FACULTY OF ENGINEERING AND ARCHITECTURE

Designing a Product Service System for Digital Product Passport in the Fashion Industry in Compliance with the European Commission's Ecodesign for Sustainable Products Regulation

Casper Van Herzele
Student number: 01803196

Supervisor: Prof. dr. Francesca Ostuzzi
Counsellors: Dr. Fatima Khitous (Oulu University), Dr. Bastiaan Baccarne

Master's dissertation submitted in order to obtain the academic degree of
Master of Science in de industriële wetenschappen: industrieel ontwerpen

Academic year 2022-2023

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nanto

empowering circular fashion

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Foreword

First and foremost, I express my gratitude to Prof. Dr. Francesca Ostuzzi for her support and belief in this project since its inception during the Design for Sustainability course. I am immensely grateful for her guidance and encouragement throughout the study. I would also like to extend my appreciation to Dr. Fatima Khitous for her enthusiasm, valuable insights and believe in this project. Our meetings have been instrumental in providing scientific background and support, greatly enriching this study's viability. I am especially grateful for all the opportunities Fatima has given me. First, I could present my design thinking approach to her business students where I has a lovely time engaging with them. After a few weeks, I was invited back at the final presentations of her students. It was lovely to see business students using design thinking to engage with the fashion wicked problem. And last but not least, thanks to the unwavering support of Dr. Fatima Khitous and Prof. Dr. Francesca Ostuzzi, this study has been selected for presentation at the New Business Models Conference 2023 in Maastricht, the Netherlands. This opportunity will allow me to share my work with fellow researchers and receive valuable feedback to further enhance the final idea. I am also grateful for Dr. Bastiaan Baccarne's flexibility in joining this study two-thirds of the way through. Despite the challenges of jumping on board late in the study, his contribution has been valuable in advancing the research.

In addition to the academic contributions, I would like to express my gratitude to my parents, sister, friends, and family. Our discussions and conversations have been a constant source of joy and inspiration. Their enthusiasm for the proposed ideas during the development and delivery phases has been immensely motivating, driving me to pursue this work with passion and dedication. I would also like to offer my sincere apologies to my family for limiting our conversations to just two subjects during the month of May: Digital Product Passports as a wicked problem in the fashion industry and the Eurovision Song Contest.

As I reflect upon the entirety of this study, I am reminded of the initial uncertainty I faced during the fuzzy-front end phase, pondering the direction in which my solution would take shape. Now, as I reach the end of this research, I take immense pride in what I have accomplished. It was a hard challenge combining (sustainable) product design within the fashion industry. But I am delighted to have been able to integrate various personal interests into this thesis, encompassing not only the fascinating realm of the fashion industry but also the domains of business development, prototyping, rendering, 3D printing, and tackling wicked problems.

“Deze masterproef vormt een onderdeel van een examen. Eventuele opmerkingen die door de beoordelingscommissie tijdens de mondelinge uiteenzetting van de masterproef werden geformuleerd, werden niet verwerkt in deze tekst.”

“This master's dissertation is part of an exam. Any comments formulated by the assessment committee during the oral presentation of the master's dissertation are not included in this text.”

Abstract

The fashion industry plays a significant role in contributing to global carbon emissions and environmental degradation. However, an issue arises when essential product-related information becomes lost once consumers acquire clothing, hindering progress towards a circular economy. To tackle these challenges, the European Commission has proposed the integration of Digital Product Passports (DPP) into its Ecodesign for Sustainable Product Regulation (ESPR) and Circular Economy Action Plan (CEAP). DPPs act as unique identifiers for products, allowing for the seamless tracking and preservation of information throughout the lifecycle of garments. This, in turn, facilitates reuse, repair, and recycling processes.

This research project focuses on developing a durable and non-removable form of DPPs, taking the shape of an innovative business model aimed at reducing the environmental impact of the fashion industry. Employing a design thinking methodology, the study addresses sub-research questions related to innovation, stakeholders, and the creation of design requirements besides durability and non-removability.

