system is presented, specifically from the perspective of the Dutch denim market. First, an ecosystem map is showcased, which identifies layers of crucial stakeholders within the denim system and outlines key challenges associated with sustainable denim production. This map is the result of comprehensive analysis and synthesis of insights from various research methods and sources. For instance, field research in Pakistan, through collaboration with Diamond Denim by Sapphire, allowed for gaining insight into their supply chain, forming the basis of a more average supply chain map as shown in Appendix F. This was used for the final ecosystem map illustrated in this chapter, in combination with earlier gathered insights through literature and expert interviews held at Kingpins and the Blackhorse Lane Atelier. Subsequently, the section delves into specific components of the map, offering more detailed explanations of the most significant steps within the supply chain. This study helped answer Research Questions 2 to 6:

RQ2 // How do the different layers of the denim supply chain and overall system interact and influence each other?

Is addressed through this section's discussion 'Zooming in'.

RQ3 // What are motivations and barriers for identified system-actors toward the implementation of alternative sustainable models?

Is addressed through this section's discussion 'Zooming in' and overall discussion 4.4 'Adoption motivations & barriers'.

RQ4 // What are 3D weaving-specific barriers toward the implementation of alternative sustainable models?

Is addressed through the overall discussion 4.5 '3D weaving-specific barriers'

RQ5 // What are potential leverage points for 3D weaving-related interventions in the current denim system?

Is addressed through Chapter 5.1.1 'Identifying leverage points'

RQ6 // How might the outcomes of the aforementioned subquestions translate into a strategy to unlock the potential of 3D woven denim, parallel to current denim?

Is addressed through Chapter 5.4 'Final Design | Discussion'

4.1.1

METHODOLOGY

SYSTEM MAPPING METHOD

Insights were gathered through **3 modes of research**.

1) First, a basic comprehension of the system and relevant Dutch elements was gained from **literature research**. 2) Furthermore, **unstructured and semi-structured interviews** were conducted with multiple experts in the field. These include denim designers and various stakeholders within denim mills. The interviews were established through visiting Kingpins Show and the Blackhorse Lane Atelier. 3) **Field research** was carried out at Diamond Denim by Sapphire, a vertical denim mill in Lahore, Pakistan. Here, a thorough understanding of a denim supply chain was obtained through interviews and department tours. **Additional tools:** preliminary giga-mapping of actors, the ecosystem and interconnected problems, as well as a supply chain map (Appendix F) led to this final result.

NOTE: Diamond Denim is a mill which is focused on investing in more sustainable supply chains where possible. Although they were open about their own current challenges, it is important to understand that many other denim mills do not have the same access to modern equipment or responsible waste management. The map is a reflection of the broader ecosystem. Therefore, distinctions are made in the map between general insights and field-specific insights.

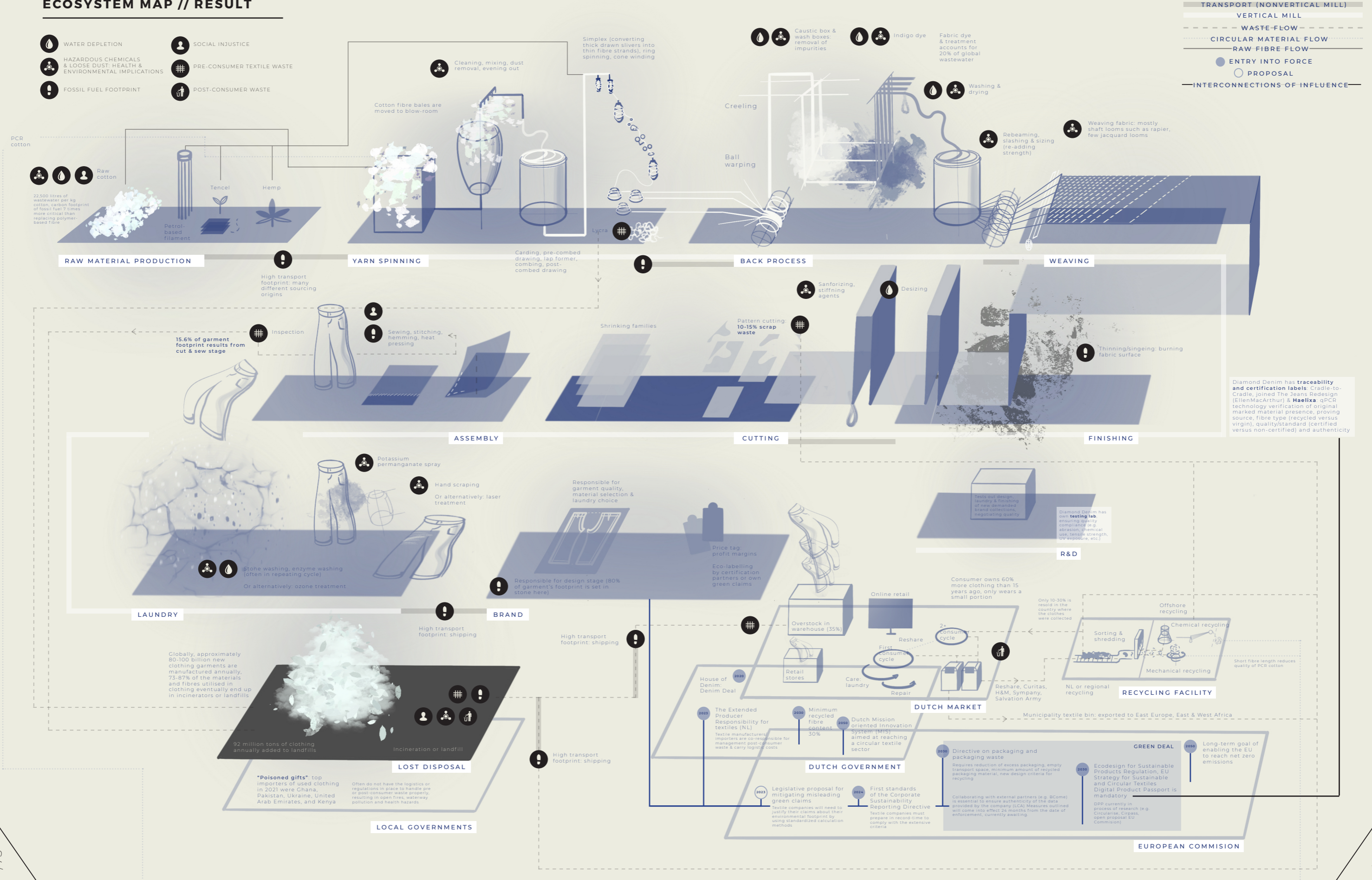


A complex problem domain necessitates a multifaceted approach to understanding, as it resides within a system comprised of diverse socio-technical elements, layers and actors (Murphy, 2022; Norman & Stappers, 2015; Sevaldson, 2009). Thus, the result of the ecosystem map is analysed in detail by zooming in on its various elements, which are further analysed in the general discussion of this chapter, together with the results from the other studies conducted (4.4).

To reduce blindspots and access otherwise intransparent details, the information gathered (forming the basis of the map) was checked in accordance with all the heads of departments at Diamond Denim (the head of every step of their in-house supply chain). Moreover, co-creative sessions held there provided another opportunity to validate the insights. The following subsection shows the final ecosystem map.









ECOSYSTEM MAP // RESULT



4 . 1 . 3

ZOOMING IN // DISCUSSION

1. RAW MATERIAL PRODUCTION

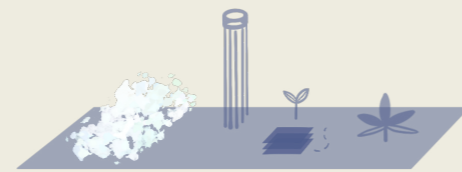
-  WATER DEPLETION
-  SOCIAL INJUSTICE
-  HAZARDOUS CHEMICALS & LOOSE DUST; HEALTH & ENVIRONMENTAL IMPLICATIONS
-  PRE-CONSUMER TEXTILE WASTE
-  FOSSIL FUEL FOOTPRINT
-  POST-CONSUMER WASTE

The initial stage of denim production involves the sourcing of raw fibre production. Traditionally, denim was exclusively produced using 100% cotton: a natural fibre. While this practice continues partially, modern denim production often incorporates a variety of other fibres, each with their own distinct production processes and associated negative impacts. Textile production relies on over 97% virgin feedstock (Ellen MacArthur Foundation, 2017).

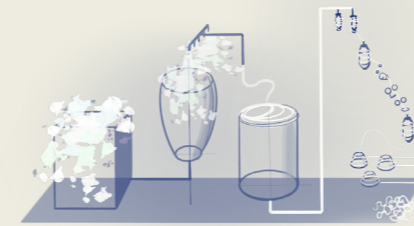
Cotton cultivation dominates the global textile industry, accounting for 31% of its fibre output. With an annual production of 26 million tonnes, cotton farming sustains millions of workers worldwide (Forum for the Future, n.d.). However, the industry faces significant challenges. Farmers endure exploitative practices, low wages, and hazardous conditions due to a **significant lack of regulation, intransparency and corruption**. Cotton cultivation is **water-intensive**, with each kilogram of cotton produced (in India) requiring 22,500 litres of non-reusable water, straining local water systems (Eartha, 2017). **Pesticide and chemical use** causes biodiversity loss, soil erosion and further compromising the health of labourers. Among the approximately 90 million cotton farmers, a mere 45,500 are Fairtrade-certified (Fairtrade Foundation, 2020). Moreover, terms as 'organic' cotton are often misleading, as they still fail to address water depletion and do not ensure fair labour conditions.

Petrochemical materials like polyester, nylon and elastane are frequently blended with cotton. These synthetic fibres are used in denim to enhance factors such as stretchability and abrasion resistance. The production of these materials not only results in significant carbon dioxide (CO₂) emissions, but also contributes to the depletion of **fossil resources**. Furthermore, microfibres are released into the environment throughout the stages of manufacturing, usage, and disposal, leading to additional environmental pollution (Parrilla-Lahoz et al., 2022) It is important to consider that the production of one kilogram of cotton t-shirts requires seven kilograms of fossil fuel. This highlights the significance of replacing fossil energy sources in the production chain or finding alternative solutions to cotton cultivation, which is **seven times more critical than replacing polymer-based fibres** (Wennberg & Östlund, 2019).

Among the emerging materials in denim with a stronger sustainable track record, lyocell and TENCEL™ stand out. Both are essentially the same regenerated cellulose fibres. However, it is important to highlight that regular lyocell faces sustainability challenges related to sourcing plant fibre and waste water disposal, whereas the branded TENCEL™ has made strides in addressing these concerns. Another noteworthy alternative to virgin cotton is hemp, a natural fibre with excellent strength and abrasion properties. Hemp cultivation requires less water and specific environmental conditions compared to cotton.



Studies investigating clothing comfort in denim fabric made from regenerated cellulosic fibres have revealed that a combination of indigo-dyed cotton warp and viscose filament/Tencel weft results in enhanced comfort when worn. Regenerated cellulosic fibre, including viscose, Modal, ProModal, TENCEL™, as well as blends of cupro, rayon and bamboo, have emerged as significant sustainable alternatives for denim production. In addition to their more eco-friendly properties, (regenerated) cellulosic fibres and yarns offer desirable characteristics such as a soft touch, lightweight feel, subtle appearance, flexibility, good fit, comfort, strength, and durability to denim garments (Kumari & Khurana, 2016).



Cotton and other materials used in denim production often originate from a variety of countries. The **transportation** of cotton to spinning mills plays a significant role in the overall impact of denim production. If a mill fails to maintain records of the material origins beyond this stage, the information becomes lost within the process, thereby **hindering traceability** once it reaches the final market. Once in the spinning mill, the cotton undergoes a cleaning process to remove impurities and eliminate seeds. The fibres are then sorted by length and carefully aligned and blended, resulting in a mixture ready for the spinning process, where the fibres are transformed into yarn.

During this process, the **release of dust** occurs, consisting of a combination of fibre fragments: particles from seed coats, organic and inorganic particles and even traces of pesticides. Prolonged exposure to this dust can potentially result in **respiratory diseases** among labourers (Periyasamy, 2020).

Spinning mills frequently utilise lycra as a material to be blended with cotton. Any waste generated during the spinning process of this material currently **lacks recycling options**. While some mills opt to save the material in anticipation of future recycling opportunities, others choose to dispose of it through landfill or incineration.



Globally, there are 513 denim mills (Fashion United, 2016). Denim mills have to align their production processes and scales with the demand from brands, ensuring they can meet the requirements and preferences of the market. The strong economic reliance on the fashion industry, particularly concentrated in countries like Pakistan, Bangladesh, India, China, and Turkey, poses significant challenges for mills in shifting towards more sustainable practices if brands aren't adapting their demands.

With or without established labour protections, garment workers in economically disadvantaged countries often endure perilous working conditions within factories while receiving minimal wages. Shockingly, fewer than 2% earns a living wage (One Planet Life, 2023).

2. YARN SPINNING







3. BACK PROCESS

After the spinning process, the yarns are subjected to ball warping, where they are carefully wound onto a beam in the form of rope. This process in itself is energy-intensive. Subsequently, the warp yarns used in denim production undergo a preparation process for rope dyeing, which involves a **chemical treatment** (Periyasamy & Periyasami, 2023). In most non-vertical denim mills, at least the yarn spinning, back process and weaving occurs on the same premises.

Indigo dyeing follows in the process. The creation of synthetic indigo dye relies heavily on **petrochemicals**. Apart from the use of crude oil, the involvement of substances like caustic soda, formaldehyde, and sodium phenyl glycinate also generates **toxic waste and unrecyclable, contaminated water**. Approximately 46% of the indigo dye delivered to mills arrives in powder form, emitting dust particles carrying aniline. Again, the inhalation of this substance can have **harmful effects on health** (Gvheff, 2021). During the dye application process to the rope, there is a significant **consumption of water**, and a mordant containing substantial amounts of **heavy metals** is utilised.

In certain cases, particularly in mills where mishandling occurs, dye baths may be improperly managed, leading to the **discharge of wastewater** directly into rivers. Consequently, these chemicals can find their way into irrigation systems and ultimately **contaminate crops** (Azanaw et al., 2022). According to recent estimates, 1.1 million tons of synthetic dyes are manufactured each year, with approximately 17% of these dyes being lost during the manufacturing and operational processes (Periyasamy 2020). The United Nations Environment Programme (UNEP, 2019) reports that fabric dyeing and treatment account for approximately 20% of global wastewater.

After rope dyeing, rebeaming occurs, which is followed by a sizing process requiring additional chemicals.

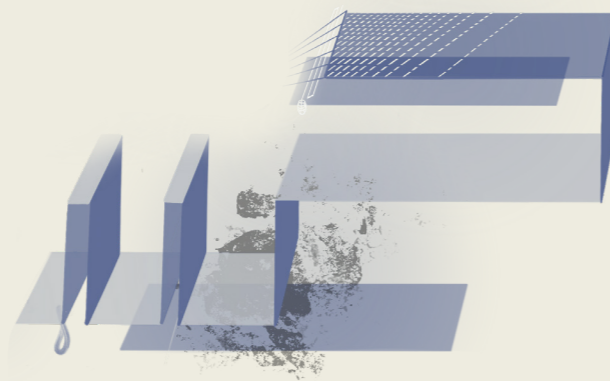
-  WATER DEPLETION
-  SOCIAL INJUSTICE
-  HAZARDOUS CHEMICALS & LOOSE DUST: HEALTH & ENVIRONMENTAL IMPLICATIONS
-  PRE-CONSUMER TEXTILE WASTE
-  FOSSIL FUEL FOOTPRINT
-  POST-CONSUMER WASTE

4. WEAVING

Following the rebeaming process, which involves redistributing the rope into individual yarn ends, denim fabric is woven. This involves interlacing the indigo-coloured warp threads with the usually undyed weft threads. The weaving process involves three key steps: shedding, picking, and battening. During shedding, the warp yarn is moved up and down to create the desired weave pattern, which is a twill weave pattern in the case of denim fabric. In the picking phase, the weft is interlaced with the warp. Finally, battening is performed to firmly press the weft into place after interlacing.

Among the four commonly used types of looms in the textile industry—the classic shuttle, projectile, rapier and air jet loom—the projectile loom stands as the predominant choice for denim weaving. With a shuttle loom, selvedge denim can be created, a more luxury traditional denim type. This refers to a weaving process where the fabric's edges are tightly-woven and self-finished (thus commonly referred to as 'selv-edge'). The durable selvedge denim can be seamlessly incorporated into the garment without the need for additional processing. However, non-selvedge denim is wider, reducing the **amount thrown away from the canvas** during the later stage of **pattern cutting**. Moreover, the creation of selvedge is time-consuming and the shuttle looms are usually very old, requiring major maintenance.

During the weaving stage, **fibre dust emissions** occur once again. The health impact on workers during this stage is comparable to what can be seen at the spinning stage (Periyasamy, 2020).



5. FINISHING

During the finishing stage, denim undergoes various treatments. Approximately **22% of all textile-related wastewater** is produced during the finishing process. Additionally, **fabric scraps, trimmings, and packaging waste** further contribute to the waste generated (Azanaw et al., 2022).

The denim finishing process includes singeing, desizing, and sanforization. Singeing involves passing the denim fabric through **brushing and burning** the surface of the fabric to remove any irregularities and fibrousness. Desizing eliminates adhesive particles from denim fabrics such as starch, for which another wet process involving **various chemicals** takes place. Thus, the desizing step, again, leads to the generation of wastewater, containing high levels of biochemical oxygen demand. Although alternative sizing detergents and agents have been explored to mitigate environmental impact, such as soy protein, chicken feather, hemp core and cellulose ether, scaling these alternatives to an industrial level is currently unachievable (Periyasamy & Periyasami, 2023). Lastly, when the fabric undergoes sanforization, moisture and heat is added to the fabric. The warp yarns shrink and the weft yarns become tightly packed. After drying the fabric, locking the fibres in their shrunken state, the fabric will only shrink a further 2-3% instead of 10% during the consumer stage. This prevents buyers from purchasing an unfitting denim garment and perhaps from disposing of it long before reaching end-of-life. However, this process is **energy-intensive**.

Additionally, denim may already undergo **treatments** during the finishing process to achieve a faded appearance. Since indigo is not water-soluble, various chemicals are used to achieve this look, which contribute to more wastewater pollution.

6. GARMENT CONSTRUCTION

During the garment construction phase, the fabric is stacked and cut into flat panels based on a marker plan, which is followed by sewing, hemming, stitching and adding embellishments. This sequence of garment construction actions is also referred to as the **cut-and-sew stage** and is known for being the **most labour-intensive** process, causing additional psychological hazard due to extreme strain in improperly managed mills. Conventional pattern cutting methods result in **wasteful usage of fabric**. As **fabric accounts for approximately half of the garment production cost**, this practice is both unsustainable and costly for the fashion industry (Enes & Kipöz, 2019). Marker efficiency, which aims to minimise waste during the cutting process, is thus a critical consideration. Diamond Denim has stated an 88-90% marker efficiency is considered sufficient, but emphasised it may not always be achievable for high-fashion or trendy patterns. Industry-reported numbers suggest that about 10-15% of produced textile is excess fabric (Enes & Kipöz, 2019). Even in an LCA performed at Nudie Jeans, a denim brand which is more focused on sustainability targets than other brands might be, it was found that approximately 14% of cutting waste occurs (Åslund Hedman, 2018). Some estimate the entire number of material wastage from fibre to garment can be as high as 46% (Eddy, 2022). As for sewing, the carbon footprint is considered even higher than with cutting (approximately twice as much), which is primarily due to high amounts of polyester and cotton thread, metal embellishments (rivets, buttons and zippers) and associated machinery (Cheng and Liang, 2021).

The entire cut-and-sew stage is estimated to account for **15.6% of a garment's footprint** during its entire lifecycle (Wennberg & Östlund, 2019). However, since this number is also dependent on industry reports, the percentage could be even higher in reality.

When polymer-based fibres are incorporated into denim fabric, **microplastic shedding** occurs during the cut-and-sew stage as well. However, this issue can be alleviated by implementing ultrasound cutting techniques.



7. LAUNDRY

In the laundry department, denim garments are given final washes and spray to achieve fading aesthetics. and One particular process, called "stone washing", which is used to give denim a worn look, exemplifies another concern of a **chemical threat**. This process not only requires significant amounts of energy and water, but involves highly toxic chemicals such as PP, which also contains heavy metals. The various enzymes used in this process can **deplete oxygen in waterways and destroy aquatic life**, if not disposed of properly. Moreover, when denim and pumice stones are combined in the large washing machine, it can lead to the formation of a substance that hardens into concrete, causing further **blockages in pipes and waterways**. While Diamond Denim for instance has its own established standards set in place to verify they do not dispose of the chemicals produced at the laundry department ('Zero Discharge of Hazardous Waste'), many others do not.

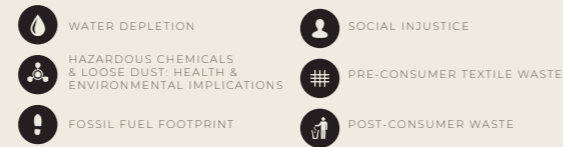
Distress and scraping also take place in the laundry department. Traditionally, this was both done by hand and is still occurring due to brands demanding this 'natural' practice for 'authenticity' purposes. Apart from being a **labour-intensive** process, the **fibre dust** released during this (and in general in the laundry department) can lead to **lung inflammation and silicosis**. However, distress and fading scrape patterns can also be achieved through modern laser technology, posing a better alternative for workers' health and labour wellbeing.

Among all processes (including, puckering, depilling, crinckling and more), another particularly highly implemented and impactful practice is sandblasting. The utilisation of hypochlorite (commonly known as Clorox, but at triple the strength) and potassium permanganate to fade or bleach jeans can result in the generation of **highly toxic fumes**, which additional use of resins containing formaldehyde in many cases as well (Choudhury, 2017). While in 2010 a 'Killer Jeans' campaign was launched to ban this process, and a report by Clean Clothes Campaign (2012) led to 40 brands promising to do so, the process has proven to continue to exist to its cost- and time-effectiveness (Muller, 2013). Performed without adequate ventilation, safety equipment, or training, sandblasting denim compromises the lives of the workers involved. Unfortunately, consumers are often unaware of this information as it is not readily disclosed (Clean Clothes Campaign, 2012).

8. BRANDS // POWER IMBALANCE

! Fashion brands represent the most critical layer within the denim industry. While consumers are often blamed for excessive clothing purchases and underutilisation, it is the brands themselves who drive the **fast fashion phenomenon**, creating a **detrimental cycle**. Brands play a pivotal role in marketing and are almost entirely responsible for the practices within their supply chains. They dictate the **production volume, fabric quality, materials, and blended yarns** used. They also determine the specific **wash processes**, including the chemicals involved, and influence **marker efficiency** through their pattern designs. Trend watchers sometimes mediate between brands and suppliers, engaging in continuous negotiations on quality with samples prior to new collection production, but pressing too hard might result in loss of influential clients, **highly impacting the suppliers whose livelihoods are economically dependent on the transaction**. Garment factories encounter intense competition for brand orders. Once they secure an order, the **factory bears the upfront financial burden**, covering fabric costs and all manufacturing expenses. Subsequently, the finished garments are shipped to the brand, who might decline reimbursement upon late shipment arrival or unmet expectations. This situation leaves the factory in a state of desperation. Essentially, **the brand wields most power, claiming the majority of the profits** (One Planet Life, 2023).

Presently, brands are capitalising on the growing consumer awareness around sustainability by promoting new eco-friendly claims. However, many brands **struggle to substantiate these claims**, resulting in **greenwashing and eroding consumer trust**. To address this issue, both governmental and EU-led initiatives are being undertaken, as discussed in a subsequent chapter. Furthermore, the interconnection between fast fashion, brands, and consumer behaviour is explored in more detail in Chapter 1.2 (Further Literary Background).



9. DUTCH MARKET

! In 2021, the Dutch Denim market was estimated at €477 million, forecasted to reach €582 million in 2026, translated to a 22% increase in five years (Cotton Incorporated, 2022). Between the years 2000 and 2015, there has been a **significant increase in fashion consumption**, with purchases surpassing double the amount. However, **the duration** for which we actually wear these items has **decreased by 36%** (Ellen MacArthur Foundation, 2017). The average Dutch consumer possesses an average of 5.4 pairs of jeans, buying more than one new pair per year (Blaazer, 2022). Through market research, trend analysis, and consumer feedback, brands proactively respond to changing preferences, emerging trends, and shifting expectations, identifying specific demand characteristics and amounts. However, the consumer also reacts to brand supply in return, **perpetuating raising demands** by consumers as well.

! The demand-supply cycle, unfortunately, does not accurately predict the exact sales outcomes. For instance, out of the 2 billion pairs of jeans produced annually, a staggering **35% remains unsold** (Goldman, 2017). This amounts to approximately 750 million pairs of jeans that either end up incinerated or in landfills, never fulfilling their intended purpose.

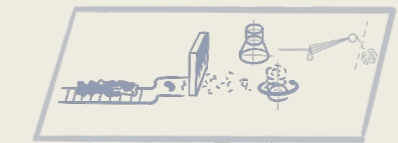
Furthermore, an average Dutch individual's wardrobe consists of around 173 items, with approximately **50 items reported to remain unused** for at least 12 months (Hogeschool van Amsterdam, 2020). These statistics illustrate the issue of overstocking persisting on multiple fronts and necessitates concerted efforts to address and mitigate its impact.

! Lastly, the Dutch consumer **disposes of 40 clothing items** each year.

10. PRE- & POST-CONSUMER RECYCLING

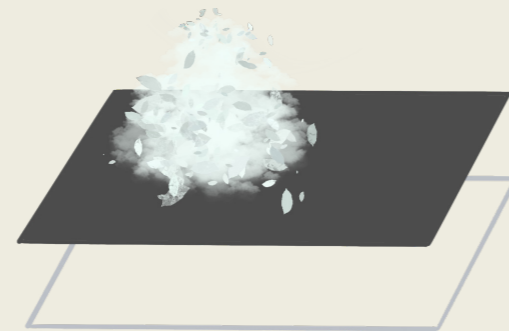
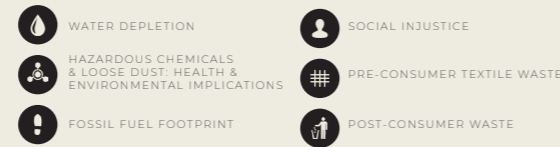
Pre-consumer recycling: Diamond denim will have their own recycling facility next year and are currently transporting all non-reusable pre-consumer waste from their own mill to a partnering recycling facility. However, many other brands do not do this, leading to exporting the material to other regions or countries where it ends up in **landfill or incineration**. It's difficult to determine what exactly happens in mills regarding this subject, due to a **lack of transparency** in this specific step and overall lack of awareness of the pre-consumer waste problem in the first place. Diamond Denim is set to establish its own recycling facility next year, focusing on pre-consumer recycling. Currently, they are transporting all their non-reusable pre-consumer waste from their mill to a partnering recycling facility. However, it is concerning that many other mills do not prioritise such practices or aren't able to, resulting in the disposal of materials through exportation to regions or countries where they ultimately end up in landfills or incineration. The lack of transparency in this particular step makes it challenging for consumers to understand the exact processes that take place in mills regarding pre-consumer waste.

Regarding post-consumer recycling, the issue of unwanted clothing generates a significant amount of waste. While some consumers donate their unwanted garments to charity, only a fraction of them, approximately 10-20%, are reused or sold (One Planet Life, 2023). When textiles reach a state where they cannot be reused in their current form, they undergo fibre sorting based on colour and material type for recycling purposes. During the shredding process, occurring before either mechanical or chemical recycling, the cotton fibres are cut into shorter lengths. This significantly reduces the quality of the cotton material, making it challenging to recover the fibres for future similar use. As such, most of the textiles at this stage are subjected to downcycling, resulting in a **decrease in their material value**. The utilisation of post-consumer recycled (PCR) cotton in the production of new jeans is currently limited and if implemented, only accounts for a small portion, often just **a few percent**. It is important to acknowledge that the limited utilisation of PCR cotton is partly attributed to the need for mills to invest in innovating their supply chains to effectively work with PCR cotton fibres while maintaining the production of high-quality garments. Unfortunately, many mills do not have the resources to invest in new machinery for this purpose.



Mechanical recycling methods face challenges when it comes to recycling mixed material, such as denim with less than 95% cotton content. In the present day, denim is often manufactured using a combination of cotton and synthetic fibre such as polyester and elastane. The latter has the tendency to melt and fuse with other fibres when subjected to high-temperature washing during the consumer phase, making the mechanical recycling process even more complex. In contrast, chemical recycling processes can effectively recycle mixed materials without devalued properties. By combining this post-consumer recycled (PCR) material with other fibres, it is possible to create a strong denim fabric once again. However, it is important to note that chemical recycling is currently a costly process compared to mechanical recycling, presenting a significant hurdle in terms of scaling up this type within existing supply chains.

! All in all, current **closed-loop recycling** only entails **less than 1%** of all textiles (Ellen MacArthur Foundation, 2017).



10. LANDFILL & GOVERNMENT

The remaining unwanted garments are often shipped to economically disadvantaged countries for resale in their local markets. The same applies to discarding clothing in regular municipality bins. Unfortunately, this practice undermines the domestic fashion market of those countries. The majority of these clothes fail to find buyers in these markets, **burdening the host country with the responsibility of waste disposal**. Compounding the problem, a staggering 80% of individuals working in these resale markets struggle to make a profit (One Planet Life, 2023). This practice places these countries in a challenging position as they lack the necessary infrastructure to handle the large quantities of textiles shipped to them, resulting in **big landfills near and in waterways, open fires, polluted air and generally hazardous conditions** for human health and environment (Wohlgemuth, 2022).

"Poisoned gifts": top importers of used clothing in 2021 were Ghana, Pakistan, Ukraine, United Arab Emirates, and Kenya (OEC - The Observatory of Economic Complexity, 2022).

Globally, approximately 80-100 billion new clothing garments are manufactured annually, 87% of the materials and fibres utilised in clothing eventually end up in incinerators or landfills. 92 million tons of clothing is added to landfills on a yearly basis (Ruiz, 2023).

CERTIFICATIONS & TRACEABILITY

In response to the EU Commission's legislation mandating the use of digital product passports by fashion brands by 2030, a multitude of eco-labels, certification schemes and traceability systems have emerged.

Having such systems in place serves several purposes, such as enhancing the sales of more sustainable products, increasing consumer awareness, improving brand image and providing guidance for manufacturers in transition-making. **Currently, less than half of the fashion brands who exhibit sustainability targets are able to trace their value chains** (Textile Exchange, 2023).

The standards for certifications predominantly rely on the **cradle-to-grave approach**, encompassing the entire life cycle of a product: including raw fibre processing, manufacturing, distribution, consumption and product-care (i.e. washing, steaming, ironing, dry-cleaning), discard and whether the final material is feeded back into the system.

Among the large amount of schemes, reportedly 449 in 2015, each contains varying levels of detail when it comes to analysing environmental impacts (Choudhury, 2015). Some schemes conduct comprehensive assessments of the entire life cycle, while others focus on specific stages of the value chain.

For example, there are numerous certifications dedicated to cotton production, including the Better Cotton Initiative, which involves stakeholders from the entire cotton supply chain. BCI has implemented a traceability system that tracks from the farm to the gin. The initiative also works with other certifications, among which Certified Organic, Fairtrade cotton and Cotton made in Africa. Moreover, there are also more specialised certifications in cotton, such as the BMP Cotton trademark, which serves as a consumer assurance that the textile product they are purchasing is made specifically from Australian cotton.

Some certifications also cover other aspects, whether on their own or a combination thereof, such as carbon offset. For example, Carbon Neutral Certification is granted after Verus Carbon Neutral calculates the carbon footprint of a business seeking certification and offsets it by retiring carbon credits. Additionally, there are labels that focus on removing harmful substances and addressing social footprints. The inclusion of bio-based or recycled material content is another example. Another note-worthy certification is the B-Corporation certification, which distinguishes business from traditional models by requiring them to meet comprehensive social and

environmental performance standards, prioritise stakeholder interests and unifying a brand.

Diamond Denim currently holds the Cradle to Cradle certification, which assesses the material safety, product circularity, renewable energy usage, clean air, water and soil quality control and social equity aspects of their products.

Some of these labels also have traceability schemes in place, but there are also **traceability schemes and Digital Product Passports** which exist separately. Examples of the latter are TrusTrace, ReCircE, Textile Genesis, Sourcemap, Circularise, FibreTrace, TrueTwins, EON, Niaga, Circular.Fashion and CIRPASS. Several entities are actively working to enhance data reliability and accessibility through technological innovations, particularly by leveraging blockchain technology. Blockchains enable fast processing of data and offer a high level of trust in accuracy and integrity. The technology is said to ensure the data remains unaltered and protected against adaptation by any outside entities. By utilising decentralised technology, these systems eliminate single points of failure, ensuring unprecedented data security. Protokol is an exemplary company specialising in the development of blockchain systems for incorporation into product passports.

Diamond Denim currently employs Haelixa as its traceability system, which utilises DNA-based verification for cotton from farm to retail. Through qPCR technology, Haelixa can identify the fibre composition at each stage of the value chain, enabling tracking of the source of origin and verifying the authenticity of claims made by previous departments. Haelixa's use of nanoparticles takes this technology a step further in accessing the conditions in which different particles interact, enabling monitoring of factors like pH, temperature, light intensity, oxidant concentration or chemical usage. In terms of data storage, Haelixa relies on its own systems and servers, which are primarily not based on blockchain, while ensuring that retailers and mills can access the data at any time. Haelixa's traceability process includes the DNA marker by labelling this on the article itself. By identifying the marker, meaning that anyone can verify the authenticity of the product. Additionally, this protects brand from their garment being copied.

SECTION TAKE-AWAYS *// MAPPING THE CURRENT DENIM SYSTEM*

OVERALL CONCLUSION

This section provides an overview of the current denim system, from the final perspective of the Dutch denim market. Through the development of an ecosystem map, key stakeholders and challenges within the denim system are identified. This map is the result of multiple research methods, including field research in Pakistan and other expert interviews, with additional support of literature review. The analysis of the denim supply chain and system interactions helps answer the research questions related to the system dynamics, motivations and barriers of system actors, 3D weaving-specific challenges, potential leverage points, and the translation of findings into a strategy for unlocking the potential of 3D woven denim.

The research identifies several significant challenges within the denim industry, mostly relating to water depletion, hazardous chemicals, environmental and health implications, fossil fuel footprint, social injustice, pre-consumer textile waste, and post-consumer waste. While certifications and traceability schemes are gaining traction, the current inability of fashion brands to effectively trace their value chains hinders progress. Furthermore, the presence of numerous certifications that focus on mere specific aspects of the interconnected system further highlights the need for a more holistic approach toward systemic change.

Overall, this study provides valuable insights into the complexities of the current denim system and necessary considerations for achieving systemic change through utilisation of 3D weaving.



TOWARD A PARADIGM SHIFT //B

4.2

UNDERSTANDING THE CONSUMER MINDSET BEFORE SHIFTING PARADIGMS

User research plays a crucial role in addressing consumer acceptance issues encountered by radical innovations in fashion (Camacho-Otero, Boks, & Nilstad Pettersen, 2019). For the development of denim products, specifically 3D woven denim, understanding user needs, preferences, and behaviours is essential, due to the vast differences in aesthetics. This section describes two rounds of user research conducted using 3D woven denim jackets (Vroom, 2022) as tangible objects. The first round involves semi-structured interviews with 20 participants, addressing Research Question 1. The insights gathered from this round of user research are then used to discuss barriers and motivations in sections 4.4, adhering to Research Question 3. The second round used an ethnographic approach, collecting feedback through user diaries from 10 participants, also primarily answering Research Question 1. It further supported Research Question 3 and 4, as well as Research Question 6. The results address the multidimensional nature of consumers' perception of clothing quality and aesthetics.

RQ1 // What are consumer's perceptions of 3D woven denim forms?
Is discussed in this section.

RQ3 // What are motivations and barriers for identified system-actors toward the implementation of alternative sustainable models?
Is addressed through general discussion 4.4 'Adoption motivations & barriers'.

RQ4 // What are 3D weaving-specific barriers toward the implementation of alternative sustainable models?
Is addressed through the general discussion 4.5 '3D weaving-specific barriers'

RQ6 // How might the outcomes of the aforementioned subquestions translate into a strategy to unlock the potential of 3D woven denim, parallel to current denim?

Is addressed through Chapter 5.4 'Final Design | Discussion'

4.2.1

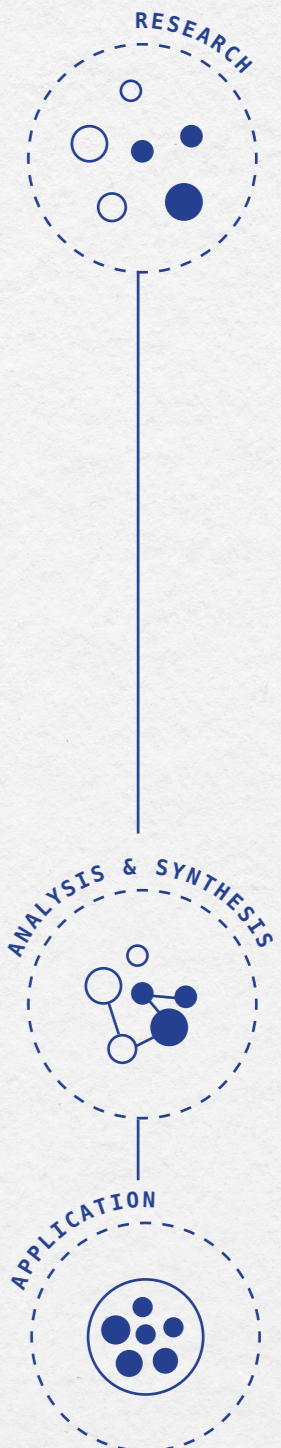
METHODOLOGY

USER RESEARCH ROUND 1

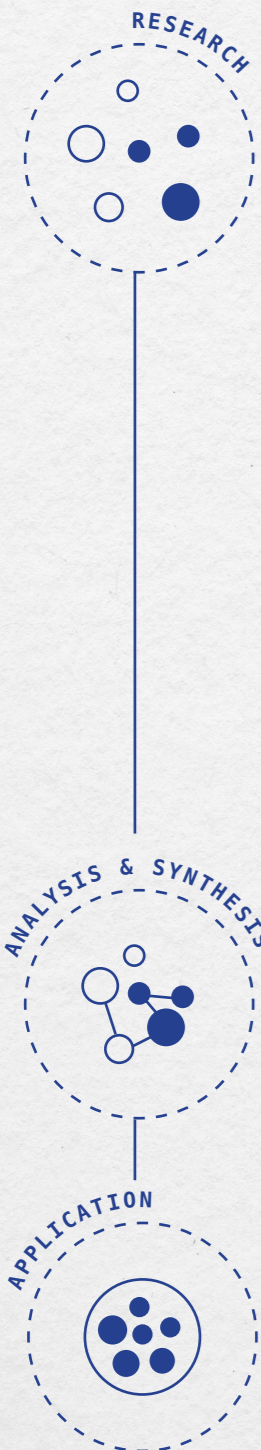
Two rounds of user research were conducted for this project. The initial round involved semi-structured interviews with 20 participants, each lasting approximately one hour. This phase occurred early in the project to explore the multidimensional nature of consumers' perception of normal denim and 3D woven denim. The interview guide was developed based on a conceptual framework derived from literature research, which will be further elaborated in subsection 4.2.2. The interview questions initially focused on normal denim and later introduced 3D woven denim jackets by Barbara Vroom as tangible artefacts to facilitate discussions specific to this woven form. The jackets and their background were explained in the concluding part of this subsection. Furthermore, visual strategy cards were employed as an additional tool during the interviews to enhance the participants' understanding of what the 3D weaving technique behind the jackets is and how they could be incorporated into the denim system in various models. These cards were designed to provide a visual representation of the potential implementation and allowed the interviewees to visualise different scenarios. This approach aimed to elicit consumer reactions and gather valuable insights regarding the integration of 3D woven jackets into the denim industry.

Following the interviews, transcription and coding were performed to identify the key cues in the information provided by participants that contribute to consumer perception. Clusters were then formed by analysing the codes, uncovering themes and patterns in the participants' responses. These findings constitute the results of the research.

Upon analysing and synthesising the results and engaging in discussion, they are utilised to address research question 1 and to further explore motivations and barriers related to the implementation of a new sustainable fashion model from the consumer perspective. This further supports research questions 4 and 5.



USER RESEARCH ROUND 2



The second round of user research was conducted at a later stage of the project, following a visit to Diamond Denim in Lahore, Pakistan. This phase involved weaving new samples of 3D woven denim jackets (Vroom, 2022) at the denim mill, which were then worn by 10 participants for an entire month as part of their daily routines. Participants were instructed to utilise the jackets as they normally would with any garment, including washing and wearing them according to their personal preferences. To capture their experiences, an ethnographic user research diary was created for each participant, allowing them to report back on their daily encounters with the jackets. This approach provided a deeper understanding of individuals' perceptions of 3D woven denim, based not just on initial impressions but on actual firsthand experiences. It enabled insights into sociocultural factors, use cases, construction improvements, material experiences, and more. Throughout the four-week period, the questions in the booklet provided to participants were slightly modified each week to assess whether their perceptions changed over time. The final week specifically aimed to understand how consumers perceived the introduction of the final design in relation to the jacket they were wearing. This phase helped identify elements of the final design that could be adapted from a consumer perspective, as well as improvements needed in the development of the 3D woven garment to instill consumer confidence in the overall strategy.

The responses from the booklets were carefully analysed and synthesised, resulting in the identification of codes, patterns, and themes within the participants' answers.

The findings were applied as recommendations for the final strategy design and insights for an iterative implementation roadmap, which forms a crucial part of the overall strategy. They contribute to research questions 1, 3, 4, and 6, further enriching the understanding of the main research question from the perspective of the consumer, previously identified as a critical group within the fashion system in the context of shifting the paradigm.

3D WOVEN DENIM JACKETS

In the first round of user research, three 3D woven denim jackets were used as tangible artefacts during the semi-structured interviews. These jackets are showcased in figure 24 to 26, as 1. 'Raw Edges,' 2. 'Finished Edges,' and 3. 'Zero Waste'. They were introduced to the participants in this order, with open-ended questions asked to gather their thoughts on each jacket. The precise methodology for this process is further described in subsection 4.2.2.

Previous chapters have explained that the 3D weaving technique offers unique advantages such as the potential for zero-waste design and a reduction in the labour-intensive cut and sew steps. Normally, a garment requires 180 metres of thread in this process, with an additional 10-15% waste generated from the pattern. For these jackets, Jacket 1 'Raw Edges' requires only 4 sewing steps instead of the usual 18 and has a calculated waste of 14%. Jacket 2 'Finished Edges' requires 4 additional sewing steps due to the finished cuffs and has a waste calculation of 15.5%. Jacket 3 has minimal waste at 1.16% and, like Jacket 1, requires only 4 sewing steps. No finishing or laundry is applied, and the material composition consists of indigo-dyed cotton for the warp and an undyed cotton/hemp blend for the weft. The main structures of the jackets consist of two-layer weave patterns, with the exception of the integrated pockets for jacket type 1 and 2, which are constructed using 1/4-layer weave structures (Vroom, 2022).

It is important to note that the waste created in the first two jackets still resembles conventional waste due to the limitations of the available loom in terms of width and repeat. As these jackets were in an early stage of research themselves, the theoretical understanding was that they demonstrate the aesthetic changes resulting from the technique while aiming to achieve true zero waste in the future through further research and the use of more suitable looms.

In the second round of user research, 5 participants were given denim jacket 1 'Raw Edges,' and the other 5 participants were given denim jacket 2 'Finished Edges.' While it would have been ideal to provide some participants with denim jacket 2 'Zero Waste' due to its notable aesthetic difference in closely adhering to the zero waste principle, unfortunately, reweaving this version was not possible.



3D WOVEN DENIM JACKET PARTS BY BARBARA VROOM (2022) | FIG 23



1

3D WOVEN DENIM JACKET 1 // RAW EDGES VROOM (2022) | FIG 24



2

3D WOVEN DENIM JACKET 2 // FINISHED EDGES VROOM (2022) | FIG 25



3

3D WOVEN DENIM JACKET 3 // ZERO WASTE VROOM (2022) | FIG 26



Figure 27

A PICTURE OF ONE OF THE PARTICIPANTS WEARING A 3D WOVEN DENIM JACKET DURING USER RESEARCH ROUND 2

4 . 2 . 2

USER RESEARCH ROUND 1

RESEARCH

CONCEPTUAL FRAMEWORK

Figure 28 depicts the conceptual framework that served as the foundation for the semi-structured interview guides. This framework was developed based on literature review, which identified key themes crucial to understanding the perception of denim garments, the new 3D woven denim jacket form, and sustainable fashion consumption. The purpose of the framework was to ensure that the interviews covered various aspects of influence on implementing a new design-to-consumer model for the 3D woven garment from a consumer perspective in a grounded manner. For a larger view of the framework, refer to Appendix H.

The literature on sustainable consumption reveals that changing consumption patterns can be approached from various ontologies, including the individual, social structures, and social practices. To explore this, researchers have examined economic (Armstrong et al., 2015; Rahman, 2011; Camacho-Otero et al., 2019), psychosocial and cultural (Rahman, 2011; 2015; Camacho-Otero et al., 2019), and socio-material (Rahman, 2011; Swinker & Hines, 2006) factors and conditions that influence the acceptance and adoption of sustainable consumption patterns. Economic factors include price, income, and the availability of product or service information. Psychosocial factors include attitudes, beliefs, values, personal norms, perceived behavioural control, emotions, and habits. Cultural factors refer to how consumption activities contribute to individuals' sense of identity and communication with others. Socio-material factors are external to the individual but can influence their engagement with practices that contribute to sustainability.

After considering a broad perspective of the aforementioned factors, among others, identified themes deemed significant for the research included 'Brand loyalty,' 'Communication strategies,' 'Eco-conscious behaviour,' 'Product characteristics and qualities,' 'Social influence,' 'Demographics,' and 'Usability and socio-material conditions.'

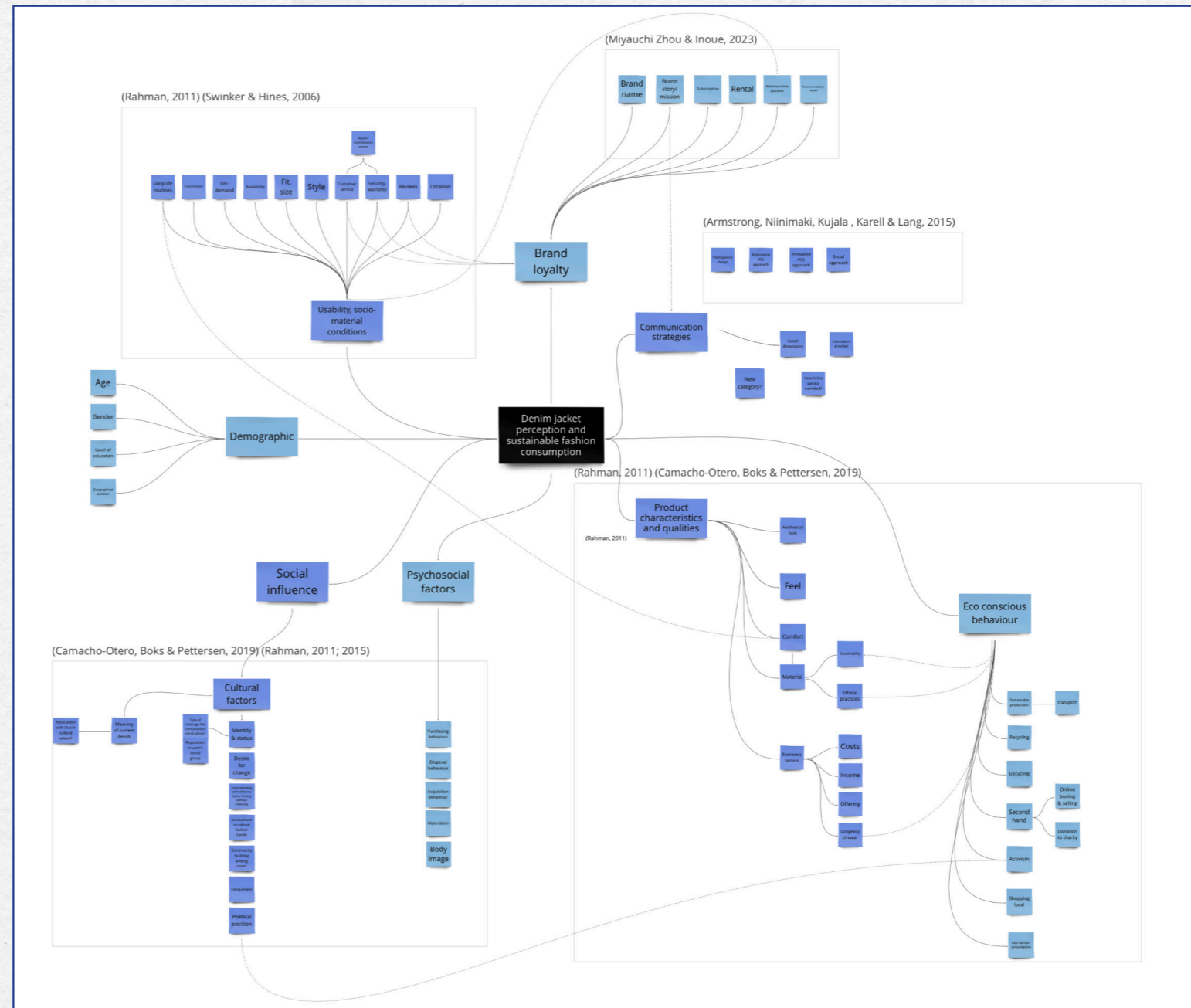


Figure 28
CONCEPTUAL
FRAMEWORK,
FURTHER SHOWCASED
IN APPENDIX H

INTERVIEW SET-UP

The interview setup involved a semi-structured progression of questions and introductions to elicit participants' perspectives on denim and the 3D woven jackets. (See figure 29 for an impression of the interview guide, access Appendix I to read it in its entirety). The process was as follows:

- **Initial questions about current denim:** Participants were asked questions regarding their perceptions of denim as it currently exists in the market. This served as a baseline understanding of their familiarity with traditional denim garments.

- **Introduction of 3 jackets:** The three jackets, namely 'Raw Edges,' 'Finished Edges,' and 'Zero Waste,' were presented to the participants in sequential order. Open-ended questions were asked to gather their perspectives on various aspects such as material, aesthetics, construction quality, etc. Importantly, participants were not provided any prior knowledge about 3D weaving at this stage.

- **Introduction of 3D weaving technique:** Following the initial jacket discussions, participants were introduced to the technique of 3D weaving. The same set of questions was repeated to gauge their perceptions after learning about this novel technique. Another aim was to understand whether participants perceived the 3D woven jackets as a distinct category separate from traditional denim or if they still considered them as denim garments.

- **Introduction of uniqueness of 3D woven garment form:** Participants were provided an explanation of the unique qualities of the 3D woven garment form, particularly emphasising the objective of zero waste. The potentially perception-altering effect, particularly on the third jacket, was tested through further discussions and questions.

- Finally, a discussion took place regarding the various avenues for introducing the jackets to the Dutch market and exploring alternative sustainable models. The focus was on considering factors such as the online presence, renowned stores, partnering brands, and the scale of implementation (high scale vs. small scale production). Participants were encouraged to share their perspectives on whether the jackets should be made available through online platforms, sold in established stores, or in collaboration with specific brands for instance. The discussion encompassed considerations regarding the scale of implementation, whether it should be on a larger scale or more unique and personalised on a smaller scale. The goal was to gather insights on the participants' preferences and opinions regarding the most effective and appropriate methods for introducing the jackets to the Dutch market, aligning with sustainable fashion models.

By following this interview setup, the aim was to gain insight into how participants' perspectives shifted throughout the process, from traditional denim to the introduction of 3D weaving and the specific attributes of the 3D woven jackets.

Visual strategy cards were used to support the process for explaining the 3D woven technique, as well as the alternative models of market introduction (see figure 30).

PARTICIPANTS

The study involved 20 participants, with various socio-cultural backgrounds and as many different perspectives of current denim wear as possible, meaning that some referred to themselves as 'true denim lovers', while others indicated to not wear denim on a regular basis due to preferences for other garment forms. There were also garment-makers and people with different eco-conscious behaviour patterns included in the selection of participants. This broad range was chosen, since the literature indicated there are elements in all these factors which influence overall perception of denim and the acceptance of alternative sustainable models for fashion.



Figure 30

VISUAL STRATEGY CARDS SUPPORTING THE INTERVIEW, APPENDIX J

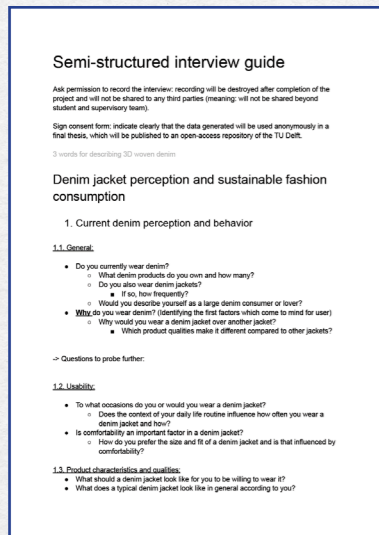


Figure 29

INTERVIEW GUIDE

RESULTS

- The participants perceived the 3D woven jackets to resemble denim to some extent, but **not identical to traditional denim garments**. The **exposed bindings** were the most notable construction element for all three jackets typifying the 3D woven element, followed by the **thin and fully woven breast and waist pockets** in the first two jacket types and the overall **less dense and less sturdy material** in all cases. In the case of the zero-waste jacket, the **entire construction** raised the most questions and concerns about aesthetics and wearability before the technique and zero-waste concept were explained, as well as after. Most of these participants found the uncuffed edges and unfamiliar construction in the upper back and collar to be less appealing.

- The **double interwoven layers on the front placket** of the zero-waste jacket made participants perceive the material to resemble regular denim the most. However, it was not necessarily their preferred choice among the jackets. Many participants found the layers with **lower fractional density in the other jackets to be more loose, allowing more airflow and smoother touch**. This quality intrigued participants, regardless of whether they were regular denim wearers or not.

- The thinner material and unique construction opened up **new use cases** compared to traditional denim. Participants

mentioned the 3D woven jackets as more elegant, suitable for formal occasions, outdoor wear, work settings, and even church. This perception extended to all three jackets, including the one with rougher, raw edges, which was perceived as more of a statement or edgy piece, yet still formal. The **low material thickness and construction** were identified as the primary reasons for this alternative perception.

- An intriguing observation was that individuals who typically did not consider themselves as denim wearers, due to either their cultural background or different perceptions of denim as a rough and uncomfortable garment type, expressed their willingness to wear the 3D woven jackets. They were drawn to these jackets because of the **new associations they formed with the unique zero-waste story, aesthetic form, the allure of smaller-scale production, and the alternative use cases facilitated by the thinner and less dense material**. This shift in perception allowed individuals who previously refrained from denim to embrace the 3D woven jackets due to their distinct attributes and sustainable qualities.

- The concept of **zero-waste, on its own, did not sufficiently convey the message of a fully sustainable garment** for most participants. Instead, it raised **immediate concerns about the sustainability of other components of the garment**. Participants questioned whether the non-zero waste elements of the jacket compromised its overall sustainability. These concerns

persisted regardless of the branding or the associated brand, but in the case of an association, this concern was reinforced by **caution toward the possibility of greenwashing practices**.

- The most significant difference in the perception of 3D woven denim was observed when the **zero-waste perspective** was introduced, rather than solely explaining the weaving technique without emphasising the zero-waste aspect. However, there was a drawback to this. While participants found the zero-waste concept unique, interesting, and previously unknown to them, their **perception varied depending on whether the 3D woven denim would be associated with an established brand or not**. Almost unanimously, participants expressed a lack of trust if the 3D woven denim was affiliated with a conventional low-pricepoint fast fashion brand like H&M. Their scepticism stemmed from the **belief that such brands were not synonymous with quality and their past experiences with unproven green claims**. Therefore, the **association with a brand significantly influenced participants' perception and trust in the 3D woven denim**.

- A noteworthy consensus emerged among almost all participants, **regardless of high eco-conscious behaviour**: they expressed a strong desire for the **3D woven denim category to exist separately within the current denim industry**, favouring a **smaller-scale production** approach, with an emphasis on **local manufacturing**. Furthermore, participants expressed

the importance of having the option for **personalisation and made-to-measure garments**, particularly at a **higher price point**. Interestingly, this desire for **individual uniqueness** stood **in contrast to their preferences for normal denim garments**, where participants typically sought more standardised option.

- Almost no participants expressed a preference for an online model when it came to the distribution of 3D woven denim. Instead, the **consensus was in favour of implementing a new model within physical spaces, preferably as part of established brand stores**. Participants emphasised the importance of being able to see and touch the jackets in person to better understand the technique, layer density, and overall structure. They believed that experiencing the physicality of the garments would significantly enhance their comprehension and appreciation of the unique qualities of 3D woven denim. Thus, participants clearly indicated a strong preference for an in-store retail experience over an online model.

- When discussing the preferred brands to potentially be associated with 3D woven denim, participants consistently mentioned **higher-priced brands** like Levi's or G-Star Raw. These established brands with a perceived reputation for quality and craftsmanship were the ones participants envisioned as suitable hosts for showcasing and retailing 3D woven denim garments.

- However, when participants were asked about their final envisioned purchasing decisions regarding the 3D woven jackets, the **economic factor of price point** emerged as the primary consideration. Ultimately, **affordability of the garment outweighed other factors such as quality or uniqueness**, matching earlier notions in literature research. Generally, participants indicated that a price exceeding 50 euros would be considered too expensive, regardless of the perceived quality or distinctive features of the 3D woven denim garment.

- Among the participants, there was one individual who stood out as a garment-maker herself, providing a unique perspective on the quality of the jackets and the brands the woven form could be associated with. This participant expressed scepticism toward the quality of 3D woven denim when associated with Levi's, as opposed to the other participants, considering it to fall below the standards the brand presents itself with. Consequently, she would not trust the 3D woven denim to exhibit the same level of quality as expected from Levi's. For this participant, the preferred option was for the 3D woven denim to establish itself as its own new brand, ensuring a more transparent look into manufacturing processes and claims. In contrast, all other participants expressed a **lack of interest if the 3D woven denim were to be branded independently without affiliation with established brands**. Their preference leaned toward the

reassurance and recognition that comes from the association with reputable and well-known brands.

- Among the three jackets, both Type 1 'Raw Edges' and Type 2 'Finished Edges' were equally positively perceived. The third jacket 'Zero Waste' was the least desirable or questionable due to the absence of buttons and the construction on the upper back.

- Demographic factors were not indicated as an influential factor in the answers for either perception of regular denim, as well as 3D woven denim.

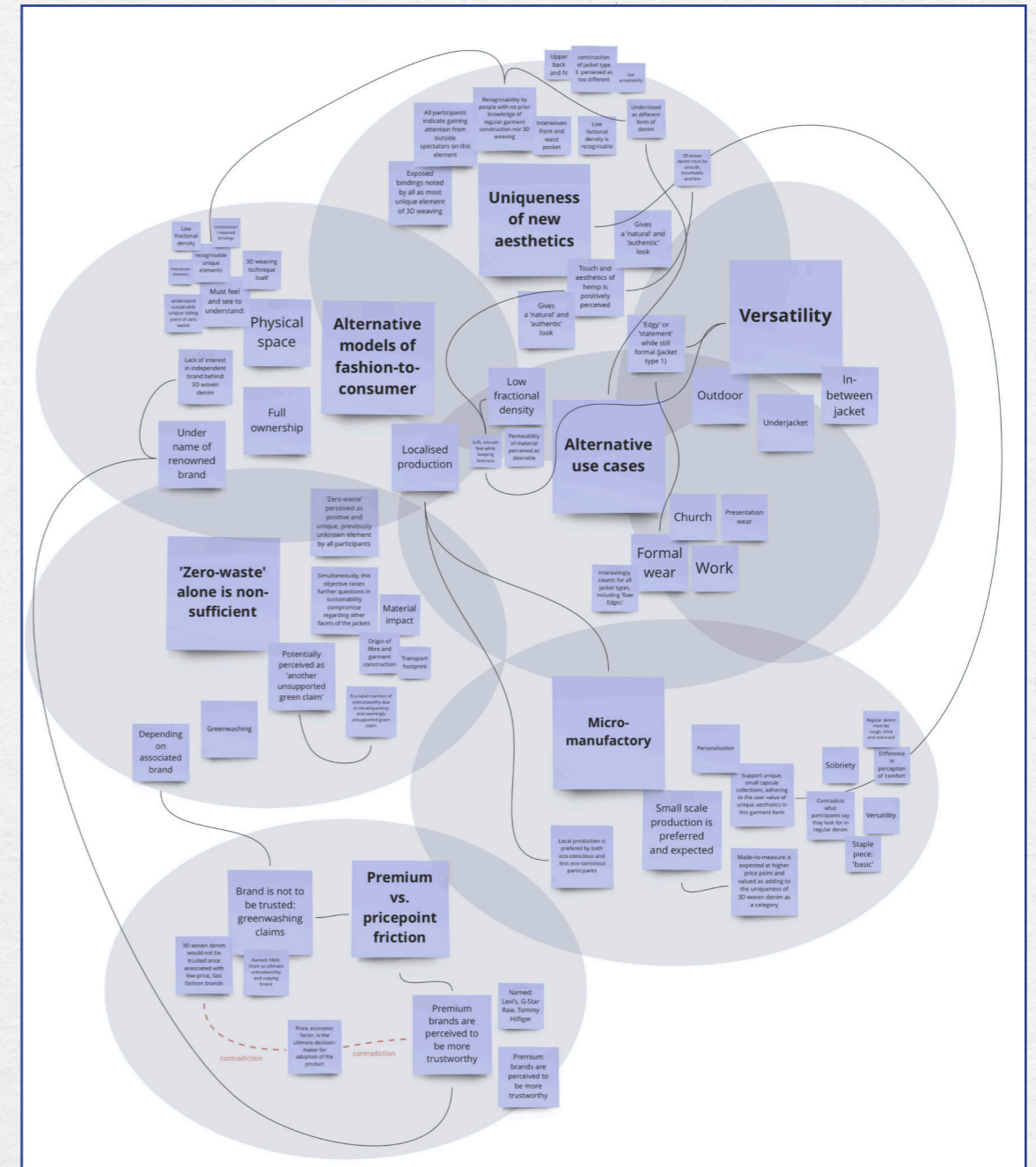


Figure 31
AN OVERVIEW OF THE CLUSTERS AND THEMES IDENTIFIED THROUGH ANALYSIS AND SYNTHESIS AFTER CODES WERE SORTED AND FORMED INTO MAIN NOTES

4 . 2 . 3

USER RESEARCH ROUND 2

RESEARCH

ETHNOGRAPHIC USER DIARY

Margaret Mead, anthropologist, encapsulated a profound insight with her well-known quote: “What people say, what people do, and what people say they do are entirely different things.”

Mead’s quote serves as a reminder to carefully consider the inconsistencies that can arise between these three aspects of human behaviour. Our understanding of our own behaviour often exhibits significant blind spots. When attempting to recall and describe our actions, there is a notable divergence between our recollections and objective evidence. Furthermore, we encounter difficulties in comprehending and articulating the complex factors that drive our actions. These observations shed light on the limitations of self-perception and the inherent challenges involved in accurately depicting and comprehending our own behaviour, meaning that the semi-structured interviews in the initial round of user research proves inadequate in providing a thorough understanding of individuals’ genuine perception of a garment form.

Ethnography typically encompasses a field study approach where researchers directly observe individuals in their natural environments, aiming to acquire a comprehensive and contextual understanding of their needs. Ethnography, as understood in the discipline of anthropology, usually necessitates the researcher’s immersion within the study environment. Given the constraints in the current research context, continuous observation of ten participants wearing a jacket over an extended period of time is not feasible. As a result, a diary study, an alternative form of product user research drawing from ethnographic methods, is employed. In this method, users independently document their experiences, thoughts and observations in a log or diary

over a predetermined period (User Interviews, n.d.). This approach still allows for repeated exposure to real-world examples, provides contextual information, and facilitates a deeper understanding of pain points, gaps, and potential opportunities, surpassing the limitations of the initial round of research.

During the course of the study, a reflexive approach was held by the researcher. It is essential to acknowledge personal investment and subjective involvement, as the researcher’s background, experiences, and perspectives can influence the interpretation and analysis of the data. Reflecting on one’s own positionality and biases helps maintain transparency and enhances the rigour of the research.

The study incorporated a set of questions that aligned with the conceptual framework as well, tailored to be suitable for diary entries. Rather than providing the entire booklet at once, it was divided into four separate weeks. After each week, the questions were modified to assess whether participants’ perceptions of the jacket evolved over time, without the possibility of being influenced by the subsequent questions.

Notably, the final week introduced the concept of the final result to explore the relationship between the 3D woven denim jacket and the ultimate outcome. The participants were, again, consisting of a range of people with different sociocultural backgrounds and different stances toward current denim. They were asked to evaluate whether the result aligned with their initial perceptions of the jacket, whether the result influenced their perception, and whether it met their expectations of the 3D woven denim jacket. Additionally, participants were encouraged to provide feedback on any aspects of the jacket that needed improvement for a better match with the final result, or the other way around. After completion of the research period, the jackets were taken back and analysed further by the researcher.

Figure 32 showcases a portion of the booklet, while Figure 33 presents an example of some participant’s responses on a few pages. For privacy reasons, the complete set of recorded participant responses is not included in this document, as indicated in Appendix K.



Figure 32

ETHNOGRAPHIC USER DIARY

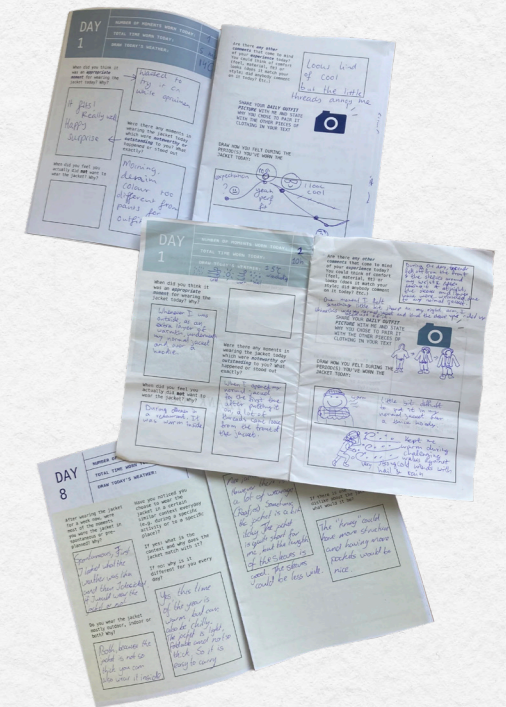


Figure 33

ETHNOGRAPHIC USER DIARY ENTRY BY SOME OF THE PARTICIPANTS

RESULTS

- The flipped, **exposed bindings** on the outside of the jackets, proved to be **recognised as a distinctive feature of the 3D woven product**, attracting attention and generating the most inquiries from others. All participants got questions of curiosity from spectators with no prior knowledge of the jackets, regular garment construction, nor the 3D weaving technique. One participant reported a family member assumed the jacket to be a "designer garment", indicating a luxury aesthetic perception.

- Participants who wore jackets with raw edges initially appreciated the design element, but found that the **fraying of yarn** became a significant source of frustration after a mere three days of wear, stimulating a more negative perception of the 3D woven product. The presence of loose threads in the jackets created inconvenience as they tended to scatter and become entangled with door handles and zippers of overjackets. The threads coming off the bindings in both jacket's cases were initially perceived as a positive element, as opposed to the negatively perceived threads coming off the sleeves' and body's edges. However, the participants who wore jacket type 1 'Raw Edges' most intensively, **ultimately reported the bindings losing threads and ultimate structural integrity as well**. One participant washed this jacket, further reinforcing the problem (see figure 34). Jacket type 2 was also washed by another

participant, only showing signs of further fraying on the bindings.

- Certain weaker parts of the jacket, such as underneath the armpit, raised **concerns about quality and justifying a higher price point** associated with the garment. The binding of the jacket sleeves easily ripped apart in the armpit construction area, probably due to an unforeseen construction overlap in the bias direction.

- The **fractional density** of the non-interwoven single layer areas of the 3D woven jacket posed a problem. While some users appreciated the ability to wear it in warmer weather or alternative use cases, it was found that the fabric quality was not suitable enough for outdoor use. Users reported instances of the fabric getting caught on objects and tearing easily. The front pocket was also perceived as unreliable, lacking structure. On the back, where jacket type 1 'Raw Edges' is lock-stitched together, the thin single-layers of non-interwoven fabric were not strong enough to prevent ripping. The jacket type 2 'Finished Edges' did not indicate a similar problem. Further research is needed to address this issue. However, the areas where two layers were interwoven received positive feedback due to their thickness and durability.

- However, the **permeability** of the material, especially in the waist pocket area, was favourably perceived in warmer outdoor settings where a normal denim jacket would feel uncomfortably hot, yet not wearing any outerwear would be too chilly.- The second

round of research reaffirmed the **distinct and formal use cases** associated with 3D woven denim, while still **maintaining its versatility**. A participant, who intriguingly wore jacket type 1 'Raw Edges,' expressed that despite the edges not being favourable at present, the garment possesses an **elegance and uniqueness that surpasses regular denim**. Notably, this participant even contemplated taking the initiative to address the edges herself, indicating a willingness to further enhance the garment.

- The **colour of the untreated jackets** (no finishing or laundry applied) is difficult to match with other denim clothes within participants' closets, while there was a high desire to combine both jacket types with regular denim items.

- The **tactile experience of hemp** in the jackets garnered significant appreciation, contributing to an intriguing and luxurious impression of the overall garment. The majority of participants expressed a positive attitude towards the hemp-cotton blend, noting that it felt pleasant to the touch and offered a distinct and favourable texture. Participants highlighted the blend's ability to provide a sturdy grip and a sense of structural integrity while simultaneously being smooth and more breathable. As one participant expressed, "The smoothness of the fabric did not compromise its firmness." However, it is important to note that some participants perceived the fabric as itchy or too rough against their skin, hindering their willingness to continue wearing the jacket.

- Users expressed a strong preference for smaller production batches to maintain the uniqueness of the garment and allow for personal interpretation and meaning.

- Users show interest in and stress the importance of developing the made-to-measure principle, even expected by some due to a luxury price point associated.

- Again, when participants were asked about their final envisioned purchasing decisions regarding the 3D woven jackets, the **economic factor of price point** emerged as the primary consideration.

- Demographic factors were not indicated as an influential factor in the answers for either perception of the 3D woven denim jackets.

- The results which contribute to recommendations for the final design, used for the concept evaluation, are further discussed in chapter 5. Overall, the final design did not seem to influence people's actual perception of 3D woven denim jacket as it was before (relating to material qualities, fit and aesthetics) but participants indicated that they thought it would contribute to gaining attention and traction from the public upon market entry, reinforcing their willingness to wear the jackets based on **social influence**.

These findings contribute to the understanding of user preferences and will inform further improvements and refinements to the product.

4 . 2 . 4

DISCUSSION



Figure 34

DEPICTING LOSS OF
THREADS AND IMPACT ON
STRUCTURAL INTEGRITY OF
THE 3D WOVEN GARMENT
AFTER CONSUMER-PHASE
LAUNDRY IS APPLIED

Both rounds of user research conducted shed light on several crucial discussion points that warrant further exploration and consideration.

- **Holistic sustainability:** The main point of discussion is the acknowledgement that **achieving zero waste in one aspect of the garment is not sufficient to ensure users' overall perception of sustainability.** This finding highlights the need for a comprehensive approach to sustainability, encompassing various elements of the garment's lifecycle, including sourcing, production, use, and end-of-life considerations. Future research should delve deeper into implementing sustainable practices throughout the entire value chain of the 3D woven denim garments.

- **Distinctive features:** The flipped, exposed bindings on the jackets emerged as a distinctive feature of the 3D woven product, attracting attention and generating inquiries from others. Participants reported that the unique aesthetic appeal of these bindings contributed to the perception of the garments as high-quality and luxurious. Retaining and emphasising these distinctive features is essential for effective branding and differentiation of the 3D woven denim category within the larger denim industry.

- **Fit and made-to-measure:** Participants expressed the importance of further developing fit and made-to-measure principles within the 3D woven denim category. Their preference for

separateness, local production, and personalisation underscores a desire for a more individualised and unique clothing experience. Future research should explore methods to enhance the customisation options and fit accuracy of 3D woven denim garments to meet the diverse preferences and body types of consumers.

- **Structural challenges:** The user research findings highlighted the presence of structural challenges in 3D woven denim forms. Participants identified issues related to fractional density, raw edges, and binding fraying. These challenges must be thoroughly researched and addressed to enhance the durability, construction quality, and longevity of the jackets. Further investigation into reinforcing methods with other fractional densities, interweaving of layers in some parts of the garment or coating of the bindings (although the exact material of coating should not decrease recyclability potential or cause additional fossil fuel depletion or environmental harm at end of life), could potentially mitigate these structural concerns.

- **Elegance and versatility:** Participants expressed a perception of slight elegance and refinement in the 3D woven denim garments when compared to regular denim. This perception was influenced by the unique texture, feel, and properties of the hemp-cotton blend, including its breathability, smoothness, and firmness. The distinct characteristics of the material provided an opportunity for alternative use cases in more formal settings, while still maintaining

the perceived versatility that participants appreciated. However, participants also highlighted a challenge in matching the colour of the untreated 3D woven denim with other clothing items in their wardrobe. This difficulty in coordination may limit the wearability and versatility of the garments when paired with existing clothing pieces, potentially leading to reduced usage and sustainability. To address this challenge, it becomes important to explore additional options or treatments that can enhance the colour compatibility of the 3D woven denim. This must be obtained through ozone or laser treatment by the most future-proof laundry machine company Tonello, both treatments providing a highly detailed and resembling aesthetic look to normal finishing and laundry practices, in a much more sustainable manner. By offering a broader range of colour variations or implementing dyeing techniques resulting in closer alignment with other commonly worn clothing items, the garments can be seamlessly integrated into individuals' existing wardrobes, fostering increased wear and sustainable practices.

- **Brand association:** Association with reputable brands or fast fashion brands significantly influenced participants' perception and trust in the 3D woven denim garments. Participants expressed a preference for well-established brands in the higher price range, indicating a desire for the 3D woven denim to be positioned as a premium and distinctive offering within the market. Building strategic partnerships with reputable brands and leveraging

their credibility in sustainability initiatives can enhance the market positioning and consumer perception of 3D woven denim.

- **Price point:** Contradictory, participants' responses underscored the significance of price as a determining factor in consumer acceptance, regardless of its distinctive features or perceived quality. However, this discussion also raises a larger question about fostering longer emotional connections with clothing and encouraging consumers to be more willing to invest in their garments. This requires exploring alternative modes of acquisition and consumption that promote sustainability and prolong the lifespan of clothing.

One approach is to consider innovative business models such as clothing rental or swapping platforms, which allow individuals to access a variety of garments for a specific period rather than owning them outright. This not only offers consumers the opportunity to try new styles and trends without committing to a long-term purchase but also promotes a circular economy by reducing the overall demand for new clothing production. By incorporating 3D woven denim into these alternative acquisition models, consumers can experience the unique qualities of the garments while minimising waste and extending their usage.

Another avenue to consider is incentivising consumers to invest in their clothing by offering pay-off options or installment plans. This approach allows individuals to

spread the cost of higher-priced garments over a period of time, making them more financially manageable and appealing. By positioning 3D woven denim as a high-quality, durable investment, consumers may be more inclined to make a larger initial investment, knowing that the garment will last longer and provide value over time.

Ultimately, shifting consumer behaviour and perceptions towards longer-lasting emotional connections with clothing and a willingness to pay more requires a multifaceted approach. It involves creating awareness about the environmental and social impacts of fast fashion, while driving change from the industry itself, promoting the unique attributes and value of sustainable garments like 3D woven denim, and offering accessible and engaging alternative modes of acquisition that align with consumers' evolving needs and values.

SECTION TAKE-AWAYS *// UNDERSTANDING THE CONSUMER MINDSET*

OVERALL CONCLUSION

In conclusion, the user research findings on 3D woven denim garments highlight their perceived elegance and refinement compared to regular denim. The unique texture and feel of the hemp-cotton blend, along with features like smoothness, permeability, and firmness, contribute to this perception and open up alternative use cases for the garments. The exposed binding serves as a highly recognisable and unique element of the technique. Balancing the value proposition with an accessible price point and aligning with reputable brands seems to be crucial for successful market positioning in the Netherlands. However, this becomes challenging when considering the user's preference for a premium garment associated with luxury brands to establish a trustworthy image and avoid greenwashing concerns. Future research should address challenges related to fraying, structural integrity, and the binding tensile strength. Additionally, while the zero-waste principle resonates with consumers, it alone is insufficient for complete acceptance of the 3D woven garment form as an alternative sustainable garment, raising concerns in whether the non-zero-waste elements of the garment compromise its overall sustainability. Overall, the research underscores the potential of 3D woven denim garments as a distinct category, small-scale produced, parallel to the current denim industry. Continued exploration and development, along with addressing these identified challenges, should be considered for successful adoption and integration into the Dutch denim market of 3D woven denim garments in an alternative, more sustainable fashion-to-consumer model.



4.3

IMPLEMENTING NEW MODELS

The aim of this study is to offer an overview of the key components for a systemic design approach towards implementing a new sustainable model for 3D weaving in the denim industry, which were identified as 'industry-led change', 'relocalisation', 'reimagining denim design roles' and 'consumer communication'. The methodology entails an integration of literature research and conducting semi-structured and unstructured expert interviews. Although the interview guides (access Appendix D and E) used for interviewing experts at Kingpins and Weffan were the same as used in the previous study 'Mapping the current denim system', this section aims to specifically understand the most crucial make-or-break points for designing a strategy to unlock the potential of 3D weaving. The unstructured interviews which contributed to this study were conducted with denim designer Mohsin Sajid, designers present at the Blackhorse Lane Atelier, UK design consultants for Diamond Denim and Japanese denim experts. It emphasises essential factors for the implementation of any sustainable model which aims to drive a paradigm shift in the current fashion industry, considering various layers of the system. This study took place before the field research opportunity at Diamond Denim arose. Again this section relates to understanding the following research questions, mainly addressing RQ2:

RQ2 // How do the different layers of the denim supply chain and overall system interact and influence each other?

Is addressed through this section's discussion 'Industry-led change', 'Relocalisation', 'Reimagining denim design roles' and 'Consumer communication'.

RQ3 // What are motivations and barriers for identified system-actors toward the implementation of alternative sustainable models?

Is addressed through this section's discussion 'Zooming in' and overall discussion 4.4 'Adoption motivations & barriers'.

RQ4 // What are 3D weaving-specific barriers toward the implementation of alternative sustainable models?

Is addressed through the general discussion 4.5 '3D weaving-specific barriers'

RQ5 // What are potential leverage points for 3D weaving-related interventions in the current denim system?

Is addressed through Chapter 5.1.1 'Identifying leverage points'

RQ6 // How might the outcomes of the aforementioned subquestions translate into a strategy to unlock the potential of 3D woven denim, parallel to current denim?

Is addressed through Chapter 5.4 'Final Design | Discussion'

4.3.1

METHODOLOGY

Given the unsustainability of the current system and the growing demands for transparency, on-demand production, and circular economy practices, it is crucial to explore alternative models within the denim industry that align with these needs instead of the fast fashion principle. The implementation of such models is essential to effectively unlock the potential of 3D weaving and thus key components of influence must be found in this context, to be taken into account in the design phase of this project.

This study utilised a combination of literature research, previously highlighted in Chapter 1 (Background) and subsection 2.2.2 (On-Demand Production), and both semi-structured and unstructured interviews with experts from the denim industry. One of the key semi-structured interviews was conducted with the founder of Weffan, an expert in 3D weaving. Figure 37 provides an overview of the interview guide specifically tailored for this interview, and the full guide can be found in Appendix E. The duration of the interview was approximately 1.5 hours.

Additional semi-structured interviews, which contributed significantly to this study, were conducted at Kingpins with various denim mills, sustainable material experts, traceability and certification experts, and House of Denim. Figure 36 displays the general interview guide used for these interviews, and the complete guide is available in Appendix D. Each interview held here had a duration of 20 minutes to 45 minutes.

Unstructured interviews were conducted, with denim designer and historian Mohsin Sajid to begin with. This interview lasted for an entire day. Additionally, interviews were also held with designers, representatives from Tonello, and members from the educational field associated with two UK universities present at the Blackhorse Lane Atelier during an event. The conversations spanned approximately four hours, during which the researcher engaged with a total of 18 individuals. A sample of a 3D woven structure was brought to explain the technique (see figure 35).

Although the interviews were unstructured in nature, the researcher had familiarised herself with many of the questions from the general interview guide, as depicted in figure 36. As a result, these questions still played a role in shaping the conversations and guiding the researcher's interactions with the interviewees.



Figure 35

UNSTRUCTURED
INTERVIEWS AT THE
BLACKHORSE LANE
ATELIER

Semi-structured interview guides for expert interviews

1. How to get out of the current capitalist system?
It drives inequality, intransparent practices, discriminatory behaviour, outright horrid social conditions along the supply chain - not to mention environmental damage.
 - What could be first steps?
 - What about the denim industry in particular? Are there special things to consider with denim in such initial steps?
2. Traceability of the supply chain and transparency between stakeholders and the communicative end towards consumers, is significant in the strategy to be designed.
 - How do you start mapping out your traces? How do ensure that every step of the supply chain works as responsibly as it's supposed to?
 - And how do you 'convince' your stakeholders to even want to change?
3. Alternatives to setting up a new 'brand' or 'retailer store'.
I want to look into creating a strategy or product service system which explores alternatives to just starting another brand to sell online or in its own retailer stores, such as all brands work right now. Also, the idea for thinking in alternative manners of transparent product-to-consumer methods coincides in my research with your statement that consumers really are looking for fitting platforms when considering responsible products.
 - Do you from your professional perspective have comments on what I need to consider when I try to think in such alternative strategy-solutions for this particular project/3D weaving technique in denim?
4. Subsidization by government:
 - Hypothetically, could subsidization also be included for a strategy to be designed for this 3D weaving technique?
 - How would that work? Where do you start in establishing such funding?
5. Including denim designers:
This technique requires a lot from denim designers, who (understandably) tend to be very focused on their current ways of working. This technique requires a constant interplay between the exact jacquard loom at hand and the skills and creativity of the designer itself.
 - I've noticed it's quite a challenge to have denim designers think along the same lines with this new technique and its potential, so what would you recommend for making such new collaborations with 3D weaving happening?
 - How can this technique be adopted by current or new denim designers, since the programs and design methods are vastly different? Or should we have denim designers staying as they are and create a new 'profession' of special 3D weaving designers?

Figure 36

GENERAL SEMI-STRUCTURED INTERVIEW GUIDE (APPENDIX D)

Figure 37

SEMI-STRUCTURED INTERVIEW GUIDE FOR 3D WEAVING EXPERT (APPENDIX E)

SEMI-STRUCTURED INTERVIEW GUIDE: GRAYSHA AUDREN, WEFFAN

Sterre de Jager, TU Delft

We've seen that post- and pre-consumer waste is a huge problem which needs to be overcome. One way to tackle this problem in the pre-consumer phase specifically is to construct new garments using such waste, or adapting materials used. However, with 3D weaving denim you could design for zero-waste patterns in the first place, tackling the problem at the root. My thesis is about designing a strategy for applying the technique of 3D weaving denim to achieve systemic change within the Dutch denim market.

The route towards a strategy is still very open.

The questions can be answered during our conversation on the 20th of April to any extent you feel comfortable with.

1. Could you tell me a bit about yourself and about Weffan?
2. On-demand, true-to-size and zero-waste:
I have seen your beautiful Loom-State 3D woven trousers in collaboration with EE Exclusives. I saw it was mentioned that they aim to solve complexities in sizing and fit and could be woven on-demand. I was wondering how on-demand and true-to-size fit is achievable with 3D weaving, because I don't understand yet how that is possible with zero-waste patterns.
 - What are the things to be aware of in supply chains to be able to achieve this?
3. Will 3D weaving inherently involve smaller scale production?
4. How can 3D weaving reduce supply chain interruptions on labour and business?
And: I know the cut & sew part of the supply chain gets shortened by 3D weaving, but which other parts of the supply chain get shortened or adapted?
5. Traceability of the supply chain and transparency between stakeholders and the communicative end towards consumers, is significant in the strategy to be designed.
 - How do you start mapping out your traces? How do ensure that every step of the supply chain works as responsibly as it's supposed to?
 - And how do you 'convince' your stakeholders to even want to change?
 - How do you stimulate interdisciplinary conversations between stakeholders and create (new/adapted) longstanding relationships between them?
 - How do you ensure more transparency along the supply chain?

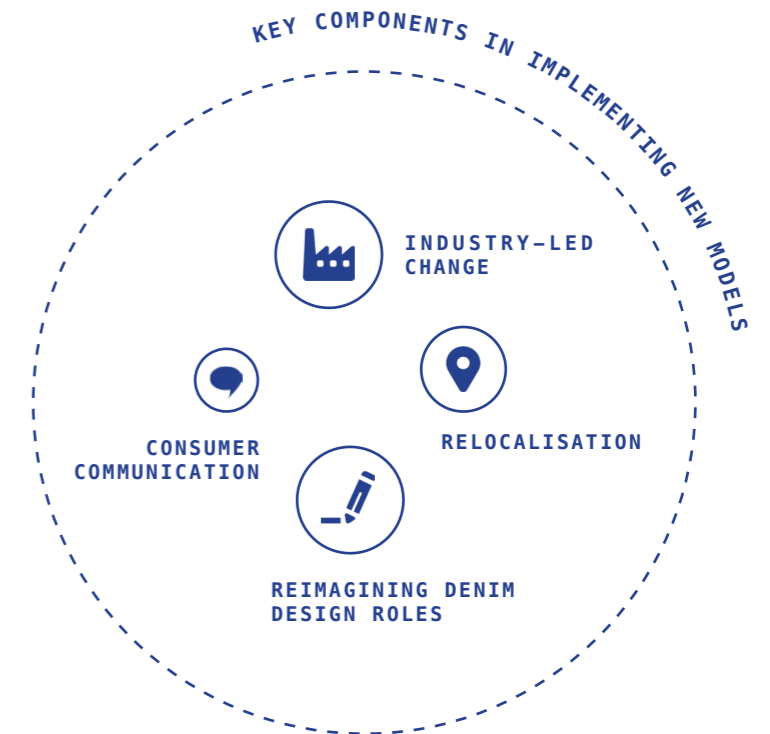
4.3.2

KEY COMPONENTS // RESULTS

The study revealed four key components essential for a systemic design approach in implementing a new sustainable model for 3D weaving in the denim industry. These components are crucial to consider in the development of a strategy, as their exclusion would likely result in an ineffective outcome. The identified components are: 'industry-led change', 'relocalisation', 'reimagining denim design roles', and 'consumer communication'. In the subsequent subsections, each of these components will be thoroughly discussed.

Figure 38

KEY COMPONENTS IN IMPLEMENTING NEW MODELS



4 . 3 . 3

INDUSTRY-LED CHANGE // DISCUSSION

THE NEED FOR INDUSTRY-LED, COLLABORATIVE MEASURES

In literature research and the interviews conducted in this study, it was found that overall, consumers must recognise fashion as a practical and meaningful necessity rather than objects of short-lived pleasure. Embracing the idea of investing in environmentally-conscious, higher-priced products is becoming increasingly inevitable (Niinimäki et al., 2020). However, relying solely on changing consumer behaviour through sustainability narratives in an effort to disrupt the fast fashion system was found to be insufficient, where an example of this is the prevalence of unverified sustainability claims by many brands, which has resulted in greenwashing practices and subsequently, consumer scepticism (Marrucci et al., 2021). Like also found in the previous study 4.2 (Understanding The Consumer Mindset Before Shifting Paradigms), the findings of the interviews with experts match this connotation.

Another significant finding of this study, which aligns with both user research and literature research, is that consumers are currently not inclined to pay a higher price for sustainable garments. Despite increasing or existing eco-conscious behaviour, economic factors still play the most significant role in consumers' garment acquisition decisions. The study reaffirmed that consumers cannot be easily categorised, and even those with a higher perception of sustainable awareness often find themselves making consumption choices based on price rather than sustainability considerations.

Furthermore, consumers are not solely responsible for driving demand in the fashion industry in any case. Fashion brands play a pivotal role by constantly fueling the demand for new cycles and seasonal trends, resulting in mass-produced and overstocked items, with marketing techniques employed for stimulating the psychological needs of the consumer. Moreover, the study clearly demonstrated that mills are highly responsive to and dependent on the demands of fashion brands, yielding to their influence in every decision they make. This dynamic persists even when mills actively strive to invest in sustainable technology and practices on their own accord. Despite their efforts, the ultimate authority lies with the brands, exerting significant control over the supply chain choices and operations.

However, the study revealed that a small and tightly knit community of modern denim mills and designers, associated with established denim brands, actively collaborate and show a willingness to invest in sustainable practices. This level of collaboration and being a small community within the fashion system is unique, interestingly enough present behind the most globally spread fashion staple. By leveraging this collaborative mindset and the shared commitment to sustainability among this group of modern denim mills and designers, innovative approaches and alternative models for denim can be explored.

4 . 3 . 4

RELOCALISATION // DISCUSSION

DE-GROWTH AND RELOCALISATION

Globalisation often leads to a decrease in the centralised manufacturing clusters as labour-intensive processes are outsourced to various subcontracting chains in countries with lower associated costs, resulting in a dispersion of economic activities. The aforementioned problems which result due to this practice, such as overproduction, intransparency, unregulated work environments, and a high distribution footprint in garments, show there is a need for relocalising supply chains. While the concept of "degrowth" is advocated by some as a beneficial solution for the environment, it may not provide practical strategies for redefining the fashion system. During interviews with many experts in the field, at both Kingpins and in local contexts explored in the UK, it became clear that degrowth does not incentivise anyone the change, since there are no clear benefits to it and it would only lead to diminishing business. It proved important to develop circular models for the fashion industry that consider the necessity for business growth and uphold the value of the industry for workers in the supply chain. He also emphasises that any incentives implemented should not undermine the powerful hedonistic and psychological enjoyment derived from fashion on the consumer-end (Environmental Audit Committee, 2019).

Hence, a more favourable approach would involve considering the relocalisation of structures across the globe, forming new self-sustaining economic circles. The argument suggests that future leading fashion brands should proactively optimise the fashion value chain by focusing on two key aspects: nearshoring and automation.

MICRO-MANUFACTURING AND ON-DEMAND PRODUCTION

Through the interviews conducted with denim mills and a 3D weaving expert, it was evident that apart from facilitating the exploration of innovative production methods, 3D weaving also has the potential to support process automation in micro-manufacturing contexts. By combining multiple steps within traditional supply chains into one, such as weaving fabric and highly reducing cutting and sewing procedures, 3D weaving could offer an example for localised innovative centres that integrate design and manufacturing processes. This finding aligns with the research conducted by Dr. Holly McQuillan (2020) on zero-waste system design in a comparable context, where the technique is employed.

Moreover, local material opportunities can be explored. By bringing users, makers, and the production process closer together while aligning with their values, a stronger symbolic bond can be formed between garments and consumers, potentially

leading to a desirable shift in consumer behaviour, such as extended garment use (McQuillan et al., 2018). Therefore, exploring how 3D weaving can align with on-demand approaches in local contexts and establishing a system for user participation can be intriguing. It's important to note that 3D weaving alone may not provide a comprehensive solution for system change, relocalisation, and user involvement, but it can serve as an initial case example, potentially initiating a cascading effect.

AUTONOMY THROUGH LOCALITY

Additionally, the Blackhorse Lane Atelier, operating as a smaller-scale, locally-based denim mill in London, has demonstrated that greater control over the supply chain can be achieved within this specific locality. Notably, their recent adoption of Tonello ozone and laser machines, as well as their autonomy in fabric selection, highlights their independence from client brands' influence.

ETHICS IN RELOCALISATION

While the idea of reshoring all outsourced manufacturing processes may seem promising, it is important to consider the ethical implications involved. Simply bringing all manufacturing back without proper consideration could have negative

consequences for overseas businesses and their employees, potentially causing them to lose their livelihoods. While some people opt for retraining programmes for current workers in those contexts, it remains unclear who will take up responsibility for this, what content such retraining programmes needs to have and which exact markets all the workers can be retrained for.

What's more, the term "rebuilding" can be misleading or inaccurate to some extent, since many of the once existing structures or local districts have disappeared almost entirely, meaning local supply chains have to be built essentially from scratch. There is a recognition that transitioning from global production to localised manufacturing should be approached with caution, considering the significant investments made in supply chains overseas. Instead of abruptly withdrawing from existing arrangements, a collaborative approach involving knowledge transfer and partnerships with overseas mills can be pursued. The cultivation of immaterial resources such as knowledge, design, information, and logistics could stimulate and prevent decline of traditional manufacturing industries in industrial districts, as well as help in the formation of new economic, centric models.

4 . 3 . 5

REIMAGINING DENIM DESIGN ROLES // DISCUSSION

3D CAD MODELLING FOR FASHION

In recent times, denim designers have become increasingly aware of the rising prominence of emerging 3D software, which offers notable cost-effectiveness and creative freedom. They acknowledge that this development is likely to bring about significant changes in their work methodologies. Anticipated shifts in priorities and company initiatives are already on the horizon. The use of 3D prototypes will redefine the sampling process. Furthermore, brands are expected to redirect their attention towards core products and embrace the concept of capsule collections with an emphasis on on-demand, true-to-size production.