Nanto Secure, a physical solution for DPPs, has been designed and tested to offer durability and non-removability. The findings gathered from a survey (N=51) indicate the positive influence of DPPs on consumer behavior. The research demonstrates the feasibility, desirability, viability and circularity of introducing an innovative fashion business model that aligns with the goals set by the European Commission to reduce the industry's environmental impact. Nanto Secure serves as an invaluable solution for preserving DPP data throughout the entire lifecycle of clothing, thereby promoting a circular economy through a Product-Service System called Nanto loopback

Keywords: Digital Product Passport, Fashion Industry, Product Service System, Ecodesign for Sustainable Product Regulation, Design Thinking

Designing a Product Service System for Digital Product Passport in the Fashion Industry in Compliance with the European Commission's Ecodesign for Sustainable Products Regulation

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***Abstract* - The fashion industry plays a significant role in contributing to global carbon emissions and environmental degradation. However, an issue arises when essential product-related information becomes lost once consumers acquire clothing, hindering progress towards a circular economy. To tackle these challenges, the European Commission has proposed the integration of Digital Product Passports (DPPs). This, in turn, facilitates reuse, repair, and recycling processes.**

This study focuses on developing a durable and non-removable form of DPPs for clothing, taking the shape of an innovative business model aimed at reducing the environmental impact of the fashion industry. Employing a design thinking methodology, the study addresses the creation of design requirements to facilitate brainstorming "solutions" to this wicked problem.

The result is Nanto Secure, a physical solution for DPPs, has been designed and tested. The findings gathered from a survey (N=51) and interviews (N=2) indicate the willingness of fashion companies to adopt DPPs and highlight the positive influence of DPPs on consumer behavior.

Nanto Secure demonstrates the circularity, feasibility, desirability and viability of introducing an innovative fashion business model that aligns with the goals set by the European Commission to reduce the industry's environmental impact. Nanto Secure serves as an invaluable solution for preserving DPP data throughout the entire lifecycle of clothing, thereby promoting a circular economy.

***Keywords* – Digital Product Passport, Fashion Industry, Product Service System, ESPR, Design Thinking**

I. Introduction

A. Context

10% of global carbon emissions come from the fashion industry which is more than the emissions of international flights and maritime shipping combined [1]. Further, due to the dominance of the fast fashion trend, global clothing consumption has doubled over the previous 20 years, while average wear duration has decreased by 50% [1]. The fashion industry has realized growths driven by the fast fashion business model favoring trendiness and low prices. Its economic value discourages most brands from adopting circular economy practices [2]. However, an issue arises when essential product-related information becomes lost once consumers acquire clothing, hindering progress towards a circular economy. This is visualized in figure 1. For example, the price tag is removed or essential labels are removed from clothing as seen in figure 1.

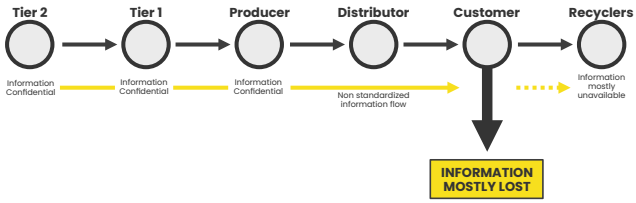

Figure 1: Information flow in a linear economy, Source: Adapted from [3]

B. European Commission's proposals

To tackle these challenges, the European Commission has proposed the implementation of Digital Product Passports (DPPs). This, in turn, facilitates reuse, repair, and recycling processes.

DPPs are part of new European proposals, such as the Circular Economy Action Plan (CEAP) [4] and Ecodesign for Sustainable Product Regulation (ESPPR) [3], [5] to make sustainable products the norm in the EU and to boost circular business models. This strategy is part of the European Green Deal [6], which aims to turn the European Union (EU) climate-neutral by 2050.

C. What is a DPP?

The definition of a DPP were extracted from [3], [5], [7], [8]

A DPP is a unique product identifier that simplifies the reuse, repair, refurbishment, redistribution, and recycling of products by enabling efficient tracking along the supply chain. It serves as a tool for registering, processing, and sharing product-related information among value chain actors, authorities, consumers, and other stakeholders, aiming to enhance transparency. DPPs provide a comprehensive record of events and transactions throughout a product's life, benefiting multiple stakeholders involved. It serves as a communication tool between stakeholders, allowing for example repairers to document their findings, recommendations, and progress, fostering trust, clear communication, and long-term relationships. Additionally, a DPP can include details of repairs, costs, contextual notes, and

digital versions of warranty, service, and insurance documentation, accessible to relevant parties.