RECONNECTING DENIM DESIGN AND MANUFACTURING

This presents an opportunity for the incorporation of 3D weaving as part of the evolving roles within the denim industry, as it aligns with these emerging perspectives. However, denim designers have highlighted the challenges of adapting to new tools, innovative manufacturing methods and 3D prototyping, especially when there is a significant disconnect from the production process. Traditionally, denim design has been quite detached from the manufacturing system, meaning that the two should be integrated in the future. In a report addressing the reshoring of

supply chains to the UK, there is a call for the establishment of open-access labs, Living Labs and networked collaborative manufacturing models (Postlethwaite et al., 2022). These initiatives could provide the necessary upskilling opportunities to meet the challenges of a forward-looking industry. Establishing such models could provide a platform for further exploring methods like 3D weaving in the context of automation, efficient 3D prototyping, on-demand production and accurate sizing requirements.

EDUCATION REORGANISATION

Furthermore, there is a growing recognition that educational reorganisation is necessary to align with the evolving role of denim design. In the UK, universities and prominent denim designers have acknowledged this and are actively promoting the challenge of redesigning education by introducing integrated master's programs tailored to this purpose. Additionally, the significance of educational restructuring is evident in other instances, such as fashion designers pursuing double major programs to cultivate cross-disciplinary skills and foster innovation (Faerm, 2017). In Ireland, there is another notable example of educational involvement in the field of fashion design. The University of Leeds has established a collaborative research centre dedicated to 3D weaving, supported by the European Regional Development Fund (University of

Leeds, 2023). Weffan for instance, a business in 3D weaving garments which' founder was interviewed in this study, is partnered with this centre. In the Netherlands, the team of innovative fashion design researchers, such as Dr. Holly McQuillan, is growing in the context of Industrial Design Engineering. For the Dutch denim and fashion market, this notion could be an opportunity for partnering industry and education in similar fashion to the innovation centre of Leeds.

The success of a denim designer extends beyond technical skills alone. It is crucial for students and established designers to join interdisciplinary programs that offer a strategic balance between new skill-building, integrative design-manufacturing methods and unique story-telling. This equilibrium between the 'what' and the 'how' enables future denim designers to effectively translate societal trends and emotional values into fashion design trends, in alignment with the evolving nature of the industry (Faerm, 2017).

4 . 3 . 6

CONSUMER COMMUNICATION // DISCUSSION

As seen in the previous study (section 4.2 Understanding The Consumer Mindset Before Shifting Paradigms), as well as earlier notions on consumer behaviour, reliable communication is crucial to support consumer understanding and the acceptance of new sustainable products and models. In this study, literature findings and the interviews held with industry experts further re-established this topic of importance.

COMMUNICATION STRATEGIES

There is limited knowledge regarding the precise reporting and communication of sustainability efforts within fashion brands (Yan et al., 2012) (Watanatada & Mak, 2011). This is compounded by the lack of a standardised definition of sustainability at the EU-level (Marrucci et al., 2021). Furthermore, Chan and Wong (2012) suggest that fashion consumers are often unfamiliar with the availability of sustainable fashion, indicating a need for relevant information to be easily accessible. In the absence of knowledge of sustainability, many people still confide in environmental messages by fashion brands regarding this topic at purchase (Teona et al., 2019). Therefore, attention must be given to the development of communication strategies which strengthen consumer understanding, as well as ensure careful documentation of socially and environmentally responsible practices in the fashion industry.

Phrasing information explicitly and adding labels or certifications from external parties can enhance the purchase intent of consumers regarding sustainable products (Brach et al., 2017). According to Watanatada and Mak (2011), the desired level of explicitness can be achieved in four ways. Firstly, it depends on clearly **defining** production processes and explaining how the product holds up to quality standards. Secondly, an emphasis can be put on the actual **delivery** of infrastructure change, capacity building, network expansion and expert connections. A third option relates to the **demonstration** of actions being aligned to established guidelines through third-party verification or own evaluation of suppliers. Lastly, collaboration with labels or certifications known for engaging in intensive marketing supports better identification of consumer needs and desires - thus stimulating both **demand** and consumer-centric sustainable products.

JUST 'ZERO-WASTE' IS INSUFFICIENT

During the previous study (see section 4.2), it was observed that consumers do not fully trust a 3D woven jacket's sustainability claims when labelled solely as "zero-waste." This is because other harmful aspects in the supply chain may not be addressed. Again, the interviews conducted in this study further emphasised this aspect of influence on new model acceptance. To build consumer trust, sustainable information about 3D

woven garments should encompass considerations such as material choices, origin, chemical usage and transparency in labour practices. A potential explanation for this consumer scepticism could be their awareness of greenwashing practices prevalent among brands, as reported by a majority of participants. Consumers react to the alignment of a company's sustainability efforts with its actual business practices. If these are perceived to be conflicting, people may believe that the company's engagement in sustainability is merely a response to consumer demand, resulting in damaged brand trust (Ellen et al., 2006). With regards to designing a strategy for 3D weaving denim, considering the **type of brand to collaborate with** and **ensuring complete transparency across the entire supply chain** are two crucial take-aways.

OTHER FORMS OF CONSUMER COMMUNICATION

Additional aspects brands could pursue include improving the communication to the consumer in the physical store, as stressed by industry experts and literature (Chan & Wong, 2012). Fashion companies can meet consumers' emotional needs by providing personalised services such as greeting and answering any eco-fashion-related questions. This can support the demonstration of sincerity and positive customer experience. Fashion stores should not only prominently showcase the sustainability efforts of their brand in storytelling, but also ensure effortless accessibility

to sustainable clothing (Cervellon & Wernerfelt, 2012). In the Netherlands, a significant 86% of consumers express their willingness to pay more for an enhanced shopping experience (Blaazer, 2022).

ECONOMIC FACTOR

While consumers are willing to pay more when provided with well grounded information behind a garment, they may still react negatively to excessively high prices, as seen in both literature and discussions with industry experts (Chan and Wong, 2012). Apart from the factor of affordability, sustainable products can also be valued for attributes such as design and quality (Camacho-Otero, Boks, & Nilstad Pettersen, 2019). A desirable combination of these attributes with pricing may lead to the alternative purchase of more conventional garments, as opposed to a more sustainable option. Yet, this indicates a strength of 3D woven garments, forming a distinct product category due to their unique visual appearance compared to traditional denim, making them not easily replaceable.

A portion of consumers seeks to construct an ethical identity, fulfilling psychological needs and a desire for self-expression. Consumers perceive a sense of advantage in engaging in a socially responsible lifestyle when purchasing branded products they associate with sustainable activities (Niinimäki, 2010). This suggests that the unique visual appeal of a 3D woven garment, which has been found to capture people's

attention in the user's social circle, can be effectively combined with a compelling and transparent sustainability narrative. Leveraging on the establishment of a connection between its aesthetic properties and a socially responsible lifestyle, could potentially help brands build their image further.

This study, in combination with earlier findings of user research, has reaffirmed the importance of consumer communication of all stages of the lifecycle, from design decisions to how garments will be disposed of. Making consumers a part of the decision-making process, bringing them closer to the origin of their garments through local production and adapting marketing content to be informative and educational in terms of sustainability, could help to build stronger relationships between stakeholders and begin to drive responsible consumption habits.

SECTION TAKE-AWAYS // IMPLEMENTING NEW MODELS

GENERAL CONCLUSION

By addressing and integrating the four identified crucial components of influence into the overall strategy to be designed, the study suggests that the implementation of a new sustainable model for 3D weaving in the denim industry can be more effective and impactful.

INDUSTRY-LED CHANGE

This component emphasises the need for proactive and coordinated efforts within the denim industry itself to drive sustainable transformation. It involves fostering collaboration and incentivising brands to break their short-lived, trend sensitive fashion cycles, to initiate and implement change, rather than solely relying on shifting consumer behaviour.

RELOCALISATION

Relocalisation refers to the idea of shifting production and sourcing practices to local or regional contexts. By reducing reliance on global supply chains, this component aims to reduce mass production cycles, lower transport footprint, enhance transparency, ensure supplier autonomy, employ micro-manufacturing contexts and support local economies through knowledge exchange with current supply chains overseas.

REIMAGINING DENIM DESIGN ROLES

This component highlights the importance of redefining the roles and responsibilities of denim designers, placing them into the context of manufacturing again. It involves embracing a holistic, creative and multidisciplinary approach that integrates sustainability considerations into the design process, fostering creativity, innovation, and responsible decision-making.

Effective communication with consumers is crucial for the successful utilisation of 3D weaving practices in the denim industry in alternative fashion models of implementation. This component emphasises the importance of transparent and informative communication to raise awareness, educate consumers about sustainable choices, and foster higher trust in sustainable information conveyed.

CONSUMER COMMUNICATION

4.4

GENERAL DISCUSSION // ADOPTION MOTIVATIONS & BARRIERS

This section serves as a discussion through structuring the main findings derived from research into motivations and barriers towards the adoption of new sustainable models in the denim industry, which can be found in figure 39 and 40. The interconnection between these motivations and barriers are also shown in the figures. This discussion is intended as a helpful contrivance towards the identification of leverage points in the denim system, as will be explained in Chapter 5 (Final Design). While the research findings were primarily found through conducting expert interviews, field research and user research, they are supported by findings from literature as well.

RQ4 // What are 3D weaving-specific barriers toward the implementation of alternative sustainable models?

- | | |
|---|--|
|  BRAND |  CONSUMER |
|  COMPETING BRAND |  GOVERNMENT |
|  AGENT SOURCING |  EUROPEAN UNION |
|  DENIM DESIGNER |  SUSTAINABLE INITIATIVE |
|  SUPPLIER |  THIRD PARTY FOR ECO-LABEL / CERTIFICATIONS |
|  THIRD PARTY |  MEDIA |

4 . 4 . 1

MOTIVATIONS

MOTIVATION	DISCUSSION	AFFECTED STAKEHOLDER	MOTIVATION	DISCUSSION	AFFECTED STAKEHOLDER
<p>SUPPLY CHAIN TRANSPARENCY</p> <p>A1. Production knowledge</p> <p>A2. Consumer-focused changes align with transparency</p>	<p>A1. Gaining a deeper understanding of production can strategically shape the responsible behaviour of consumers (Brun et al., 2020). LCA's and accompanying certifications for traceability and transparency are tools which could be utilised for increasing the knowledge of consumers (Iraldo & Barberio, 2017).</p> <p>A2. Brands are in turn incentivised to initiate consumer-focused changes towards more responsible practices within their supply chains, as rebuilding consumer trust relies on transparent communication and access to information (Asmi et al., 2022).</p>	<p>CONSUMER</p> <p>BRAND</p>	<p>EDUCATION</p> <p>E1. Shaping a new designer mindset</p>	<p>E1. Some designers exhibit a rigid mindset in their practices, which presents challenges in embracing sustainable changes throughout later stages in their career as they perceive it as outside the scope of their role (Claxton & Kent, 2020). Thus, the development of new educational programs, currently underway in the UK, is necessary to foster a more interdisciplinary approach to alternative methods of design, embodying circular principles from the outset. Design leaders are known to have a greater influence on a brand's strategic direction when they actively engage in education regarding approaches to sustainability (Claxton & Kent, 2020).</p> <p>Moreover, restructuring the designer-manufacturer relationship in education can further support a more integrated design approach. This can be achieved by reframing the term "factory" which holds negative and distant connotations, encouraging designers to be more receptive to manufacturing roles (Postlethwaite et al., 2022).</p>	<p>DESIGNER</p> <p>BRAND</p> <p>DESIGNER</p> <p>SUPPLIER</p>
<p>REPUTATION</p> <p>B1. Gaining traction and building brand loyalty</p>	<p>B1. The marketing of sustainable activities within the current fashion market positively impacts brand image, trust, and satisfaction, while also fostering brand loyalty. This could encourage the further development of effective sustainable management strategies, creating a positive vicious circle.</p>	<p>BRAND</p> <p>SUPPLIER</p>	<p>LOW EFFORT</p> <p>F1. Creating guidance to adapt supply chains in a less complex manner</p>	<p>F1. The growing demand for transparency places significant time and financial constraints on brands, compelling them to simplify their supply chains. Tracing every step within the complex and fragmented supply chain is an immense challenge. Moreover, complying with the high number of present certifications adds further complexity due to the extensive paperwork involved (Iraldo & Barberio, 2017). Therefore, transferring this responsibility from stakeholders to external parties would be a significant contribution to motivating the adoption of more sustainable models.</p>	<p>CONSUMER + GOV + EXT. PARTY</p> <p>BRAND</p> <p>SUPPLIER</p>
<p>AFFORDABILITY</p> <p>C1. Affordable adoption of greener technology</p> <p>C2. Funding for active participation in innovation</p>	<p>C1. Affordability of new technological solutions empowers mills to embrace sustainable initiatives (Asmi et al., 2022). The same applies to brands, as their primary concern revolves around economic factors.</p> <p>C2. Establishing a financial support network that facilitates collaborative research on sustainable fashion solutions could serve as an incentive for brands to actively participate (Postlethwaite et al., 2022).</p>	<p>BRAND</p> <p>SUPPLIER</p> <p>BRAND</p> <p>THIRD PARTY</p>	<p>INSPECTION INNOVATIONS</p> <p>F1. Early identification of chemical substances and fiber composition</p>	<p>There is a growing demand for European brands to take responsibility in managing chemical risks and providing safety information in their supply chains (Notten, 2020). Since some suppliers are taking initiative themselves, brands could be further stimulated to track and share such information. For instance, vertical mill Diamond Denim has implemented a chemical solution capable of verifying and validating other chemical substance usage and fibre compositions. This measure ensures compliance with quality and health regulations while confirming the accuracy of information provided in the previous stages of their supply chain.</p>	<p>CONSUMER + GOV + COMPETITOR</p> <p>BRAND</p> <p>SUPPLIER</p> <p>DENIM DESIGNER</p> <p>BRAND</p> <p>SUPPLIER</p> <p>THIRD PARTY</p> <p>CONSUMER + GOV</p> <p>BRAND</p> <p>SUPPLIER</p> <p>BRAND</p>
<p>COLLABORATION</p> <p>D1. Power dynamics</p> <p>D2. Building on trust</p>	<p>D1. Brands are compelled to embrace sustainability due to stakeholder pressure arising from customers, governmental action and competition (Seuring & Muller, 2008). For instance, the recent EU-level advancements advocating for an international law could exert governmental pressure on a brand, since it mandates firms to identify, report, and mitigate the adverse impact of their operations on human rights and the environment (European Parliament, 2023).</p> <p>D2. Once trust is established among stakeholders collaboration becomes feasible in reaction to the experienced pressure. The denim community, being relatively small and inherently collaborative, is well-suited for such collaborations. They can take the form of vertical partnerships involving suppliers, brands and customers, or horizontal alliances with brand competitors and third parties such as NGOs (Brun et al., 2020).</p>	<p>CONSUMER + GOV + COMPETITOR</p> <p>BRAND</p> <p>SUPPLIER</p> <p>DENIM DESIGNER</p> <p>BRAND</p> <p>SUPPLIER</p> <p>THIRD PARTY</p>			

Figure 39
DISCUSSION OF STAKEHOLDER
MOTIVATIONS TOWARDS ADOPTING NEW
SUSTAINABLE MODELS

4 . 4 . 2

BARRIERS

BARRIER	DISCUSSION	AFFECTED STAKEHOLDER	BARRIER	DISCUSSION	AFFECTED STAKEHOLDER
<p>INDUSTRY DETACHMENT</p> <p>A1. Long and complex global value chain</p> <p>A2. Highest profit margins</p> <p>A3. Outsourcing has provided European markets with an opportunity to overlook issues within their supply chains.</p> <p>A4. The textile industry lacks a strong advocacy platform to push for meaningful reconstruction.</p>	<p>A1. Fashion brands strategically place orders with upstream suppliers wherever they can maximise their profit margins (Kumar et al., 2017). While some establish direct sourcing relationships with vertical mills, others prefer an sourcing agent model, resulting in a complex network that connects producers and brands in the value chain. This network often involves numerous intermediaries or sub-contractors, leading to lengthy and fragmented supply chains. Many brands neglect to disclose or oversee their second-tier suppliers, thereby heightening the risk of human and labour rights violations. (Gereffi & Frederick, 2010).</p> <p>A2. Brands are unwilling to cover the cost of both sustainable development and rising production costs due to recent inflation. Consequently, the quality of denim is minimised to the greatest extent possible, while retail prices are increased to maximise profits. Since suppliers have to follow brand demand, this reinforces suppliers' inability to invest in new sustainable technologies.</p> <p>A3. The delocalisation of production activities has led to diminished transparency, adverse social and environmental consequences, as well as challenges in managing a complex network of operations. The European fashion market capitalises on this situation by conveniently disregarding these consequences (Kumar et al., 2017).</p> <p>A4. Industry workers encounter challenges in organising and advocating for their rights and sustainable needs, primarily due to cultural norms or policies preventing unionising and collective bargaining (Clean Clothes Campaign, 2020).</p>		<p>EXCESSIVE ECO-LABELS</p> <p>D1. There are too many untrustworthy eco-labels and certifications</p>	<p>D1. There is a high variety of labels and certifications, mostly unchecked by licensed third parties (Marrucci et al., 2021). Brands and suppliers often experience confusion in the high number of recent eco-labelling programs (Dendler, 2014). The labels are also often perceived as 'money scams' and contributors to greenwashing due to their failure in proving effectiveness, resulting in two consequences:</p> <p>1) Brands either investing in a label purely for its name without significant contribution to sustainability; 2) Refraining from pursuing <i>any</i> labels or certifications due to uncertainty regarding their value, thereby hindering potential improvement.</p>	
<p>UNRELIABLE FUNDING</p> <p>B1. Lack of strong financial support medium and policies</p>	<p>B1. Unreliable funding towards grassroots initiatives for worker-led sustainable action makes long-term strategic planning and accountability difficult (Johnston & Land-Kazlauskas, 2019).</p>		<p>COMMUNICATION</p> <p>E1. Lack of consumer belief in the communication of sustainability</p> <p>E2. Specific lack of consumer belief in zero-waste products</p>	<p>E1. Many consumers are aware of greenwashing strategies within fashion brands, leading to scepticism towards all communication regarding sustainable practices of certain brands (Marrucci et al., 2021). Consumer perception of greenwashing makes people less inclined to make sustainable purchases and has a highly negative effect on brand reputation. Moreover, when a brand is suspected of engaging in such practices, it severely damages the trust bond between the business and its stakeholders. This is another reason for brands to postpone action, in fear of missteps (Lu et al., 2022).</p> <p>E2. Regarding consumer perception of zero-waste products, it seems there is a lack of belief regarding their contribution to environmental protection. Similar to the point above, the dissemination of false information and the use of exaggerated claims in advertising further increases consumer distrust. For this product category, extra attention must be given to communicate its environmental benefits in a trustworthy manner (Sang et al., 2022).</p>	
<p>EU STRATEGY & PROTECTION</p> <p>C1. Lack of one clear EU strategy and compliance example leads to fearing potential missteps</p>	<p>C1. Starting in 2024, over 50,000 EU-based companies are obligated to adhere to the Corporate Sustainability Reporting Directive (CSRD) (Consultancy.nl, 2022). Furthermore, the EU is currently enhancing consumer protection measures. However, denim brands are insecure in the precise reporting expectations of their sustainability efforts and there is no EU-level consensus on the meaning of 'sustainability' in the context of marketing (Marrucci et al., 2021). This uncertainty makes them apprehensive about disclosing incorrect information, fearing media coverage on greenwashing and wary customers. Consequently, brands refrain from experimenting with new sustainable technologies, highlighting the importance of providing tangible knowledge.</p>				

Figure 40
DISCUSSION OF STAKEHOLDER BARRIERS TOWARDS ADOPTING NEW SUSTAINABLE MODELS

4.5 GENERAL DISCUSSION // 3D WEAVING- SPECIFIC BARRIERS

As for the supply chain implementation of 3D weaving in particular, certain specific barriers were identified, shown in figure 41. These findings are based on the interviews held with a 3D weaving expert, The Blackhorse Atelier, Diamond Denim and multiple denim designers. Moreover, some insights matched one of the sources consulted during literature research, which is therefore referred to as well. Most importantly, while 3D weaving garments and zero-waste pattern design have gained traction in recent years, their implementation has primarily remained limited to academic research or consultancy/business-focused initiatives like Weffan or Unspun. However, brands and mills encounter challenges in embracing 3D weaving as the existing barriers are substantial and there is a lack of knowledge on how to effectively integrate this new design approach in their current structures. Consequently, there is a need to reconsider the framework that grants brands access to relevant information and offers incentives for their engagement in these practices.

RQ4 // What are 3D weaving-specific barriers toward the implementation of alternative sustainable models?

Due to the limitations of existing jacquard machines, the **fractional density** of each layer (becoming lower at the increase of layer amount) currently raises concern for consumers, designers and mills regarding **garment quality**.

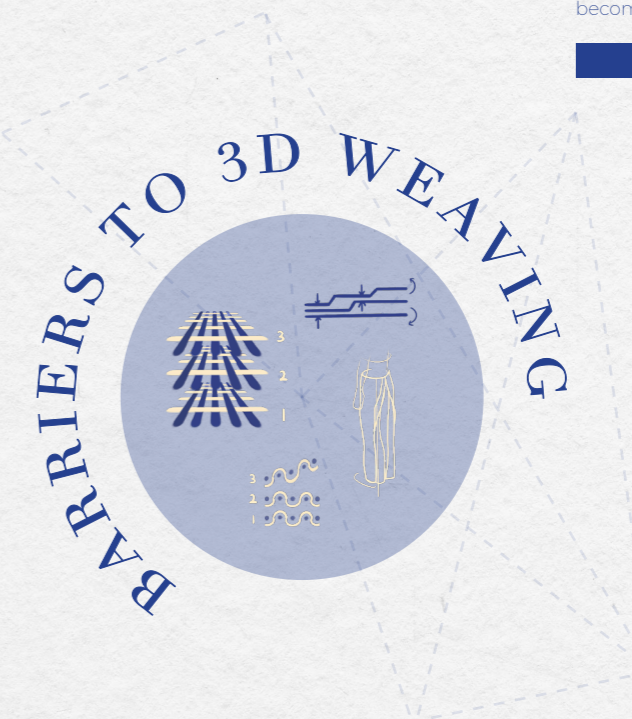
Investing in suitable jacquard looms (often not available in denim weaving mills) and the construction of 3D woven garments is an **expensive and high-risk investment**. Reasons are the expected **low production scales**, current **low demand** by brands and a **time-consuming design & cutting process**. Especially the new loom Unspun is developing would be too high of an investment risk. Rather, mills would prefer to invest in a machine built by combining the most suitable qualities of already existing jacquard looms, which would include the possibility to be adapted with future add-ons.

Traditionally, denim **designers are disconnected from the manufacturing system**. However, in order to develop garments with 3D weaving and produce lower volumes, denim design and manufacturing need to be **integrated**, granting access to machinery and new tools (Postlethwaite et al., 2022). To comply with trends in on-demand and true-to-size developments, this need becomes even more prevalent.

QUALITY PERCEPTION

HIGH (RISK) INVESTMENT

ADAPTING DESIGN ROLES



Understanding and mastering the intricate process of cutting 3D woven fabrics involves significant **trial and error**. The disconnect between designers and manufacturers caused by outsourcing further complicates the cutting process, making it both time-consuming and costly. However, this challenge also presents an **opportunity** for supply chain **relocalisation**, as in-house hand cutting would be a more viable option for 3D weaving. Nevertheless, the **inefficiency** of this approach should be addressed through researching innovative tools such as 3D cutting technology (Postlethwaite et al., 2022).

DIFFICULTY IN CUTTING

Figure 41

DISCUSSION OF
BARRIERS AND THEIR
INTERCONNECTION
TOWARDS IMPLEMENTING
3D WEAVING IN SUPPLY
CHAINS

3D digital design and automation tools, such as Clo3D, are crucial for the development of 3D woven garments and have the potential to speed up the product development process. However, manufacturers often don't know how to **translate 3D patterns into garment construction** and **funding** for giving micro-design studios and manufacturers access to such tools remains absent (Postlethwaite et al., 2022).

3D DESIGN TOOLS

CHAPTER TAKE-AWAYS // THE STUDY

OVERALL CONCLUSION

This chapter provides a comprehensive overview of the studies conducted within the project. The analysis began with an examination of the current state of the denim industry, including the creation of an ecosystem map and a detailed discussion of its elements. The chapter proceeded to discuss the findings from two rounds of user research, which utilised 3D woven denim garments. Despite variations in the research setups, both rounds yielded similar outcomes, subsequently explored. The third study focused on identifying key factors in the adoption of alternative design-to-consumer models in both the 3D weaving context and the broader denim industry. These factors have been extensively examined. Finally, a comprehensive discussion brought together all research, emphasising the interconnections among relevant actors, their motivations and barriers towards implementing new models, and the specific implications for 3D weaving. This chapter provided valuable insights into driving a paradigm shift within the denim industry and lays the groundwork for the subsequent chapter, where research translates into design.

THE PRESENT

A map of the current denim system has been provided, through the lens of the Dutch denim market. Through the analysis of the denim supply chain and stakeholder interactions, key challenges were identified in water depletion, hazardous chemicals, social injustice and waste problems. The research further aided in answering various research questions related to system dynamics, motivations and barriers, 3D weaving-specific challenges, leverage points, and strategy development for 3D woven denim within the next chapter.

The user research on understanding consumer perception of 3D woven denim garments highlighted their perceived elegance and refinement compared to regular denim, where the story of zero-waste proved to be impactful in a positive perception. The unique texture and feel of the hemp-cotton blend contribute to this perception, offering alternative use cases for the garments. Challenges regarding price point and brand positioning arise when balancing accessibility with the user's preference for premium garments. Future research should address fraying, structural integrity, and binding strength, while considering the overall sustainability of non-zero-waste elements as well. The research emphasises the potential of 3D woven denim garments as a distinct and small-scale produced category.

The third study identified four essential components for a systemic design approach in implementing a new sustainable model for 3D weaving in the denim industry. These components, including 'industry-led change', 'relocalisation', 'reimagining denim design roles,' and 'consumer communication', are crucial for the development of an effective strategy.

The findings from all studies were discussed. The interconnections between various factors and system actors were presented, and their consequential motivations and barriers toward adopting sustainable models in the denim industry. 3D-weaving specific barriers related to implementation were also discussed. Brands and mills could face substantial challenges in integrating 3D weaving due to existing barriers in quality perception, high risk investment, adapting design roles, difficulty in cutting and a lack of knowledge in using 3D CAD modelling. There is a need to reevaluate the framework that supports brands in accessing relevant information on niche innovative design-manufacturing methods, and incentivises their engagement in sustainable practices.

**TOWARD A
PARADIGM SHIFT
// UNDERSTANDING
THE CONSUMER
MINDSET**

**TOWARD A
PARADIGM SHIFT
// IMPLEMENTING
NEW MODELS**

**BARRIERS AND
MOTIVATIONS**

FINAL DESIGN: NEW-FASHIONED DENIM DIMENSIONS

A '3D WOVEN DENIM' LABEL
DESIGNED FOR COLLABORATIVE
CHANGE

CHAPTER 5

This chapter begins by identifying leverage points derived from the research outlined in the previous chapter. These leverage points inform the formulation of a design direction, leading to the emergence of a basic idea. The conceptualisation of this idea is then further developed through a co-creative process involving industry experts at Diamond Denim (5.1). After this, the chapter introduces the final concept, explaining all of the facets of the Systems-Oriented strategy and showing visual manifestations of its various elements (5.2). The concept is evaluated through the incorporation of the results of the second round of user research, additional consumer validation and expert validation. The aspects addressed through evaluation either remain as recommendations to be further explored in future research, or are used in an extensive iteration of the roadmap, leading to a more tactical and detailed version (5.3). Finally, the concept is discussed, reflecting on its suitability with the earlier defined design requirements (5.4).

5.1	NEW MODELS FOR FASHION
5.1.1	IDENTIFYING LEVERAGE POINTS
5.1.2	DESIGN DIRECTION
5.1.3	CO-CREATION OF A CONCEPT
5.2	INTRODUCING A LABEL: NEW-FASHIONED DENIM DIMENSIONS
5.2.1	THE INITIATIVE
5.2.2	THE LABEL
5.2.3	TRAINING PROGRAMME
5.2.4	IMPLEMENTATION ROADMAP
5.3	CONCEPT EVALUATION RESULTS
5.3.1	USER VALIDATION
5.3.2	EXPERT VALIDATION MARKETING
5.3.3	EXPERT VALIDATION STRATEGY
5.3.4	ROADMAP ITERATION // TACTICAL
5.4	CONCEPT DISCUSSION
	CHAPTER TAKE-AWAYS

5.1

NEW MODELS FOR FASHION

The fashion system is a complex network of interconnected layers, subsystems, and actors, in which numerous leverage points can be found, according to Meadows (1997; 2008) and Kanial et al. (2018). This project's ultimate objective is to implement the 3D weaving technique within a new model, and identifying various leverage points within the system can facilitate this in a more effective way. This section specifically addresses Research Question 5, aiding in formulating a design direction for the remainder of the project. Furthermore, it aims to answer Research Question 6 by engaging in a conceptualisation co-creation process at Diamond Denim, to determine the necessary elements for a new model utilising the 3D weaving technique from an industry expert perspective. Through this collaborative approach, the project seeks to uncover insights and perspectives from multiple industry groups to inform the Systems-Oriented design further, grounding the approach toward a future vision.

RQ5 // What are potential leverage points for 3D weavings-related interventions in the current denim system?

RQ6 // How might the outcomes of the aforementioned subquestions translate into a strategy to unlock the potential of 3D woven denim, parallel to current denim?

5.1.1

IDENTIFYING LEVERAGE POINTS

In order to achieve systemic change, identifying leverage points is crucial. This means finding the places in a system where an intervention could yield the highest impact, while devoting the least effort (Meadows, 1997; 2008). Gaining a complete understanding of the most effective leverage points does require an exhaustive process due to the complexity of the system at hand. Therefore, it is necessary to acknowledge that while this project focuses on utilising systemic design practices to identify leverage points, the outcome is restricted due to the initial project parameters and the limited timeframe.

A system comprises multiple layers or subsystems, in which numerous leverage points can be found (Murphy, 2022). At the onset of the project's research phase, an in-depth analysis was conducted to outline and understand these layers, providing a foundation for the identification of these points across the different layers of the system. Instead of merely addressing a single point where 3D weaving could be inserted, disregarding other focal issues, this strategy aims to work towards a more comprehensive solution that showcases the potential of the technique, which could accelerate the rest of the system into transformation.

Figure 42 provides an overview of the potential leverage points that have been identified based on mapping out the most significant insights and problems. It is important to note that these insights and problems are not isolated, but rather interconnected. This implies that the leverage points identified are based on the notion that solving one problem can potentially address another problem as well. This map was built upon the six conditions of systemic change introduced by Kanial et al. (2018), who provide a more approachable framework in response to Meadows (1997; 2008). The content is hierarchised, since the lower rows relate to models which are more difficult to change, yet could be more impactful. One key observation made by the authors is that the majority of systemic change initiatives tends to focus on the top row of the model, but without integrating the lower two, the change is unlikely to be sustained.

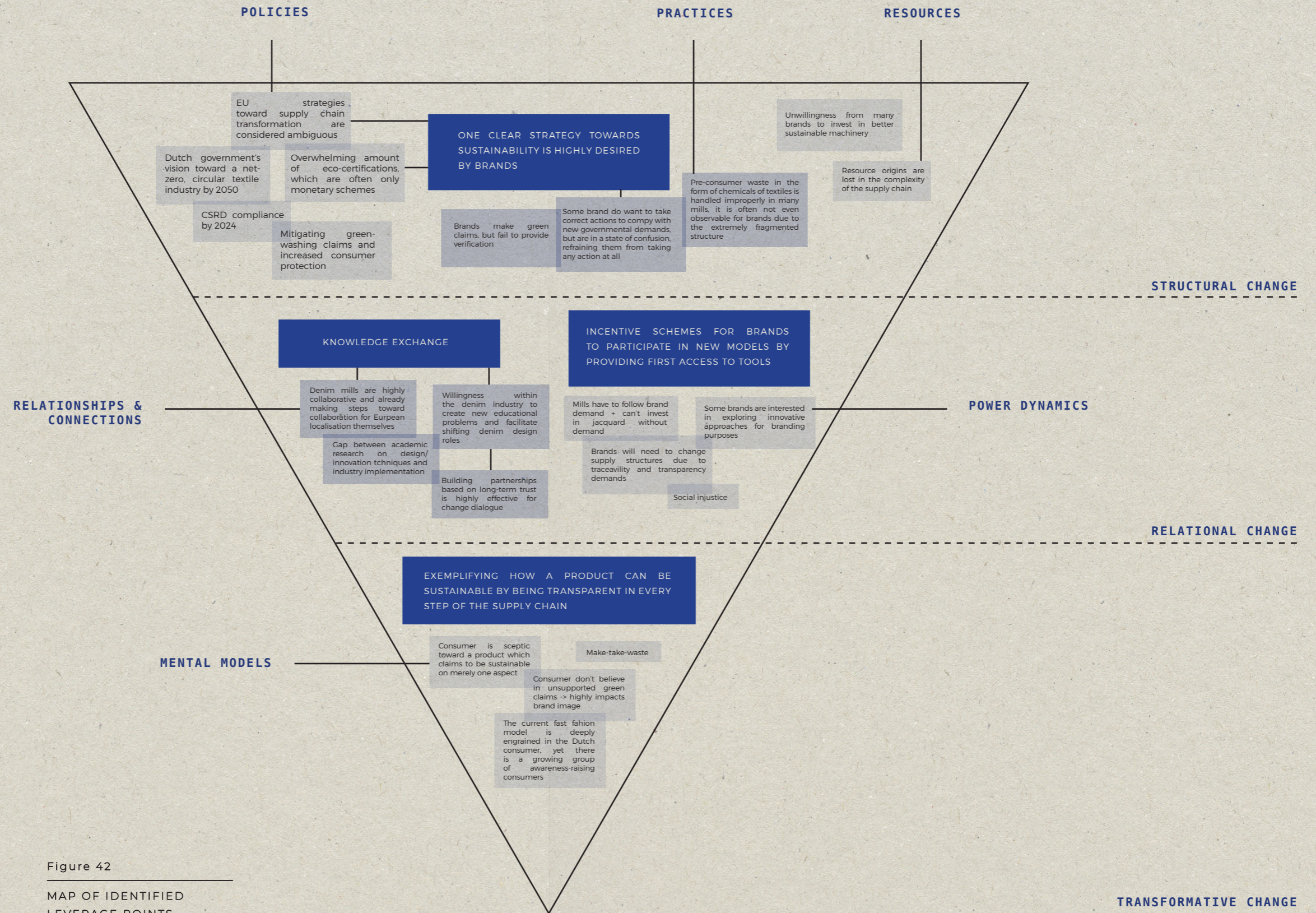


Figure 42
 MAP OF IDENTIFIED LEVERAGE POINTS ACCORDING TO THE MODEL OF KANIAL ET AL. (2018)

5 . 1 . 2

DESIGN DIRECTION**THE ESSENCE OF THE DESIGN VISION**

In order to create an intervention through which 3D weaving could be integrated into the Dutch denim market, it is crucial to generate demand for 3D woven denim garments. This demand must originate from within the industry itself, as top-down approaches merely targeting consumers have proven insufficient for sustainable transformation. Additionally, without ongoing demand from fashion brands, mills will be unable to invest in the necessary machinery for 3D weaving. To stimulate consumer interest, it is essential to demonstrate the potential of 3D woven garments in multiple sustainable aspects, to both the group already concerned with industry practices and the group that is not yet aware. Apart from the zero-waste objective, various factors including origin transparency, materials and sustainability communication, must be carefully considered.

The key lies in aligning the various actors within the industry, leveraging the collaborative relationship between mills and denim designers to incentivize self-driven industry transformation.

DESIGN DIRECTION

The design direction primarily emphasises relational change, with secondary emphasis on transformative change, as indicated by the model of Kanial et al. (2018). By prioritising these levels of change, the aim is to initiate a process that sets the gears in motion towards achieving greater systemic change in the future. The statement of the design direction is as follows:

DESIGN A COLLABORATIVE INITIATIVE WHICH INCENTIVISES BRANDS TO RAISE DEMAND FOR 3D WOVEN DENIM GARMENTS IN THE NETHERLANDS BY...

1) GIVING ACCESS TO THE TOOLS NECESSARY FOR THE 3D WEAVING DESIGN & PRODUCTION PROCESS

2) PROVIDING GUIDANCE ON HOW TO NAVIGATE COMMUNICATION TOWARDS THE CONSUMER IN A TRUSTWORTHY MANNER

DESIGN REQUIREMENTS**THE DESIGN SOLUTION SHOULD...**

// Encourage fashion brands to take the lead in integrating 3D weaving into their practices as part of their commitment to sustainability

// Define a network of multiple actors and their roles in the form of an initiative

// Stimulate dialogue between multiple stakeholders in the system and emphasise collaboration

// Provide guidance on the design process of 3D weaving garments and access to the information needed for acquiring the necessary equipment; The intervention aids designers in devising actionable ideas for 3D weaving garments

// Effectively and transparently communicate sustainability benefits of 3D woven denim garments to the consumer, in a trustworthy manner

// Take future relocation of supply chains into account

// Be feasible, viable and desirable

FUTURE VISION

The extensive range of research findings unveiled numerous interrelated challenges and opportunities within the denim industry. The final strategy to exhibit the potential use of 3D weaving denim is meant to act as a catalyst within the system towards higher level transformation, leveraging on multiple layers. To illustrate the desired trajectory, an ideal future vision is included, considering the contextual factors at play.

The pre-consumer phase of the textile industry has witnessed a significant reduction in both textile and chemical waste, approaching near-zero levels. The adoption of zero-waste pattern-making techniques, by utilising advancements such as 3D weaving, has gradually gained prominence. Complete transparency and effective communication between all stakeholders have stimulated a paradigm shift in the global political landscape, among brands and consumers. Production processes have become slower and production scales have decreased. Consumers are increasingly inclined to invest more in their made-to-measure clothing, opting for diverse acquisition or leasing models, and simultaneously prioritising the longevity of their garments. Repair and collection services have become more robust, completely transforming the perception of post-consumer textiles from waste into a valuable resource. Supply chains have been repositioned within local markets, without adversely affecting existing actors in the current developing countries' supply chains. Material choices have shifted away from petroleum-based fibres as the primary option and these materials can now be effectively recycled, giving them a second purpose. The decision to use cotton in denim production is no longer straightforward. It is primarily employed in areas where cotton is grown in close proximity to relocated local supply chains. Otherwise, alternative natural fibres, locally available, are the new standard.

5 . 1 . 3

CO-CREATION OF A CONCEPT

METHODOLOGY

Sanders and Stappers (2012) propose a classification of value types in co-creation, which includes monetary value, use/experience value, and societal value. They also suggest that the type of value in co-creation is connected to the timing of the co-creation process. To illustrate this relationship, figure 44 provides an overview which indicates where these specific co-creation sessions are situated and which value they correspond to. Additionally, it depicts the placement of other research actions undertaken in this study.

The co-creative sessions serve as a valuable method to generate use and experience value during the design exploration phase. These sessions align with the design direction of the graduation project, which aims to create a collaborative initiative to incentivise brands in the Netherlands to increase demand for 3D woven denim garments in a sustainable manner, by providing access to the necessary tools for 3D weaving design and production, as well as offering guidance on effective and reliable communication strategies to establish consumer trust. Figure 43 presents an initial concept that has been developed based on the research questions addressed in Chapter 4, the identified leverage points in section 5.1.1, and the formulated design direction. The strategy contains the development of an initiative and accompanying research centre in the Netherlands, where 3D woven zero-waste denim garments would be both designed and manufactured. The initiative would

be driven by a few sustainable leading brands which cater to the Dutch denim market, who simultaneously co-develop a strong eco-label with every step of the supply chain behind it being verifiable and trustworthy towards the consumer.

By conducting co-creative sessions with industry experts at Diamond Denim, including suppliers and professionals in the denim mill industry, valuable insights can be gained for further development of the basic idea. These experts possess in-depth knowledge about working with brands and retail, and they are well-versed in supply chain sustainability, financial considerations, regulatory compliance and machinery. Through their expertise, they can provide feedback on potential loopholes in the concept, areas that require further refinement, and any non-negotiable aspects to be considered, otherwise unknown to the researcher. Their input is critical for addressing the identified leverage points, from incentivising brands to participate in new models, to promoting supply chain transparency. Throughout the co-creative sessions, the researcher utilised a prepared template as the primary tool. This template was filled in during the conversations with participants, capturing the key points and insights discussed during each session. The co-creative way of designing further fits the overall goal of designing a strategy in a Systems-Oriented manner.

PARTICIPANTS

A total of four co-creative sessions were conducted to gather valuable insights and knowledge. The first session involved the head of the testing lab at

Diamond Denim and a German client considered experts in denim material health. They could provide expertise on future localisation of production to European contexts through knowledge exchange ideas on sustainability practices in both Europe and Pakistan.

The second session involved a senior manager of product development and the head of the spinning facility, who provided valuable information on material sustainability, transparency and traceability issues early on in the supply chain, recyclability and innovative combinations of cellulose-based fibres. They discussed the potential use of hemp from France and how they are innovating utilising the shorter fibre lengths in this specific region-grown hemp, and its implications for future localisation efforts.

Another session was held with the head of the jacquard machinery and the senior manager of product development, focusing on understanding the technical specifications of the loom and supply chain considerations for 3D weaving. This session provided interrelated insights into the constraints and demands from brands.

The final co-creative session involved the design and product development manager of Diamond Denim, who brought perspectives from the brand and retail sectors, as well as design. Strategies to incentivise brands to adopt new models for sustainable fashion development were discussed, the barriers currently preventing their adoption, how effective communication with consumers can be obtained, and which marketing and branding

elements could encourage brands to participate in leading the way for 3D weaving. It was recognised that while the primary goal for brands is profitability, niche, innovative, and 'quirky' initiatives can inspire brands to make genuine efforts towards sustainability and become pioneers in the industry.

RESULTS

The insights gathered from all co-creative sessions were documented and consolidated, as shown in figure 45, which provides an overview of the key findings and outcomes. These results were subsequently analysed and discussed to extract the most valuable insights for informing the details of the design concept. For reading the results in full resolution, consult Appendix L.

**BASIC IDEA FOR
DESIGN CONCEPT
// ELEMENTS OF
THE STRATEGY**



Figure 43

OVERVIEW OF BASIC IDEA OF CONCEPT BEFORE CO-CREATION, SHOWING THE VARIOUS ELEMENTS THE STRATEGY WOULD CONSIST OF

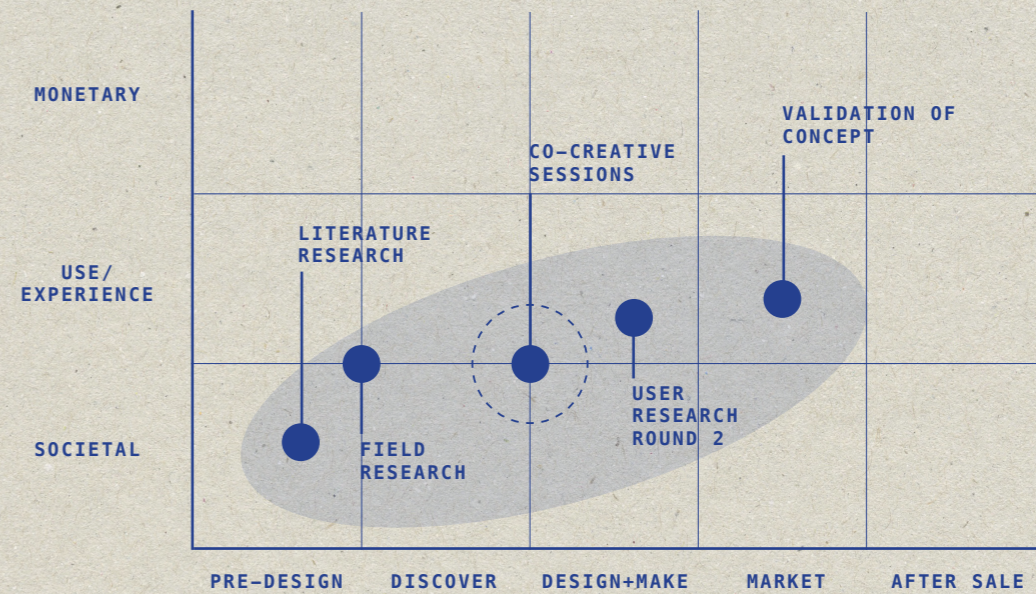


Figure 44

ADAPTED MODEL FROM SANDERS & STAPPERS (2012), SHOWCASING WHERE THE CO-CREATIVE SESSIONS ARE SITUATED AND WHICH VALUE THEY CORRESPOND WITH

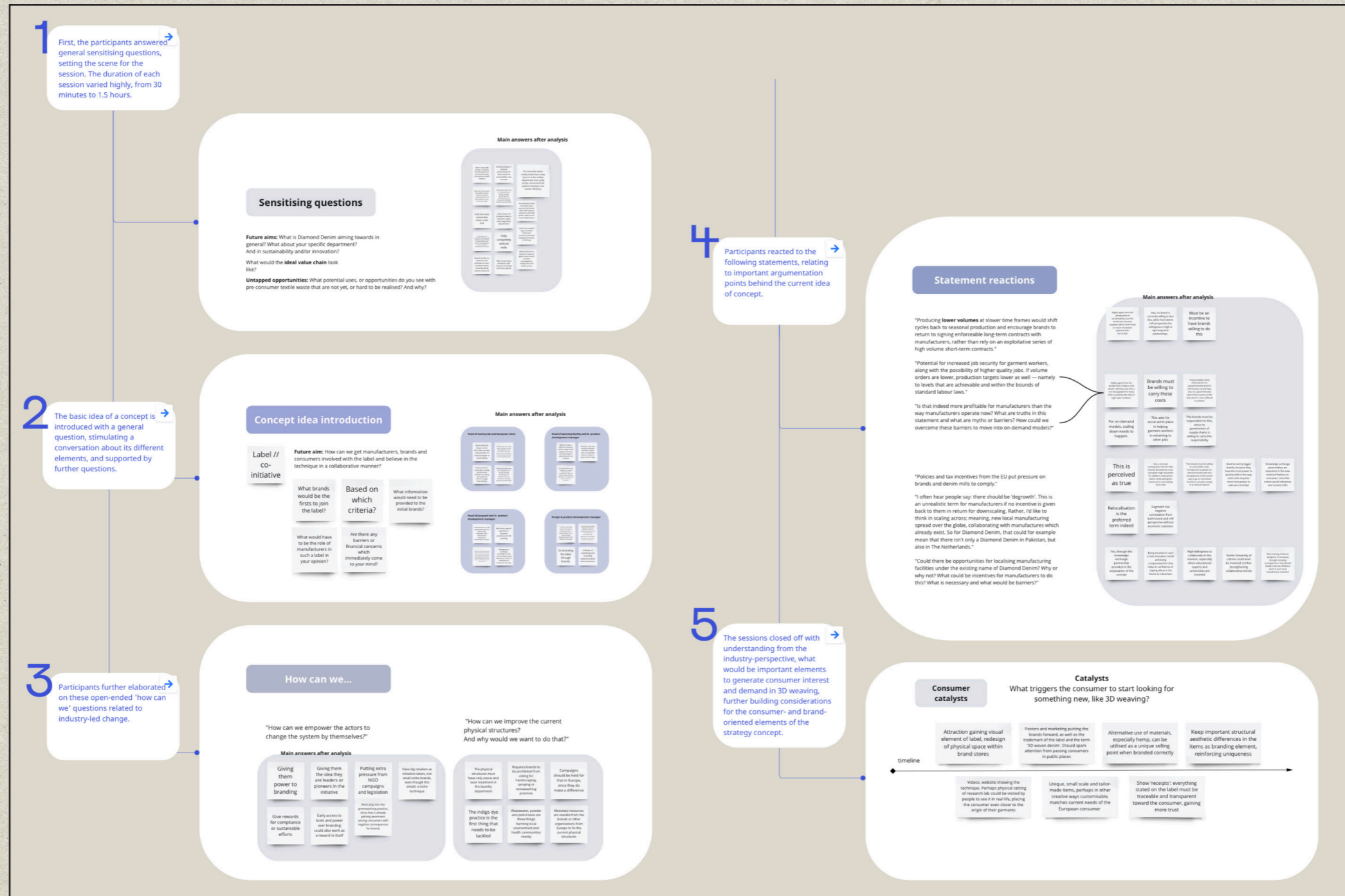


Figure 45
OVERVIEW OF CO-CREATIVE SESSION
TEMPLATE WITH MAIN ANSWERS OF
PARTICIPANTS AFTER ANALYSIS

DISCUSSION AND FURTHER CONCEPT DEVELOPMENT

After analysing the insights gathered from the co-creative sessions, several key discussion points emerged that guided the final development of the concept:

- **Initiative:** It is crucial to establish knowledge exchange partnerships early in the process with Diamond Denim as denim mill expert, to collaborate on building effective machines and automation, since they are already looking into ways of doing this with European actors themselves. Together with educational experts from the Netherlands, they could provide valuable input, and funding can be allocated to compensate Diamond Denim for their involvement. Moreover, the initiative should focus on sharing knowledge in creating self-sustainable economic design-manufacturing hubs in different regions, ensuring relocalisation does not result in a loss of business but rather fosters tailored cultural and geographical growth in the regions where current suppliers are located as well. After having Diamond Denim involved as knowledge exchange partner, the aim should be to do the same with all current denim mills behind each brand which joins the initiative in further stages of the strategy. However, then the monetary compensation must be carried by the brand itself.