DPPs will be introduced from 2027-2030 for product categories under the ESPR, such as toys, fishing gears, ceramic products, furniture, and textiles, which is this study's focus.

D. Research question and goal

This study focuses on developing a durable and non-removable form of DPPs for clothing, taking the shape of an innovative business model aimed at reducing the environmental impact of the fashion industry.

II. Methodology

A. Design thinking

This research relies on a design thinking (DT) methodology. DT has been gaining momentum as an innovation method that allows organizations to reach breakthrough innovations [9]. Moreover, recent research suggests that DT plays a central role in driving innovation [9], [10]. DT is based on two principles, diverge and converge which are applied in four distinctive phases [11]: discover, define, develop, and deliver. The here presented extended abstract only focusses on the last two phases.

B. Innovation through the Sustainable Innovation Sweet Spot

As the research question suggest, the goal is to create a solution that is innovative. Four parameters are used to reach innovation within design thinking [12], [13]. The process aims to create a solution that is desirable, feasible, viable and sustainable. Sustainable innovation is reached by focusing on all four aspects of the design process. In the context of this study, circularity is defined instead of sustainability.

C. Design requirements

Creating a framework of design requirements are essential for the development of a DPP in clothing, more specifically on the physical aspect of it. By establishing clear guidelines and specifications, design requirements enhance the overall understanding of a DPP. The list of requirements have been made out of European documents [4], [5], [14], [15] and by analyzing it through the lens of an industrial designer.

1: Non-removability: The DPP should be non-removable by fashion consumers to ensure its data-carrying potential is preserved. It should be attached securely to the garment using a method that is difficult to remove.

2: Removability: The DPP should be disassemble by recyclers, upcyclers, and repairers to increase the circularity of the DPP tag. It should be easy to remove without damaging the garment.

3: Styling: The size, visibility, and design of the DPP tag should be small, so it does not add unnecessary bulk to the garment. It should also be aesthetically appealing.

4: Versatility: The tag should be compatible with different textile materials and garment types to streamline and standardize the process of recycling and repurposing.

5: Non-damaging to textiles: The tag should minimize any potential damage to the textile, both during the initial application and any subsequent reapplication. This to increase the potential refurbishment of textiles.

6: Ergonomics: Fashion consumers will be the ones who will have to 'wear' this DPP the majority of the time. Therefore, it should not cause irritation or an allergic reaction. Furthermore, it should be lightweight and compact.

7: Circularity: This means that the DPP identifier itself should be designed with a focus on minimizing the environmental impact throughout its lifecycle, from its production to its end-of-life disposal.

8: Signifiers: Across the value chain, stakeholders should be able to identify the DPP through visual clues.

9: Cost: For the functionality of the product, it is desirable that the material and production costs are low.

10: Durability: The DPP tag should be durable enough to withstand water, soap, heat, moist, dirt, sand and chemicals throughout the life-cycle of the garment.

11: Scannability: Every stakeholder in the value-chain should be equipped with the right knowledge and tools to access the DPP.

These design requirements have been verified through shortly interviewing fashion consumers (N=22), an innovation engineer at a Belgian fashion company (N=1), a Belgian fashion rental platform (N=1), and experts in hardware development (N=3).

D. Wicked problem

Wicked problems is a term that is used to describe problems which are operationally complex, lacks a singular clear solution, involves behavior change and are multi-faceted [16]. Furthermore, they are hard to define and categorize, there are no real 'solutions' to wicked problems where it is better to improve the current situation.

Here, the development of a DPP tag is a wicked problem due to its complex nature and the multiple conflicting requirements involved. The design requirements for the DPP highlight the multi-faceted nature of the problem. Balancing the need for a non-removable tag for consumers with the requirement for removability by recyclers, upcyclers, and repairers creates a challenge in achieving material efficiency in a circular economy. Additionally, the tag must be securely attached to the garment while being easily applied and removed without damaging the textile. It should also be small and unobtrusive yet visible enough to communicate its importance to consumers. Non-removability and durability are important for reaching a circular economy, but there is a challenge in finding a solution that remains unremovable. Moreover, different stakeholders involved in the use of the tag have contradictory wishes, such as consumers who may not want extra labels in their clothing, while identifiers are essential for achieving a circular economy. These conflicting requirements and challenges make the development of a DPP in clothing a wicked problem.