- **Marketing and branding:** The marketing and branding element of the strategy for the 3D woven denim initiative should involve two distinct approaches, each serving different purposes.

The first strategy aims to attract brands by emphasising the innovative and niche nature of 3D woven denim, positioning participating brands as pioneers in this field. The website landing page should showcase visual manifestations of the label, allowing brands to understand they will lead in codesigning the branding further. Arguments should be presented to highlight the benefits of brand openness and transparency, contrasting it with the consumer scepticism and greenwashing perceptions often associated with current eco-labels and certifications. It should be stressed that the European Union is actively promoting compliance with sustainability issues, positioning the initiative as an example in developing the right path to compliance early on. The goal is to showcase that participating brands can regain consumer trust, enhance brand reputation, and meet EU regulations. It is anticipated that other brands will follow suit as 3D woven denim gains popularity, inspired by the successful and early policy compliance of the first brands.

The second marketing and branding approach should be focused on consumer communication. It aims

to educate consumers about the intricacies of 3D weaving, highlighting its zero waste possibilities and the initiative's commitment to transparency. The consumer should have access to comprehensive information, from the origin of the fibres to the final garment in their hands, as well as the actions and effects of the participating brands through a website and physical store spaces. This approach seeks to build consumer awareness and engagement, fostering a deeper understanding of the unique and sustainable aspects of 3D woven denim.

By employing these two marketing strategies, the initiative could effectively engage both brands and consumers, establishing a strong market presence for 3D woven denim and promoting sustainable practices throughout the industry.

- **Brand selection:** When selecting brands to participate in the 3D woven denim initiative, it is recommended to target luxury price point brands. These brands typically have larger budgets allocated for innovative and more sustainable manufacturing methods, making them well-suited for the implementation of 3D woven denim. For example, Levi's already has their separate, more sustainable laundry line in the mill to ensure quality, demonstrating a certain commitment to sustainable practices.

Choosing luxury higher price point brands aligns with the goal of establishing a mindset where consumers are willing to pay more for their clothing. By starting with a premium price range, the initiative can set a higher standard for quality and sustainability, effectively positioning 3D woven denim as a premium product. Moreover, although the reduced supply chain steps, automation opportunities and elimination of transportation could be understood as being more affordable of a manufacturing process, this would probably not be the case in reality. The creative design-manufacturing process requires a lot of time and work and the initiative entails a local, small-scale manufacturing setting. These factors, along with the use of high-quality fibres, better indigo dye, ozone treatment, and other sustainable manufacturing practices, would naturally result in a higher price for the garment.

By collaborating with more higher-end brands, the initiative can leverage their existing resources and expertise to create a strong foundation for the adoption of 3D woven denim. This approach supports the goal of shifting consumer perspectives towards valuing and investing in more sustainable and higher quality garments.

- **Visual communication and design of the eco-label:** When it comes to communication and the design of the eco-label, it is recommended to create a visually elegant manifestation that

aligns with the desired luxury feel of the 3D woven garments. The design should strike a balance between sophistication and simplicity, avoiding an overly bold or flashy appearance.

To capture the interest of consumers and emphasise the unique 3D element of the category, the eco-label should incorporate a catchy, creative element that aspires to gain attention.

The sustainability information conveyed on the eco-label should be comprehensive and detailed. It should provide consumers with a sense of confidence in the label, portraying it as a thoroughly researched and reliable certification in itself. By offering transparency and thoroughness in the information provided, the eco-label can instill trust and assurance in consumers, strengthening their perception of the 3D woven garments as genuine and sustainable products.

Overall, the design of the eco-label should be visually appealing, elegant, and captivating, while also conveying the necessary information to educate and engage consumers about the unique qualities and sustainability of the 3D woven garments.

- Inclusion of roadmaps towards implementation: To ensure the successful implementation of the strategy, the design should incorporate detailed roadmaps that outline the necessary steps and actions required

to make the concept a reality, allowing industry experts and relevant stakeholders in the Dutch denim market to understand the potential of the technique on systemic level. The roadmaps should not only highlight what needs to be done but also identify areas that require further thought and expertise. By presenting detailed roadmaps, the design can showcase the feasibility and practicality of the initiative, demonstrating that it is indeed possible to create new models for fashion using such niche techniques.

- Include a training programme:

Additionally, the initiative should include a training programme, with a visual representation, to exemplify the strategy's further commitment to changing the rigid denim design roles that currently exist. It should showcase the necessary skills and knowledge that designers need to adapt and embrace in order to fully utilise the potential of the design-manufacturing technique of 3D weaving, unlocking greater design creativity in a niche innovation setting. By including this element, highlighting the importance of alternative training and skill development, the final concept can demonstrate its dedication to not only creating a new product category, but also revolutionising the way denim designs are approached and executed.



A PICTURE WITH SOME OF THE PEOPLE INVOLVED IN THE CO-CREATIVE SESSIONS AT DIAMOND DENIM, MAY 2023 | FIG 46

5.2

INTRODUCING A LABEL: NEW-FASHIONED DENIM DIMENSIONS

The final design is a Systems-Oriented strategy which revolves around the collaborative establishment of the 'New-Fashioned Denim Dimensions': an innovative eco-label, which represents locally produced 3D woven denim garments. The strategy begins by outlining the setup of the label through an initiative that brings together key stakeholders of the Dutch Denim system (5.2.1). Five prominent fashion brands are involved as pioneers, gaining early access to expertise, a research lab and the label's own development. Subsequently, these brands will take the first step of introducing 3D woven denim as a novel product category in their stores. The initiative will provide comprehensive support, including financial, technical and ethical assistance. The strategy further encompasses the envisioning of various manifestations for the label itself, associated marketing efforts (5.2.2) and a training programme for future brand partners (5.2.3). To guide the implementation of the label, a roadmap outlines key actions and milestones on a timeline (5.2.4). The ultimate aim of the New-Fashioned Denim Dimensions label is to create a cascading effect, inspiring denim brands to further explore future transitions towards local and sustainable models in the broader fashion industry, extending beyond the realm of 3D weaving.



Figure 47
AN OVERVIEW OF THE SYSTEMS-ORIENTED STRATEGY WITH VISUAL MANIFESTATIONS

5.2.1

THE INITIATIVE

NEW-FASHIONED DENIM DIMENSIONS IS AN INNOVATIVE ECO-LABEL FOR A NEW, DUTCH 3D WOVEN DENIM PRODUCT CATEGORY – ESTABLISHED THROUGH A COLLABORATIVE EFFORT.

At the heart of the label's establishment is an **initiative**, which focuses on the foundation of an experimental research lab. This lab serves as a co-creative space, bringing together educational experts, governmental actors and five renowned denim brands which are active in the Dutch market. The **primary objective** of this initiative is to foster a **collaborative endeavour** aimed at establishing a **new Dutch supply chain for 3D woven garments as an original denim product category** within the country. This endeavour should serve as a **pioneering example** of how denim supply chains can be (re-)developed in a more sustainable manner, with the intention of inspiring more brands to follow suit in the future by granting access to the label and its resources upon joining the initiative. As a **starting point**, this initiative intends to set the stage for denim brands to embrace holistic approaches that encompass various facets of their operations, creating a **cascading effect** towards forward-thinking design strategies that extend beyond 3D woven denim as a single product category.

Figure 48 shows an overview of each body of stakeholders involved in the initiative, pointing out their main actions. These actions are further elaborated on in the remainder of this subsection and structured through a timeline in section 5.2.4 (Implementation Roadmap).

RATIONALE FOR THE INITIATIVE

Research conducted within this project has consistently highlighted the importance of fostering a **strong connection** between fashion designers and manufacturers (Postlethwaite et al., 2022). To achieve this, a **central body** is required to facilitate accessible resources and business support, enabling brands to enhance and expand their operations in a new local context effectively. Two critical aspects for brands to be inclined to change their ways of working are ensuring the availability of **crucial, standardised information** and providing **tangible proof** of the efforts made in return. Rather than merely presenting yet another eco-label with one-sided rules, essentially serving solely as



Figure 48
OVERVIEW OF INITIATIVE STRUCTURE, WITH THE MAIN ACTIONS FROM EACH BODY OF STAKEHOLDERS

a monetary scheme, an initiative could strive to offer comprehensive support from one consolidated place.

Additionally, under the umbrella of this initiative, there is an opportunity to establish not only a collaborative network, but also a dedicated physical space which facilitates the advancement of the innovative 3D woven design and manufacturing technique. By actively engaging five prominent denim brands as primary participants in this initiative, they are provided crucial roles in shaping both the branding of the new 3D woven denim product category and the associated label. In this way, brands are able to showcase and promote their progressive actions directly to their consumers in a manner they personally consider to be valuable. Lastly, by necessitating the automatic involvement of their current suppliers for knowledge exchange, an initiative could create a natural incentive for these brands to spearhead the urgently needed **industry-led change**.

POTENTIAL ENTITY RESPONSIBLE FOR INITIATIVE'S FOUNDATION

The first question which arises concerning this initiative is: which entity will take the initial action to kickstart the initiative and lab space?

The establishment of the initiative and research lab can be initiated through a collaboration between TU Delft and the Dutch House of Denim, with House of Denim taking the lead as the final responsible party. House of Denim's existing work in supporting sustainable practices in the denim industry and their strong connections with the government, funding sources, industry collaborators make them a suitable partner for driving the initiative forward. The industry collaborations

encompass both denim mills and fashion brands, providing a valuable starting point for connecting with brands that have already demonstrated an interest in sustainable denim innovation. This existing network makes it easily accessible to engage with these brands and further develop partnerships to drive the initiative's objectives forward. Additionally, the associated Jean School and Denim City in Amsterdam, provide valuable connections with educational experts as well.

Alternatively, the TU Delft could share the responsibility with other Dutch university partners, and a promising option is a collaboration with Eindhoven University of Technology. This partnership could assist in securing funding for the initiative through their educational funds. The European Supply Chain Forum (ESCF), affiliated with TU/e, offers access to supply chain professionals who can drive innovation. Additionally, as this forum is focused on collaborative supply chain development, the fund offers access to a network of experts in this field. This expertise can significantly contribute to the knowledge and skills required to support the development of the initiative, ensuring a strong foundation for its success.

EACH BODY OF STAKEHOLDERS WILL BE ASSIGNED DISTINCT ROLES AND RESPONSIBILITIES TO ENSURE THE INITIATIVE'S HOLISTIC APPROACH TO ESTABLISHING:
 – THE 3D WOVEN DENIM LABEL
 – THE COLLABORATIVE LOCAL SUPPLY CHAIN BEHIND IT...

1. GOVERNMENTAL ACTORS

Apart from their influence in policy-making, governmental actors can play a crucial role in **securing funding** for the initiative. The European Commission offers various funding options that can support businesses and organisations alike. By utilising the Europe District Europe Direct information relays, which provide detailed information on numerous funding routes, it becomes possible to identify the most suitable funding option tailored to the specific needs and objectives of this initiative. One appropriate funding avenue is the European Regional Development Fund (ERDF), which aims to strengthen economic, social and regional cohesion in local contexts in the European Union. More specifically, the ERDF supports investments that contribute to a 'smarter, greener, more connected and socially inclusive' Europe, which is in alignment with the values of the initiative https://ec.europa.eu/regional_policy/funding/erdf_en. The 3D Weaving Innovation Centre, established by the University of Leeds, also leverages this fund to support the development of their tools and industry collaborations. The initiative will need to comply

with specific requirements outlined by the ERDF. For example, Member States are expected to allocate at least 8% of their funds to urban development, delivered through local development partnerships and creation of various tools. Given that the establishment of the collaborative research lab in this initiative aligns with this objective, meeting the fund requirements should not be an issue, but rather a natural fit. While the funds provided by the European Commission may only cover a portion of the project's expenses, they are argued to have a substantial leverage effect. Securing EU funding often encourages other partners to join the initiative, which could point to the involvement of the first participating brands in this specific case.

Furthermore, this funding opportunity is supported by an established system of shared responsibility between the European Commission and national authorities. National -level regulatory frameworks are already in place, facilitating effective financial management. To ensure efficient operation of the management and monitoring system, A Dutch auditing body will be appointed to monitor the initiative's progress and verify control systems. Additionally, they assist in facilitating negotiations among stakeholders and allocating required resources https://ec.europa.eu/regional_policy/funding/financial-management_en. This collaborative approach between the European Commission and Dutch authorities through the ERDF ensures a comprehensive and accountable framework for the effective utilisation of funds and scaling of the initiative.

2. EDUCATIONAL FIELD

The involvement of educational experts is crucial in providing specialised knowledge and insights related to sustainable fashion, supply chain traceability and innovative design/manufacturing techniques. In the Dutch educational field, several actions can be undertaken to support the initiative:

- **Conducting Life Cycle Assessments (LCAs) and mapping out current supply chains.** This involves investigating the existing supply chains, identifying areas of intransparency and environmental impact and conducting gap analyses. By obtaining a comprehensive understanding of the current reality, brands participating in the initiative can demonstrate their commitment to transparency. Furthermore, a comparison can be made between the traditional denim supply chain and the new localised supply chain associated with the 3D woven denim product category. Such research would also aid in marketing the initiative's concept to the intended participating brands, by providing compelling arguments for why they should take action and join the initiative in the first place.

- **Product passport and traceability research.** Educational experts can assist in developing product passports and traceability systems. Firstly, this helps in exchanging knowledge with existing suppliers behind brands. While suppliers contribute by bringing their expertise on efficient supply chains under their current business names, they also receive assistance in overcoming transparency gaps within their own supply chains. Additionally, this research can stimulate trustworthy proof of the new supply chain for the associated label.

- **Business model innovation.** Educational experts can support brands in paving the way for new business models to be ready for upcoming legislation. This refers to both the implementation of 3D weaving as a brand, as well as recommendations of steps for future transformations in the industry.

- **Development of a 3D weaving training program:** Educational experts collaborate with denim designers from the initial participating brands to develop a comprehensive 3D weaving training program. This program focuses on providing denim designers from further brand partners with efficient tools for the pattern design and manufacturing of 3D woven garments. Exploring 3D design tools like CLO3D and researching 3D cutting tools can enhance the efficiency of zero-waste pattern cutting. By collaborating with educational experts in the denim field, such as the Jean School by House of Denim, a consensus can be reached on best practices for 3D woven denim. This collaboration also provides an opportunity to develop new educational courses on 3D weaving for aspiring denim designers, enabling them to enter the industry with a creative skillset and an open mind towards innovative design methods which centralise manufacturing. This not only benefits the current initiative, but also sets a foundation for shifting design roles in future innovative and sustainable models beyond the scope of this particular project.

- **Exploration of regional raw fibre.** To further advance sustainable practices behind 3D woven denim in the local context, an important area of focus is the development of regional materials. For instance, the establishment of hemp cultivation centres could be a topic of interest. By sourcing materials locally, the environmental impact caused by long-distance transportation can be significantly mitigated.

Moreover, this approach would address the concerns associated with cotton fields highlighted in Chapter 2. By diversifying the raw material sources and reducing dependence on problematic cotton fields, the initiative can promote more environmentally friendly alternatives. To determine the feasibility and potential benefits of such an approach, thorough research is required. Continuing on hemp as an example, this research would assess various factors such as the availability of suitable land for hemp cultivation, the environmental impact of regional material production and the economic viability of establishing hemp cultivation centres. By conducting a comprehensive analysis, the initiative can determine if this opportunity aligns with its objectives and presents a promising pathway towards a completely traceable and sustainable 3D woven denim label.

3. FIRST DENIM BRAND PARTNERS

The 'Big 5' refers to brands which cater to the Dutch denim market and are intended to join the initiative first. The selected companies are Levi Strauss & Co, Tommy Hilfiger, Calvin Klein, Mud Jeans and Scotch & Soda.

Upon joining the initiative, the brands are informed that they will play a pioneering role in the development of all the facilities provided by the initiative. While the European Regional Development Fund (ERDF) is intended to fund a significant portion of the project, the brands will be required to contribute an investment fee. In return, they will gain early access to the expertise and network offered by the initiative and will have the opportunity to co-create crucial components, thereby

establishing their own branding as the leaders in these efforts. The main actions expected from the brands include the following:

- **Collaborative branding of the New-Fashioned Denim Dimensions label.** The brands will work together to establish a strong and recognisable brand identity for the New-Fashioned Denim Dimensions label, reflecting their shared commitment to sustainable and innovative denim.

- **Developing marketing strategies to promote 3D woven products.** The brands will strategise and implement effective marketing campaigns to raise awareness and generate demand for 3D woven denim products, highlighting their eco-friendly nature, transparent background and cutting-edge design.

- **Conducting user research to refine and improve 3D woven prototypes.** The brands will continue thorough user research with their customer segments to gather valuable insights and feedback, enabling them to make continuous improvements to the design, fit, comfort and overall user experience of 3D woven denim prototypes, in combination with the label.

- **Creating unique and distinctive 3D woven designs while adhering to a unified standardised label.** The brands will leverage their own creative expertise to develop captivating and distinctive 3D woven designs, while adhering to the standards and guidelines set by the New-Fashioned Denim Dimensions label, ensuring consistency and quality across all products.

- **Recruiting emerging denim designers to actively participate in the lab's activities and become leading 3D weaving designers.** The brands will actively seek out their own or emerging denim designers and

provide them with opportunities to contribute to the lab's activities, fostering their growth and positioning them as future leaders in the field of 3D weaving, driving innovation and pushing the boundaries of denim design.

- **Redesigning physical stores to enhance accessibility of 3D woven denim products.** The brands will redesign their retail spaces to create an engaging environment for customers to explore and purchase 3D woven denim products, ensuring easy accessibility and showcasing the unique qualities of these garments.

SELECTION OF BRANDS

Several factors contribute to the selection of the first brands. Firstly, the European fashion industry is currently facing challenges such as inflation and geopolitical tensions, which are expected to hinder growth and escalate production and retail costs. These challenges are particularly relevant for denim brands, with raw cotton prices experiencing a 40% projected increase (Fibre2Fashion, 2022). Field research has indicated that many denim brands are compromising on quality while maintaining or even increasing retail prices to maximise profit margins, often without transparently communicating these changes to consumers. However, this trend does not encompass the higher-end fashion sector, which is projected to still experience sales growth in 2023 (Amed et al., 2022). Thus, the selected brands are more likely to be willing to invest in the initiative.

Furthermore, the brands stand out due to their already growing interest in setting new standards within the industry. For instance, at Diamond Denim, it became

clear that Levi's demands an entire finishing line separate from all other brands in the mill, to meet their own determined quality standards. They have shown a commitment to maintaining quality without sacrificing it for higher profit margins at the current moment. Furthermore, these brands often already have dedicated innovation centres or teams in-house that actively seek out new sustainable design and manufacturing methods. Co-creation with industry professional Jayesh Mandalia - the Design & Product Development Manager at Diamond Denim who has close connections with many retailers - has indicated a high level of interest from these brands to act as pioneers in this initiative.

Finally, if House of Denim is involved in the initial stages of the initiative, it would facilitate a seamless dialogue with the chosen brands, as they are already either co-founders or partners of the foundation. This also indicates the brands' existing interest in sustainable and innovative denim production.

It is important to note that while G-Star Raw is a brand strongly associated with Dutch denim, they were not initially targeted for this initiative due to their recent downsizing of their innovation team, making their involvement more challenging to align with the current goals of the initiative.

4. SUPPLIERS BEHIND THE BRANDS

The suppliers associated with the participating brands will actively contribute to the establishment of the new research lab and local supply chain dedicated to 3D weaving. Through a knowledge exchange partnership, they will provide valuable expertise in areas such as jacquard machinery and efficient processes within the Netherlands. This collaboration will occur under their own business name and they will be compensated through the funding provided by the initiative. In return, the suppliers will receive assistance in innovating their own supply chains. Specifically, they will have access to the developed product passport and traceability schemes without incurring high investment costs, as this information is often difficult to access for suppliers and brands are unwilling to bear the associated expenses for them to be able to invest. Furthermore, the educational expertise within the initiative will assist them in creating roadmaps towards establishing their own sustainable local supply chains in the future, extending beyond the scope of 3D weaving.

By fostering knowledge exchange partnerships with suppliers, the initiative takes an ethical approach towards the redevelopment of local supply chains in the Netherlands. This approach recognises the importance of maintaining the stability of the outsourced industry, having become a significant economic dependency for many countries - albeit through a more localised approach there as well, to ensure long-term viability.

5. NON- GOVERNMENTAL ACTORS

Fashion-related NGOs could play a significant role in the success of the initiative. To start, they often already possess an existing network involving a wide array of stakeholders. Furthermore, prioritising transparency is at the forefront of their agenda. Brun et al. (2020) exemplify this through the case of the decade-old NGO 'Fashion Revolution', which advocates for fashion companies to disclose supply chain information. Through their marketing and educational efforts, Fashion Revolution actively engages consumers, enabling them to demand transparency. This bottom-up approach allows consumers to influence brands and encourages greater accountability.

Involving NGOs like Fashion Revolution in this initiative could be effective, as they bridge the existing gap between consumers and supply chains. Their involvement could help create a clearer line of communication between all parties involved, driving the demand for transparency and responsible practices.

Furthermore, NGOs often maintain close connections with governmental actors, providing an additional incentive for the development of clear regulations and demands from a higher level.

5 . 2 . 2

THE LABEL

THE NEW-FASHIONED DENIM DIMENSIONS LABEL AIMS TO SET A NEW STANDARD FOR TRANSPARENCY IN THE DUTCH MARKET BY PROVIDING FULL VISIBILITY INTO EVERY STEP OF THE PRODUCTION PROCESS BEHIND 3D WOVEN DENIM GARMENTS.

Consumers are often unsure about the specifics of what they are paying for when purchasing eco-labeled garments. Consequently, they may be reluctant to pay higher prices without understanding the underlying reason. This highlights the importance of providing consumers with accurate and credible information about the production process behind eco-labeled garments. By ensuring transparency and trustworthiness in conveying this information, brands can address the needs and concerns of consumers effectively, while protecting their brand-image (Brun et al., 2020).

DEFINE, DELIVER, DEMONSTRATE, DEMAND

In 2011, Watanatada and Mak already stressed the diminishing trust in some eco-labels. Therefore, it is crucial for brands with ambitious sustainability commitment statements to establish reliable methods for evaluating the progress of their value chains. Eco-labels can serve as powerful tools that combine standards and branding to deliver transparency and credibility. However, the vision of the New-Fashion Denim Dimensions goes beyond merely introducing another label. Instead of conveying a single sustainable aspect, such as a 3D woven garment involving a zero-waste pattern, the New-Fashioned Denim Dimensions

label aims to build a fashion system ethically and sustainably in its entirety.

In continuation of the criteria outlined by Watanatada and Mak (2011), the initiative will undergo a series of stages to ensure the credibility of the information provided by the eco-label:

1. The first stage is to **define** the key information that needs to be presented to consumers.
2. In the **delivery** stage, the label's branding and information will be designed to effectively communicate the message to their consumer segments.
3. The **demonstration** stage involves the initial brand partners showcasing the label by offering the first batches of 3D woven denim garments in their stores. Through additional marketing efforts, the goal is to create a demand for this new product within their customer segments.
4. By generating consumer demand for these products, the aim is to stimulate **broader demand** for change in the overall denim supply chain. The demonstration of how it is possible to produce garments sustainably and ethically in this case of the 3D weaving category, should serve as an inspiration and catalyst for transformative change in the Dutch market and beyond.

Figure 49 illustrates envisioned manifestations for effectively conveying the necessary information on the label, based on current research. The section continues on the following pages, elaborating on the specifics behind this information.



Figure 49

ENVISIONING A POTENTIAL
MANIFESTATION OF THE LABEL -
3-PART DESIGN

DESIGN OF THE LABEL

The variation in design and communication formats of eco-labels can result in various interpretations among consumers. Luchs et al. (2010) highlight that there are distinct differences in how products are marketed, influencing consumers' confidence in relying on sustainability information. Their research shows that consumers tend to associate higher product ethicality with communicative phrases related to gentleness, while perceiving lower ethicality with attributes associated with strength. The latter could even work counterproductive and result in consumers opting for a 'safer', less sustainable option. Hence, the design and statements of the label adopt a minimalist approach, using gentle language choices like "safe and secure livelihoods" and "finding harmony in nature: carefully chosen raw fibre" (see figure 50). This is in contrast to using bold branding and strong statements such as "a new groundbreaking, local label" or "the first cutting-edge, zero-waste denim design". Moreover, the label's prioritisation of explicit messages aims to enhance purchase intentions towards the product (Hyllegard et al., 2012).

The tag featuring an origami-inspired form, free from any phrases, is intentionally designed to captivate attention and entice customers to explore the rest of the label.

In figure 51 the tag design with an explanation behind 3D weaving can be found.



Figure 50

THE LABEL'S 'NEW-FASHIONED DENIM DIMENSIONS' TAG WITH INFORMATION BEHIND THE CONCEPT

CONVEYED INFORMATION

The selection of the information conveyed in the label is primarily based on Brun et al. (2020) and other previous research findings. In the design, all information should become accessible for further reading in the form of a QR-code.

- **Zero-waste, zero compromise on sustainability.** Firstly, an explanation is provided on the unique value of 3D weaving, particularly its ability to create zero-waste pattern designs that eliminate pre-consumer waste, typically destined for incineration or landfills. Additionally, the label must clearly display the percentage of carbon footprint reduction achieved through this innovative manufacturing process. Preferably, this percentage should be calculated per garment. However, accurately determining these figures has proven to be complex, as indicated by the work of Barbara Vroom (2022). Therefore, further research is necessary to develop precise calculations. In the absence of specific data, the label should display the average percentage of carbon footprint reduction achieved, providing consumers with an indicative measure of the environmental benefits of the 3D weaving.

- **Local and liable.** This section points out how the new local supply chain greatly minimises transportation-related impacts. Additionally, it addresses overcoming the loss of transparency commonly observed in complex global supply chains. Finally, disclosing the involved local control bodies (governmental actors), shows how liability is achieved.

- **Traceable and transparent.** This involves disclosing a supply chain sourcing map to ensure transparency and which tools were used to achieve the map's creation.

- **Safe and secure livelihoods.** Here, the production conditions of the new local supply chain are pointed out. Moreover, the manner of collaborating in a knowledge exchange partnership with current suppliers is also explained. This way, brands can account for better labour conditions, as well as a secure livelihood for the workers in the future.

- **Clean indigo and high quality standards.** First and foremost, brands provide information to demonstrate their efforts in using bio-indigo dye, as well as employing ozone finishing by Tonello and laser techniques to reduce harmful chemical pre-consumer waste. Moreover quality assurance must be given to the fabric and construction of the garment. After conducting the user research described in chapter 4, the issue of low fractional density with an increase in the number of layers is crucial to address. While some users appreciated the thinner and smoother fabric of the garment compared to regular denim, it became evident that the construction at its known weak spots was inadequate. It is essential for the label to establish and uphold a stringent quality standard, particularly since it would involve higher-priced products within the first involved retailers. Following comprehensive research conducted in the collaborative lab involving suppliers and educational experts, significant efforts should be made to enhance this aspect. The label has to effectively communicate the subsequent quality standard to consumers. Furthermore, according to Jung & Jin (2016), the implementation of a high-quality and high-priced strategy in slow fashion can lead to consumers perceiving greater value for their purchases. This, in turn, motivates them to prolong the lifespan of



Figure 51
ANOTHER TAG WITH INFORMATION BEHIND THE 3D WEAVING, TEXT IS SHOWCASED IN BIGGER FORMAT IN APPENDIX M

“CERTIFICATION LABELS, CLAIMS AND LOGOS CAN HELP PEOPLE MAKE CHOICES THAT ARE RIGHT FOR THEM, BUT THEN THOSE PROMISES SHOULD NOT TURN OUT BE EMPTY PROMISES.”

MARTIJN SNOEP, CHAIRMAN OF THE BOARD OF ACM (2020)

their clothing items by wearing them for a longer period.

- **Finding harmony in nature: carefully chosen raw fibre.** The New-Fashioned Denim Dimensions label prioritises the utilisation of sustainable raw materials in its production processes. For instance, materials such as Tencel, but the label also seeks to explore the potential of sourcing hemp from local regions, like France, and potentially even closer to the Netherlands in the future. By embracing these alternatives, the initiative aims to reduce the environmental impact associated with traditional denim production from current cotton sourcing.

- **Actions & effects.** The label not only outlines its goals, but also emphasises the importance of implementing these objectives in a tangible and effective manner. Therefore, the consumer is referred to the label's associated website, where every **action** from the brand partner in question is accessible. Furthermore, the website highlights the environmental and societal impacts behind the new 3D woven garments, providing transparency regarding the **consequences** of brands' actions. By openly communicating the effects of their actions, the label aims to foster accountability and trustworthiness to both consumer and other brands.

- **Uniting for long-term commitment.** This statement refers to the active participation of brands in the collaborative initiative behind the label, clearly defining their roles and responsibilities. It also shows their long-term commitment to the initiative, demonstrating their dedication to transform their practices.



Figure 52
VISUAL MANIFESTATION OF THE WEBSITE TOWARD CONSUMERS, RELATING TO HORIZON 3 AND 4

MARKETING TOWARD THE CONSUMER



Figure 53
VISUAL MANIFESTATION OF A CAMPAIGN, RELATING TO HORIZON 3 AT FIRST MARKET ENTRY

5 . 2 . 3

THE TRAINING PROGRAMME

AS PREVIOUSLY MENTIONED, THE INITIATIVE'S RESEARCH LAB COLLABORATES WITH PARTNERS TO CREATE A TRAINING PROGRAMME FOR DENIM DESIGNERS WHO WILL BE ASSOCIATED WITH THE LABEL. THE PRIMARY OBJECTIVE IS TO EQUIP DESIGNERS WITH NEW SKILLS, WHILE MAINTAINING OPEN AND ADAPTIVE ACCESS TO INFORMATION FOR ALL PARTICIPATING BRANDS, ENSURING THAT NO BRAND CAN MONOPOLISE THE KNOWLEDGE.

To ensure the development of a comprehensive and effective training programme, extensive research should be conducted by a diverse range of educational experts from Dutch universities. This collaborative effort should involve zero-waste design researchers like Dr. Holly McQuillan from the TU Delft, denim design educators from House of Denim's Jean School for example, and experts from mechanical fields, delving into the intricacies of machinery. Their collective expertise will shape the programme and determine the essential tools and knowledge to be included.

The training programme encompasses a range of essential courses to equip designers with the necessary tools. In Figure 54, another visual representation is provided of the information which is currently expected to be crucial, offering a glimpse into the depth and breadth of the forthcoming training programme (consult Appendix N for the flyer in 2D). Some of the programme's key courses should include:

- **Mastering 3D Design with Clo3D:** Harness the power of the innovative 3D design tool Clo3D, to

enable immediate visualisation and development requirements in three dimensions.

- **Designing for Zero-Waste Patterns:** Learn how to design denim garments by using every piece of fabric creatively and effectively. This course also addresses overcoming fractional density challenges associated with 3D weaving and ensuring structural integrity by carefully considering the bias direction within the product, in order to maintain a high-quality garment construction.

- **New Jacquard Loom Proficiency:** Explore the capabilities of newly introduced jacquard loom, specifically designed for optimal performance with 3D weaving, on the basis of existing machinery. Learn about design freedom and pattern repeats, loom width and adaptability of the machine with potential add-ons for future projects. Finally, understand how to utilise AI for the creation of surface patterns, translate this into a map of bindings and program the patterns correctly into the software to minimise fabric wastage through trial and error.

- **Efficient Utilisation of 3D Cutting Tools:** Learn how to maximise the efficiency of 3D cutting tools for 3D weaving, ensuring optimal use of time and resources.

- **Sustainable Embellishments:** Gain insights into utilising embellishments like screw-on buttons effectively, considering both aesthetic appeal and future recycling purposes.

- **Exploring Sustainable Material Combinations:** Dive into the world of denim beyond conventional cotton. Discover suitable combinations of TENCEL and hemp for instance, while also considering the implications of blended yarn on end-of-life recyclability.



Figure 54

VISUAL MANIFESTATION
OF THE TRAINING
PROGRAMME

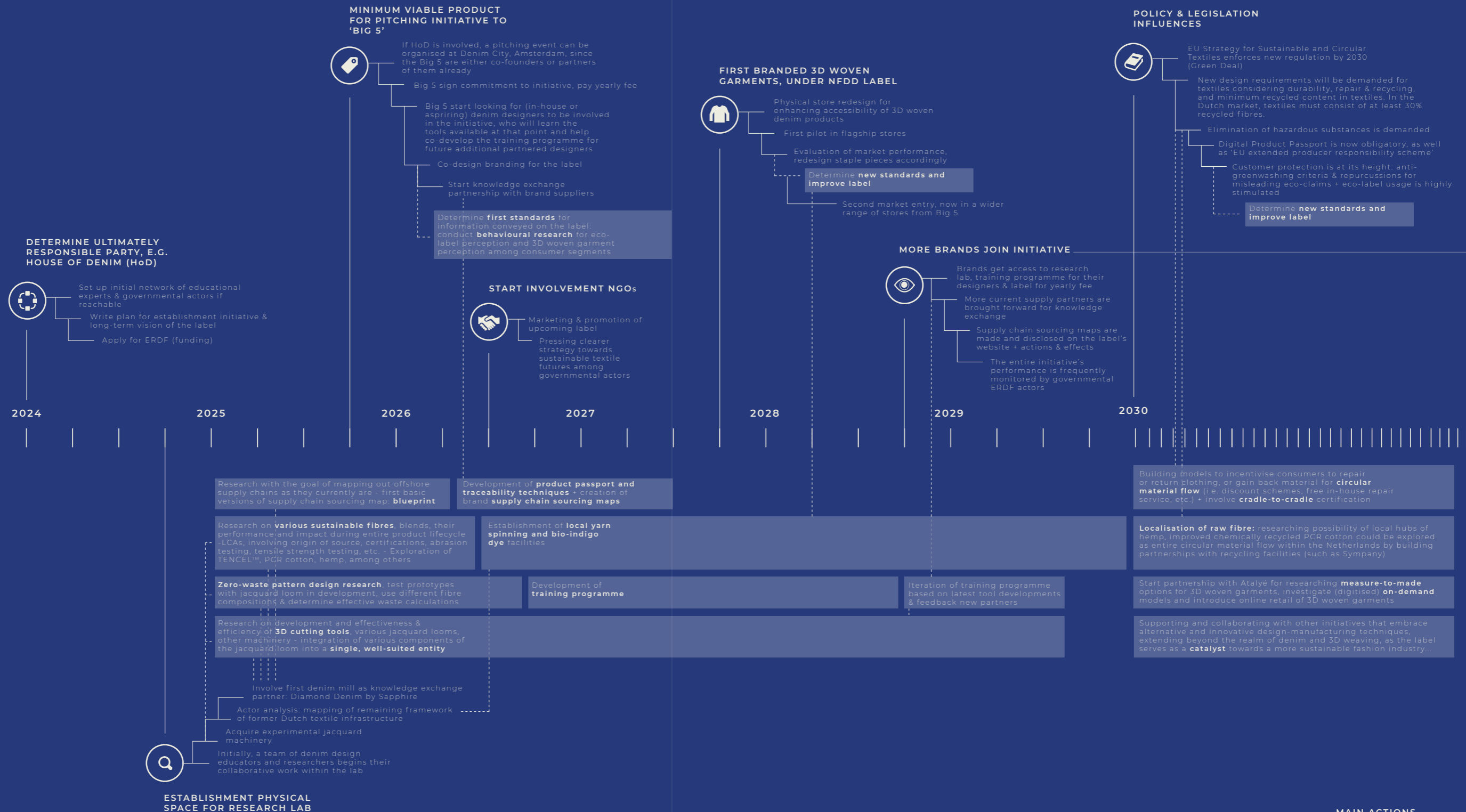
5.2.4 // IMPLEMENTATION ROADMAP

HORIZON 1: IGNITING COLLABORATION, UNLOCKING INNOVATION.

HORIZON 2: EMERGING PIONEERS.

HORIZON 3: EXPANDING THE LABEL.

LONG-TERM VISION: CENTRAL & CRADLE-TO-CRADLE.



MAIN ACTIONS
SUBACTIONS

----- INTERCONNECTIONS -----

5.3

CONCEPT EVALUATION RESULTS

The above concept underwent evaluation from both users and an expert specialising in product passports. User input was collected in two ways: firstly, through ethnographic user research (described in Chapter 4.2 Understanding The Consumer Mindset) where ten participants wore 3D woven jacket samples by Barbara Vroom for a month and provided daily feedback on their usage experiences. This feedback helped assess people's perceptions of this new 3D denim category and identify areas for improvement, helpful for a more grounded definition of actions to be undertaken in the first horizon of the implementation roadmap. Secondly, users without prior knowledge evaluated the label itself to ensure its communication met the required standards identified in the research. In terms of expert validation, marketing and branding recommendations were obtained through validation by a denim consultant. Dr. Boriana Rukanova, a TU Delft researcher specialising in complex infrastructure and supply chain traceability, evaluated the foundational elements of the concept. Based on the evaluation results, it was determined that more detailed information was needed regarding the steps for providing passport product information in the roadmap. These evaluation findings were then utilised to iterate and enhance the roadmap, making it more tactical and focused on growth strategies across different layers of the label's initiative.

5.3.1

USER VALIDATION

The evaluation of the label design was conducted through two separate methods. Firstly, through the last round of ethnographic user research, 10 participants were asked to provide feedback on how the label aligns with their perception of the jacket and whether it influences their perception after its introduction. The goal was to identify any visual or contextual changes that could enhance the positive contribution of the label to user perception.

Secondly, interviews were conducted with 10 individuals who had no prior knowledge of the final concept or previous studies. The objective was to understand their initial perceptions of the label and determine if it effectively communicates the intended message and generates interest among first-time consumers of 3D woven garments.

USER RESEARCH ROUND 2 RESULTS & DISCUSSION

The key findings from the second round of user research are as follows:

- The fractional density of the single layer areas of the 3D woven jacket posed a problem. While some users appreciated the ability to wear it in warmer weather or alternative use cases, it was found that the fabric quality was not suitable enough for outdoor use. Users reported instances of the fabric getting caught on objects and tearing easily. Further research is needed to address this issue. However, the areas

where two layers were interwoven received positive feedback due to their thickness and durability.

- Certain weaker parts of the jacket, such as underneath the armpit, raised concerns about quality and justifying the higher price point associated with the garment. The binding of the jacket sleeves easily ripped apart in the armpit construction area probably due to an unforeseen construction overlap in the bias direction.

- The touch and feel of hemp in the jackets were highly regarded, adding an interesting and luxurious appeal to the overall perception of the garment.

- Participants who wore jackets with raw edges initially appreciated the design element but found that the fraying of yarn became a significant source of frustration after just a few days of wear, stimulating a more negative perception of the 3D woven product.

- The flipped binding on the outside of the jackets, proved to be recognised as a distinctive feature of the 3D woven product, attracting attention and generating the most inquiries from others. It is crucial to retain this element for effective branding of the product category as its own within the larger denim industry.

- Users expressed a strong preference for smaller production batches to maintain the uniqueness of the garment and allow for personal interpretation and meaning.

- Users show interest and stress the importance of developing the made-to-measure principle and is even expected by some due to a luxury price point associated.
- The label was perceived as positively contributing to the overall perception of both 3D woven jackets utilised (5 times 'Raw Edges', 5 times 'Finished Edges').
- However, the research set-up of the last of 4 weeks had a flaw in that participants were not provided with information about the specific website to which the label would refer and its contents. As a result, while participants expressed their positive attitude towards the transparent information presented about various aspects of the garment, they mentioned that the amount of text was overwhelming, indicating a preference for accessing further information about the supply chain in the form of a website.
- Another point to consider is that this group of participants already had pre-knowledge of what 3D weaving entails as a technique. Thus, there is no way of accurately determining whether the label with 3D weaving explanation is well-understood by consumers hypothetically engaging with the label for the first time.

Thus, further concept evaluation took place with first-time viewers, in order to gain a better view of how consumers perceive the physical label without prior knowledge.

FURTHER USER VALIDATION RESULTS & DISCUSSION

- Information on traceability and transparency: Participants perceived the information conveyed on the label as positive and trustworthy, leading to a more favourable perception of the involved brands. The indication that detailed information about the 3D weaving supply chain and brand actions can be found online was sufficient to convince consumers of its trustworthiness. Most participants expressed a preference for bringing the icons more to the forefront and incorporating less text, as knowing they can access more information online was deemed satisfactory.
- The blue colour of the label reinforced a sense of trust among participants.
- The minimalist style and non-bold branding choice of the label were perceived positively, enhancing the overall perception of the label and the 3D woven garment category. Participants did not view it as a form of greenwashing or raise scepticism about the claims made.
- Regarding the origami part of the label - while it was expected to generate interest and curiosity among consumers, there were concerns about its environmental impact and potential paper waste. This feedback underscored the expectation among consumers that garments marketed as 'sustainable' should consider all elements of sustainability. Suggestions were made to

either limit the origami feature to the initial market entry phase to attract attention or repurpose it as a keychain. Some participants also proposed utilising the hollow back of the label to provide summary information about the key steps in the supply chain, as they expected additional information when examining the label.

Overall, the evaluation of the label design provided valuable insights for potential improvements and adjustments, ensuring that the label effectively communicates sustainability aspects and resonates positively with consumers.

5 . 3 . 2

EXPERT VALIDATION MARKETING

RETAIL EXPERT VALIDATION OF MARKETING

With input from a denim industry consultant, closely aligned with retail, the overall strategy and marketing elements were validated, particularly focusing on two distinct target audiences: the brands and the consumers. These insights serve as recommendations for further development of this part of the strategy.

For the marketing campaign aimed at brands, it is recommended to utilise clear arguments and showcase promising sample results from the research lab during an effective pitching session. The introduction of a 'mark 1' garment can serve as an exemplary element, emphasising that brands will have the opportunity to create their own branded, unique 3D woven denim garments. A website landing page should highlight the unique selling points discussed during the physical pitch and outline the expected actions and engagement with their consumer segments. This marketing campaign should be further developed in future research and will be considered as a recommendation for the iteration of the implementation roadmap.

The second marketing campaign, targeted at consumers, should involve advertisements through posters (as previously perceived positively in promoting the brands), collaborations with social media influencers in denim (such as Kelly Harrington, who was

previously present at the Blackhorse Lane Atelier) and the creation of a website similar to the one previously shown. While the website's content idea is commendable, it is important to ensure third-party verification of the claims made about brand actions, supply chain information, and traceability in the early stages of development, as it might not be clear to consumer yet that the NFDD should serve as a 'certification' on its own. This can be achieved by establishing partnerships with reputable organisations, such as the European Regional Development Fund, House of Denim, or renowned product passport schemes. Incorporating this verification aspect into the website is considered for a further iteration of the implementation roadmap.

Overall, the validation with the denim industry consultant provided insights to enhance the overall strategy and marketing approach. The recommendations for both brand-focused and consumer-focused marketing campaigns will contribute to the implementation of the initiative and the effective communication of the sustainability benefits of 3D woven denim garments.

5 . 3 . 3

EXPERT VALIDATION STRATEGY

POSITIVE ASPECTS

+ **Arrangements can be effectively established on a national level.** However, complications arise when crossing borders in the context of the fashion industry. Monitoring processes, international agreements, and ensuring compliance with legislative developments, such as the Extended Producer Responsibility, can become challenging. While a country may have well-implemented systems, ensuring seamless coordination and adherence to international standards requires careful consideration and collaboration among multiple stakeholders.

+ The approach is ambitious, yet considering design as a central part of the initiative is commendable and crucial. ***"It is intriguing to observe how this integration with design will unfold and contribute to localisation of supply chains."*** Boriana acknowledges the significance of design in the context of supply chain research, highlighting that conventional researchers often overlook its importance and are only able to focus solely on subsequent phases. Therefore, this case serves as an illustration of how design can be effectively incorporated to provide a comprehensive perspective.