E. Weighted decision matrix

Each approach for navigating through wicked problems requires its own approach [16]. Here, a weighted decision matrix will be used to weight the 11 design requirements according to their importance. For example, non-removability and durability are weighted 5/5 because of their importance for ensuring data will be accessible in clothing as long as possible.

The weighted decision matrix is used to compare benchmarks as well as brainstormed 'solutions'. From this, valuable results will be made according to the development of a physical DPP tag in clothing.

F. Benchmarking current DPP's

1) QR codes in labels as DPPs

The current standard for bringing additional information to customers is by displaying a QR code on a price tag or a clothing label [17]. Displaying it on a price tag is not desirable because they are designed to be removed. Displaying a QR code on a label is more complex than it seems. Researching label methods reveals that there are two main types: woven and printed labels.

Figure 2 shows a woven label. Although more expensive, they are perceived as more professional-looking, durable, and long-lasting compared to printed labels [18], [19]. Woven labels do not fade easily, even with intense use or washing, while printed labels may fade after 10 washes or exposure to sunlight, chemicals, or water [19]. Woven labels are less prone to falling off compared to printed labels. However, woven labels pose challenges in terms of unique identification required for a DPP. The manufacturing process for woven labels is not feasible for DPPs since each tag should be uniquely woven, leading to potential waste. It's estimated that the price for one unique custom DPP woven labels is €4,40, compared to €0,20 for a batch of 1000 of the same labels.

Figure 2: QR code in label [20]

Printing QR codes directly on textiles is an alternative option, eliminating the need for physical tags. Heat transfer printing is commonly used but has drawbacks such as potential allergic reactions and environmental waste [21]. Pad printing is a more cost-effective and efficient method, but it may fade over time depending on the type of die used [19], [22], [23].

The most important factor why QR code labels may not be suitable for DPP's, is that consumers may like to remove these tags, may be allergic to it or find it irritating . Therefore, all the time and money going into developing a DPP is easily wasted by a scissor.

G. Other identifications

Besides QR codes, there are other visual based identifiers such as barcodes or serial numbers. The downside of barcodes is that they cannot store as much as QR codes because they are one dimensional, whereas QR codes are two dimensional [24]. Why serial numbers may not be the best solution in the case of DPP's, is that relying solely on serial codes can create a bottleneck in the tracking process, as each code would need to be scanned and entered manually into a database or other tracking system [24].

1) NFC as DPPs

Besides visual scanning exists other technologies to access data, such as Near Field Communication (NFC) and Radio Frequency Identification (RFID). Both rely on using radio frequency signals [25] but the disadvantage of RFID is that it cannot be scanned with a smartphone whereas NFC can [26], [27].

When it comes to implementing NFC tags in clothing, it is crucial to choose the right type of tag. Various NFC tags are available in the market. For example, TouchLink is a DPP looking like a zipper. Maribert include NFC chips in their buttons. Besides NFC integrated in existing parts, NFC tags exist as laundry tags, regular or tiny. The most durable tags, known as laundry tags, are made of PPS polymer. Regular NFC tags, without any specialized capsule around them, are designed to be molded with polymers or resin. However, these options are not suitable for circularity as it becomes impossible to separate the polymer and NFC tag components without damaging the NFC chip. Last, tiny NFC tags measuring 5x5mm exist. These tags are water and weather resistant. The price per unit for a batch of 1000 tiny NFC tags is $0.36, and the reading distance varies from 1 to 10cm depending on the reading device.

As TouchLink and Maribert outline, is that NFC chips needs an additional casing to be functioning as a DPP. But due to circularity concerns, a different shell should be designed, whilst keeping the opportunities from the benchmarks in mind.

H. Brainstorm

Five different concepts were defined out of the design requirements and knowledge from the benchmarks. These concepts included incorporating NFC chips in clothing patches, redesigning security pins and combining NFC chips in existing parts, such as rivets and jeans buttons. Using the weighted distribution matrix to compare brainstormed ideas to one another and to the benchmarks confirmed the wickedness of the problem where no concept stood out. The goal is to combine the opportunities from the brainstorm and benchmarks into 1 singular concept to result in a concept where every design requirement gets at least gets a 1/2 score.

I. Conclusion brainstorm

The combined concept in figure 3 goes as followed. Here, the security tag is optimized for DPPs in the clothing industry to enhance desirability. It involves a pin inserted through the fabric, secured with a locking mechanism. The tag is small, lightweight, and non-removable by consumers but can be removed by specific stakeholders. Clothing brands can cover it with a label or leather patch or use it as a button. Styling, integration, ergonomics and logistical considerations will be explored in the deliver phase of the feasibility study.

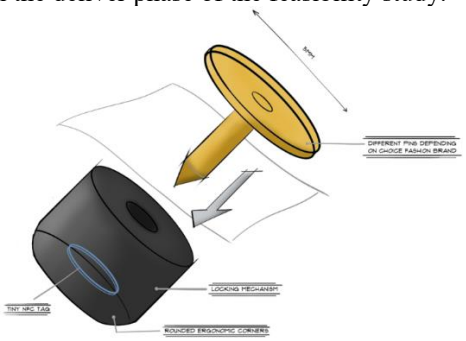

Figure 3: Combined idea (own figure)

III. DELIVER

First, the name of this product is Nanto Secure, suggesting in a durable and reliable DPP solution. The company who produces Nanto Secure is Nanto. The goals was to create a name that is simple, elegant , future-proof and can be read in English, Dutch and French without weird pronunciations.

A. *Nanto Secure, a Circular DPP tag*

The company Nanto relies on a Product-Service System (PSS) designed for the clothing industry, named Nanto Loopback as seen in figure 4. It offers a tag that can be reused in new clothing, promoting circularity [28]. To ensure efficient removal of Nanto Secure, stakeholders such as recyclers and upcyclers scan the NFC tag to access relevant DPP information, including the original owner and the destination address for returning the tag. Professional handheld scanners equipped with cameras and laser aimers can be used for scanning, along with large NFC scanning pads. Automatic shipping labels can be generated to facilitate the return process. Nanto aims to establish partnerships with relevant institutions to provide necessary knowledge, packaging materials, and tools for disassembly, creating a closed-loop system that promotes circularity in the fashion industry.

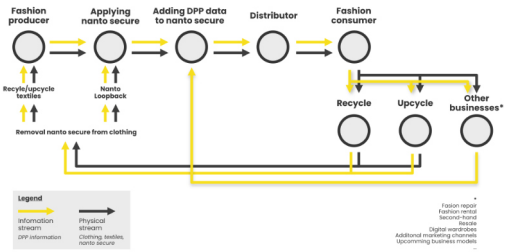

Figure 4: Information stream in a circular economy (own figure)

B. *Nanto Secure, a Feasible DPP tag*

The feasibility development included researching, benchmarking and brainstorming existing locking mechanisms, ranging from spring-loaded security pins to getting inspiration from watch backs and security screws.

First, the spring-loaded security pin was further developed as a potential way to create a system that is non-removable by consumer but removable with the right tools. But after further prototyping and testing this system, it has been concluded that such system is mechanically too complex, could be too heavy and it was estimated that creating a smaller tag would not be feasible to reach in this study. Therefore, other methods for securing pins through clothing were further researched, prototyped, developed in multiple iterative cycles, leading to the final feasible DPP tag.

Nanto Secure is the result of an extensive feasibility development. This summary outlines the key features and functionality of Nanto Secure. Designed to be both durable and difficult to remove by consumers, Nanto Secure ensures the preservation of data when customers acquire clothing. It comprises two main components: a pin that is applied through clothing and a locking mechanism that securely holds the pin in place on the other side. The internal components are resistant to water and weather, while the outer shell is made from a special heat and chemical-resistant material, enhancing its overall durability. A render can be seen in image 5.

Figure 5: Nanto Secure

Thanks to the size of the internal components and the use of a tiny NFC, Nanto Secure weights 3,49grams, which is comparable to the weight of a two eurocent coin. If five of such coins are stacked, the height of Nanto Secure is reached, as seen in image 6. Depending on the NFC scanning device, Nanto secure can be scanned from 1-10cm away, which is quite remarkable for its size.

Figure 6: Size of Nanto Secure (own figure)

The use of a pin to secure DPP data onto clothing ensures that textiles are not damaged, and the tag can be applied anywhere on the garment. Fashion companies that purchase Nanto Secures from Nanto have the flexibility to choose how to implement Nanto Secure in their clothing. They can opt to make the pin visible or even utilize their own pins. Additionally, Nanto Secure can be discreetly placed in clothing pleats to avoid contact with the customer's skin. Fashion companies may also position Nanto Secure on the edge of clothing and cover it with their own label. Another option is to reverse the orientation, making the locking part visible, allowing Nanto Secure to serve as a button or jeans rivet. This versatility highlights Nanto Secure as a flexible DPP tag.