+ It is worthwhile to consider how brands can gain control of supply chains with the technology they are using, and which words they choose to link to their platform. There are usually two approaches to achieving

control: one from the governmental side, aiming for widespread influence and regulation, and the other from the brand side, taking full responsibility for production and usage practices. If these ideas are developed and effectively promoted, the power of marketing becomes a formidable tool. **Brands hold significant influence and can drive transformative change by making sustainability fashionable and leveraging their influence on style and social media through marketing.** The current generation is highly receptive to trends, making it a powerful avenue for change. Moreover, when it comes to scaling up initiatives such as this one, working with big companies, although often criticised, can be advantageous due to their marketing, machinery, extensive resources, and capability to rapidly scale operations. While starting as a niche and modest project in the Netherlands, there is potential to expand using these bigger brands currently selected if the model proves successful. **By presenting compelling arguments about the importance of a brand's positive carbon footprint, it becomes an appealing package for these companies, encouraging them to explore and adopt sustainable practices.**

+ **The concept of reshoring and collaborating with current offshore supply chains is undeniably significant.** It's crucial to avoid a scenario where large companies simply relocate without considering the devastating impact it would have on local economies. Finding a

balanced approach to create self-sustaining circles is essential. This shift towards self-sustainability and circularity is likely to occur. Knowledge sharing becomes vital in this process. We can learn from each other to help these regions develop self-sustainable and circular practices while they, in turn, aid us in reestablishing our industry within a new framework. This reciprocal exchange promotes the development of local economies on a global scale. The concept of a just transition is significant, as it addresses the substantial challenges associated with climate mitigation, circularity and social rights. Additionally, reducing the significant carbon emissions from shipping is a compelling reason for such a transition. **Discussions on degrowth indeed highlight the potential divide in technological advancements, where certain sectors manage to navigate these challenges while others are left behind.** It's important to acknowledge that 'growth' in resource-decoupled services is possible in more sustainable ways - people still need to earn a living, and the trade-offs involved with using schemes with the mere point of 'degrowth' make the situation complex to transition.

RECOMMENDATIONS // FIRST HORIZON ROADMAP

- **A comprehensive gap analysis is essential to map the visibility within the current supply chain.** By understanding the existing practices and identifying areas

that require improvement, it becomes possible to transition towards a new and more effective situation. This analysis serves as a valuable benchmark and provides input on the current state of visibility and the necessary considerations for the present context. The research conducted at Diamond Denim which led to the ecosystem map in this particular project is an example of this.

- Furthermore, conducting a thorough analysis allows for strong argumentation.

For instance, since the reshoring of operations would carry significant costs and compliance with EU regulations, a compelling case should be made to argue towards fashion brands why they need to be involved in the label. The new situation can be designed to be simpler (less labour steps for example), while still addressing environmental concerns, thereby providing tangible benefits.

Having these two analyses - one focused on the current national context, including legislative requirements such as ecodesign regulations and complexity, and the other outlining the desired new situation - is advantageous. This comprehensive approach enables companies to align with environmental implications in both scenarios and appeals to their desire to be perceived positively by customers. By considering these factors, a well-rounded and persuasive argument can be presented.

- **The actor analysis of the new local context must be integrated indeed.** The Netherlands still has remains of the old framework for textile production in place. It could therefore be desirable to give some examples of this in the roadmap to show there is a starting point.

RECOMMENDATIONS // SECOND HORIZON ROADMAP

- Many companies are already eager to make changes because they are aware of impending legislation. The big brands, often associated with pollution, have the resources and global networks to quickly implement sustainability measures on a large scale if they choose to do so. Legislation mandates the use of product passports and regulations, urging brands to comply. However, brands are currently confused as they try to implement these requirements in their own unique ways, prompting the need for standardisation and guidance regarding content and technical infrastructure. The European Commission is working to establish standards and structure, not only in the textile sector but also in areas like batteries and electronics. To foster collaboration and coherence, an alignment community has been formed, bringing together various stakeholders in the textile industry to propose solutions regarding this friction point. Fashion brands are actively seeking to participate in this community, so it might be worthwhile to integrate this alignment community in the implementation roadmap.

- **Additionally, collaboration with customs agencies is crucial.** At the European and national levels, customs regulations will align with environmental regulations, creating complexities as legislation becomes more international. Customs agencies will play a significant role once goods cross borders and need to be monitored and regulated. While there is currently a lack of customs legislation specifically addressing sustainability (since the customs-side is always the last one to receive requirements, but have to comply in a very short amount of time), Dutch customs, for example, should already be anticipating its effects. Uncertainty prevails as legislation is still being developed, but preparations need to be made for its eventual implementation. The dynamics in this space are intriguing and unintended consequences could arise despite the best intentions of legislation. Therefore, collaboration among businesses, government entities, and IT providers is necessary to experiment together with customs, identify challenges and provide feedback for a smooth process in acquiring necessary resources for localising the 3D weaving supply chain.

Overall, the field is complex and navigating it requires collaboration, experimentation, and continuous evaluation. The process ahead is uncharted territory with a strong emphasis on product passports and digitisation. Scepticism exists regarding the potential complexity of all existing relevant initiatives, but there is a political will to drive change. Legislation serves as a powerful

incentive for brands to share information and motivate transformative actions. However, it is important to strike a balance as extremes can lead legislators to reconsider their approach. Therefore, it is desirable to include more current product passport developments in the roadmap, such as CIRPASS. This could both give an overview of current possibilities and make room for formulating strategic recommendations to facilitate the alignment of product passport initiatives with the New-Fashion Denim Dimensions.

RECOMMENDATIONS // FOURTH HORIZON ROADMAP

- **Try to work on the front and back of the chain.** Include loyalty systems on blockchain and make incentive schemes to have resources brought back to the brands, in order to start closing loops by entering partnerships on this back-end.

- **Dutch market.** The reason why in the Dutch market current circular models have not been effective yet, and the make-take-waste linear approach is so rigid, is that **the clothes are very uncostly, while repair is very expensive.** If this repair link is not managed by brands themselves, people will keep throwing things away, which must be considered for working out the business model in the future. Unless solving the high labour costs occurs, the closed loop won't be reached in the Dutch context.

- When discussing textiles and supply chains, the question arises as to whether the localised success should be **kept within a specific region or expanded to other countries in close proximity,** such as Belgium and Germany, potentially reintroducing trade routes and complexities.

TAKE-AWAY

The validation provided by both consumers and expert perspective either remain as recommendations for future research, or are integrated into a final iteration of the roadmap in the following subsection. This roadmap is more tactical, providing detailed steps in the implementation of the roadmap after all research had been completed.

5.3.4

ITERATION // TACTICAL ROADMAP

2030

HORIZON 1: IGNITING COLLABORATION, UNLOCKING INNOVATION.

HORIZON 2: EMERGING PIONEERS.

HORIZON 3: EXPANDING THE LABEL.

LONG-TERM VISION: CENTRAL & CRADLE-TO-CRADLE.

FUNDING

ENSURING A STABLE FUNDING STREAM TO SUPPORT THE ESTABLISHMENT OF THE LAB.

TU Delft initiates collaborative efforts with HOD (House of Denim) to establish the foundational network of key stakeholders and secure initial funding...

OTHER FUNDING OPPORTUNITIES IN FIRST HORIZON FOR THE REMAINING 90% OF EXPENSES.

Potentially provided by Diamond Denim as they are the first mill to be involved. Dutch Textile Museum. Korea/Jike Ten Care NV.

FUNDING BY BIG 5.

Big 5 pay a minimum fee for labeling of the initiative in return for gaining free access. The fee is determined by the cost of unprocessed vegetable operations.

SPONSORSHIPS.

After the HOD campaign by Fashion Revolution and participation in the Fashion Events through State of Fashion, other sponsors could be requested to sponsor the initiative.

SELF-SUSTAINING LABEL.

The first-time investment fees are cheapest to incentivise further brands to participate. As customs legislation is now likely in place, importing goods from other countries has become considerably expensive...

RESEARCH LAB OPERATIONS

ESTABLISHMENT PHYSICAL RESEARCH LAB.

Ensure a collaborative space and stable operations structure by assigning each first involved actor in the lab a role and key goals.

Zero-waste fashion designers and weavers identify the most optimal width and repeat of the current jacquard looms to facilitate 3D weaving experiments...

Technology and Policy Management researchers (CA) on regular denim products and current supply chain mapping with first collaborative denim mill (Diamond Denim). Cap analysis will be conducted here as well...

Strategic Product Designers creation of business model, future vision for 3D woven label standards and carrying out actor analyses of remaining denim label frameworks in the Netherlands.

EXPERIMENTATION FIRST 3D DENIM WOVEN SAMPLES.

Develop an optimization process for factorial density and create a comprehensive guide highlighting potential challenges in the fabric's bias direction. Conduct thorough research to determine the most suitable sustainable fibre or blends for the initial prototypes...

MINIMUM VIABLE PRODUCT.

Argumentation pitch at Denim City (HOD) event in Amsterdam, to have the Big 5 sign intensive contract.

CO-DETERMINE FIRST LABEL STANDARDS.

Product Passport solution will prove every step of the local supply chain from the production in NL and where the fibre content originates from. This will increase consumer confidence and early compliance to upcoming legislation.

CO-DEVELOPMENT OF TRAINING PROGRAMME.

Determine the exact 3D weaving course material for teaching near coming denim sector graduate students or denim designers from future partner brands.

CO-DETERMINE SECOND SET OF LABEL STANDARDS.

Adapted standards according to consumer evaluation after pilot launch. The time locally spun yarn will be included in the label as well.

BUSINESS MODEL SCHEMES FOR CLOSING THE LOOP.

Business model schemes need to be created for the participating brands to provide a sufficient take-back solution for their 3D woven garments. To foster a long-lasting relationship between consumers and their garments, it is crucial to provide free repair services...

SUPPORT OF OTHER SIMILAR INITIATIVES.

The initiative aims to extend its support to other innovative design/manufacturing methods in the textile industry as part of its overarching strategy to create a cascading effect throughout the fashion sector.

INDUSTRY & EDUCATIONAL COLLABORATIONS

COLLABORATION WITH DIAMOND DENIM.

Will be the first knowledge exchange partner. Is currently actively engaged in establishing collaborations with European actors in order to facilitate relocation efforts under its business name.

COLLABORATION WITH LAHORE UNIVERSITY OF TEXTILES.

Diamond Denim had a connection with a DUT university. Establishing a partnership between TU Delft and the Textiles University would facilitate the development of an efficient supply chain and provide access to knowledge and resources that TU Delft currently lacks.

COLLABORATIONS WITH IDENTIFIABLE REMAINING ACTORS FROM FORMER TEXTILE INDUSTRY.

The Textile Museum can assist in the establishment of a dedicated research lab space, provide expertise in jacquard machinery and contribute to further actor analysis. Collaboration with Kuraatle's Ten Care NV offers another opportunity for research lab space and access to jacquard machinery.

JEAN SCHOOL (HOD) TALENT ACQUISITION.

Searching for denim designers or sewing which have the ability to think in unconventional design and manufacturing techniques.

COLLABORATION WITH CUSTOMS.

Prepare for any problems with importing raw material for local production of the fabric.

BIO-INDIGO DYE FACILITY RESEARCH.

In collaboration with researchers from the TU Delft and Diamond Denim. Utilising bio-ribs with foam-dyeing could prove to be an ideal approach for mass-manufacturing the 3D woven products.

TRACEABILITY/DIGITAL PRODUCT PASSPORT COLLABORATIONS.

Joint alignment community ESCF (European Supply Chain Forum) CIRCASS can be introduced as product passport partner through the TU Delft Faculty of Technology and Policy Management. Helvia currently partnered with Diamond Denim is also accessible through this collaboration.

FINISHING FACILITY RESEARCH.

Apart from digital printing already having been explored, a laser machine and ozone washing machine from Tomello must be acquired for achieving sustainable washed, distressed and scuffed finishes.

THE BIG 5.

Design of the label will be co-created by the Big 5 who have expertise on trend research in the Dutch market and their own consumer segments. Conducting user research with their consumer segments using the virtual 3D prototype developed will enable to understand the requirements for creating desirable, high-quality results and define the communication of information on the label itself.

CO-BRANDING OF THE LABEL.

In collaboration with researchers from the TU Delft and Diamond Denim. Utilising bio-ribs with foam-dyeing could prove to be an ideal approach for mass-manufacturing the 3D woven products.

MARKETING.

Marketing supporting 3D woven designs through partner-led channels, social media, YouTube, followed advertisement and website.

NGO PARTNERSHIPS.

Fashion Revolution NL, Marketing supporting 3D woven design through own actionable programmes, stimulating more governmental support & more alignment in current legislative processes for which they can take example from this initiative.

PILOT LAUNCH IN BIG 5 FLAG-SHIP STORES.

Store redesign, creating an inviting and accessible environment for the customer. Introducing a small collection. Providing videos with images explaining the process of 3D weaving and providing insight into the research lab.

SECOND MARKET ENTRY.

Iteration of products based on consumer evaluation. Introduction of additional 3D woven designs.

PARTNERSHIPS WITH LOCAL RECYCLING FACILITIES.

To further close the loop, partnerships could be made with Sympany or recycling facilities associated with Salvation Army.

PARTNERSHIPS FOR ON-DEMAND AND TRUE-TO-SIZE ACHIEVEMENT.

In the future, there is potential for collaboration with Uniqlo once again, and the current initiative has established trust in the 3D weaving technique. Uniqlo could serve as a valuable collaborator through the acquisition of their jacquard loom and by assisting in the development of on-demand and true-to-size models for this label.

ONLINE RETAIL.

Recommended after the consumer has gained a sense of familiarity with the 3D woven product category.

BUSINESS

BUSINESS TEAM ESTABLISHMENT.

To explore business opportunities, a dedicated business team will be assembled, led by a committed business manager. This team will be responsible for developing growth strategies, determining acquisition targets and closely monitoring potential collaborations to further enhance the initiative's success.

MARKETING OF LABEL TOWARD FIRST BRAND PARTNERS (BIG 5).

Create a product portfolio of current minimum viable product. Design an initial website that showcases the marketing value of the label to consumers, to drive the first brand partners before they join the initiative.

MARKETING OF LABEL TOWARD CONSUMERS.

Develop a comprehensive website that serves as a communication platform for consumers, increasing sewing supply chain maps of the business current denim experts (change supported by established Product Passport) to promote transparency and showcasing the supply chain map of their 3D woven products highlighting their pioneering role in relocation and sustainability efforts.

ADAPTING MARKETING TOWARDS FUTURE BRAND PARTNERS AND CONSUMERS.

After pilot launch.

5.4

CONCEPT DISCUSSION

This research project aimed to exemplify how the emerging fashion design-manufacturing technique of 3D weaving can be employed for changing into more sustainable design-to-consumer models through a holistic strategy. In this section, the final designed Systems-Oriented strategy and its fit to the established design requirements is discussed, which were defined to support the overall aim of contribution.

// ENCOURAGE FASHION BRANDS TO TAKE THE LEAD IN INTEGRATING 3D WEAVING INTO THEIR PRACTICES AS PART OF THEIR COMMITMENT TO SUSTAINABILITY.

The requirement of encouraging fashion brands to take the lead in integrating 3D weaving into their practices as part of their commitment to sustainability aligns with the approach of giving the five brands access to the tools of the research center and connecting them with relevant actors, including educational experts. By providing fashion brands with access to the research center's resources, they can gain valuable knowledge and insights into 3D weaving techniques and its potential for sustainable fashion production.

Access to tools and equipment at the research centre allows brands to experiment and explore the possibilities of 3D weaving within their own branded design and production processes. The availability of educational experts further supports this initiative by offering a platform for brands to ask questions, seek guidance, and acquire a deeper understanding of 3D weaving, while giving them agency in the design decisions as well. This collaboration enables brands to take an active role in integrating this innovative technique into their practices.

By engaging with the research centre and relevant actors, the first involved brands can become pioneers in implementing

3D weaving, pushing the boundaries of traditional denim production and contributing to a more sustainable fashion industry.

Through this collaborative approach, brands have the opportunity to drive change and inspire other industry stakeholders to follow suit. By sharing their experiences and successes on their own platforms, these brands can act as role models and influence the broader fashion community to embrace 3D weaving as part of their commitment to sustainability.

// DEFINE A NETWORK OF MULTIPLE ACTORS AND THEIR ROLES IN THE FORM OF AN INITIATIVE.

The initiative behind the label is structured to thoroughly depict and describe the stakeholders involved in the Dutch denim market and their roles. By mapping out the relevant actors and their roles, the initiative provides a clear understanding of their contributions to integrating 3D weaving into sustainable denim production. Each stakeholder's responsibilities are defined, ensuring accountability, and the implementation and tactical roadmap outline the specific actions and milestones that each stakeholder must achieve at different stages. The initiative also facilitates communication and knowledge-sharing among the actors in both the Netherlands, and overseas, enabling them to work together towards a common goal.

// STIMULATE DIALOGUE BETWEEN MULTIPLE STAKEHOLDERS IN THE SYSTEM AND EMPHASISE COLLABORATION.

Stimulating dialogue and promoting collaboration is achieved through various measures. The 'Big 5' brands are given first access to the research centre, tools, and all involved experts, empowering them to actively engage in the development of standards for the label, design of the labels, and marketing and branding strategies. They are also encouraged to design their own 3D woven branded garments within the research centre, allowing them to utilise the label while maintaining their individual brand identities. Along the way, they learn what a more sustainable supply chain entails precisely, and that on-demand and local production is achievable and better aligned with the policies and regulations soon coming into force.

To ensure transparency and traceability, brands are required to comply with rules regarding the disclosure of information related to their current supply chains, as well as including the suppliers in the form of knowledge exchange partnerships with the initiative, promoting mutual learning, more ethical relocalisation efforts and overall collaboration.

By providing brands with the means to actively participate in the dialogue and collaborate in the development of standards, as well as promoting transparency and

knowledge exchange within their supply chains, the initiative fosters a collaborative environment on multiple levels of the system.

// PROVIDE GUIDANCE ON THE DESIGN PROCESS OF 3D WEAVING GARMENTS AND ACCESS TO THE INFORMATION NEEDED FOR ACQUIRING THE NECESSARY EQUIPMENT; THE INTERVENTION AIDS DESIGNERS IN DEVISING ACTIONABLE IDEAS FOR 3D WEAVING GARMENTS.

In the first horizon, educational experts specialising in zero-waste pattern design and professionals from the Jean School collaborate with the initial participating brands. Their expertise aids in understanding and experimenting with the creation of small collections of 3D woven garments. This guidance supports designers in developing actionable ideas and implementing them effectively.

In the second horizon, a training programme is developed to further assist brands and their denim designers. The programme focuses on shifting their design roles, acquiring new creative and relevant skills in 3D weaving technique, unlocking an overall more creative thinking ability and greater adaptability to manufacturing advancements. Moreover, it aims to inform existing educational programs for aspiring denim designers, enabling them to adapt

and expand their skill sets into their practice from an early stage, which proved to be important in the domain of denim as a rigid design field.

// EFFECTIVELY AND TRANSPARENTLY COMMUNICATE SUSTAINABILITY BENEFITS OF 3D WOVEN DENIM GARMENTS TO THE CONSUMER, IN A TRUSTWORTHY MANNER.

While eco-labels can play a vital role in delivering transparency and credibility, the vision of this initiative extends beyond introducing a label on a single sustainable aspect. Instead, the aim is to build an ethically and sustainably driven local system for 3D weaving as a whole.

To ensure credibility, a focus was placed on actively demonstrating the viability of producing garments sustainably and ethically, particularly in the 3D weaving category, with transparency in all supply chain steps, actions and effects, as well as brand information of the partners involved. Traceability schemes and digital product passports will play a role in the establishment of a successful initiative.

Furthermore, the design and communication of the label itself play a crucial role in consumer interpretation. By adopting a minimalist approach and using gentle language choices, the label aims to convey messages in a manner identified as trustworthy as found in user research and

literature. This contrasts with otherwise bold branding and strong statements that may inadvertently undermine the perception of ethicality. The label's explicit messaging aims to overcome the value-action gap in more clearly defining what are usual grey areas of consumption - in other words: not knowing how sustainable a purchase with some green claims is in actuality.

Transparency and accountability are central to the initiative. The associated website provides consumers with access to information about every action taken by brand partners, emphasising the environmental and societal impacts of their decisions. By openly communicating the consequences of brands' actions, the initiative aims to foster trustworthiness and accountability among consumers and brands themselves.

// TAKE FUTURE RELOCALISATION OF SUPPLY CHAINS INTO ACCOUNT.

Relocalisation has been carefully considered in the initiative by taking steps to build a future self-sustaining vertical supply chain for 3D weaving. The roadmap begins by addressing key challenges such as zero-waste pattern design workflows and resolving open ends. Additionally, efforts are made to introduce the right cutting tools, develop efficient CAD modelling workflows, and create an ideal jacquard loom for 3D weaving.

Each phase of the initiative involves the integration of new steps to further support relocalisation. For instance, the acquisition of bio-indigo technology enables on-site dyeing, reducing the reliance on external sources. Incorporating ozone and laser machines from Tonello contributes to achieving desired laundry aesthetics while minimising environmental impact. Looking ahead, collaboration with local recycling facilities and research into establishing local hubs for cellulose-based fibres are envisioned, completing the entire supply chain within the locality.

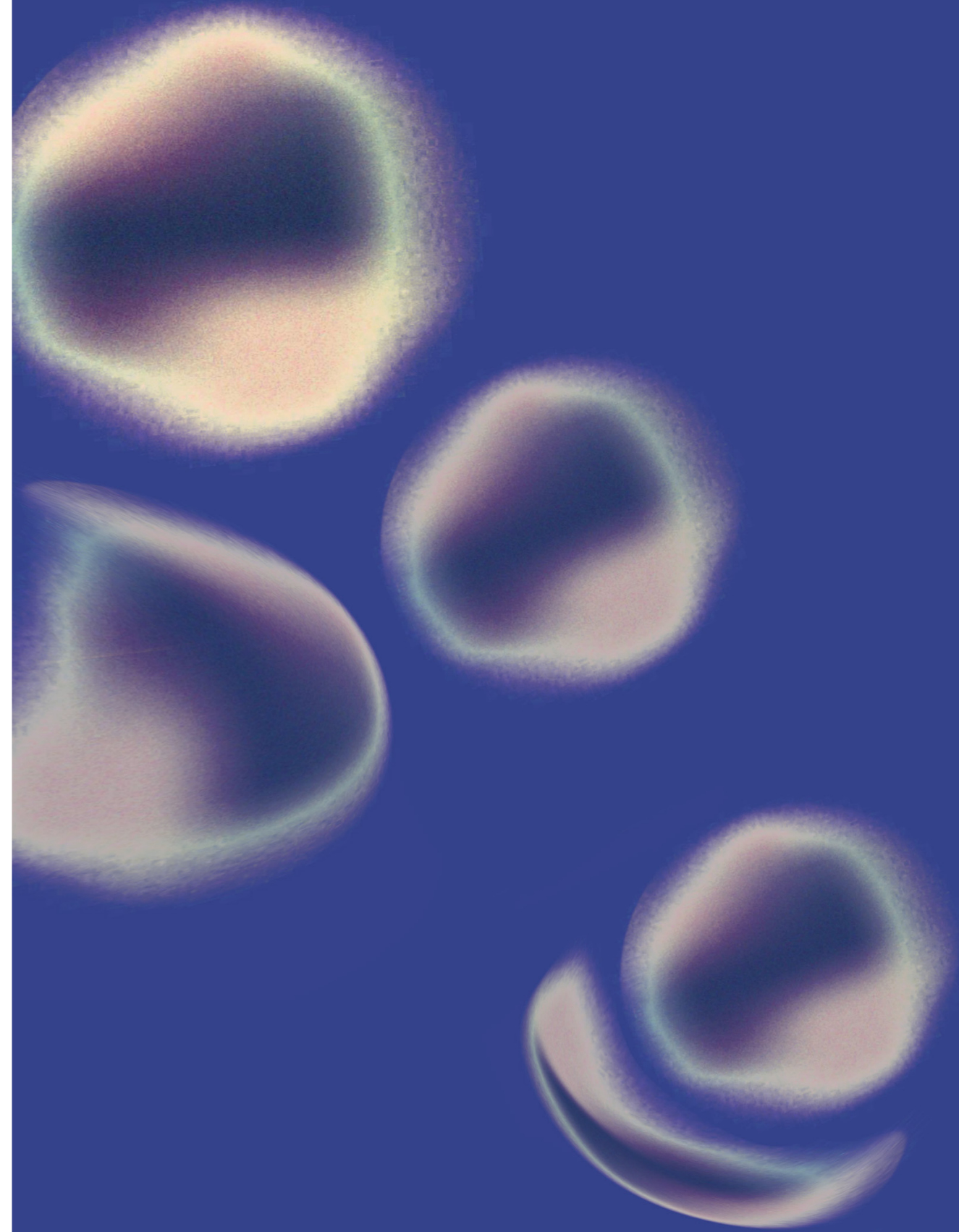
// BE FEASIBLE, VIABLE AND DESIRABLE.

The overall Systems-Oriented strategy aims to adhere to feasibility by firstly building upon the previous, carefully defined and conducted research in this project. Furthermore, aligning the relevant actors and securing funding from sources such as the European Regional Development Fund could make the entire initiative a reality. The collaborative approach helps create an environment where the implementation of 3D weaving becomes attainable and practical.

The future viability of the strategy is further supported by the validation received from industry experts during co-creative sessions and concept evaluations, demonstrating that it is both a realistic solution and holds potential within the brand-led approach,

especially with the first 5 chosen brands, to have further brands join in and sustain the initiative.

To address desirability, the strategy illustrates the perspectives of multiple layers within the system. The perspectives of consumers, industry experts, and organisations like the House of Denim are taken into account to ensure that the proposed 3D weaving approach resonates with the desires and preferences of the target audience and the broader industry.



CHAPTER TAKE-AWAYS // FINAL DESIGN // NEW-FASHIONED DENIM DIMENSIONS

NEW MODELS FOR FASHION

This chapter began by identifying leverage points derived from the research outlined in the previous chapter, to implement the 3D weaving technique in the form of a new model for fashion. These leverage points inform the formulation of a design direction, leading to the emergence of a basic idea. They were defined as 1) providing 'one clear strategy towards sustainability for brands', 2) building 'knowledge exchange', 3) creating 'incentive schemes for brands to participate in new models by providing first access to tools' and 4) 'exemplifying how a product can be sustainable by being transparent in every step of the supply chain'.

The design direction was as follows:

'Design a collaborative initiative which incentivises brands to raise demand for 3D woven denim garments in the Netherlands by...

- 1) giving access to the tools necessary for the 3D weaving design & production process;
- 2) providing guidance on how to navigate communication towards the consumer in a trustworthy manner.'

The basis of the concept was further developed through a co-creative process involving industry experts at Diamond Denim. Through their expertise, they could provide feedback on potential areas that require further refinement, and any non-negotiable aspects to be considered, otherwise unknown to the researcher.

In conclusion, New-Fashioned Denim Dimensions (NFDD) takes a comprehensive approach to effectively and transparently create and communicate the sustainability benefits of 3D woven denim garments, not only from the objective of zero-waste. The strategy involves bringing together key stakeholders, including educational experts, governmental actors, and House of Denim, to establish an initiative that fosters collaboration and knowledge exchange. Five prominent fashion brands would be involved as pioneers, gaining early access to expertise, the physical research lab and the label's own development. Subsequently, these brands will take the first step of introducing 3D woven denim as a novel product category in their stores, branded as their own, while carrying the NFDD label.

By providing guidance on the design process, facilitating access to information and equipment, and offering training programmes, the strategy empowers brands and designers to explore the possibilities of 3D weaving and integrate it into their garment portfolios from a local supply chain.

Steps and responsibilities of each stakeholder involved in the initiative are outlined through two versions of a roadmap in detail, also keeping track of their fit with compliance to new policies and regulations coming into force on both Dutch and EU level.

By emphasising relocalisation, New-Fashioned Denim Dimensions aims to foster self-sustainability, reduce dependence on global supply chains, and strengthen local collaboration capabilities. Not only from the perspective of the Netherlands alone, but also fostering economic resilience and promoting regional development through knowledge exchange with current suppliers overseas.

The ultimate aim of the New-Fashioned Denim Dimensions label is to create a cascading effect, inspiring denim brands to further explore future transitions towards local and sustainable models in the broader fashion industry, extending beyond the realm of 3D weaving.

NEW-FASHIONED DENIM DIMENSIONS // FINAL DESIGN OF SYSTEMS- ORIENTED STRATEGY

CONCLUSION

CHAPTER 6

- 6.1 **CONCLUSION**
- 6.2 **DISCUSSION**
- 6.3 **RECOMMENDATIONS FOR FUTURE RESEARCH AREAS**
- 6.4 **PERSONAL REFLECTION**

6.1. CONCLUSION

This project has shed light on the urgent need for sustainable transformation within the fashion industry, particularly in the context of denim production. The prevailing fast fashion paradigm, driven by consumerism and characterised by the rapid production and disposal of low-quality garments, has led to detrimental environmental consequences, social injustice and excessive waste.

The exploration of 3D weaving as an emerging fashion design-manufacturing technique, demonstrated its potential in enabling alternative, more sustainable design-to-consumer models. It addresses both the often overlooked issue of pre-consumer waste in denim design, and aligns with more holistic approaches to enhance sustainability in the industry. As on-demand, micro-manufacturing, and localised supply chains gain significance, 3D weaving could provide an innovative and holistic solution to these challenges. Moreover, it offers the opportunity to revolutionise the aesthetic form of denim itself, potentially unfolding a new category of denim, parallel to the current industry.

The fashion system encompasses a network of individual actors, organisations, material inputs, manufacturing processes, regulations, brand demand, consumers, and material outputs, among other interconnected elements. Within this complex system, pre-consumer waste represents only a fraction of the overall complexity, and addressing individual components in isolation is unlikely to lead to effective solutions. Recognising this complexity and the challenge of achieving systemic change through niche innovative methods like 3D weaving, the aim of this research is to exemplify how 3D weaving, as an emerging fashion design-manufacturing technique, can be utilised to transition towards more sustainable design-to-consumer models, a multi-faceted approach.

Through a Systems-Oriented design approach, considering the interconnectedness and interdependencies of various elements within the fashion system, an in-depth analysis of the current denim system has revealed the urgent need for a fundamental reevaluation of design and manufacturing practices. The stagnant design of denim, with its

unchanged aesthetic form over the past century and significant pre-consumer waste during pattern cutting, needs to be questioned and addressed. Further studies conducted within this research, including user research utilising 3D woven denim garments and an investigation into key factors driving the adoption of alternative models, highlight the potential of 3D weaving by leveraging on the following points: **1)** providing 'one clear strategy towards sustainability for brands', **2)** building 'knowledge exchange', **3)** creating 'incentive schemes for brands to participate in new models by providing first access to tools' and **4)** 'exemplifying how a product can be sustainable by being transparent in every step of the supply chain'.

Moving forward, a collaborative approach involving various stakeholders within the denim industry is necessary. This project proposes a Systems-Oriented strategy, centred around the establishment of a collaborative, local label for 3D woven denim alongside traditional denim. This initiative serves as a stepping stone towards a more sustainable and localised supply chain in the Netherlands, providing access to tools, training programmes for reimagining the role of denim design, and co-development of branding and ongoing research. Ensuring traceability and transparency in an honest and clear way is a core element, crucial for both effective consumer communication and change led by brands, inspiring other denim brands to undertake similar sustainable transitions with niche innovative design-manufacturing methods.

Ultimately, by embracing innovative techniques like 3D weaving and adopting a holistic approach to design and manufacturing, the fashion industry can evolve towards a more sustainable and circular future. This work has aimed to illustrate how the potential of 3D weaving can be unlocked toward systemic change within the Dutch denim market and the broader fashion industry. By showcasing the feasibility of this innovative technique, it is hoped that it will further catalyse similar transformative shifts towards sustainability and circularity in the denim industry and beyond.

BY SHOWCASING THE FEASIBILITY OF THIS INNOVATIVE TECHNIQUE, IT IS HOPED THAT IT WILL FURTHER CATALYSE SIMILAR TRANSFORMATIVE SHIFTS TOWARDS SUSTAINABILITY AND CIRCULARITY IN THE DENIM INDUSTRY AND BEYOND...

6.2

DISCUSSION

The implementation of 3D woven zero-waste pattern design in the denim industry requires thorough research and understanding of the technique. Time-consuming adjustments and effective stakeholder communication are necessary to integrate 3D weaving into the production process. Further user engagement in design and production stages could enhance personalisation and emotional attachment to garments. Strategies for garment recycling and incentivising circular practices should be given more priority. Overcoming barriers for small to medium-sized brands and educating consumers about the value of sustainable choices are key challenges to be overcome. Balancing unique designs with promoting sustainable consumption habits is crucial. Exploring alternative revenue streams and adapting to new aesthetics are important considerations. A friction remains in the development of new garments, which would arguably still contribute to the capitalist mindset of the present. A final question is whether and how the strategy should be scaled, where customs regulations and knowledge sharing are crucial considerations.

EFFICIENCY FRICTION, ON-DEMAND & SLOW FASHION

There are several important considerations for the implementation of 3D woven zero-waste pattern design in the denim industry. One key aspect is the time and research needed to fully understand and integrate this technique into the production process. Thorough comprehension of 3D woven design patterns and the necessary adjustments during the cutting and unfolding process requires expertise, dedicated research-through-design and effective communication. This time-consuming process becomes more challenging when short cycles of new pieces would be introduced on a small scale. The implementation of a smooth and efficient local supply chain necessitates substantial research and development efforts, with more particular emphasis on on-demand models. One potential approach could involve reevaluating the inclusion of small capsule collections in physical stores. Instead, a complete on-demand system could be considered, where customers undergo body scanning to ensure accurate sizing, and then choose garment elements from a selection of tangible samples. Implementing an on-demand model not only alleviates the pressure to meet short timeframes and sales targets in the design-production process, but also prompts a critical question about the necessity for consumers to always seek immediate access to new clothing and whether the potential decrease in speed and efficiency should even be viewed as a drawback. By challenging the perpetuation of fast fashion and a capitalistic mindset, it becomes imperative to encourage a shift towards more intentional and sustainable consumption practices. This approach emphasises the importance of mindful choices and responsible consumption, fostering a more sustainable and thoughtful model for fashion.

USER ENGAGEMENT

Another critical aspect is the need for increased user involvement in the design and production stages. Involving users in the decision-making process could help ensure that the resulting garments align with their

preferences and needs, thus fostering stronger emotional attachment and longer usage (McQuillan et al., 2018). On-demand production holds the potential to offer greater personalisation through measure-to-made principles. However, beyond custom sizing, there is an opportunity to explore additional levels of customer involvement to create a sense of uniqueness and personalization. This could involve allowing customers to choose embellishments, select specific fits, or express preferences in binding placement or digitally printing surface patterns, among other customisable options. This level of involvement not only enhances the customer experience, but also aligns with the growing demand and value for meaningful and unique fashion choices.

END-OF-LIFE

Additionally, greater focus should be placed on the end of the product lifecycle, considering effective strategies for collecting and stimulating the return of garments for recycling or repurposing. Incentive schemes should be developed further and gain more attention in the establishment of the initiative, encouraging consumers to participate in circular practices and contribute to a more circular system.

EXCLUSION OF SMALL-TO-MEDIUM SIZED BRANDS

It is important to acknowledge that the adoption of 3D weaving through the current strategy depicted, may face barriers for small to medium-sized brands. Access to the necessary resources, technology, and expertise required for implementing this technique could be limited for these brands due to the fees, luxury pricepoint level and having only small teams of denim designers available. Overcoming these barriers and making 3D weaving more accessible to a broader range of brands would be crucial for more widespread systemic impact.

CONSUMER BEHAVIOUR AND HIGHER PRICE-POINTS

Shifting consumer behaviour towards a willingness to pay more for sustainable clothing involves additional challenges. While there is a growing interest in sustainable fashion, it requires extensive work to communicate the value and benefits of such garments to consumers, while fast fashion is still prevalent and a high portion of the consumer still considers the economic factor to be determinant. Educating consumers and brands about the positive environmental and social impact of sustainable choices is crucial for creating a market demand that supports higher price points and phasing out the current make-take-waste mindset. Effective ways to employ this should be explored.

NEW PRODUCTION

One of the central points of discussion within this project pertains to the fact that 3D woven garments would still be subject to new production. While the creation of unique pieces may enhance emotional attachment and promote longer usage, there is a concern that it could also stimulate the desire for consumers to purchase new versions of these garments, even when they already possess one. This poses a challenge in finding the right balance between offering unique designs while promoting a shift towards a more sustainable approach that prioritises utilising the garments already present in one's closet, further amplified by the implications for brands seeking to generate profits within the current capitalist economy. On the other hand, brands may need to adapt and explore new revenue streams or alternative strategies that focus on providing value-added services, such as repair, customization, or rental options. By offering these services, they can cater to the evolving consumer demands for sustainability, while still generating revenue potentially.

NEW AESTHETICS AND ACCEPTANCE

The introduction of new aesthetics through 3D woven garments significantly impacts the traditional form of denim. While this project aimed to unlock a new product category within the denim system rather than replace it entirely, it raises the question of the actual scale of systemic impact achieved, if no further consideration is given to embracing these new aesthetics on a cultural level. It is important to recognise that consumers should become accustomed to these aesthetics, not only derived from 3D weaving but also from other woven and knitted alternative textile forms in similar design-manufacturing settings. The innovative nature of these techniques provides opportunities to explore novel and distinctive aesthetics, captivating consumers' interest and challenging conventional notions of fashion, challenging the established woven form that has been prevalent for so long. Further research on consumer perception of such textile forms is necessary.

STRATEGY SCALING AND ACCESS TO KNOWLEDGE

When considering the expansion of this strategy to involve other countries, several considerations arise, such as customs regulations and the handling of sensitive information. To start, it would be essential to work closely with relevant stakeholders, including governmental bodies and customs authorities, to navigate any potential challenges or barriers due to upcoming EU regulation and policy changes of relevance. Furthermore, regarding the sharing of knowledge, there are different approaches to consider. One option is to keep the information within the initiative itself, treating it as proprietary knowledge to maintain a competitive advantage for the brands involved and maintaining their image as 'pioneers' - a crucial element of the current proposed strategy to have the brands lead transformative measures. This approach would involve entering into contractual agreements to

ensure confidentiality and restrict public access to sensitive details. By keeping the information undisclosed to the wider public, new initiatives can continue to emerge within the framework of the initiative, fostering innovation and safeguarding the intellectual property associated with the strategy. The other consideration is to distribute the garments from the Dutch local supply chains to retailers in neighbouring countries. However, this involves high future friction at customs and reduces the locality of the system again, implying both transport emissions and lower adaptability to cultural and regional values in the designs. Ultimately, the approach chosen would depend on various factors, including the specific legal considerations in years to come, balancing the need for confidentiality with access to knowledge, and ensuring brand leadership and initiative-taking.

LIMITATIONS

- The researcher possessed no prior knowledge in 3D weaving or fashion design. While making efforts to comprehend these subjects (through doing a two-week intensive course in the fundamentals of textile systems and personal research) and validate research findings with experts, this might have resulted in limited understanding of certain details.
- The outcomes of the ethnographic user research were restricted in their applicability due to a small participant pool and the timing of the research, which occurred towards the end of the project. Additionally, the limited time available for analysing the results may have resulted in overlooking certain details.
- Some of the individuals interviewed during the initial phase of user research, as well as other research connections, had close relationships with the researcher. This proximity could have inadvertently introduced biases from both the participants' and the researcher's perspectives. Therefore, a more diverse and personally distant group of participants is necessary to foster a more reflexive approach.

6.3.

RECOMMENDATIONS FOR FUTURE RESEARCH AREAS

By addressing the following research areas for future exploration, we can deepen our understanding of effective knowledge exchange, explore alternative paradigms for industry-led change, test on-demand production models, expand the application of 3D weaving to other fields, advance jacquard loom development, and enhance traceability and transparency in the fashion industry.

- Further research should be conducted to effectively establish **knowledge exchange partnerships** with current suppliers, facilitating an ethical transition towards relocalised and self-sustaining economic circles across the globe. This idea's feasibility was from an industry perspective only validated by Diamond Denim, who are more advanced in terms of strategic partnerships, future thinking, and sustainability compared to most other mills. Exploring successful models for collaboration and identifying potential barriers or challenges in implementing such partnerships would be valuable for future research.

- Additionally, it is crucial to explore **alternative approaches that move away from the current capitalist system** in which this strategy is situated. Research should investigate different economic models for industry-led change that go beyond considerations of reputation and profitability, which could perhaps better prioritise sustainability and innovation without always relying on creating new products.

- Testing **on-demand production models in local regions** can provide better insight into the benefits of personalization, made-to-measure principles and consumer engagement in decision-making. More focus on understanding how these models could contribute to fostering stronger emotional attachments to garments from both consumer behaviour and cultural perspectives would be valuable for future research.

- The methods explored in this project could be applied to **other fields** such as architecture, technical fabrics, military applications, interior design, and automotive industries. Some of the research in this project pointed out that there are many opportunities and probable interests in these domains for researching 3D woven zero-waste design.

- **Continuous development in jacquard loom technology** is essential. Research should focus on either designing the perfect jacquard loom, perhaps just introduced by Unspun, or exploring effective ways to combine components of existing looms for 3D weaving, like this current research favoured more towards. Understanding the technical aspects, desirability within the supply chain, and the responsible stakeholders

involved in this transformative process are areas that require further exploration, as well as questioning whether and who gets to capitalise of such innovation. This further raises the point of discussion on whether the tools and methods of innovative niche technologies should be open access or not, or to what extent.

- More attention must be given to establishing **traceability and transparency schemes, or implementing digital product passports throughout the entire roadmap already**, should be considered beyond mere recommendations. Further research is needed to develop practical solutions and frameworks for ensuring traceability and transparency at every stage of the supply chain in a strategy alike.

6.4.

REFLECTION

With a background in industrial design and anthropology, I've always recognised the strong connection between design, human perspective and addressing complex challenges. In today's fast-paced, industrialised world, understanding social patterns and interconnections becomes crucial for driving meaningful change, even at higher systemic levels. It is within this realm that I am driven to make a contribution, and my passion has led me to focus on transformation within the fashion industry in particular. The immense damage inflicted from both social and environmental viewpoint in this domain, in mere decades, deeply troubles me.

Throughout my studies, I acquired various methods, tools and experiences to understand intricate patterns in behaviour and society, and how to combine those with design. I was determined to apply these skills effectively, even if any project I had ever done only had a very limited scope and timeframe, and often just a hypothetical connection to the real world. This graduation experience allowed me to fully immerse myself in an industry and community for the first time, and I am truly amazed by the amount of knowledge and insights I gained through engaging with stakeholders in the denim system, doing my best to communicate with them openly and effectively. This project was undeniably the most challenging undertaking of my studies, both in terms of its complexity and the depth of the research involved.

At the start of the project, I had a clear vision of the goal I wanted to achieve: demonstrating how innovative techniques like 3D weaving can be effectively utilised to drive systemic change, rather than remaining confined to the research stage. Although I didn't have a background in fashion design, I immersed myself in learning about 3D weaving, believing that a thorough understanding was crucial at the outset. It was initially difficult to envision how I would execute my further research with industry professionals and other important system stakeholders. However, by seizing every opportunity and dedicating countless hours to connecting with these individuals, opportunities quickly unfolded and became a reality. This required immense flexibility and unconventional working hours, including multiple

trips abroad to achieve my objectives. However, such challenges are inherent in complex projects, especially when operating within a tight timeframe of just 4.5 months. Certain research activities could only be carried out at later stages, such as the visit at the denim mill in Pakistan and the weaving of new jacket trials for an additional month of testing. Therefore, I consistently sought to iterate and maximise the utilisation of findings from each stage, ensuring efficient progress and grounding without compromising the overall project completion.

I am aware that there is a vast realm of untapped potential behind each aspect I have addressed in this thesis, eagerly awaiting further exploration, examination, and resolution. However, it is important to acknowledge that solving everything within the constraints of a single project, let alone within a limited time frame, is simply not feasible. Of course, at certain points, a grave feeling of overwhelm wanted to take over. Nonetheless, I endeavoured to make the most of the opportunity by connecting with numerous individuals and conducting thorough research. Throughout the project, I discovered that many steps I undertook to uncover and align various facets within this complex context felt instinctively natural, as if each step naturally led to the next. On one hand, this was a positive aspect as it provided a clear sense of direction in achieving the ultimate goal, even when stakeholder connections were not yet established. However, my supervisors reminded me that these steps and methodologies have distinct names, and it is beneficial to explicitly identify the models I was employing. This additional step helps to further solidify the grounding of the research and final design. For instance, I already intended to uncover leverage points and understood how my research setup would lead to their discovery, even before my trip to Pakistan. Yet, this uncovering became much more structured and clear when I came across the model developed by Kanial et al. in 2018.

Again, I am acutely aware that there is an entire realm of untapped possibilities beyond the points I have addressed in this work. There is an abundance of work to be done, and I hope that my contribution, no matter how small, has made a positive impact. Moving forward, I aspire to continue my research in the field of textiles, exploring areas beyond denim and 3D weaving, while improving my research competencies. I

am also interested in further delving into topics such as traceability and product passports within fashion, as there is a pressing need to address these issues within this context. Although difficult for me to express, as I often find myself feeling that my final outcomes are not sufficiently adequate, realistic, or detailed (I must admit, I am a perfectionist by nature, although I realise it is a very unattainable ideal), I feel proud of what I have accomplished in the span of 4.5 months. I hope to dedicate the remainder of my career to tackling challenges as complex and meaningful as this, ultimately paving the way towards a better future through a systemic, holistic, and social lens.

PROJECT CONTRIBUTORS

TU Delft:

Dr. Holly McQuillan | Zero-waste fashion design and systems researcher, Chair

Dr. Ingrid Mulder | Transformative and social design researcher, Mentor

Barbara Vroom, MSc | Industrial Fashion Designer

A special thanks to Dr. Holly McQuillan for helping us in setting up this research collaboration and Milou Voorwinden for finding the time to help out with the weaving files.

Dr. Boriana Rukanova | Complex infrastructure and supply chain traceability researcher

Field research at Diamond Denim by Sapphire, Lahore, Pakistan:

Maurizio Baldi | Fabric Techno-Designer

Farhan Afzal | Product Development Head

Jayesh Mandalia | Design & Product Development Manager

Faisal Masood Malik | Sr. Manager Product Development

Salamat Ali | Manager

All Heads of Departments

A special thanks to Muhammad Shahbaz and his sampling member of staff for your efforts on constructing the new 3D woven garment samples.

Unstructured interviews and semi-structured expert interviews in London, UK:

Mohsin Sajid | Denim Designer & Historian | Endrime

Craysha Audren | 3D Woven Fashion Designer & CEO | Weffan

Jayesh Mandalia | Design & Product Development Manager | Diamond Denim

Micheal Traina | Trend Researcher and Design Consultant Diamond Denim & Traina

Liane | Blackhorse Lane Atelier

Han | Blackhorse Lane Atelier

Wrangler designers

Levi's designers

Tonello

Many other denim designers and experts at the Blackhorse Lane Atelier event

Unstructured interviews at Kingpins Show:

Denim Prive

Kaltex

A hemp material expert

House of Denim

TENCEL

Cone Denim

Many others



Thank you for reading.

Author // Sterre Lidwine de Jager

REFERENCES

A

Armstrong, C. M., Niinimäki, K., Kujala, S., Karell, E. & Lang, C. (2015). Sustainable Product-Service Systems for Clothing: Exploring Consumer Perceptions of Consumption Alternatives in Finland. *Journal of Cleaner Production*, 97, 30-39. <https://doi.org/10.1016/j.jclepro.2014.01.046>

Åslund Hedman, E. (2018). Comparative Life Cycle Assessment of Jeans – A case study performed at Nudie Jeans. In [kth.diva-portal.org](https://kth.diva-portal.org/smash/get/diva2:1221104/FULLTEXT01.pdf). KTH Royal Institute of Technology. <https://kth.diva-portal.org/smash/get/diva2:1221104/FULLTEXT01.pdf>

Asmi, F., Zhang, Q., Anwar, M. A., Linke, K. & Zaid, Y. B. (2022) Ecological footprint of your denim jeans: production knowledge and green consumerism. *Sustain Sci* 17, 1781-1798. <https://doi.org/10.1007/s11625-022-01131-0>

Aakko, M., & Niinimäki, K. (2013). 0 % Waste, 100 % Aesthetics. In Proceedings of "Crafting the Future" The 10th European Academy of Design Conference, April 17-19, 2013 University of Gothenburg.

ACM. (2020). ACM: misleading information and certification labels regarding sustainability must stop. ACM.nl. <https://www.acm.nl/en/publications/acm-misleading-information-and-certification-labels-regarding-sustainability-must-stop>

Ahmad, N., Salman, A., & Ashiq, R. (2015). The Impact of Social Media on Fashion Industry: Empirical Investigation from Karachiites. *ResearchGate*, https://www.researchgate.net/publication/275714886_The_Impact_of_Social_Media_on_Fashion_Industry_Empirical_Investigation_from_Karachiites

Amed, I., Balchandani, A., Beltrami, M., Berg, A., Hedrich, S., & Rölkens, F. (2019). Fashion on demand. McKinsey & Company. <https://www.mckinsey.com/industries/retail/our-insights/fashion-on-demand>

Amed, I., André, S., Balchandani, A., Berg, A., & Rölkens, F. (2022, 29 november). The State of Fashion 2023: Holding onto growth as global clouds gather. McKinsey & Company. <https://www.mckinsey.com/industries/retail/our-insights/state-of-fashion>

Atik, D., Cavusoglu, L., Ertekin, Z. O., & Firat, A. F. (2022). Fashion, consumer markets, and democratization. *Journal of Consumer Behaviour*, 21(5), 1135-1148. <https://doi.org/10.1002/cb.2061>

Azanaw, A., Birlie, B., Teshome, B., & Jemberie, M. (2022). Textile effluent treatment methods and eco-friendly resolution of textile wastewater. *Case Studies in Chemical and Environmental Engineering*, 6, 100230. <https://doi.org/10.1016/j.csee.2022.100230> Belina, A. (2023). Semi-structured interviewing as a tool for understanding informal civil society. *Voluntary Sector Review*, 14(2), 331-347. <https://doi.org/10.1332/204080522x16454629995872>

B

Belina, A. (2023). Semi-structured interviewing as a tool for understanding informal civil society. *Voluntary Sector Review*, 14(2), 331-347. <https://doi.org/10.1332/204080522x16454629995872>

Berg, A., Hedrich, S., Ibanez, P., Kappelmark, S., Magnus, K., & Seege, M. (2019). Fashion's new must-have: sustainable sourcing at scale | McKinsey Apparel CPO Survey 2019. In McKinsey.com. <https://www.mckinsey.com/-/media/mckinsey/industries/retail/our%20insights/fashions%20new%20must%20have%20sustainable%20sourcing%20at%20scale/fashions-new-must-have-sustainable-sourcing-at-scale-vf.pdf>

Bernal, G. T. (2023, January 19). A look at upcoming European regulations that will shape fashion in 2023. BCome. Retrieved April 15, 2023, from <https://bcome.biz/blog/a-look-at-upcoming-european-regulations-that-will-shape-fashion-in-2023/>

Blaazer, E. (2022, December 7). A Guide to the Dutch Fashion Market. FashionUnited. <https://au.fashionunited.com/uncategorised/a-guide-to-the-dutch-fashion-market/2022120718494>

Blazquez, M., Henninger, C. E., Alexander, B., & Franquesa, C. (2020). Consumers' Knowledge and Intentions towards Sustainability: A Spanish Fashion Perspective. *Fashion Practice*, 12(1), 34-54. <https://doi.org/10.1080/17569370.2019.1669326>

Brach, S., Walsh, G., & Shaw, D. (2017). Sustainable consumption and third-party certification labels: Consumers' perceptions and reactions. *European Management Journal*, 36(2), 254-265. <https://doi.org/10.1016/j.emj.2017.03.005>

Brun, A., Karaosman, H., & Barresi, T. (2020). Supply Chain Collaboration for Transparency. *Sustainability*, 12(11), 4429. <https://doi.org/10.3390/su12114429>

C

Camacho-Otero, J., Boks, C., & Nilstad Pettersen, I. (2019). User acceptance and adoption of circular offerings in the fashion sector: Insights from user-generated online reviews. *Journal of Cleaner Production*, 231, 928-939. <https://doi.org/10.1016/j.jclepro.2019.05.162>

Cernansky, R. (2021, April 29). Can on-demand manufacturing solve fashion's waste problem? *Vogue Business*. <https://www.voguebusiness.com/sustainability/can-on-demand-manufacturing-solve-fashion-waste-problem>

Cervellon, M. & Wernerfelt, A. (2012). Knowledge sharing among green fashion communities online. *Journal of Fashion Marketing and Management: An International Journal*, 16(2), 176 - 192. <https://doi.org/10.1108/13612021211222860>

Chan, T., & Wong, C. W. Y. (2012). The consumption side of sustainable fashion supply chain. *Journal of Fashion Marketing and Management*, 16(2), 193-215. <https://doi.org/10.1108/13612021211222824>

Cheng, Y., & Liang, H. E. (2021). Calculation and evaluation of industrial carbon footprint of cotton denim jacket. *Journal of Engineered Fibers and Fabrics*, 16, 1-8. <https://doi.org/10.1177/15589250211020387>

Cholachatpinyo, A., Padgett, I. & Crocker, M. (2002). A conceptual model of the fashion process-part 1: the fashion transformation process model. *Journal of Fashion Marketing and Management*, 6(1), 11-23. [10.1108/13612020210422428](https://doi.org/10.1108/13612020210422428).

Choudhury, A. K. R. (2015). Development of Eco-labels for Sustainable Textiles. *Roadmap to Sustainable Textiles and Clothing*, 137-173. [10.1007/978-981-287-164-0_6](https://doi.org/10.1007/978-981-287-164-0_6).

Choudhury, A. K. R. (2017). Finishing of denim fabrics. In *Principles of Textile Finishing* (pp. 383-415). Woodhead Publishing. <https://doi.org/10.1016/B978-0-08-100646-7.00012-6>

Claxton, S., & Kent, A. J. (2020). The management of sustainable fashion design strategies: An analysis of the designer's role. *Journal of Cleaner Production*, 268, 122112. <https://doi.org/10.1016/j.jclepro.2020.122112>

Clean Clothes Campaign (2012). Deadly Denim: Sandblasting in the Bangladesh Garment Industry-Summary. <https://2018.schoneklaren.nl/informatie/publicaties/brochures-en-rapporten/deadly-denim-sandblasting-in-the-bangladesh-garment-industry/view>

Clean Clothes Campaign. (2020, October 22). Union Busting. [Cleanclothes.org](https://cleanclothes.org/union-busting). Retrieved March 22, 2023 from <https://cleanclothes.org/union-busting>

Consultancy.nl. (2022, August 31). Move to Impact: 'Begin op tijd met implementatie van CSRD.' Consultancy.nl. Retrieved April 13, 2023, from <https://www.consultancy.nl/nieuws/42404/move-to-impact-begin-op-tijd-met-implementatie-van-csrd>

Cotton Incorporated. (2022, September 26). Cotton Incorporated's Supply Chain Insights Denim Jeans Netherlands Edition. Cottoninc. <https://www.cottoninc.com/market-data/supply-chain-insights/denim-jeans-2022-netherlands/>

Crosby, G. (1999). Comfortable casuals in Cologne. *Canadian Apparel*, 23(2), 25-27.

Crouth, D. (2022, February 10). Industry Focus: Denim—What advancements and innovations within denim make you hopeful for the future of the industry, and how will these contributions create progress in the category? *California Apparel News*. <https://www.apparelnews.net/news/2022/feb/10/industry-focus-denimwhat-advancements-and-innovati/>

D

Digitally Empowering Fashion. (2021, August 10). What Is Fashion On-Demand in 2023 And How Does It Work? [tg3ds.com](https://www.tg3ds.com/blog/fashion-on-demand). <https://www.tg3ds.com/blog/fashion-on-demand>

Dissanayake, D., & Weerasinghe, D. (2021). Towards Circular Economy in Fashion: Review of Strategies, Barriers and Enablers. *Circular Economy and Sustainability*, 2(1), 25-45. <https://doi.org/10.1007/s43615-021-00090-5>

DDW (2022). Your own demand t-shirt by Atalyé. <https://ddw.nl/nl/programma/7589/your-own-demand-t-shirt>

Dendler, L. (2014). Sustainability Meta Labelling: an effective measure to facilitate more sustainable consumption and production? *Journal of Cleaner Production*, 63, 74-83. <https://doi.org/10.1016/j.jclepro.2013.04.037>

Dobrosielski, C. (2023, February 7). Tonello Unveils Ego, Its 'Simplest' Ozone Finishing System. *SourcingJournal*. <https://sourcingjournal.com/denim/denim-mills/tonello-ego-ozone-finishing-system-denim-manufacturing-bleaching-water-consumption-415792/>

Doúglass, R. (2022, March 10). Fashtech Innovation Centre opens in London to support production solutions. *FashionUnited*. <https://fashionunited.uk/news/business/fashtech-innovation-centre-opens-in-london-to-support-production-solutions/2022031061938>

E

Eartha. (2017). A Big Step For Mankind: What Is A Water Footprint And Why Is It Important? – EARTHA. EARTHA. <http://www.earthamag.org/stories/2017/3/27/what-is-a-water-footprint-and-why-is-it-important>

Eco, U. (1986). Lumbar Thought. In *Faith in fakes*. Vintage Minerva. <https://nathanvaughanblog.files.wordpress.com/2016/06/lumbarthought.pdf>

Eddy. (2022, August 4). Upcycling Fashion: The Art of Designing with Waste Materials. *Closed Loop Fashion*. <https://closedloopfashion.com/innovative-design/upcycling-fashion-the-art-of-designing-with-waste-materials/>

Enes, E. & Kıpöz, Ş. (2019). Turkey Fashion Industry's Cut-and-Sew Waste Problem and Its Waste Management Strategies. *Tekstil ve Mühendis*, 26: 113, 97-103. <https://doi.org/10.7216/1300759920192611311>

Enes, E., & Kıpöz, Ş. (2020). The role of fabric usage for minimization of cut-and-sew waste within the apparel production line: Case of a summer dress. *Journal of Cleaner Production*, 248, 119221. <https://doi.org/10.1016/j.jclepro.2019.119221>

Egels-Zandén, N., Hulthén, K., & Wulff, G. (2015). Trade-offs in supply chain transparency: the case of Nudie Jeans Co. *Journal of Cleaner Production*, 107, 95-104. <https://doi.org/10.1016/j.jclepro.2014.04.074>

Environmental Audit Committee. (2019). Fixing fashion: clothing consumption and sustainability | Sixteenth Report of Session 2017-19. In *publications.parliament.uk*. UK Parliament. <https://publications.parliament.uk/pa/cm201719/cmselect/cmenvaud/1952/full-report.html#heading-9>

Ellen MacArthur Foundation. (2017). A New Textiles Economy: Redesigning fashion's future. <https://ellenmacarthurfoundation.org/a-new-textiles-economy>

Ellen MacArthur Foundation. (2021). The Jeans Redesign. <https://ellenmacarthurfoundation.org/the-jeans-redesign>

Ellen, P.S. Webb, D. J. & Mohr, L. A. (2006). Building corporate associations: Consumer attributions for corporate socially responsible programs. *Journal of the Academy of Marketing Science*, (34)2, 147-157. <https://doi.org/10.1177/0092070305284976>

Esteve-Turrillas, F. A., & De La Guardia, M. (2017). Environmental impact of Recover cotton in textile industry. *Resources Conservation and Recycling*, 116, 107-115. <https://doi.org/10.1016/j.resconrec.2016.09.034>

European Commission. (2022, March 30). Green Deal: New proposals to make sustainable products the norm and boost Europe's resource independence. [ec.europa.eu](https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2013). https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2013

European Commission. (n.d.). How is the EU making fashion sustainable? environment.ec.europa.eu. Retrieved March 15, 2023, from https://environment.ec.europa.eu/topics/circular-economy/reset-trend/how-eu-making-fashion-sustainable_en

European Parliament. (2023, June 1). MEPs push companies to mitigate their negative social and environmental impact. [europarl.europa.eu](https://www.europarl.europa.eu). Retrieved June 1, 2023, from <https://www.europarl.europa.eu/news/en/press-room/20230524IPR91907/meps-push-companies-to-mitigate-their-negative-social-and-environmental-impact>

Evans, M (1989). Consumer behavior towards fashion. *European Journal of Marketing*, 23(7), 7-16. <https://doi.org/10.1108/EUM00000000000575>

F

Faerm, S. (2017). The shifting role of the fashion designer. In K. Vaidya (Ed.), *Fashion design for the curious: Why study fashion design?* Perth: The Curious Academic Publishing, The University of Western Australia. https://www.researchgate.net/publication/347493664_The_Shifting_Role_of_the_Fashion_Designer

Fairtrade Foundation. (2020). Fairtrade and Cotton. In [fairtrade.org.uk](https://www.fairtrade.org.uk/wp-content/uploads/2020/10/Cotton_commodity_briefing_2020.pdf). https://www.fairtrade.org.uk/wp-content/uploads/2020/10/Cotton_commodity_briefing_2020.pdf

Fibre2Fashion. (2022, April 29). 40% rise in cotton prices in 2022 due to Ukraine war: World Bank. <https://www.fibre2fashion.com/news/textile-news/40-rise-in-cotton-prices-in-2022-due-to-ukraine-war-world-bank-280380-newsdetails.htm#:~:text=Cotton%20prices%20are%20expected%20to,response%20to%20reduced%20cotton%20supplies>

Fletcher, K. (2010). Slow fashion: An invitation for systems change. *Fashion practice*, 2(2), 259-265. <https://doi.org/10.2752/175693810X12774625387594>

Fletcher, K. and Tham, M. (2019). *Earth Logic Fashion Action Research Plan*. London: The J J Charitable Trust.

Forum for the Future. (n.d.). Cotton 2040. Retrieved March 1, 2023, from <https://www.forumforthefuture.org/cotton-2040>

G

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, 31(8-9), 1257-1274. [https://doi.org/10.1016/S0048-7333\(02\)00062-8](https://doi.org/10.1016/S0048-7333(02)00062-8)

Gereffi, G. & Frederick, S. (2010). The Global Apparel Value Chain, Trade and the Crisis: Challenges and Opportunities for Developing Countries. The World Bank, Policy Research Working Paper Series. https://www.researchgate.net/publication/46444042_The_Global_Apparel_Value_Chain_Trade_and_the_Crisis_Challenges_and_Opportunities_for_Developing_Countries

Gilliland, N. (2019, April 9). Four factors fuelling the growth of fast fashion retailers. [Econsultancy](https://econsultancy.com/four-factors-fuelling-the-growth-of-fast-fashion-retailers/). <https://econsultancy.com/four-factors-fuelling-the-growth-of-fast-fashion-retailers/>

Gleason, E. (2023, February 9). Jeans Are The Fabric Of Society, But How Has One Famous Style Stayed In Fashion For 150 Years? *NZ Herald*. <https://www.nzherald.co.nz/viva/fashion/jeans-are-the-fabric-of-society-but-how-has-one-famous-style-stayed-in-fashion-for-150-years/S5YAXY3CQRG4JCVYHPYPWTCLLM/>

Goldman, E (2017). What Makes Amsterdam a Denim City?. Retrieved from <https://sourcingjournal.com/denim/denim-brands/amsterdam-denim-city-96273/>

Goworek, H., Fisher, T., Cooper, T., Woodward, S. & Hiller, A. (2012). The sustainable clothing market: an evaluation of potential strategies for UK retailers. *International Journal of Retail & Distribution Management*, 40, 935-955. <https://doi.org/10.1108/09590551211274937>

Granskog, A., Laizet, F., Lobis, M., & Sawers, C. (2020). Biodiversity: The next frontier in sustainable fashion. McKinsey & Company. <https://www.mckinsey.com/industries/retail/our-insights/biodiversity-the-next-frontier-in-sustainable-fashion>

Gueye, S. (2021, June 22). The trends and trailblazers creating a circular economy for fashion. [EllenMacArthurfoundation.org](https://ellenmacarthurfoundation.org/articles/the-trends-and-trailblazers-creating-a-circular-economy-for-fashion). <https://ellenmacarthurfoundation.org/articles/the-trends-and-trailblazers-creating-a-circular-economy-for-fashion>

Gvheff. (2021). Denim Mis-information. *Kingpins Show*. <https://kingpinsshow.com/denim-misinformation/>

Gwilt, A. (2016, May 13). Zero waste fashion design [Slide show]. [stagplacements.files.wordpress.com](https://stagplacements.files.wordpress.com/2016/04/gwilt_zero_waste_slides.pdf). https://stagplacements.files.wordpress.com/2016/04/gwilt_zero_waste_slides.pdf

H

Han, G. Y., Shin, H., & Kim, S. W. (2008). Optimization of bio-indigo production by recombinant *E. coli* harboring *fmo* gene. *Enzyme and Microbial Technology*, 42(7), 617-623. <https://doi.org/10.1016/j.enzmictec.2008.02.004>

Harrell, A. (2023, March 22). How Jeanologia Slashes Garment Finishing Water Usage From 100 Liters To 1. SourcingJournal. <https://sourcingjournal.com/denim/denim-sustainability/jeanologia-reduces-water-consumption-100-liter-to-one-garment-finishing-world-water-day-424918/>

Hawley, J. M. (2011). Textile Recycling Options. In *Shaping Sustainable Fashion Changing the Way We Make and Use Clothes* (1st ed.). Earthscan, London, United Kingdom. <https://www.taylorfrancis.com/chapters/edit/10.4324/9780203126172-21/4-1-textile-recycling-options-jana-hawley>

Hekkert, M., Reike, D., Rainville, A., & Negro, S. (2021). Transition to Circular Textiles in the Netherlands: An innovation systems analysis. In *government.nl*. Copernicus Institute of Sustainable Development. <https://www.government.nl/documents/reports/2021/01/12/transition-to-circular-textiles-in-the-netherlands-an-innovation-systems-analysis>

Hirschman, E. C., & Holbrook, M. B. (1982). Hedonic Consumption: Emerging Concepts, Methods and Propositions. *Journal of Marketing*, 46(3), 92-101. <https://doi.org/10.2307/1251707>

Hogeschool van Amsterdam. (2020, May 12). Measuring the Dutch clothing mountain. Hogeschool Van Amsterdam. <https://www.hva.nl/kc-fdmci/gedeelde-content/projecten/projecten-fashion/measuring-the-dutch-clothing-mountain.html>

Hyllegard, K. H., Yan, R., Ogle, J. H., & Lee, K. (2012). Socially Responsible Labeling. *Clothing and Textiles Research Journal*, 30(1), 51-66. <https://doi.org/10.1177/0887302x11433500>

I

Igini, M. (2022). 10 Concerning Fast Fashion Waste Statistics. Earth.Org. <https://earth.org/statistics-about-fast-fashion-waste/>

Iraldo, F., & Barberio, M. (2017). Drivers, Barriers and Benefits of the EU Ecolabel in European Companies' Perception. *Sustainability*, 9(5), 751. <https://doi.org/10.3390/su9050751>

J

Jia, F., Yin, S., Chen, L., & Chen, X. (2020). The circular economy in the textile and apparel industry: A systematic literature review. *Journal of Cleaner Production*, 259, 120728. <https://doi.org/10.1016/j.jclepro.2020.120728>

Johnson, K. K. P., Schofield, N. A., & Yurchisin, J. (2002). Appearance and dress as a source of information: A qualitative approach to data collection. *Clothing and Textiles Research Journal*, 20(3), 125-137. <https://doi.org/10.1177/0887302X0202000301>

Johnston, H., & Land-Kazlauskas, C. (2019). Organizing on-demand: Representation, voice, and collective bargaining in the gig economy. *International Labour Organization*, Geneva. https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---travail/documents/publication/wcms_624286.pdf

Jones, P. H. (2014). Systemic design principles for complex social systems. In G. S. Metcalf (Ed.), *Social systems and design* (pp. 91-128). Springer Japan.

Jung, S., & Jin, B. (2016). From quantity to quality: understanding slow fashion consumers for sustainability and consumer education. *International Journal of Consumer Studies*, 40(4), 410-421. <https://doi.org/10.1111/ijcs.12276>

K

Kania, J., Kramer, M., & Senge, M. (2018). The water of systems change. https://www.fsg.org/resource/water_of_systems_change

Korhonen, J., Nuur, C., Feldmann, A. E., & Birkie, S. E. (2018). Circular economy as an essentially contested concept. *Journal of Cleaner Production*, 175, 544-552. <https://doi.org/10.1016/j.jclepro.2017.12.111>

Kumar, V., Hallqvist, C., & Ekwall, D. (2017). Developing a Framework for Traceability Implementation in the Textile Supply Chain. *Systems*, 5(2), 33. <https://doi.org/10.3390/systems5020033>

Kumari, A., & Khurana, K. (2016). Regenerated Cellulose-Based Denim Fabric for Tropical Regions: An Analytical Study on Making Denim Comfortable. *Journal of Textiles*, 2016, 1-10. <https://doi.org/10.1155/2016/4614168>

Kwok, Y. I. L., Wong, A. S., Li, Y. I., & Zhang, X. (2006). Sensory comfort of denim product. In *Clothing Biosensory Engineering*, 335-349. Woodhead Publishing. Retrieved from <https://books.google.nl/>

L

Leinenga, M. (2019). Dutch sustainable clothing consumption and the influence of materialism, fashion clothing involvement and environmental awareness [Masters Thesis]. University of Twente. https://essay.utwente.nl/79038/7/Leinenga_BA_faculty.pdf

Lennon, S. J., Johnson, K. K., Noh, M., Zheng, Z., Chae, Y., & Kim, Y. (2014). In search of a common thread revisited: what content does fashion communicate? *International Journal of Fashion Design, Technology and Education*, 7(3), 170-178. <https://doi.org/10.1080/17543266.2014.942892>

Longhurst, R. (2009). Interviews: In-Depth, Semi-Structured. In Elsevier eBooks. 580-584. <https://doi.org/10.1016/b978-008044910-4.00458-2>

Lu, X., Sheng, T., Zhou, X., Shen, C., & Fang, B. (2022). How Does Young Consumers' Greenwashing Perception Impact Their Green Purchase Intention in the Fast Fashion Industry? An Analysis from the Perspective of Perceived Risk Theory. *Sustainability*, 14(20), 13473. <https://doi.org/10.3390/su142013473>

Luchs, M. G., Naylor, R. W., Irwin, J. R., & Raghunathan, R. (2010). The Sustainability Liability: Potential Negative Effects of Ethicality on Product Preference. *Journal of Marketing*, 74(5), 18-31. <https://doi.org/10.1509/jmkg.74.5.18>

Luján-Ornelas, C., Gúereca, L. P., Franco-García, M.-L., & Heldeweg, M. (2020). A Life Cycle Thinking Approach to Analyse Sustainability in the Textile Industry: A Literature Review. *Sustainability*, 12(23), 10193. MDPI AG. <http://dx.doi.org/10.3390/su122310193>

M

Marrucci, L., Iraldo, F. & Daddi, T. (2021). Investigating the management challenges of the EU Ecolabel through multi-stakeholder surveys. *Int J Life Cycle Assess* 26, 575-590. <https://doi.org/10.1007/s11367-021-01866-5>

Martino, G., Iannone, R., Fera, M., Miranda, S., & Riemma, S. (2017). Fashion retailing: A framework for supply chain optimization. *Uncertain Supply Chain Management*, 243-272. <https://doi.org/10.5267/j.uscm.2016.12.002>

Mason, W., Conroy, F. R., & Smith, E. R. (2007). Situating Social Influence Processes: Dynamic, Multidirectional Flows of Influence Within Social Networks. *Personality and Social Psychology Review*, 11(3), 279-300. <https://doi.org/10.1177/1088868307301032>

McCracken, G. D. and Roth, V. J. (1989). "Does clothing have a code? Empirical findings and theoretical implications in the study of clothing as a means of communication". *International Journal of Research in Marketing*, 6(1), 13-33. [https://doi.org/10.1016/0167-8116\(89\)90044-X](https://doi.org/10.1016/0167-8116(89)90044-X)

McDonald, S., Oates, C. J., Alevizou, P. J., Young, C. W., & Hwang, K. (2012). Individual strategies for sustainable consumption. *Journal of Marketing Management*, 28(3-4), 445-468. <https://doi.org/10.1080/0267257X.2012.658839>

McDougall, F. (2001). Life Cycle Inventory Tools: Supporting the Development of Sustainable Solid Waste Management Systems. *Corporate Environmental Strategy*, 8(2), 142-147. [https://doi.org/10.1016/S1066-7938\(01\)00083-5](https://doi.org/10.1016/S1066-7938(01)00083-5)

McDougall, F. R., White, P. R., Franke, M., & Hindle, P. (2001). *Integrated Solid Waste Management: a Life Cycle Inventory* (2nd ed.). Blackwell Science. <https://www.eng.hokudai.ac.jp/labo/waste/english/wp-content/uploads/2014/03/integrated-solid-waste-managemen-a-life-cycle-inventory.pdf>

McQuillan, H. (2019a). Weaving Futures: Adopting alternative postures to develop new methods for the construction of textile-forms in the context of micro-manufacturing. Paper presented at Making Futures Conference, Plymouth College of Art, Plymouth, UK.

McQuillan, H. (2019b). Hybrid zero waste design practices. Zero waste pattern cutting for composite garment weaving and its implications. *The Design Journal*, 22(1), 803-819. [10.1080/14606925.2019.1613098](https://doi.org/10.1080/14606925.2019.1613098)

McQuillan, H., Archer-Martin, J., Menzies, G. F., Bailey, J. E., Kane, K., & Derwin, E. F. (2018). Make/use: A system for open source, user-modifiable, zero waste fashion practice. *Fashion practice*, 10(1), 7-33. <https://doi.org/10.1080/17569370.2017.1400320>

McQuillan, H. (2020) *Zero Waste Systems Thinking: Multimorphic Textile-forms*. PhD Thesis. Edited by L. Hallnäs. University of Borås. Retrieved from <http://urn.kb.se/resolve?urn=urn:nbn:se:hb:diva-23961>

Meadows, D. H. (1997). Leverage points: Places to intervene in a system. *Whole Earth*, 91(1).

Meadows, D. H. (2008). *Thinking in systems: A primer*. Chelsea Green Publishing.

Miller, C. M., McIntyre, S. H., & Mantrala, M. K. (1993). Toward formalizing fashion theory. *Journal of marketing research*, 30(2), 142-157.

Miller, D., & Woodward, S. (2011). *Global Denim | The Global Denim Project* (2nd ed.). Berg Publishers. <https://www.ucl.ac.uk/anthropology/people/academic-and-teaching-staff/daniel-miller/global-denim-project>

Miyauchi, R., Zhou, X., & Inoue, Y. (2023). Design Elements That Increase the Willingness to Pay for Denim Fabric Products. *Textiles*, 3(1), 11-25. <https://doi.org/10.3390/textiles3010002>

Mizrachi, M. S., & Tal, A. (2022). Regulation for Promoting Sustainable, Fair and Circular Fashion. *Sustainability*, 14(1), 502. <https://doi.org/10.3390/su14010502>

Morris, M. A. & Prato, H. H. (1981). Consumer Perception of Comfort, Fit and Tactile Characteristics of Denim Jeans. *Textile Chemist & Colorist*, 13(3), 24-30. <https://web.s.ebscohost.com>

Muller, D. (2013). *Breathless for Blue Jeans | Health hazards in China's denim factories*. IHLO, SACOM, Clean Clothes Campaign & War on Want. https://www.cleanclothes.at/media/common/uploads/download/breathless-for-blue-jeans-health-hazards-in-china-s-denim-factories/Report_Breathless_130703.pdf

Murphy, R. J. A. (2022). Finding (a theory of) Leverage for Systemic Change: A systemic design research agenda. *Contexts—The Systemic Design Journal*, 1. <https://doi.org/10.58279/v1004>

N

National Institute for Public Health and the Environment. (2023, April 4). Safe recycling of textiles possible, but still in its infancy. RIVM.nl. <https://www.rivm.nl/en/news/safe-recycling-of-textiles-possible-but-still-in-its-infancy#:~:text=For%20textiles%2C%20the%20aim%20is,at%20least%2030%25%20recycled%20fibres>

Newman, G. E., & Dhar, R. (2014). Authenticity is contagious: brand essence and the original source of production. *Journal of Marketing Research*, 51(3), 371-386. <https://doi.org/10.1509/jmr.11.0022>

Niinimäki, K. (2010). Eco-clothing, consumer identity and ideology. *Sustainable Development*, 18(3), 150-162. <https://doi.org/10.1002/sd.455>

Niinimäki, K. (2014). Green Aesthetics in Clothing. *Artifact*, 3(3), 3. <https://doi.org/10.14434/artifact.v3i3.3653>

Niinimäki, K., Peters, G., Bontempi, E., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment*, 1(4), 189-200. <https://doi.org/10.1038/s43017-020-0039-9>

Norman, D. A., & Stappers, P. J. (2015). *DesignX: Complex Sociotechnical Systems*.

Notten, P. (2020). Sustainability and Circularity in the Textile Value Chain - Global Stocktaking. UN Environment Programme. https://www.oneplanetnetwork.org/sites/default/files/unep_sustainability_and_circularity_textile_value_chain_1.pdf

O

OEC - The Observatory of Economic Complexity. (2022). Used Clothing. OEC.world. Retrieved May 15, 2023, from <https://oec.world/en/profile/hs/used-clothing>

Oleniacz, L. (2021, October 27). "Digital denim" is almost as good as the real thing. *Futurity*. <https://www.futurity.org/digital-denim-fabric-inkjet-printing-textiles-2648262/>

One Planet Life. (2023, May 11). Break the Cycle of Fast Fashion and Change the World. <https://oneplanetlife.com/category/protect-the-planet/>

Östlund, A., Roos, S., Sweet, S., & Sjöström, E. (2020). Investor Brief: Sustainability in Textiles and Fashion, *Mistra Dialogue*, Stockholm. https://www.mistra.org/wp-content/uploads/2020/09/mistradialogue_rapport_investor_brief_textiles_final.pdf

P

Parrilla-Lahoz, S., Mahebadevan, S., Kauta, M., Zambrano, M. C., Pawlak, J. J., Venditti, R. A., Reina, T. R., & Duyar, M. S. (2022). Materials challenges and opportunities to address growing micro/nanoplastics pollution: a review of thermochemical upcycling. *Materials Today Sustainability*, 20(3), 100200. <https://doi.org/10.1016/j.mtsust.2022.100200>

Paul, R. C. (2015). Denim and jeans. In *Elsevier eBooks* (pp. 1-11). <https://doi.org/10.1016/b978-0-85709-843-6.00001-9>

Pavarini, M. C. (2022, November 20). Is the Dutch Denim Deal helping jeans become more sustainable? *the-spin-off.com*. <https://www.the-spin-off.com/news/stories/The-Trends-Will-the-Dutch-Denim-Deal-achieve-its-2023-targets-16830>

Periyasamy, A. P. (2020). Environmental hazards of denim processing - I. *Asian Dyer*, 17, 58-62. https://www.researchgate.net/publication/342353695_Environmental_hazards_of_denim_processing_-_I

Periyasamy, A. P., & Periyasami, S. (2023). Critical Review on Sustainability in Denim: A Step toward Sustainable Production and Consumption of Denim. *ACS Omega*, 8(5), 4472-4490. <https://doi.org/10.1021/acsomega.2c06374>

Postlethwaite, S., Thiel, K., & Atkinson, D. (2022). Reshoring UK Garment Manufacturing with Automation: Recommendations for Government. Royal College of Art & Innovate UK KTN / Made Smarter. <https://ualresearchonline.arts.ac.uk/id/eprint/17991/1/Reshoring%20UK%20Garment%20Manufacturing%20with%20Automation%20Thought%20Leadership%20Paper.pdf>

R

Radhakrishnan, S., & Senthil Kumar, V. A. (2018). Recycled Cotton from Denim Cut Waste. *Textile Science and Clothing Technology*. https://doi.org/10.1007/978-981-10-8515-4_3

Rahman, O. (2011). Understanding Consumers' Perceptions and Behaviors: Implications for Denim Jeans Design. *Journal of Textile & Apparel Technology & Management (JTATM)*, 7(1).

Rahman, O. (2015). Denim jeans: A qualitative study of product cues, body type, and appropriateness of use. *Fashion Practice*, 7(1), 53-74. <https://doi.org/10.2752/175693815X14182200335691>

Rainey, B. (2021, January 4). How On-Demand Manufacturing Can Limit Supply Chain Disruptions. *Supply & Demand Chain Executive*. <https://www.sdexec.com/sourcing-procurement/manufacturing/article/21205537/gooten-how-ondemand-manufacturing-can-limit-supply-chain-disruptions>

Real, M., & Lizarralde, I. (2017). A set of systemic design tools for the design of flourishing local fashion systems. *Relating Systems Thinking and Design 6 (RSD6)*, Systemic Design Research Network, Birger Sévaldson, Oslo Architecture of School, Oct 2017, Oslo, Norway. hal-01703912 <https://hal.science/hal-01703912>

Rinaldi, F. R., Di Bernardino, C., Cram-Martos, V., & Pisani, M. T. (2022). Traceability and transparency: enhancing sustainability and circularity in garment and footwear. *Sustainability: Science, Practice and Policy*, 18(1), 132-141. <https://doi.org/10.1080/15487733.2022.2028454>

Rissanen, T. (2011). *Designing Endurance. In Shaping Sustainable Fashion Changing the Way We Make and Use Clothes* (1st ed.). Earthscan, London, United Kingdom. https://www.academia.edu/35416369/Alison_Gwilt_Timo_Rissanen_Shaping_Sustainable_Fashion_Changing_the_Way_We_Make_and_Use_Clothes

Rissanen, T. 2013. Zero-waste fashion design: A study at the intersection of cloth, fashion design and pattern cutting, PhD Thesis, University of Technology Sydney, Sydney. Retrieved from <http://hdl.handle.net/10453/23384>

Rissanen, T. (2023). About Timo Rissanen. <https://timorissanen.com/about/>

Rogers, E. M. (1983). *Diffusion of innovations*. The Free Press, New York.

Ruiz, A. (2023). 17 Most Worrying Textile Waste Statistics & Facts. *TheRoundup.org*. Retrieved May 20, 2023, from <https://theroundup.org/textile-waste-statistics/#:~:text=Clothing%20and%20textiles%20currently%20make,in%20either%20incinerators%20or%20landfills>

S

Sammarra, A., & Belussi, F. (2006). Evolution and relocation in fashion-led Italian districts: evidence from two case-studies. *Entrepreneurship & Regional Development*, 18:6, 543-562. <https://doi.org/10.1080/08985620600884685>

Sanders, E. B. N., & Stappers, P. J. (2012). Convivial design toolbox: Generative research for the front end of design. P 31. BIS Publishers.

Sang, Y., Yu, H., & Han, E. (2022). Understanding the Barriers to Consumer Purchasing of Zero-Waste Products. DOAJ (DOAJ: Directory of Open Access Journals). <https://doi.org/10.3390/su142416858>

SER. (2023, June 6). EU Proposal for a Directive on Green Claims: Enhancing Transparency and Trust in Environmental Marketing. SER.nl. <https://www.ser.nl/en/Publications/News/imvo-eu-greenwashing>

Seuring, S & Muller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, 16(15), 1699-1710. <https://doi.org/10.1016/j.jclepro.2008.04.020>

Sevaldson, B (2009). About Systems Oriented Design. Retrieved December 2022, from <http://www.systemsorienteddesign.net/index.php/sod/about-sod>.

Smart Indigo. (n.d.). Electricity Instead of Chemicals | The Most Sustainable Way to Dye Denim. In SmartIndigo.com. Retrieved May 26, 2023, from <https://www.smartindigo.com/wp-content/uploads/2023/05/Smart-Indigo-2023.pdf>

Smelik, A., & Feitsma, M. (2016). Jeans: from an American Icon to Dutch Denim. In *Transnational Mediations. Negotiating Popular Culture between Europe and the United States*. Heidelberg: Winter Universitätsverlag. https://www.researchgate.net/publication/327629049_Jeans_from_an_American_Icon_to_Dutch_Denim

Swinker, M. E., & Hines, J. D. (2006). Understanding consumers' perception of clothing quality: a multidimensional approach. *International Journal of Consumer Studies*, 30(2), 218-223. <https://doi.org/10.1111/j.1470-6431.2005.00478.x>

T

Tai, C. (2017, December 28). Vietnam's chance to become a leader in sustainable fashion manufacturing. *South China Morning Post*. Retrieved April 22, 2023 from <https://www.scmp.com/lifestyle/fashion-luxury/article/2125808/how-vietnam-could-upgrade-its-textiles-industry-become-eco>

Tamborrini, P., Remondino, C. and Marino, C. (2018). Data, Fashion System and Systemic Design approach: An information flow strategy to enhance sustainability. In: *Proceedings of RSD7, Relating Systems Thinking and Design 7*, 23-26 Oct 2018, Turin, Italy. https://openresearch.ocadu.ca/id/eprint/2705/1/Marino_DataFashion_2018.pdf

Teona, C., Ko, E., & Kim, S. H. (2020). Environmental claims in online video advertising: effects for fast-fashion and luxury brands. *International Journal of Advertising*, 39(6), 858-887. <https://doi.org/10.1080/02650487.2019.1644144>

Textile Exchange. (2023, May 5). Trackit paves the path for the industry to achieve its climate goals. *TextileExchange.org*. Retrieved June 6, 2023, from <https://textileexchange.org/trackit/>

Tse, T. (2016). *Four Myths of Fashion: An Ethnographic Research on the Fashion Media Industry in Hong Kong and Mainland China*. The International Sociological Association E-Symposium, Sage Publication. <https://www.academia.edu>

U

United Nations Environment Programme. (2019). Fashion's tiny hidden secret. UNEP. <https://www.unep.org/news-and-stories/story/fashions-tiny-hidden-secret>

University of Leeds. (2023). 3D Weaving Innovation Centre. 3dweaving.leeds.ac.uk. <https://3dweaving.leeds.ac.uk/>

Unspun (2023). 3D weaving by VegaTM. <https://www.unspun.io>

User Interviews. (n.d.). *Ethnography: UX Research Methods for Discovery*. [userinterviews.com](https://www.userinterviews.com). Retrieved December 21, 2022, from <https://www.userinterviews.com/ux-research-field-guide-chapter/ethnography>

V

van Boeijen, A., Daalhuizen, J., & Zijlstra, J. (2020). *Delft Design Guide: Perspectives, models, approaches, methods* (2nd edition). BIS Publishers. <https://www.bispublishers.com/delft-design-guide-revised.html>

van Raan, L. (2019). *Towards a Circular Denim Industry* [Masters Thesis]. TU Delft. <http://resolver.tudelft.nl/uuid:3d440f5a-5a80-4e66-8104-3427178b45af>

van der Wijst, L. (2016, August 1). *gfk.com*. Retrieved from <https://www.gfk.com/nl/insights/news/nederlandse-consument-is-nog-geen-voorloper-op-het-gebied-van-duurzame-kledingconsumptie/>

Venkatesh, J., Vivekanandan, K., & Bali, D. (2012). Relationship among emotions, mood, personality and clothing: an exploratory study. *Elixir Psychology* 45 (2012) 7923-7926. [https://www.elixirpublishers.com/articles/1350909637_45%20\(2012\)%207923-7926.pdf](https://www.elixirpublishers.com/articles/1350909637_45%20(2012)%207923-7926.pdf)

Vroom, A. B. (2022). 3D woven denim jacket: Exploration and development of 3D weaving as a more sustainable way to produce a denim jacket [Masters Thesis], TU Delft. <http://resolver.tudelft.nl/uuid:88bb6ff2-5e56-4b7c-a8ef-545eebc63fd3>

W

Watanatada, P., & Mak, H. (2011). *Signed, sealed ... delivered?* London, UK: SustainAbility. <https://www.slideshare.net/sustainablebrands/signed-sealed-delivered-behind-certifications-and-beyond-labels>

Wennberg, M. V., & Östlund, Å. (2019). *The Outlook Report 2011-2019: Mistra Future Fashion Final Program Report*. Mistra Future Fashion: Stockholm, Sweden. <http://mistrafuturefashion.com/wp->

West, J., Saunders, C., & Willet, J. (2021). A bottom up approach to slowing fashion: Tailored solutions for consumers. *Journal of Cleaner Production*, 296, 126387. <https://doi.org/10.1016/j.jclepro.2021.126387>

White, K. M., Habib, R., & Hardisty, D. J. (2019). How to Shift Consumer Behaviors to be More Sustainable: A literature review and guiding framework. *Journal of Marketing*, 83(3), 22-49. <https://doi.org/10.1177/0022242919825649>

Wohlgemuth, V. (2022, April 22). How Fast Fashion is using the Global South as a dumping ground for textile waste - Greenpeace International. Greenpeace International. <https://www.greenpeace.org/international/story/53333/how-fast-fashion-is-using-global-south-as-dumping-ground-for-textile-waste/>

Y

Yan, R., Hyllegard, K. H. & Blaesi, L. F. (2012). Marketing eco-fashion: The influence of brand name and message explicitness. *Journal of Marketing Communications*, (18)2, 151-168. <https://doi.org/10.1080/13527266.2010.490420>

Yeşilpınar, S., & Aytaç, V. (2009). An Approach Aimed at Fabric Consumption in Shirt Production. *Textile Research Journal*, 79(5), 461-467. <https://doi.org/10.1177/0040517508090491>

Yin, H., Chen, H., Yan, M., Li, Z., Yang, R., Li, Y., Wang, Y., Guan, J., Mao, H., Wang, Y., & Zhang, Y. (2021). Efficient Bioproduction of Indigo and Indirubin by Optimizing a Novel Terpenoid Cyclase Xial in *Escherichia coli*. *ACS Omega*, 6(31), 20569-20576. <https://doi.org/10.1021/acsomega.1c02679>

Z

Zibell, L., Beznea, A., Torres, P., & Sikora, I. (2021). Expanding the knowledge base around the role of consumers in the circular economy. In europa.eu. European Environment Agency.

IMAGE REFERENCES

Artcurial (2017). Affiche ISSEY MIYAKE. Exposition "ISSEY MIYAKE AUN". [image]. <https://www.artcurial.com/en/lot-affiche-issey-miyake-exposition-issey-miyake-aun-musee-des-arts-decoratifs-5-octobre-31>

Bild, U. (1972). 1972: Big-Ass Cuffs [photograph]. Getty Images. Retrieved from <https://www.cosmopolitan.com/style-beauty/fashion/g10286087/trendy-jeans-the-year-you-were-born?slide=5>

DDW (2022). Your o(w)n demand t-shirt by Atalyé. [image]. <https://ddw.nl/nl/programma/7589/your-own-demand-t-shirt>

Desmet, P.M.A. (2018). PrEmo - Emotion Measurement Instrument (2.0). Zenodo. <https://doi.org/10.5281/zenodo.3727497>

Fashion Technology Academy. (2022, March 4). KORNIT DIGITAL X FASHION - ENTER: OPEN FIRST EVER SUSTAINABLE FASHTECH INNOVATION CENTRE. [photograph]. fcfta.com. <https://fcfta.com/insights/latest-news/kornit-digital-x-fashion-enter-open-first-ever-sustainable-fashtech-innovation-centre/>

Gwilt, A. (2016, May 13). Zero waste fashion design. [Slide show, photograph]. stagplacements.files.wordpress.com. https://stagplacements.files.wordpress.com/2016/04/gwilt_zero_waste_slides.pdf

Liu, M. (2016). Zero-Waste Design. [photograph, 2007]. <http://www.drmarkliu.com/zerowaste-design-1>

McQuillan, H. (2020). Zero Waste Systems Thinking: Multimorphic Textile-forms. PhD Thesis. Edited by L. Hallnäs. University of Borås. [photographs]. Retrieved from <http://urn.kb.se/resolve?urn=urn:nbn:se:hb:diva-23961>

Roberts, J. & Hooper, G. (2018) Subtraction Cutting. [photographs]. <https://subtractioncutting.tumblr.com/post/171212024241/zero-waste-subtraction-cutting-with-natural-dyeing>

Shuck, D. (2018, May 9). A cinematic history of denim. Heddels. [photographs]. <https://www.heddels.com/2013/04/a-cinematic-history-of-denim/>

Unspun (2023). 3D weaving by VegaTM and custom-fit jeans. [photographs]. <https://www.unspun.io>

Unspun (2021). Unspun // how to create the perfect 3D scan. [video still frame]. <https://www.youtube.com/watch?v=RWMEDNW6Mc>

Vroom, A. B. (2022). 3D woven denim jacket: Exploration and development of 3D weaving as a more sustainable way to produce a denim jacket. TU Delft. [photographs]. <http://resolver.tudelft.nl/uuid:88bb6ff2-5e56-4b7c-a8ef-545eebc63fd3>

Weffan (2022). 3D woven trousers. [photograph]. instagram. <https://www.instagram.com/wef.fan/>

Yeohlee (2023). Lightweight Denim Wide Leg Elastic Waist Culottes. [image]. <https://yeohlee.com/products/lightweight-denim-wide-leg-elastic-waist-culottes>

APPENDIX

A	CULTURAL IMPORTANCE & PERCEPTION OF DENIM
B	GENERAL EMERGING OPPORTUNITIES IN THE DENIM INDUSTRY
C	EMERGING OPPORTUNITIES // ZERO-WASTE FASHION DESIGN
D	GENERAL SEMI-STRUCTURED INTERVIEW GUIDE FOR INDUSTRY EXPERTS
E	SEMI-STRUCTURED INTERVIEW GUIDE FOR 3D WEAVING EXPERT
F	SUPPLY CHAIN MAP
G	CONSENT FORM
H	CONCEPTUAL FRAMEWORK
I	SEMI-STRUCTURED INTERVIEW GUIDE USER RESEARCH ROUND 1
J	STRATEGY CARDS
K	ETHNOGRAPHIC RESEARCH DIARY USER RESEARCH ROUND 2
L	CO-CREATIVE SESSIONS
M	THE TAGS OF THE LABEL
N	THE TRAINING PROGRAMME
O	PROJECT BRIEF

APPENDIX A // CULTURAL IMPORTANCE & PERCEPTION OF DENIM

Consumers have a variety of needs and desires that they seek to fulfill when selecting products, including utilitarianism, sensory/aesthetics, self-relevancy, pleasurable experience, and emotional enhancement factors (Rahman, 2011). Therefore, fashion designers must consider these multiple attributes and benefits, rather than focusing solely on the tangible or physical aspects of a product, in order to effectively meet the diverse dimensional values sought by consumers (Rahman, 2011). Understanding these diverse dimensional values is often understood through a narrative which is primarily based on historical research. However, there is very little existing literature which is based on social science, through qualitative and ethnographic studies, which is also significant in gaining an understanding of the complete story. Therefore, it is worthwhile to integrate both historical and social literature in understanding Dutch consumer perception of denim.

GROWN INTO AN ICON

According to Miller and Woodward (2011), denim can be referred to as an example of the 'blindingly obvious': partly due to its ubiquity, there isn't much consideration given to the reasons behind becoming a globally dominant form of clothing. Denim has a combination of three factors behind its apparent universal appeal, which is not found in other typically worn daily attire. Firstly, because of its ubiquity, denim is often regarded as consumers' top pick of clothing when other options aren't considered, creating a generic or 'staple' image. Furthermore, it is generally the only type of clothing available for purchase with pre-applied distress. A worn-out appearance due to distress is not only associated with denim's longevity of wear, but is also argued to contribute to the final factor: intimacy. Although regarded as ubiquitous, denim is simultaneously perceived as personal. Additionally, distress, whether pre-applied or appearing after intense wear, further forms itself based upon the unique form of the individual body (Miller & Woodward, 2011)

However, in order to understand how these factors came into place and contributed to denim's universal appeal, the manner in which clothing has the potential to embody personal meaning will be illustrated. With denim in particular, historical and cultural studies are analysed, to recognise how consumer perception of this clothing category came into existence.

CLOTHING EMBODIES MEANING

Although clothing could essentially be understood through its utilitarian properties, the notion of fashion is intricately linked to social behavior (Niinimäki, 2014). McCracken & Roth (1989) explain the concept of fashion as a medium of communication that expresses a range of social information.

Clothing is an extension and expression of individuality, exhibiting psychological reflections

on one's own identity (Venkatesh et al., 2012). In a social context, consumers may use certain garments to appear distinguishable from the crowd (Miller et al., 1993). It is only through socialisation that fashion acquires symbolic meaning (Hirschman and Holbrook, 1982).

Many consumers intentionally choose to wear certain garments to specifically help shape the opinions others may form about an individual, based on the cues provided by the item. Perceivers of such cues will attach specific meanings to them, steering associations between the individual's fashion choices and a variety of characteristics – a process otherwise known as 'impression formation'. Characteristics include perceived sexuality, sense of empathy, types of addictive behaviour and language competencies (Lennon et al., 2014). According to Johnson, Schofield & Yurchisin (2002), perceivers act as if such associations are accurate, enabling people to act towards an individual's fashion choices according to the meaning one believes the individual wearer intends. Although the associations might not always be accurate and are prone to change over time, many individuals manage their personal image to present their desired identities to others. As such, denim garments can be used as a social signifier to maintain or elevate an individual's image (Rahman, 2011). In other words, the symbolic meaning attributed to clothing guides socially interactive behaviour (Lennon et al., 2014).

Apart from using clothes to communicate and establish one's social identity to others, fashion also acts as a symbol of people's connection to other individuals. Thus, the social group (or multiple groups) an individual is a member of, can affect the person's self-perception and influence their fashion choices in turn as well (McCracken & Roth, 1989).

As a dynamic phenomenon, fashion changes frequently in a variety of cultural, social, economic, political, and aesthetic milieus (Evans, 1989). Different trends emerge, are adopted and

eventually disappear (Cholachatpinyo et al., 2002). The term "fashion phenomenon" refers to the adoption of a product within a specific theme by the majority of consumers, over a certain period of time (Rogers, 1983).

Textiles are thus a major component of material culture. They may be viewed as the products of technology, as cultural symbols, as works of art, or as items of trade. The textile arts are a fundamental human activity, expressing symbolically much of what is valuable in any culture.

THE EVOLUTION OF DENIM'S OWN MEANING

When analysing denim as a clothing phenomenon, it seems denim garments have achieved something no other fashion category has. Through both contemporary and historical perspective, it becomes apparent that motives for wearing denim garments entail more than physical needs and benefits. The intersection of historical and anthropological perspectives can aid in comprehensively accounting for denim and illustrating the impact of global denim, highlighting how the two fields can mutually inform each other in this endeavor (Smelik & Feitsma, 2016).

Originally known as "serge de Nimes," a fabric resembling current denim emerged in France. However, it was through attempts to replicate this fabric in Italy that it eventually transformed into the denim we recognize today, which is also where the first association with the term 'jeane' originates from. In the 1800s, denim fabric found its purpose in the creation of labour-intensive pants, primarily driven by the need for robust workwear during the California Gold Rush. The indigo dye of denim was deliberately selected to effectively conceal dirt and stains, especially when worn by miners.

It was during this time that Levi Strauss, a salesman, and Jacob W. Davis, a tailor, collaborated to meet the demands of a client seeking exceptionally durable pants for harsh labour conditions. This collaboration led to the creation of the first pair of denim waist overalls best resembling denim jeans as we know them today: reinforced with rivets. While denim fabric initially served as a practical choice for its durability in the making of pants, it was also employed in the creation of long-sleeved shirts as its reputation grew.

The first rise in popularity of denim can be attributed to the prevalence of Western style movies from approximately 1930. Through these films, men were exposed to the portrayal of cowboys like John Wayne, engaging in victorious battles, often portrayed in blue jeans. Consequently, blue jeans transitioned from being associated solely with working-class attire to being embraced on the main streets of numerous American cities, carrying a robust status. Furthermore, Elvis Presley, James Dean, and Marlon Brando, known for their charisma and rebellious personas, actively sported jeans during the early stages of their popularity. The endorsement of renowned singers and their captivating rebellious image contributed to the elevated status of jeans in the realm of American fashion. It was during World War II that the influence of jeans expanded beyond American borders, as American soldiers stationed in Europe and Japan would frequently wear jeans in their free hours. As rumours of this defiant style began to circulate, it became evident how jeans would gradually permeate the fashion choices of Allied troops who served alongside them.

In the United States, the widespread adoption of "jeans" by the teenage audience played a pivotal role in redefining their popularity and shifting away from the term "waist overalls." Jeans became a unifying element that bridged social disparities, breaking down the traditional divide between the rich, who typically wore

formal attire, and the poor, who relied on workwear and worn-out clothing. From the 1960s onwards, jeans became emblematic of various countercultures and subcultures, ranging from hippies to skinheads. Denim became an enduring symbol of social rebellion and youth culture, fueling the spirit of defiance and challenging traditional authority and social norms. Even in the 1970s, jeans retained their status as a symbol of protest against established conventions. However, by the 1980s, denim jeans experienced an unprecedented surge in popularity and significance, paralleling the era's heightened focus on fashion. Prominent model campaigns promoted denim in innovative ways, igniting the attention of designers who dedicated their efforts to jeans. These pants swiftly became a coveted status symbol, solidifying social pressure toward becoming a must-have item for everyone.

The 1980s marked the beginning of the outsourcing trend in denim supply chains. However, in the late 1990s, a resurgence of "true American denim" emerged. Meanwhile, by now emerged so-called 'denim heads' (enthusiasts), grew interest in Japanese denim, which had been established ever since Japan gained deep interest in post-World War II American culture. Japanese denim manufacturers targeted a niche audience of denim connoisseurs by creating jeans from raw and selvedge fabrics produced on traditional shuttle looms. These meticulous manufacturing processes deliberately incorporated natural imperfections into the fabric, imbuing it with a distinctive character. In response to the declining quality of American denim during the 1970s and 1980s, Japanese brands such as Evisu, Denime, Japan Blue, Samurai, Fullcount, and Studio D'Artisan had perfected techniques that preserved the vintage-inspired denim manufacturing process rooted in American heritage.

(Rahman, 2011)
(Paul, 2015)
(Sajid, 2023, [personal communication])

VINTAGE

Denim, known as being a versatile staple garment, crafted from durable fabric, turned out to require minimal maintenance and had a notable stain-resistance. Consequently, consumers began to appreciate the way denim garments acquired an aged appearance over time. The worn-out and washed look, coupled with loose-fit styles and distress, became intrinsically linked to denim, forming a deeply ingrained, positively perceived symbol of a "pre-loved" garment. To this day, consumers currently attribute characteristics to vintage clothing that are typically part of authenticity discourse such as it being of exceptional quality, original, handcrafted, made from natural fibers, and providing continuity with the past (Fischer, 2015).

However, this desire for the aged and distressed denim look led to the emergence of practices including chemical stone washes, bleaching, hand scraping and sand-spraying, to artificially achieve the desired appearance - leading to the now known negative consequences for the contemporary denim industry.

CULTURAL IMPORTANCE OF DENIM IN THE NETHERLANDS

Denim has come to signify Dutch fashion culture and even identity, with the Netherlands often referred to as a 'denim country'. Yet, the idea that denim fits a 'typically' Dutch attitude of preference for sobriety, functionality and moderation doesn't mean The Netherlands should be referred to a 'denim country' necessarily. This idea is based on ideological framing by the fashion industry and city councils, through nation/city branding aimed at improving the creative Dutch fashion industry. Instead, the success of "Dutch Denim" can be attributed to a process of local appropriation, where the American denim icon encountered the specific Dutch context, where shared values and cultural

encounters - sobriety and adhering to the norm - led to its adoption and subsequent emergence as a thriving clothing category. This highlights how imitation, reception and appropriation shape and redefine cultural identities, blurring the boundaries between nations while gaining an image of geographical typicality (Smelik & Feitsma, 2016).

THE INFLUENCE OF SENSORY COMFORT IN DENIM PERCEPTION

The sensory experience of wearing denim is a complex interplay between comfort and discomfort. While denim is often valued for its comfort, the fit of the garment plays a crucial role in determining its level (Morris and Prato, 1981).

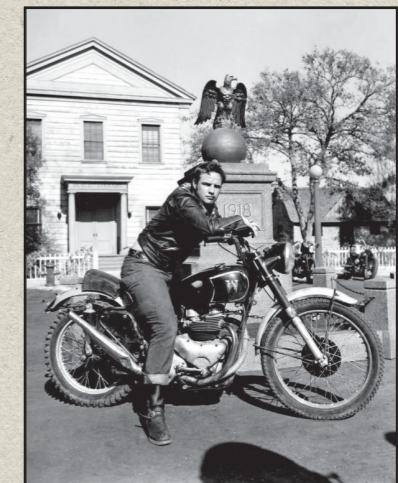
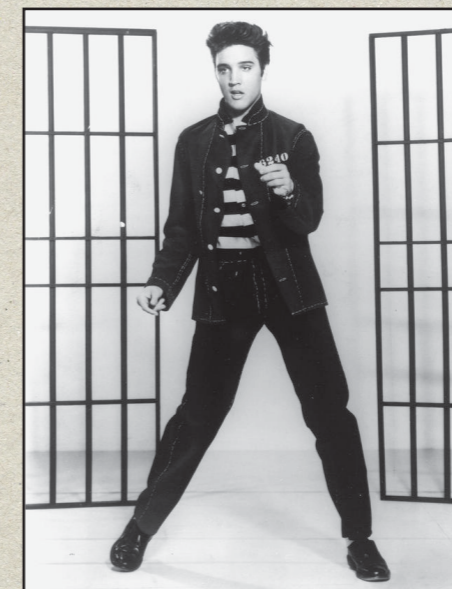
In his essay "Lumbar Thought," renowned writer and semiotician Umberto Eco reflects on his personal discomfort caused by his blue jeans. He delves deeper into the idea of clothing, including denim, as "semiotic devices" and explores the interconnectedness of external objects and internal thought processes. Eco suggests that clothing, such as jeans, can have a profound impact on our thinking and questions how past thinkers may have been influenced by their attire. He intriguingly notes that "thought abhors tight," questioning the influence of physical comfort on cognitive processes in relation to historical figures.

Eco also observes that denim jeans, by gripping the lumbar area, possess a distinctive characteristic that goes beyond simply hanging at the waist. This observation aligns with the findings of Morris and Prato (1981), who studied consumer perceptions of denim and emphasized the importance of dimensional stability in fabrics.

The perception of desirable qualities in denim varies among consumers. Crosby (1999) notes

that the casual look is often associated with comfort and softness, while younger individuals tend to prioritize new denim blends and technical fabrics.

When purchasing denim apparel, moisture comfort and pressure comfort emerge as crucial factors regardless of the season. Previous research has established a strong correlation between moisture and thermal comfort. Therefore, understanding fabric heat transfer and moisture-management properties becomes essential in studying the overall comfort of denim garments (Kwok et al., 2006).



WAR-RELATED AND CINEMATIC INFLUENCES ON DENIM BECOMING A GLOBAL ICON (SHUCK, 2018).

APPENDIX B // GENERAL EMERGING OPPORTUNITIES IN THE DENIM INDUSTRY

The waste hierarchy employed in the circular economy follows the three 'R's: Reduce, Reuse and Recycle. Some also refer to a more extensive version, typically encompassing the following steps in order: re-use, materials recycling, composting, incineration with energy recovery, incineration without energy recovery and landfill (McDougall, 2001). Matching the report of Ellen MacArthur on The Jeans, there are numerous emerging opportunities to rethink denim from the early stages of design and implement strategies for reuse and recycling throughout the various phases of manufacturing.

PRE- AND POST-CONSUMER RECYCLED COTTON

The textile and apparel industry has a low recycling rate, where less than 1% is situated in closed-loop recycling (Ellen MacArthur Foundation, 2017). However, the Dutch market has shown significant attention to improving the recycling process and incorporating post-consumer recycled (PCR) cotton in the production of new denim garments. Despite organic cotton cultivation reducing environmental impact by avoiding the use of pesticides, it still involves environmental impacts associated with water for seed growth, ginning and dyeing processes. The use of recovered cotton eliminates the environmental impact of both cotton cultivation and dyeing. This is achieved through colour-selection of raw materials after shredding takes place. The latter is also the only process which requires a significant energy footprint, meaning that overall the use of PCR cotton provides a more sustainable option for material choice than organic cotton (Esteve-Turrillas & De La Guardia, 2017). In the pre-consumer phase, there is also a growing focus on recycling pattern cutting waste as a secondary raw material, contributing to both clearing waste in the denim supply chain and the creation of partially recycled new denim (Radhakrishnan & Senthil Kumar, 2018).

BIO-INDIGO & INNOVATIVE DYEING TECHNIQUES

Indigo, the oldest known textile dye, was traditionally extracted from plant species such as *Indigofera* and *Polygonum tinctorium* for dyeing cotton and wool fabrics. However, in the late 19th century, the textile industry changed to the use of synthetic indigo, with a currently estimated annual production of 22,000 metric tons (Han et al., 2008). The dye boxes used for synthetic dye, in which ropes of yarn are dipped up to eight times, used to contain up to 3,000 litres of water and dye (Cvheff, 2021). While this has greatly improved, having been reduced to 700 litres, it is still a water-intensive process. In order to address all environmental concerns associated with synthetic indigo dye, which involves chemical processes with high energy consumption, hazardous acids and alkalis, and wastewater generation, there have been extensive studies on the development of bio-indigo. Bio-indigo, also known as microbial synthesis of indigo and indirubin, offers a sustainable and green alternative that neither relies on petrochemical precursors nor seasonal plant-based production (Yin et al., 2021). While bio-indigo has shown promise in terms of sustainability, scaling up production has proven to be challenging, making it more suitable for smaller-scale production (Han et al., 2008).

Periyasamy and Periyasami (2023) explore innovative dyeing techniques for denim. For instance, they discuss the benefits of digital-spray technology, which significantly reduces water and chemical consumption compared to traditional methods. This not only leads to a substantial decrease in effluent discharge but also limits dye amount by only affecting the fabric's surface. In contrast, conventional spray dyeing or rope dyeing involves deep penetration and solid coloration. By adopting digital-spray dyeing, the carbon footprint of the dyeing process can be reduced by more than 85%.

Another emerging technology is foam-dyeing, which can reduce liquid by at least 40%, energy by 50%, and dyes and chemical usage by 20% (Periyasamy and Periyasami, 2023). Industry leader Wrangler and Cadira Denim by DyStar are a few examples of brands using and co-developing water-saving foam-dye technologies, calling it "Dry Indigo", which they claim can reduce water usage by up to 100% (Cvheff, 2021).

Another notable example is "Smart-liquid-Indigo", which refers to dyeing through an electrochemical process. This method consumes only indigo pigment, caustic soda, water, and electricity, with the discharge consisting solely of oxygen (Smart Indigo, n.d.).

OZONE FADING TECHNOLOGIES, LASER & DIGITAL PRINTING

In contemporary laundry facilities, Tonello and Jeanologia offer new technologies that significantly reduce water usage by 70 to 80 percent. Jeanologia reports a decreased water consumption from 100 to just one liter, using a closed-loop system (H2Zero). This treats water and leaves it in optimal condition for reuse during the washing and finishing processes without the need for chemicals. They often complement this with their G2 Ozone air-washing machine, which achieves vintage and stonewash effects without the use of chemicals or pumice stones. The average water consumption in a denim laundry for a single pair of jeans is reported to be around 70 liters through this laundry process (Gvheff, 2021) (Harrell, 2023). On the other hand, Tonello, an Italian company specialising in ozone washing, is renowned for its durability in long-term use in comparison to other ozone technologies. Their primary ozone machines reduce water consumption by up to 80 percent compared to traditional bleaching methods. They also include wastewater purification systems and contribute to lower production costs. Additionally, their latest innovations include laser technology, enabling the creation of incredibly natural aesthetics such as *dégradé*, sunfaded looks, and *distress*—all achieved in a zero-waste manner (Dobrosielski, 2023). Specifically tailored for small-scale productions, this last innovative solution is well-suited for conducting garment experiments and research directly on the fabric. They have been developed in close partnership with Candiani Denim and are currently being found in modern mills, including Diamond Denim and the Blackhorse Lane Atelier.

Lastly, digital printing replaces laundry-based aesthetics by directly applying textile colourant to the fabric surface. It is a water and energy-efficient, print-on-demand process. High-resolution scanning of jean samples and converting them into computer files allows for unlimited colours and eliminates certain traditional colouration steps. Unlike traditional printing, the cost remains the same regardless of the number of colours used. Digital printing also enables pattern printing on fabric. Modern mills like Diamond Denim employ digital printers for these benefits (Oleniacz, 2021)

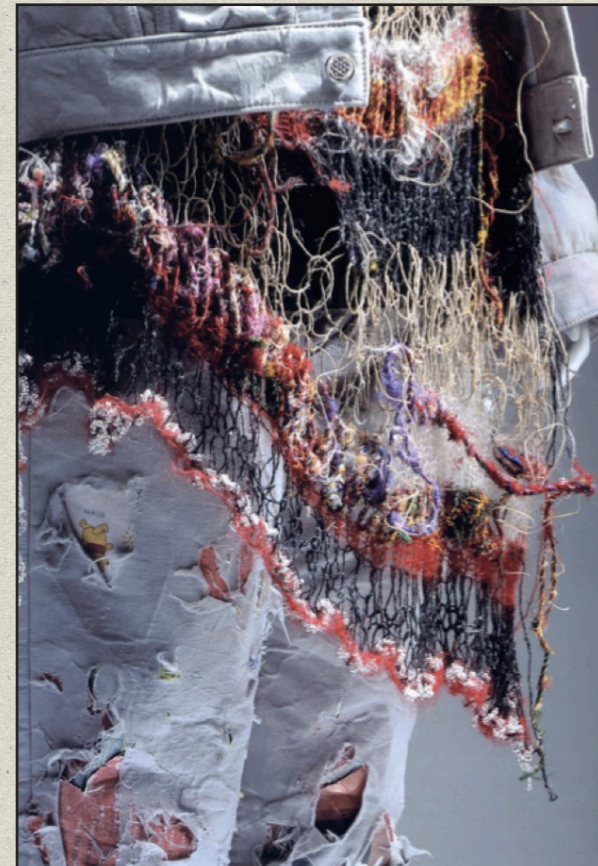
DESIGNING WITH WASTE

There are many initiatives emerging which use pre-consumer waste in the making of new fashion designs. Toton Januar, Ratna Dewi Paramita and Daciadhia Phoebehana are all fashion designers who use pre-consumer textile waste in the creation of new garments. Recently, they participated in a panel hosted by Closed Loop Fashion, discussing upcycling material availability, production scalability, pricing, business cases and changing perspectives in fashion academia and the overall industry (Eddy, 2022). Januar explains that upon obtaining pre-consumer denim scrap, he discovered the tools and freedom for designing with waste are limited. Thus, he emphasises the need for designers to think of unconventional manners to create new denim aesthetics, such as employing a rip-and-stitch technique (cut strips from the denim and stitching onto plain cotton fabric).

Upcycled clothing generally carries a higher price tag, pointing to the importance of brands setting their margins more flexibly to use pre-consumer waste in fashion. Production time and creative craftsmanship are in need of brand support, if it were to ever be implemented on a large scale in the fashion value chain (Eddy, 2022).

Nozomi Ishiguro has created denim designs that embrace the concept of using waste materials to create an aesthetic representation of aging. These designs feature double-layered reclaimed cotton and denim jeans, with layers of scraps and plastic bags in between. As the denim naturally deteriorates, the underlying materials are gradually exposed, adding a unique visual element to the garments (Gwilt, 2016).

Cut-and-sew waste is also reused to design non-woven textiles, meaning that downscaling is also occurring (Hawley, 2011).



DESIGNING DENIM WITH WASTE BY NAZOMI ISHIGURO (GWILT, 2016).

APPENDIX C // EMERGING OPPORTUNITIES // ZERO-WASTE FASHION DESIGN

TOOLS FOR MINIMISING CUT & SEW WASTE

A newly developed software has introduced innovative waste minimisation models for clothing manufacturing processes (Yeşilpınar & Aytaç, 2009). It enables the calculation of fabric consumption rates for various garment models prior to production, effectively reducing waste and saving time in the manufacturing process.

Another form of minimising pre-consumer waste in denim production is the inconsistent weft shrinkage during the template laying process. E-Last presents a solution by offering greater fabric consistency in its products, effectively eliminating weft shrinkage. This approach improves dimensional stability, allowing garment makers to cut and sew patterns more consistently. Due to reduced size variations, even fewer laundry, labour and production time is necessary (Sourcing Journal, 2022).

According to Enes & Kipöz (2020), the amount of fabric used in garment production is influenced by various factors such as the number of patterns and pattern spacing. They emphasise the need to assess this issue from sustainable and ecological perspectives, which calls for interdisciplinary research involving design.

ZERO-WASTE FASHION DESIGN

Zero-waste pattern design is a way to eliminate pre-consumer cutting waste from

the outset, as previous points have indicated that this design-led approach is utmost important. It removes all gaps between the main pattern pieces on the marker plan. Therefore, cut-and-sew waste is eliminated (Rissanen, 2011).

Advanced pattern making skills are necessary to achieve zero cut-and-sew waste in fashion production. This involves manipulating basic pattern blocks and creating all pattern pieces of a garment on the same fabric without leaving any waste (Aakko and Niinimäki, 2013). To achieve this, pattern cutting, garment manufacturing practices, pattern grading, and marker making processes should be integrated. Necessary steps have to be taken in order for zero-waste design to be adapted to the level of the fashion industry.

Examples in regards to developing innovative design methods in reducing or completely eliminating waste: Issey Miyake, Yeohlee Teng, Mark Liu, Julian Roberts, Timo Rissanen, Holly McQuillan and Barbara Vroom.

ISSEY MIYAKE

Fashion designer Issey Miyake incorporated elements of Japanese aesthetics, such as origami principles, aiming to redefine the relationship between textiles and the wearer. By integrating technology and tradition, Miyake explored uncut and untailed garments, commissioned high-tech textiles and fabric manipulation. For instance, instead of cutting and sewing pre-

pleated fabric, oversized garments made of memory yarn were first cut and sewn in the collection ISSEY MIYAKE A-ÜN, 1988. After heatpressing, the garment was shrunk into the desired size, leaving a user with a perfectly fitted piece while preventing any pre-consumer scrap. Another collection that exemplified a zero-waste design approach was the 1998 A-POC (A Piece of Cloth) collection, three-dimensionally knitting a continuous tube using digital technology, all from a single thread. Cutting the tubular fabric open revealed a final garment, in which any leftover sections could even be repurposed by turning them into other pieces of clothing.

YEOHLEE TENG

Yeohlee Teng designs fashion driven by maximizing the use of each fabric, with the aim of achieving one-size-fits-all principles in every garment, in addition to being gender neutral.

MARK LIU

Becoming increasingly dissatisfied with conventional fashion design tools, Dr. Mark Liu explored alternative thinking in 3D to achieve zero-waste patterns, shifting his role as a designer to a design-technologist.

JULIAN ROBERTS

Fashion designer and academic Julian Roberts uses a versatile application of 'Subtraction Cutting' in creating various fashion garments, accessories and even architectural and interior installations.

TIMO RISSANEN

Fashion designer, researcher and artist Dr. Timo Rissanen completed a practice-based PhD on zero-waste fashion design. Published in 2016, he co-authored Zero Waste Fashion Design with Dr. Holly McQuillan as a sustainable approach to fashion design that combines both research and practice. The book includes patterns, assignments, criteria and digital technologies to get a thorough understanding of the design process (Rissanen, 2023).



/ISSEY MIYAKE A-ÜN. 1988.



ZERO-WASTE DESIGN BY MARK LIU,
2007.



ZERO WASTE SUBTRACTION CUTTING WITH
NATURAL DYEING BY JULIAN ROBERTS AND
GEORGINA HOOPER, 2018.



DENIM CULOTTE BY YEOHLEE TENG.

APPENDIX D

// GENERAL

SEMI-STRUCTURED

INTERVIEW GUIDE FOR

INDUSTRY EXPERTS

Semi-structured interview guides for expert interviews

1. How to get out of the current capitalist system?
It drives inequality, intransparent practices, discriminatory behaviour, outright horrid social conditions along the supply chain - not to mention environmental damage.
 - What could be first steps?
 - What about the denim industry in particular? Are there special things to consider with denim in such initial steps?
2. Traceability of the supply chain and transparency between stakeholders and the communicative end towards consumers, is significant in the strategy to be designed.
 - How do you start mapping out your traces? How do ensure that every step of the supply chain works as responsibly as it's supposed to?
 - And how do you 'convince' your stakeholders to even want to change?
3. Alternatives to setting up a new 'brand' or 'retailer store'.
I want to look into creating a strategy or product service system which explores alternatives to just starting another brand to sell online or in its own retailer stores, such as all brands work right now. Also, the idea for thinking in alternative manners of transparent product-to-consumer methods coincides in my research with your statement that consumers really are looking for fitting platforms when considering responsible products.
 - Do you from your professional perspective have comments on what I need to consider when I try to think in such alternative strategy-solutions for this particular project/3D weaving technique in denim?
4. Subsidization by government:
 - Hypothetically, could subsidization also be included for a strategy to be designed for this 3D weaving technique?
 - How would that work? Where do you start in establishing such funding?
5. Including denim designers:
This technique requires a lot from denim designers, who (understandably) tend to be very focused on their current ways of working. This technique requires a constant interplay between the exact jacquard loom at hand and the skills and creativity of the designer itself.
 - I've noticed it's quite a challenge to have denim designers think along the same lines with this new technique and its potential, so what would you recommend for making such new collaborations with 3D weaving happening?
 - How can this technique be adopted by current or new denim designers, since the programs and design methods are vastly different? Or should we have denim designers staying as they are and create a new 'profession' of special 3D weaving designers?

- Should such a collaboration start with **commercial purpose** and then move into **disruptive systems change**? Or would it be better to go against any capitalist/commercial purpose from the beginning?

6. **Localisation of supply chains:**

It would be extremely **expensive** to change existing supply chains abroad, so for example in Pakistan or Bangladesh, etc. Let alone if you would want to build new supply chains in closer proximity to the local system at hand (i.e. The Netherlands in this case). Moreover, while local production does have many advantages – e.g. regulations of working conditions and also a reduced transport footprint – in the end, people have become very dependent in such countries on that industry.

- What would your opinion be about **localising** the supply chain for this technique?
- How would you think it is possible to deconstruct the current fashion industry without all those workers losing their **livelihoods**? This strategy is meant to consider social responsibility at every step of the supply chain, as far as possible.

7. **Hemp as local material:**

The quality of recycled materials, leather alternatives, silk and more have a long way to go in terms of improvement and would also require **subsidization**. In the 3D woven denim items I am working with currently, the design is made with a cotton and hemp blend. **Hemp** could be very interesting in terms of sustainability and Dutch consumers seem to be very open to this material. I was playing around with the idea of creating **local hubs** in which this material could be grown.

- Do you have any comments on things I need to consider on thinking this part of the supply chain out?

8. **Communication to the consumer:**

While this technique still produces new items, I do not want to stimulate consumers to stay in the capitalist mindset of always desiring more clothing. I want to stimulate a **responsible purchase** with longevity of wear in mind. Therefore, I want to implement a careful consideration of the way the product would be **communicated** to the consumer within the entire strategy.

- Do you have any **thoughts or frictions** regarding this point of attention?

9. **A new category of clothing:**

In the first phases of this project, the 3D woven denim garments were discussed to act as a **new category of clothing**, parallel to the denim industry, rather than having the purpose of taking over the entire denim industry as it is now.

- Do you have an opinion on this statement?
- If it were to be a new separate category of clothing towards consumers, should it even be **labeled with 'denim'** as a term? Do you think that would work against achieving a new character or would it benefit in terms of adoption of the technique?

APPENDIX E

// SEMI-STRUCTURED INTERVIEW GUIDE FOR 3D WEAVING EXPERT

SEMI-STRUCTURED INTERVIEW GUIDE: GRAYSHA AUDREN, WEFFAN

Sterre de Jager, TU Delft

We've seen that post- and pre-consumer waste is a huge problem which needs to be overcome. One way to tackle this problem in the pre-consumer phase specifically is to construct new garments using such waste, or adapting materials used. However, with 3D weaving denim you could design for zero-waste patterns in the first place, tackling the problem at the root. My thesis is about *designing a strategy for applying the technique of 3D weaving denim to achieve systemic change within the Dutch denim market*.

The route towards a strategy is still very open.

The questions can be answered during our conversation on the 20th of April to any extent you feel comfortable with.

1. Could you tell me a bit about yourself and about Weffan?

2. **On-demand, true-to-size and zero-waste:**

I have seen your beautiful Loom-State 3D woven trousers in collaboration with EE Exclusives. I saw it was mentioned that they aim to solve complexities in sizing and fit and could be woven on-demand. I was wondering how on-demand and true-to-size fit is achievable with 3D weaving, because I don't understand yet how that is possible with zero-waste patterns.

- What are the things to be aware of in supply chains to be able to achieve this?

3. Will 3D weaving inherently involve smaller scale production?

4. How can 3D weaving reduce supply chain interruptions on labour and business?

And: I know the cut & sew part of the supply chain gets shortened by 3D weaving, but which other parts of the supply chain get shortened or adapted?

5. **Traceability of the supply chain and transparency between stakeholders and the**

communicative end towards consumers, is significant in the strategy to be designed.

- How do you start **mapping out your traces**? How do you ensure that every step of the supply chain works as responsibly as it's supposed to?
- And how do you 'convince' your stakeholders to even **want to change**?
- How do you stimulate interdisciplinary **conversations** between stakeholders and create (new/adapted) longstanding **relationships** between them?
- How do you ensure more **transparency** along the supply chain?

12. **User testing:**

Woven If you test your products in the market, what do you exactly test? I'm in the process of weaving new trials and setting up more extensive user research in which I am giving the items out to consumers over a period of a month. Do you have any tips on elements which are important to consider?

13. **Localization of supply chains:**

It would be extremely **expensive** to change existing supply chains abroad, so for example in Pakistan or Bangladesh, etc. Let alone if you would want to build new supply chains in closer proximity to the local system at hand (i.e. The Netherlands in this case). Moreover, while local production does have many advantages – e.g. regulations of working conditions and also a reduced transport footprint – in the end, people have become very dependent in such countries on that industry.

- What would your opinion be about **localizing** the supply chain for this technique?
- How would you think it is possible to deconstruct the current fashion industry without all those workers losing their **livelihoods**? This strategy is meant to consider social responsibility at every step of the supply chain, as far as possible. I know **retraining programmes** is something you've mentioned before, but how do you ensure this happens and whose responsibility is it?

14. **Hemp as local material:**

In the 3D woven denim items from Barbara I am working with, the design is made with a cotton and hemp blend. **Hemp** could be very interesting in terms of sustainability and Dutch consumers seem to be very open to this material. I was playing around with the idea of creating **local hubs** in which this material could be grown.

- Do you have any comments on things I need to consider on thinking this part of the supply chain out?
- Are you also working with localizing fibre production?

15. **Circularity:**

How in your vision is 3D weaving connected to creating a circular supply chain?

16. **Communication to the consumer:**

While this technique still produces new items, I do not want to stimulate consumers to stay in the capitalist mindset of always desiring more clothing. I want to stimulate a **responsible purchase** with longevity of wear in mind. Therefore, I want to implement a careful consideration of the way the product would be **communicated** to the consumer within the entire strategy.

- Do you have any **thoughts or frictions** regarding this point of attention?

In general, a **paradigm shift** in consumer demand is necessary. However, up until now top-down strategies have not seemed to work well enough to slow consumer demand down.

- What are your thoughts on creating this paradigm shift? Can this perhaps be more driven through the industry itself instead of only at the consumer-end?

17. **A new category of clothing:**

In the first phases of this project, the 3D woven denim garments were discussed to act as a **new category of clothing**, parallel to the denim industry, rather than having the purpose of taking over the entire denim industry as it is now.

- Do you have an opinion on this statement?

12. User testing:

Woven If you test your products in the market, what do you exactly test? I'm in the process of weaving new trials and setting up more extensive user research in which I am giving the items out to consumers over a period of a month. Do you have any tips on elements which are important to consider?

13. Localization of supply chains:

It would be extremely **expensive** to change existing supply chains abroad, so for example in Pakistan or Bangladesh, etc. Let alone if you would want to build new supply chains in closer proximity to the local system at hand (i.e. The Netherlands in this case). Moreover, while local production does have many advantages – e.g. regulations of working conditions and also a reduced transport footprint – in the end, people have become very dependent in such countries on that industry.

- What would your opinion be about **localizing** the supply chain for this technique?
- How would you think it is possible to deconstruct the current fashion industry without all those workers losing their **livelihoods**? This strategy is meant to consider social responsibility at every step of the supply chain, as far as possible. I know **retraining programmes** is something you've mentioned before, but how do you ensure this happens and whose responsibility is it?

14. Hemp as local material:

In the 3D woven denim items from Barbara I am working with, the design is made with a cotton and hemp blend. Hemp could be very interesting in terms of sustainability and Dutch consumers seem to be very open to this material. I was playing around with the idea of creating **local hubs** in which this material could be grown.

- Do you have any comments on things I need to consider on thinking this part of the supply chain out?
- Are you also working with localizing fibre production?

15. Circularity:

How in your vision is 3D weaving connected to creating a circular supply chain?

16. Communication to the consumer:

While this technique still produces new items, I do not want to stimulate consumers to stay in the capitalist mindset of always desiring more clothing. I want to stimulate a **responsible purchase** with longevity of wear in mind. Therefore, I want to implement a careful consideration of the way the product would be **communicated** to the consumer within the entire strategy.

- Do you have any **thoughts or frictions** regarding this point of attention?

In general, a **paradigm shift** in consumer demand is necessary. However, up until now top-down strategies have not seemed to work well enough to slow consumer demand down.

- What are your thoughts on creating this paradigm shift? Can this perhaps be more driven through the industry itself instead of only at the consumer-end?

17. A new category of clothing:

In the first phases of this project, the 3D woven denim garments were discussed to act as a **new category of clothing**, parallel to the denim industry, rather than having the purpose of taking over the entire denim industry as it is now.

- Do you have an opinion on this statement?

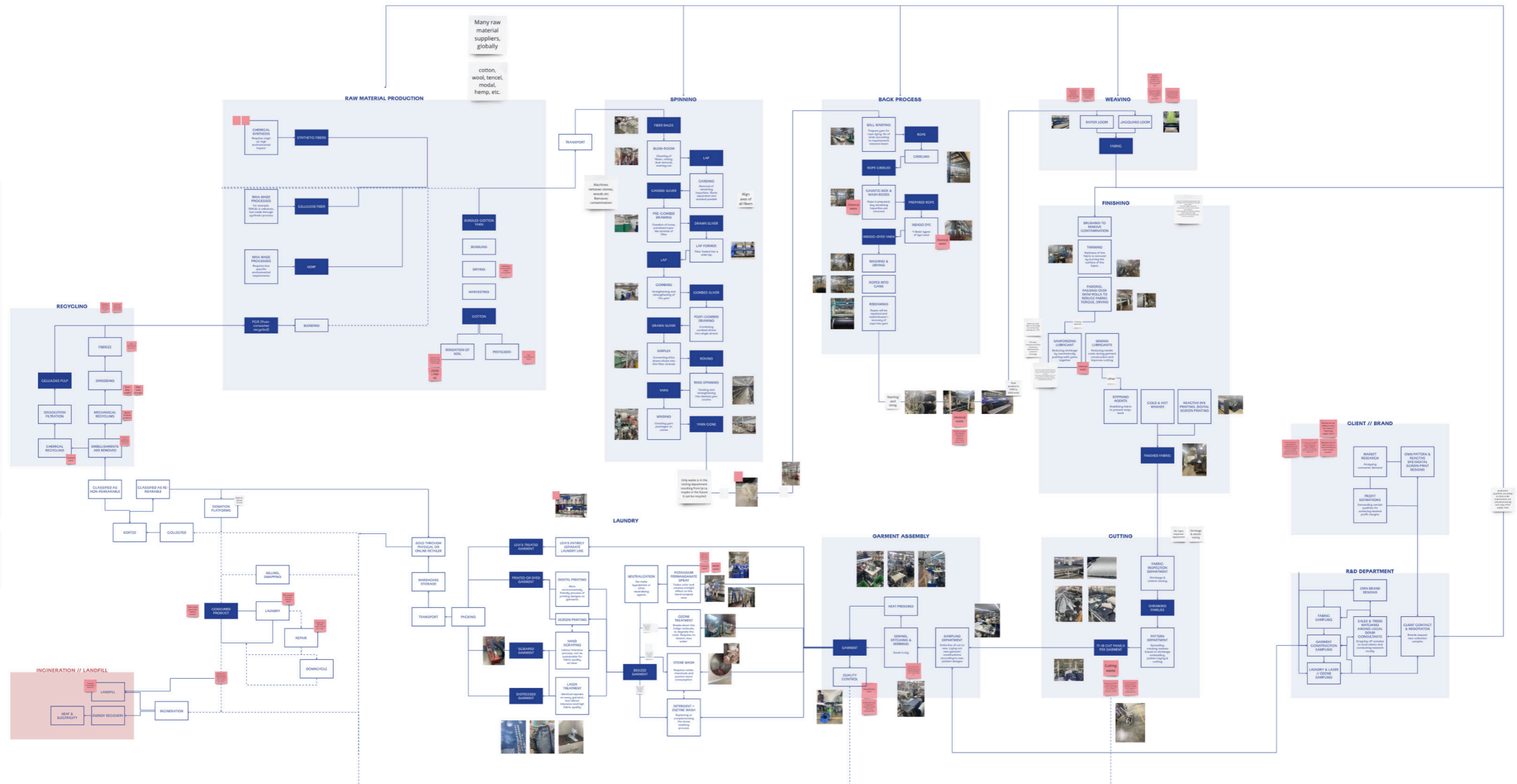
- If it were to be a new separate category of clothing towards consumers, should it even be **labeled with 'denim'** as a term? Do you think that would work against achieving a new character or would it benefit in terms of adoption of the technique?

Thank you in advance,
Sterre de Jager

S.L.deJager@student.tudelft.nl

APPENDIX F // SUPPLY CHAIN MAP

[CLICK HERE TO ACCESS THE MAP IN MIRO FOR HIGHER RESOLUTION](#)



APPENDIX G

// CONSENT FORM

To protect the participants' privacy, the signed forms are not included in this document.

INFORMED CONSENT AGREEMENT

Audio-recorded interview

27-03-2023

You are being invited to participate in a MSc graduation research study titled 'Designing a brand strategy to exhibit potential use of 3D woven denim'.

This study is being done by MSc student Sterre de Jager from the TU Delft.

The purpose of this research study is gain insight into people's perception of the prototypes to be presented and the interview will take you approximately 30 to 60 minutes to complete. The session will be audio-recorded, but the recording will not be shared with anybody other than myself. The audio-file will be deleted permanently after completion of the graduation project. The gathered data will be used for graduation purposes and can or will be anonymously published in the thesis which is to be submitted to the open-access TU Delft repository. This signed consent form will be attached in the Appendix of the thesis, but will not be linked to any data used throughout the document. You will be asked several questions, after which I will be asking you to interact with the prototypes, followed by several questions again.

As with any activity the risk of a breach is always possible. To the best of my ability your answers in this study will remain confidential. The collected anonymous data will be stored carefully on my own phone and computer, own Notion and Miro space and will not be shared with others outside of me and my supervisory team, consisting of Dr. Holly McQuillan and Dr. Ingrid Mulder.

Your participation in this study is entirely voluntary **and you can withdraw at any time**. You are free to omit any question you do not wish to answer.

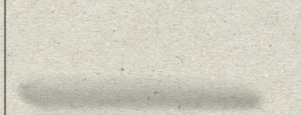
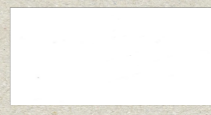
For further details, you are free to contact me anytime:
Sterre de Jager

INFORMED CONSENT
Explicit Consent points

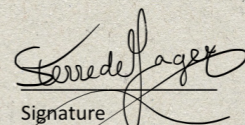
PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated 27-03-2023, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	<input checked="" type="checkbox"/>	<input type="checkbox"/>
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	<input checked="" type="checkbox"/>	<input type="checkbox"/>
3. I understand that taking part in the study involves:	<input checked="" type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> Answering questions from the interviewer; Written notes by the interviewer; An audio-recorded interview; The audio recording will be transcribed as text and the recording, as well as the transcript, will be destroyed after completion of the project. 		
4. I understand that the study will end 21-07-2023.	<input checked="" type="checkbox"/>	<input type="checkbox"/>
<i>Note that this is a preliminary date of the completion of the project. There is a chance it could be extended.</i>		
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
5. I understand that taking part in the study involves the potential risk of breach (referring to Personal Data and the potential for re-identification). I understand that the following steps will be taken to minimise the threat of data breach, and protect my identity in the event of such a breach:	<input checked="" type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> Secure limited-access data storage of anonymously collected data (i.e. audio recordings, transcripts and written notes) within the researcher's and supervisory team's workspaces. 		
6. I understand that taking part in the study also involves collecting the following specific personally identifiable information (PII) and associated personally identifiable research data (PIRD) with the potential risk of my identity being revealed:	<input checked="" type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> Age; Gender; Information about educational or professional background; Personal consumer behaviour; Potential social groups the participant is part of. 		
7. I understand that some of this PIRD is considered as sensitive data within GDPR legislation, specifically:	<input checked="" type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> Religion; Political views. 		
8. I understand that personal information collected about me that can identify me, such as my name or where I live, will not be shared beyond the graduation supervisory team.	<input checked="" type="checkbox"/>	<input type="checkbox"/>
9. I understand that the (identifiable) personal data I provide will be destroyed after completion of the graduation project.	<input checked="" type="checkbox"/>	<input type="checkbox"/>
<i>Anticipated date is 21-07-2023.</i>		

C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
10. I understand that after the research study the de-identified information I provide will be used for:	<input checked="" type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> A written master thesis, published to the open-access TU Delft repository. (The master thesis might include anonymous quotes from the interview.) Potential policy-, service- or product development in which third parties could be involved. 		
11. I agree that my responses, views or other input can be quoted anonymously in research outputs.	<input checked="" type="checkbox"/>	<input type="checkbox"/>
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
12. I give permission for the de-identified data that I provide to be used in the contents of a thesis form which is to be archived in the TU Delft repository so it can be used for future research and learning.	<input checked="" type="checkbox"/>	<input type="checkbox"/>
13. I understand that access to this repository is open to the public.	<input checked="" type="checkbox"/>	<input type="checkbox"/>

Signatures



9-4-2023
 Name of participant Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

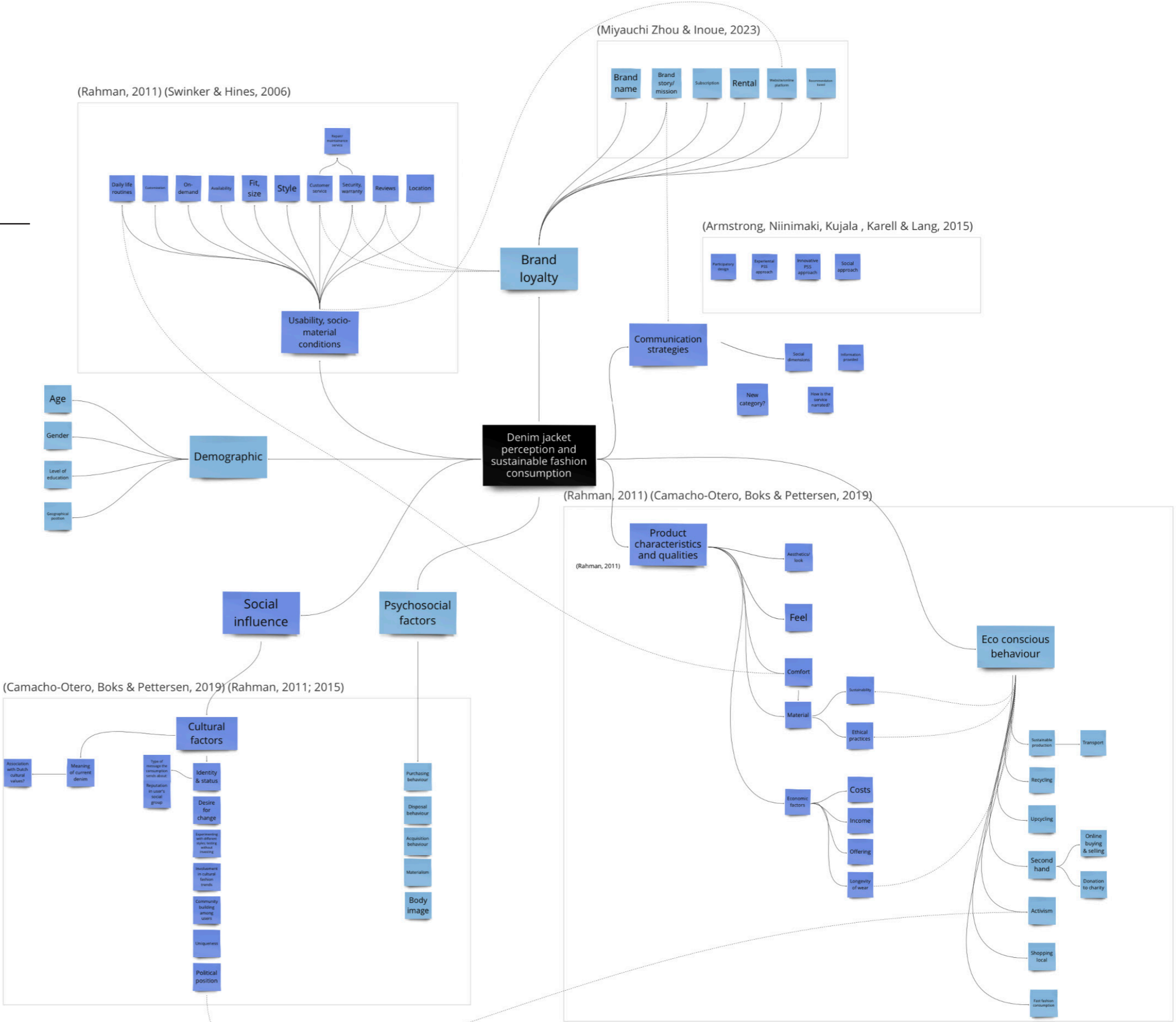
Sterre de Jager

9-4-2023
 Researcher name Signature Date

Study contact details for further information:
Sterre de Jager



APPENDIX H // CONCEPTUAL FRAMEWORK

[CLICK HERE TO ACCESS THE FRAMEWORK IN MIRO FOR HIGHER RESOLUTION](#)



APPENDIX I

// SEMI-STRUCTURED INTERVIEW GUIDE

USER RESEARCH ROUND 1

Semi-structured interview guide

Ask permission to record the interview: recording will be destroyed after completion of the project and will not be shared to any third parties (meaning: will not be shared beyond student and supervisory team).

Sign consent form: indicate clearly that the data generated will be used anonymously in a final thesis, which will be published to an open-access repository of the TU Delft.

3 words for describing 3D woven denim

Denim jacket perception and sustainable fashion consumption

1. Current denim perception and behavior

1.1. General:

- Do you currently wear denim?
 - What denim products do you own and how many?
 - Do you also wear denim jackets?
 - If so, how frequently?
 - Would you describe yourself as a large denim consumer or lover?
- **Why** do you wear denim? (Identifying the first factors which come to mind for user)
 - Why would you wear a denim jacket over another jacket?
 - Which product qualities make it different compared to other jackets?

-> Questions to probe further:

1.2. Usability:

- To what occasions do you or would you wear a denim jacket?
 - Does the context of your daily life routine influence how often you wear a denim jacket and how?
- Is comfortability an important factor in a denim jacket?
 - How do you prefer the size and fit of a denim jacket and is that influenced by comfortability?

1.3. Product characteristics and qualities:

- What should a denim jacket look like for you to be willing to wear it?
- What does a typical denim jacket look like in general according to you?

- What should the fabric feel like?

1.4. Social influence:

- To what extent do you follow current fashion trends and does that influence the type of denim jacket you would wear?
- Do you wear a denim jacket to match with a social group you consider yourself part of?
 - What do you think are the reasons for the social group you belong to for wearing denim jackets (in the first place)?
 - Do you think it would make a difference in how you would perceive yourself or how other members of the group perceive you if you would choose *not* to wear a denim jacket?
- Do you (then still) look for uniqueness in the jacket you choose to wear and in what way?

1.5. Psychosocial factors:

- How did you acquire your denim jacket(s)?
- How do you buy your clothes in general?
- Do you value an often-occurring change in your closet and does that influence the amount of clothing items you own?
 - Does this also count for denim jackets?
- For how long do you wear a clothing item?
 - Is there a difference in how long you wear a denim jacket for as opposed to other clothing items?
- How do you dispose of your clothing?
 - Is there a difference in how you would dispose of a denim jacket as opposed to other clothing items?

1.6. Eco-conscious behavior:

- Do you have any considerations you take into account regarding sustainability when you acquire a clothing item?
 - Themes to probe further:
 - Longevity of wear?
 - Second hand buying?
 - Sustainable production?
 - Ethical production?
 - Geographical location of production?
 - Transport?
 - Shopping local?
 - On-demand vs. high pre-availability?
- Going back to the disposal of a denim jacket:

- Do you donate to a specific cause and why? (e.g. charity)
- Online buying/selling platform?
- Do you or would you consider up- or downcycling your jacket?
- If you were to purchase a denim jacket brand new, does the material of a jacket make a difference in your buying decision?
 - Are there certain materials you prefer over others and why?
 - Do you look for certain qualifications or labels and why?

1.7 Brand loyalty:

- Would a certain brand name be important in your decision to acquire a new denim jacket and why? *Story/mission -> for 3D weaving section*
 - *If yes:* would you consider gaining access to a denim jacket through the same brand if it only offers subscription or rental models? Why or why not?
 - *If no:* what do you base your decision on in choosing for a certain brand in the end?
- Would you be more inclined to acquire a denim jacket from a brand which offers a repair or maintenance service?
 - *If very loyal to a certain brand:* would that steer you away from the current brand you are loyal to when they do not offer a repair or maintenance service in the case where other brands do?
- Does the geographical location at which a denim jacket is designed influence your willingness to acquire it and why (not)?

1.8. Economic factors:

- To what extent does the cost of a denim jacket influence your decision to buy it in the case where it's brand new?
 - Would you be willing to pay more for a denim jacket if it scores better on sustainability factors -> so it's a more eco-conscious purchase?
 - Would you be willing to pay more for a denim jacket if you would be able to wear it for over a (significantly) longer time period?

1.9. Closing off this section:

- If you had to use only three words to describe a denim jacket, what would your choice of words be?

2. 3D weaving

First communication strategy, without story about zero-waste

Card design:

Shows images of how 3d weaving works without explaining what makes it special

Fit, longevity, product qualities, context of use

investigate whether they find the form very different as opposed to a normal denim jacket
would they consider it as its own separate category next to their own denim garments,
especially considering most people probably wear them for a long time?

Different washes of a denim jacket?

Does it suit your style enough that you would wear it and to what extent does that matter?

3 words to explain the jackets:

Second communication strategy: combi-strategy

Emotional value (i.e. meaning) influenced by a sustainable communication strategy?

Cultural value

Awareness

Would it matter to you what PSS is at hand?

-> PSS strategies chosen

Would it (still) matter to you if this is part of an established brand(s) or introduced on its own
as something new?

Are there any other non-mentioned factors which you think influence your decision to acquire
such a jacket?

Material of this denim jacket? => cotton/hemp

Does the brand matter?
Bedrijfspersona's

3 words to explain the jackets:

APPENDIX I // SEMI-STRUCTURED INTERVIEW GUIDE USER RESEARCH ROUND 1

These cards were used to support the interview. First, participants were tested on their perception of the 3D woven denim jackets without explanation of the technique, nor uniqueness. Then, card 1 was introduced, supporting the explanation of merely the technique, again testing consumer perception. Lastly, card 2 and its accompanying story of zero waste and other benefits was shown to the participants, again, trying to understand whether this element influences consumer perception of the 3D woven item.

3D WEAVING



Unlike traditional weaving, which produces flat fabrics, 3D weaving involves the interlacing of multiple layers above each other, weaving in 'seams' automatically in certain places. Hence, the structure only has to be cut open in certain places, revealing an almost complete garment in 3D. Thus, no cutting into many flat panels and sewing them together afterwards is necessary anymore.

1

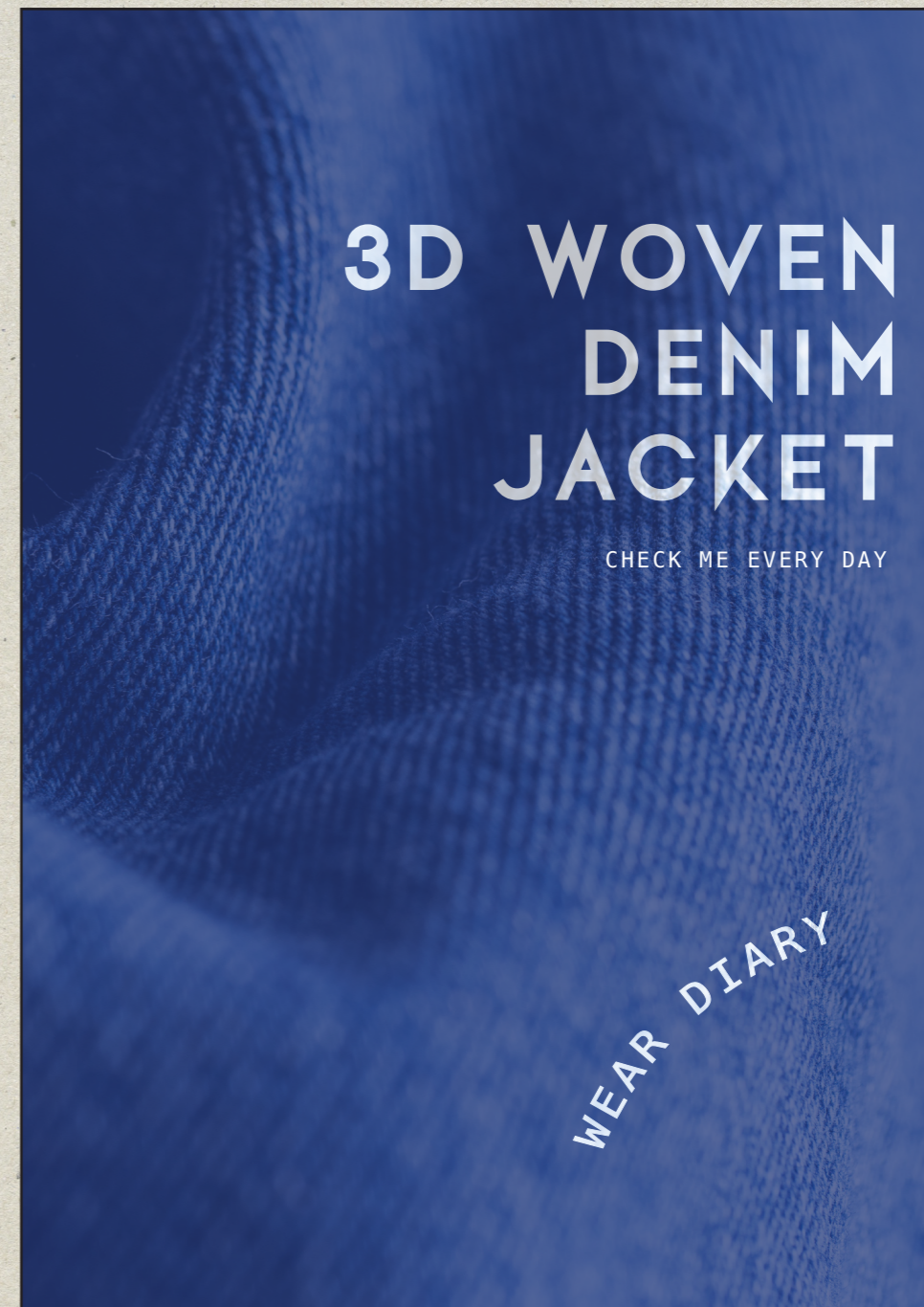
2

ZERO- WASTE



Normally, denim pattern designs leave a lot of scrap material, 10-15% waste of per garment, often sent straight to landfills. Newly woven material, only to be handled as useless right away. It is estimated to account for more than 15% of the garments' entire footprint, and thought to be even higher. 3D weaving allows for zero waste as its multi-layer structured pattern design minimizes or eliminates excess material. It also reduces the many steps needed at the normal cut and sew stage, which is the most labour-intensive of all production phases.

APPENDIX K
// ETHNOGRAPHIC
RESEARCH DIARY
// USER RESEARCH
ROUND 2



DEAR PARTICIPANT...

Thank you for your willingness to participate in this user research.

In this study, I ask you kindly to fill in this booklet every day for the next 4 weeks. It should not take more than 5 minutes of your time.

By now, you've received a denim jacket which is 3D woven. This weaving technique has been previously explained to you, but if there are any further questions, do not hesitate to contact me.

The purpose of this study is to find out your perception as a user of this particular denim item. Please wear the jacket daily, in accordance with your own schedule, of course. Use the item as you would normally. That means: washing is allowed, any filth is not a problem and the occasions in which you wear the jacket are up to you.

In the case of a rip/tear or other damage occurring, this also is not an issue! Rather, it's interesting for us to note.

After every week, an extension of this booklet will be given to you, in which the questions asked will change a bit.

After the completion of this study, around June 16th, the jacket and booklet will be collected.

PLEASE NOTE:

THIS JACKET IS PART OF CONFIDENTIAL RESEARCH. THE DESIGN OF THIS JACKET IS MADE BY BARBARA VROOM AND IS NOT MEANT TO BE SHARED BY THIRD PARTIES IN THE FORM OF PICTURES OR ANY OTHER DOCUMENTATION.

THANK YOU!

Sterre de Jager

PARTICIPANTS WERE INSTRUCTED TO DRAW THEIR EMOTIONS USING THE EMOTION MEASUREMENT INSTRUMENT BY DESMET (2018)

Pride The feeling when you possess (or have accomplished) something that exceeds your own expectations, or that others find praiseworthy.	Shame The feeling when someone knows something bad about you. You believe this to be true, so you also feel bad about yourself.	Hope The feeling when you believe (but are not certain) that something good or desirable may happen in the future.	Fear The feeling when something can harm you or someone you care about, and you are not sure whether you can do anything about it.
Admiration The feeling when you look up to someone who has excellent abilities or impressive accomplishments.	Contempt The feeling when someone is inferior or unworthy in your eyes; they have done something blameworthy.	Satisfaction The feeling when something meets or exceeds your expectations.	Anger The feeling when someone does something bad that harms or offends you, and you blame that other person.
Joy The feeling when something good happens to you. You fulfil a need, achieve something, or make progress towards achieving a goal.	Sadness The feeling when you have lost something that was important to you, and believe it cannot be undone.	Desire The feeling when you anticipate that something will be beneficial once acquired or consumed.	Disgust The feeling when you find something repulsive and want to avoid having contact with it in any way.
		Fascination The feeling when you encounter something new and interesting that you do not immediately understand.	Boredom The feeling when there is nothing interesting or engaging to do or experience.

PAGES DAY 1-7 WERE THE SAME

DAY 1

NUMBER OF MOMENTS WORN TODAY:	
TOTAL TIME WORN TODAY:	
DRAW TODAY'S WEATHER:	

Are there *any other comments* that come to mind of your *experience* today? You could think of comfort (feel, material, fit) or looks (does it match your style; did anybody comment on it today? Etc.)

SHARE YOUR **DAILY OUTFIT PICTURE** WITH ME AND STATE WHY YOU CHOSE TO PAIR IT WITH THE OTHER PIECES OF CLOTHING IN YOUR TEXT



DRAW HOW YOU FELT DURING THE PERIOD(S) YOU'VE WORN THE JACKET TODAY:

When did you think it was an **appropriate moment** for wearing the jacket today? Why?

Were there any moments in wearing the jacket today which were **noteworthy or outstanding** to you? What happened or stood out exactly?

When did you feel you actually did **not** want to wear the jacket? Why?

WEEK 2

GLUE THIS SIDE TO THE LAST PAGE OF THE BOOKLET OF WEEK 1

WEAR DIARY

DAY 8	NUMBER OF MOMENTS WORN TODAY:		What is your overall opinion of the jacket after wearing it for a week? You could think of comfort (feel, material, fit) or looks (does it match your style for example)?
	TOTAL TIME WORN TODAY:		
	DRAW TODAY'S WEATHER:		

After wearing the jacket for a week now, were most of the moments you wore the jacket in spontaneous or pre-planned? Why?

Have you noticed you choose to wear the jacket in a certain similar context everyday (e.g. during a specific activity or to a specific place)?

If yes: what is the context and why does the jacket match with it?

If no: why is it different for you every day?

Do you wear the jacket mostly outdoor, indoor or both? Why?

If there is one thing you dislike about the jacket, what would it be?

DAY 9	NUMBER OF MOMENTS WORN TODAY:		DAY 10	NUMBER OF MOMENTS WORN TODAY:	
	TOTAL TIME WORN TODAY:			TOTAL TIME WORN TODAY:	
	DRAW TODAY'S WEATHER:			DRAW TODAY'S WEATHER:	

When did you decide to wear the jacket today? Why?

When did you decide to wear the jacket today? Why?

Which *emotion/feeling* describes your experience in wearing the jacket today best and why?

Were there any moments in wearing the jacket today which were *noteworthy or outstanding* to you? What happened or stood out exactly?

Have you noticed any *changes* occurring in the jacket's material, edges, color, seams, etc.? If so, why did that happen do you think?

Free space for any other comments I must know about:

PAGES DAY 9-14 WERE THE SAME

WEEK 3

GLUE THIS SIDE TO THE LAST PAGE OF THE BOOKLET OF WEEK 2

WEAR DIARY

DAY 15	NUMBER OF MOMENTS WORN TODAY:		What is your <i>overall opinion</i> of the jacket after wearing it for 2 weeks? You could think of comfort (feel, material, fit) or looks (does it match your style for example)?
	TOTAL TIME WORN TODAY:		
	DRAW TODAY'S WEATHER:		

After wearing the jacket for 2 weeks now, were most of the moments you wore the jacket in spontaneous or pre-planned? Why?

Have you noticed you choose to wear the jacket in a certain similar context everyday (e.g. during a specific activity or to a specific place)? Or has it changed within the last week?

If yes: what is the context and why does the jacket match with it?

If no: why is it different for you every day or why has it changed?

Do you wear the jacket mostly outdoor, indoor or both? Why?

What are your dislikes about the jacket?

DAY 16	NUMBER OF MOMENTS WORN TODAY:		DAY 17	NUMBER OF MOMENTS WORN TODAY:	
	TOTAL TIME WORN TODAY:			TOTAL TIME WORN TODAY:	
	DRAW TODAY'S WEATHER:			DRAW TODAY'S WEATHER:	

When did you decide to wear the jacket today? Why?

When did you decide to wear the jacket today? Why?

Which *emotion/feeling* describes your experience in wearing the jacket today best and why?

Were there any moments in wearing the jacket today which were *noteworthy or outstanding* to you? What happened or stood out exactly?

Free space for any other comments I must know about:

Have you noticed any *changes* occurring in the jacket's material, edges, color, seams, etc.? If so, why did that happen do you think?

PAGES DAY 16-21 WERE THE SAME

WEEK 4

GLUE THIS SIDE TO THE LAST PAGE OF THE BOOKLET OF WEEK 3

WEAR DIARY

DAY
22

NUMBER OF MOMENTS WORN TODAY:	
TOTAL TIME WORN TODAY:	
DRAW TODAY'S WEATHER:	

After wearing the jacket for 3 weeks now, were most of the moments you wore the jacket in spontaneous or pre-planned? Why?

Does the label make it clear what this jacket type stands for? Would it catch your attention when you see it hanging in a store? Why?

Do you trust the information on the label? Why or why not?

Would you want to check the website on the label to find out more about its statements?

Is there anything you miss on the label or another comment which comes to mind regarding its design or information conveyed?

If you see this jacket with the label hanging in the store - does the brand which sells it make a difference in your opinion? Why or why not? Please specify with brand examples.

Would the label make you more interested in buying the jacket? Why or why not?

Please take a look at this label. Imagine the jacket you're currently wearing is hanging in a store, with this label attached to it. Turn the page to see the information on the back of the tags, then proceed to answer the questions from week 4.



EXPERIENCE THE FUTURE OF SUSTAINABLE FASHION WITH 3D WEAVING...
 a new technique that transforms the way denim garments are made. Say goodbye to wasteful cutting and sewing of flat fabrics, and welcome a zero-waste design approach. In a single process, multi-layered structures are formed, integrating layers (now called bondings) into the fabric. After cutting the pattern open in strategically chosen places, an almost final garment emerges, eliminating the need for excess material and reducing cut & sew labour. Working with zero-waste patterns alone already saves 15% of the garment's footprint, but here Fashioned Denim Dimensions takes steps even further...

PARTICIPANTS WERE GIVEN EXTRA INFORMATION ON THE LABEL

PAGES DAY 23-27 WERE THE SAME

<i>DAY</i> 23	NUMBER OF MOMENTS WORN TODAY:	<i>DAY</i> 24	NUMBER OF MOMENTS WORN TODAY:
	TOTAL TIME WORN TODAY:		TOTAL TIME WORN TODAY:
	DRAW TODAY'S WEATHER:		DRAW TODAY'S WEATHER:

When did you decide to wear the jacket today? Why?

When did you decide to wear the jacket today? Why?

Which *emotion/feeling* describes your experience in wearing the jacket today best and why?

Were there any moments in wearing the jacket today which were *noteworthy or outstanding* to you? What happened or stood out exactly?

Have you noticed any *changes* occurring in the jacket's material, edges, color, seams, etc.? If so, why did that happen do you think?

Free space for any other comments I must know about:

<i>DAY</i> 28	NUMBER OF MOMENTS WORN TODAY:	<i>THANK YOU FOR PARTICIPATING!</i>
	TOTAL TIME WORN TODAY:	
	DRAW TODAY'S WEATHER:	

After 4 weeks of wearing, what is your overall opinion of the jacket?

Has your opinion changed in the last week after introducing the label? Why or why not?

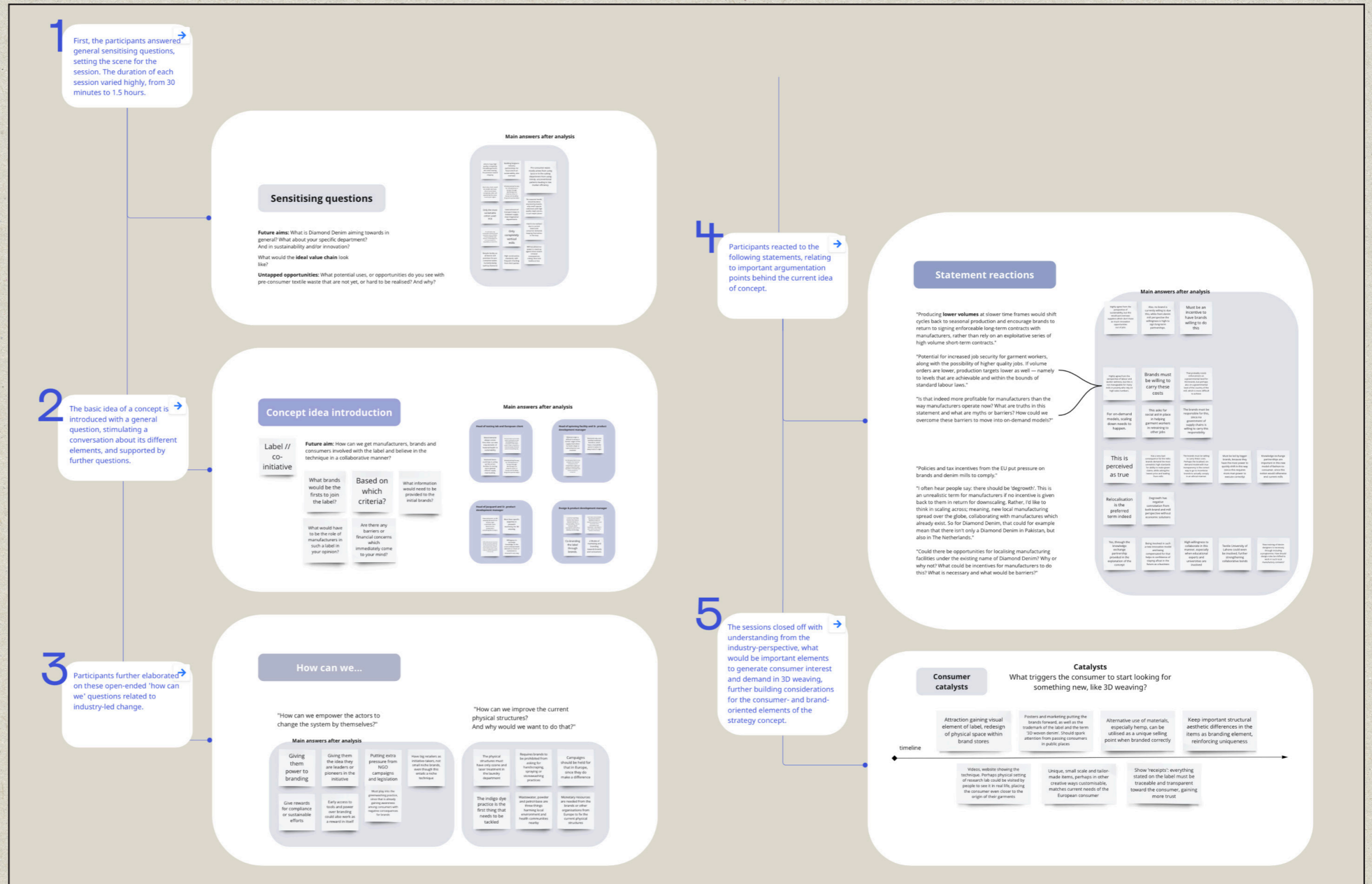
What is your absolute most important point regarding this jacket after wearing the jacket for four weeks? It can be anything, be critical.

FINAL DAY OF PARTICIPATION. GARMENTS WERE TAKEN BACK AND ANALYSED

APPENDIX L

// CO-CREATIVE SESSIONS

[CLICK HERE TO ACCESS THE TEMPLATE IN MIRO FOR HIGHER RESOLUTION](#)



APPENDIX M // THE TAGS OF THE LABEL



EXPERIENCE THE FUTURE OF SUSTAINABLE FASHION WITH 3D WEAVING...

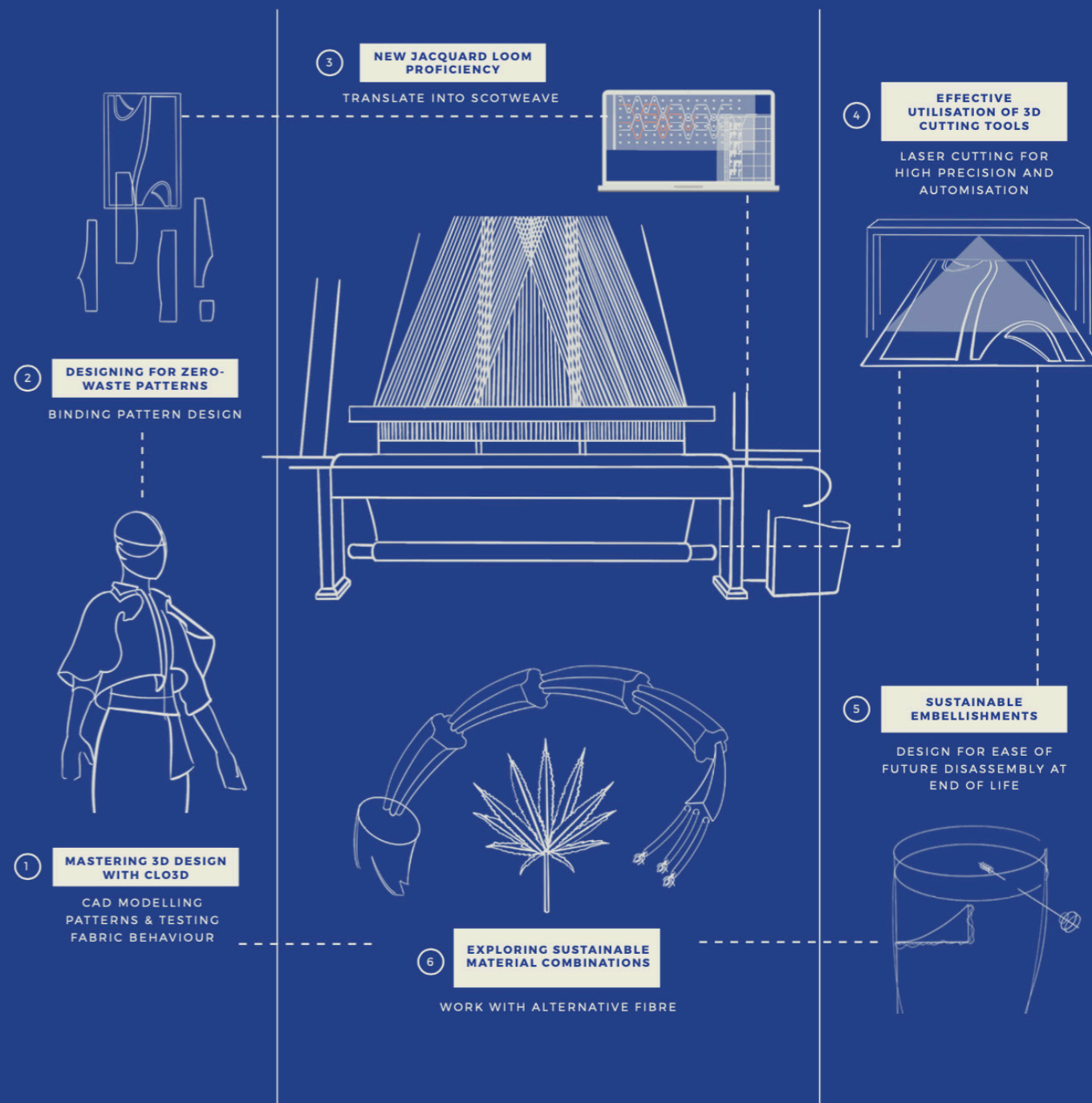
a new technique that **transforms** the way denim garments are made. Say goodbye to wasteful cutting and sewing of flat fabrics, and welcome a **zero-waste design approach**. In a single process, multi-layered structures are formed, integrating 'seams' (now called 'bindings') into the fabric. After cutting the pattern open in strategically chosen places, an almost final garment emerges, eliminating the need for excess material and reducing cut & sew labour. Working with zero-waste patterns alone already saves **15%** of the garment's footprint, but New-Fashioned Denim Dimensions **takes steps even further...**



APPENDIX N // THE TRAINING PROGRAMME

TRAINING PROGRAMME

NEW-FASHIONED
DENIM
DIMENSIONS



APPENDIX 0

// PROJECT BRIEF

To protect the privacy of the parties involved, some private details are removed.

IDE Master Graduation

Project team, Procedural checks and personal Project brief

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

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

! USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name	De Jager	Your master programme (only select the options that apply to you):
initials	S.L. given name Sterre Lidwine	IDE master(s): <input type="radio"/> IPD <input type="radio"/> Dfl <input checked="" type="radio"/> SPD
student number	4644492	2 nd non-IDE master: _____
street & no.	_____	individual programme: _____ (give date of approval)
zipcode & city	_____	honours programme: <input type="radio"/> Honours Programme Master
country	_____	specialisation / annotation: <input type="radio"/> Medisign
phone	_____	<input checked="" type="radio"/> Tech. in Sustainable Design
email	_____	<input type="radio"/> Entrepreneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair	Dr. Holly McQuillan	dept. / section: SDE
** mentor	Dr. Ingrid Mulder	dept. / section: HCD/DCC
2 nd mentor	_____	_____
organisation:	_____	
city:	_____	country: _____
comments (optional)	_____	

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v.

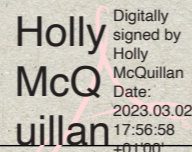
! Second mentor only applies in case the assignment is hosted by an external organisation.

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

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Dr. Holly McQuillan date 02 - 03 - 2023 signature  Digitally signed by Holly McQuillan Date: 2023.03.02 17:56:58 +01'00'

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

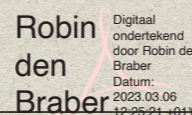
Master electives no. of EC accumulated in total: 15 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 15 EC

List of electives obtained before the third semester without approval of the BoE

YES all 1st year master courses passed

NO missing 1st year master courses are:

name Robin den Braber date 06 - 03 - 2023 signature  Digitaal ondertekend door Robin den Braber Datum: 2023.03.06 12:25:21 +01'00'

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name Monique von Morgen date 21 - 03 - 2023 signature _____

/293

Personal Project Brief - IDE Master Graduation

Designing a brand strategy to exhibit potential use of 3D woven denim project title

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

start date 27 - 02 - 2023 21 - 07 - 2023 end date

INTRODUCTION **

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

Over the course of the last century, the fashion industry has grown into one of the most significant economies worldwide, accounting for 1.3 trillion US dollars and 300 million employees along its value chain (Ellen MacArthur Foundation, 2017) [1]. The current system is built upon fast production, distribution and abandonment. When focusing on denim specifically, it becomes clear how big implications are for both the environment and human health. A single pair of jeans requires approximately 10.000 liters of water, causes the emission of roughly 33.4 kg of CO2 and is treated with highly toxic chemicals, effectuating inadequate and unsafe working conditions. (Gordon-Martin, 2021) [2] The current techniques of producing denim involve a large chain of versatile processes, fragmented across geographical space, of which the most labour-intensive aspects are often located in lower-cost countries. A consequential imbalanced relationship between global producer and consumer, in combination with intransparency, obscures the industry's unethical practices. (Gereffi & Frederick, 2010) [3]

However, alternative techniques for the textile industry are emergent, such as 3D weaving. This process allows for designing patterns with a zero-waste objective, as opposed to the regular cutting and sewing of flat fabrics during the production phase. The latter leaves behind scrap material, accounting for at least 15% of a garment's entire footprint. (Moretz, 2020) [4] With 3D weaving, multi-layered structures can be created at once. 'Seams' (bindings) are already woven into the structure, meaning that cutting the structure open in certain layers could create one larger piece of fabric, which normally would have required the joining of multiple separate panels (see fig. 1). In short, the technique offers a limited necessity of additional machining and joining, a reduction in material wastage and lowers the amount of material during the lay-up process. (Perera et al., 2021) [5] Technical equipment for 3D weaving is already commercially available, such as the long-established Jacquard loom. (Bilisik, 2012) [6] Engaging with this method based on the same principles which compose denim clothing, could explore new alternative forms of garments (parallel to the current denim industry).

During her PhD trajectory, Dr. Holly McQuillan researched systemic and methodological opportunities for creating zero waste textile forms. Designing for whole garment weaving was an integral part of it, which brought about the starting point for this graduation project (McQuillan, 2020) [7]. Investigating whether new zero-waste textile forms could reconstruct relationships between consumer and garment, as well as translating them into change on a systemic level, was discussed to be a new field of research.

Gaining a more comprehensive understanding of current supply chains and potential leverage points for intervention, is intended to be obtained through a collaboration with Diamond Denim by Sapphire. This is a Pakistan-based manufacturer of yarn, (Jacquard) denim and whole garments, among other things. This supplier values innovative, creative and transparent work approaches with the objective of sustainable solution-making. One of the small-to-medium denim brands associated with Diamond Denim will be involved in the project as well. This could be desirable from a strategic perspective, since it would allow for co-creating a design strategy with an already existing market segment.

space available for images / figures on next page

/294

introduction (continued): space for images

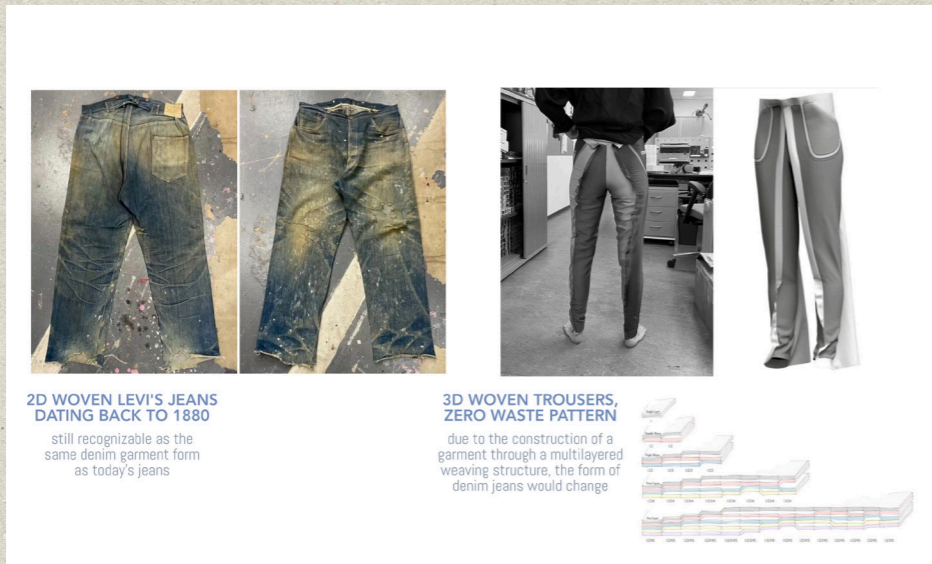


image / figure 1: 3D weaving would cause change of 150-year-old denim form (Cantor, 2022) [8] (McQuillan, 2020) [7]

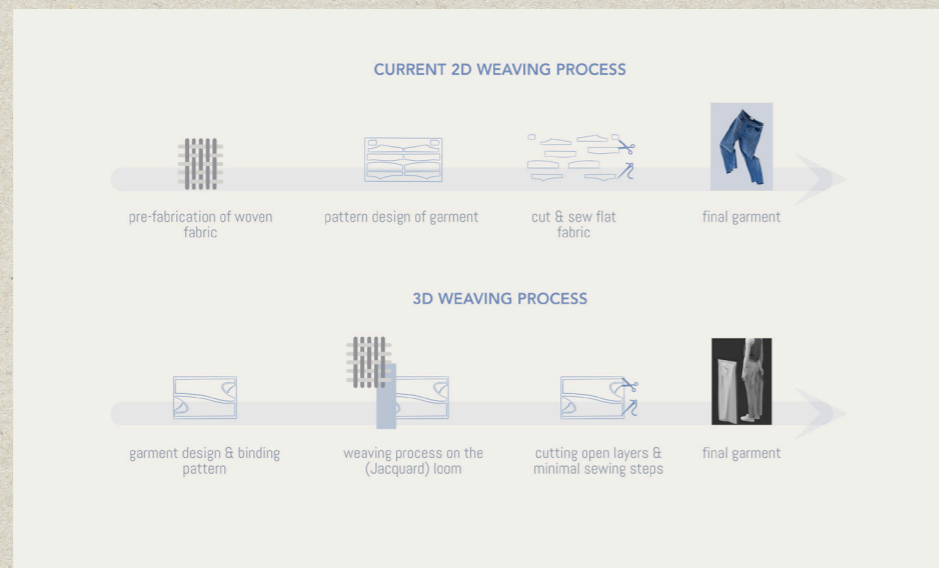


image / figure 2: Overview of 2D vs. 3D weaving processes - image & design trousers from (McQuillan, 2020) [7]

/295

PROBLEM DEFINITION **

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

While 3D weaving has potential to inform the current fashion industry with a more sustainable production technique, change is needed within current supply chains to be implemented extensively. Moreover, this technique has consequences for the form of garments, which tend to look contrasting as opposed to the hardly changed denim clothes people have been used to for approximately 150 years (fig. 1). Thus, gaining an understanding of consumer's perception of such garment forms is a necessary first step towards exploring new categories to which 3D weaving can be applied.

The current denim industry is very fragmented, without much transparency or communication between different producers. Moreover, access to textile supply chains from a designer's point of view is often limited, while 80% of the environmental footprint a textile item causes (throughout its entire lifespan) is set in stone during the design phase (Östlund et al., 2020) [9]. This calls for the consideration of an alternative strategy within garment design, in which designer, consumer and supplier are brought closer to each other.

To narrow down the scope for the project, as well as due to consideration of The Dutch government's intention to strive towards a fully functioning circular textile economy by the year 2050, the choice has been made to focus on brand-targeted systemic change within the Netherlands. However, to stimulate sustainable innovation with 3D weaving on a higher systemic level, recommendations for future scaling actions will be included towards the end of the project.

The main research question is: how can the technique of 3D weaving denim be used to achieve systemic change within the Dutch denim market?

With the following sub-research questions: What are consumer's perceptions of 3D woven denim forms?; What are the leverage points for interventions with 3D weaving in the current supply chains of denim?; How might the outcomes of the two subquestions translate into new brand opportunities to apply 3D weaving to, parallel to current denim?

ASSIGNMENT **

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

Designing a brand strategy for applying the technique of 3D weaving denim to achieve systemic change within the Dutch denim market.

In order to achieve the desired result, this graduation project will entail the following steps:

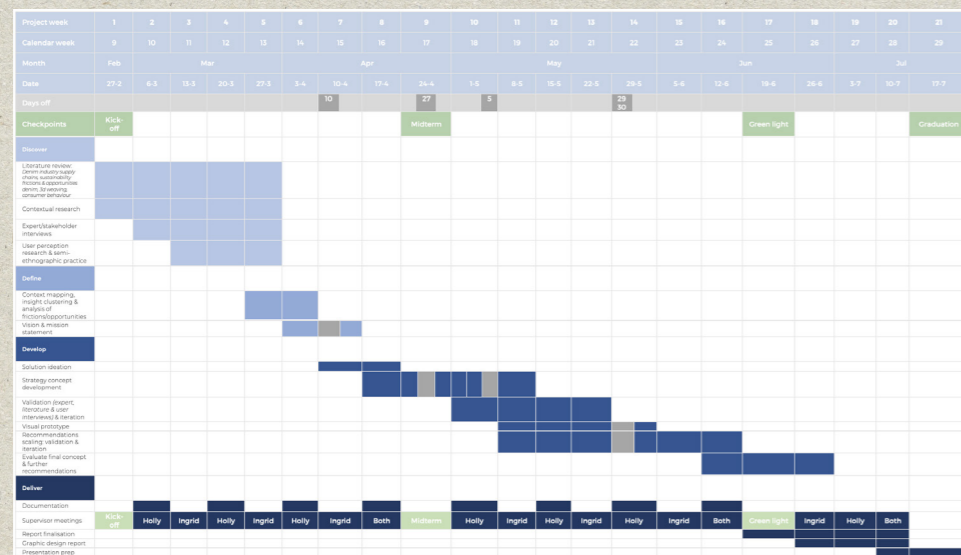
1. Understanding the current denim system and context
 - Research on 3D weaving processes & investigating possibilities through literature review and interviews with Diamond Denim, House of Denim and potential brand stakeholders
 - Consumer research with 3D woven denim samples:
 - Investigate general perception of 3D woven denim forms and explore different categorical applications
 - Short-term ethnographic practices to take social dimensions and cultural values into account (researching the underlying web of meaning people create for 3D woven denim)
2. Designing an introduction strategy
 - Assessment of necessary transitional infrastructure and opportunities within the Dutch market
 - Interviews with the Dutch House of Denim/Denim City and other potential brand stakeholders
 - Investigate re-localization of production in the Netherlands through literature research and interviewing local weaving mills (i.e. Textile Lab Tilburg and Enschede Textielstad)
 - Investigate communication strategies, to involve customers in the origins of their 3D woven garments
 - Find opportunities for brand transparency and customer involvement
3. Developing recommendations for future scaling
 - Literature + stakeholder interviews

/296

PLANNING AND APPROACH **

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

start date 27 - 2 - 2023 end date 21 - 7 - 2023



This planning is based on the Double Diamond approach, divided in four phases: 'Discover' (diverge), 'Define' (converge), 'Develop' (diverge) and 'Deliver' (converge). Documentation of process will be done on a bi-weekly basis, to prevent any writing or feedback delays in later stages of the project.

- Important dates:
- Kick-off Meeting takes place at the beginning of calendar week 9, Monday February 27
 - Midterm Evaluation takes place in calendar week 17, around April 24-28
 - Green Light Meeting takes place in calendar week 25, around June 19-23
 - Submitting deliverables at the end of calendar week 28, Friday July 14
 - Graduation ceremony is aimed at July 21
 - Taking some days off during national holidays is taken into account, translating to a total of one week

1297

MOTIVATION AND PERSONAL AMBITIONS

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

Throughout my Bachelor's programme, I developed a desire to understand the complex systems and social dimensions behind design. This led me to pursue a degree which both industrial design and cultural anthropology/development sociology were prevalent. When continuing with a Master's in Strategic Product Design, I tried to apply the social research competences I achieved during my time in anthropology to many transformative and systemic challenges. More specifically, a passion for cultural and environmental sustainability in the fashion and textile industry emerged. Multiple projects within this space followed, such as building a social venture around an inclusive circular system for sneakers. Another entailed reimagining the fashion system by creating artisanal co-creative services - i.e. designing a scaling strategy starting at grassroots. Most recently, I put in effort to understand 2D and 3D weaving hands-on, through personal exploration and participating in the course 'The Fundamentals of Textile Systems' from Dr. Holly McQuillan, in preparation for this graduation project.

This project would allow me to gain more firsthand insight into an otherwise rather unapproachable industry, hopefully resulting in in-depth knowledge about the technique of 3D weaving and current denim supply chains. This is important, since I want to further develop my research capabilities and value gaining more experience beyond merely conducting literature research within this field. Furthermore, I want to take the opportunity to include short-term ethnographic methodology in carrying out user research, to carefully understand what is necessary from a diverse consumer's perspective. Another ambition is to explore communication strategies, which might turn out to be crucial for engaging consumers in a garment design process based on this relatively unknown technique, which also creates textile forms people haven't seen before. Apart from that, I am also open to exploring new methods to capture the content's complexity in a holistic, yet framed manner: particularly, I am interested in looking into Systems Oriented Design.

Finally, as a personal ambition, I hope to create a foundation with this research project which allows for continuation in the form of a PhD track. To strive towards substantial societal change to the best of my ability, I am driven to translate my obtained competences into an extensive project after the completion of my Master's, in which the space is given to research a similar subject much more thoroughly.

RESOURCES (continues in 'final comments')

[1] Ellen MacArthur Foundation. (2017). Fashion and the circular economy. <https://archive.ellenmacarthurfoundation.org/explore/fashion-and-the-circular-economy>; [2] Gordon-Martin, T. (2021, August 10). Cleaning denim's reputation. <https://www.dw.com/en/denim-clothing-sustainability-recycle-pollution/a-56951179>; [3] Gereffi, Gary & Frederick, Stacey. (2010). The Global Apparel Value Chain, Trade and the Crisis: Challenges and Opportunities for Developing Countries. The World Bank, Policy Research Working Paper Series.; [4] Moretz, C. A., (2020) "Zero Waste: The Spiral Pattern Cutting Technique", Sustainability in Fashion 1(1). doi: <https://doi.org/10.31274/susfashion.11489>; [5] Perera, Y. S., Muwanwella, R., Fernando, P. R., Fernando, S., & Jayawardana, T. S. S. (2021). Evolution of 3D weaving and 3D woven fabric structures. Fashion and Textiles, 8(1). <https://doi.org/10.1186/s40691-020-00240-7>; [6] Bilisik, K. (2012). Multiaxis three-dimensional weaving for composites: A review. Textile Research Journal, 82(7), 725-743. <https://doi.org/10.1177/0040517511435013>; [7] McQuillan, H. (2020, December 10). Zero Waste Systems Thinking: Multimorphic Textile-forms. Holly McQuillan. <https://hollymcquillan.com/portfolio/hybrid-zero-waste-practice/>;

FINAL COMMENTS

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

[8] Cantor, M. (2022). 'Made by white labor': the vintage Levi's that point to America's dark past. The Guardian. <https://www.theguardian.com/fashion/2022/oct/15/vintage-denim-jeans-chinese-exclusio>; [9] Östlund, A., et al., 2020, Investor Brief: Sustainability in Textiles and Fashion, Mistra Dialogues, Stockholm (https://www.mistra.org/wp-content/uploads/2020/09/mistradiologue_rapport_investor_brief_textiles_final.pdf) accessed 30 August 2021.

1298