Furthermore, Nanto Secure is designed with disassembly and assembly in mind, aligning with the principles of a circular economy. This design ensures that Nanto Secure meets the criteria for a removable, yet non-removable and durable DPP tag thanks to the snap joints (figure 7).

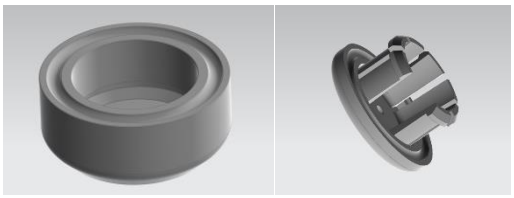

Figure 7: Nanto Secure shell (left) and inside (right) (own figure)

The material costs for 1 Nanto Secure is €1,33 for a quantity of 1000. The fixed costs, such as the mold, decrease when more parts are produced. The price of one uniquely woven QR code is €4,40. Therefore, Nanto Secure provides a more cost-effective solution based on material prices.

C. *Nanto Secure, a Desirable DPP tag*

Nanto Secure creates value for various stakeholders by addressing their desires and expectations. Large fashion brands would prefer Nanto Secure over QR code labels because it guarantees reliable data access, enabling additional marketing, sales, and business operation channels to enhance the customer experience. The tag's durability and removability by recyclers also incentivize brands to choose Nanto Secure, as they can retrieve and reuse the tags, reducing costs. Small-scale fashion brands benefit from the opportunity to reuse tags, further reducing investment expenses. Suppliers and manufacturers collaborate with Nanto to promote a circular economy by

delivering and producing Nanto DPPs. Software providers would want to engage with a durable and non-removable DPP tag so their software can be accessed at all costs. Retailers can offer clothing with Nanto Secure, ensuring data remains intact, thereby eliminating consumers' concerns about fading or irritating labels. Recyclers and upcyclers benefit from efficient data access, facilitating a more circular recycling process and enabling seamless tag incorporation into upcycled designs. Existing sustainable retailers, such as second-hand stores and fashion rental businesses, benefit from Nanto Secure's reliability because consumers want more transparent information [29]. Repair businesses rely on accessible and retained information in clothing for effective repairs. Finally, regulators and NGOs find value in a reliable, durable and non-removable DPP solution for tracking the sustainable performance and claims of fashion companies.

For consumers, Nanto Secure's desirability will be tested in the last data collection.

D. Nanto Secure, a Viable DPP tag

Nanto, a B2B company, offers physical DPP solutions to fashion brands. Key partners include suppliers, manufacturers, and data providers. Key activities involve product development, partnership establishment, and marketing/sales efforts. Key resources include physical components/materials and expertise/knowledge in fashion, circular economy, and technology.

The value proposition is to deliver a seamless and durable data access. Nanto provide a secure and durable DPP tag that ensures data remains available throughout the entire lifecycle of clothing. Furthermore, fashion brands can benefit from the flexible design of the Nanto Secure, as it can be applied in various ways to meet their specific preferences. Whether it is as a pin, a button, a rivet, or covered with a label, Nanto Secure ensures that the tag seamlessly integrates into the design of the clothing, maintaining both aesthetics and functionality. And most important, it is a circular economy facilitator. First, it assures data will not get lost after consumers acquired clothing. Additionally, Nanto enables a closed-loop system by ensuring the tag is reusable and can be returned to the original business after use.

Customer relationships are providing assistance and support for fashion companies willing to implement Nanto solutions in their clothing. Channels include direct sales, partnerships, and a reuse system through a PSS. Customer segments are large and small-scale fashion brands, upcyclers, and fashion consumers. The cost structure includes research and development, production costs, marketing/sales expenses, and partnerships/collaborations. Revenue streams come from product sales, service fees, and potential funding opportunities.

E. Survey

Nanto Secure will only be tested to fashion consumer because if the amount of stakeholders within this study. They'll be the ones who will wear and engage with it the most.

For this, a survey has been designed with Likert scales, ranging from 1 to 5. The survey measures:

- Relevant design requirements for consumers of Nanto Secure vs QR code (paired samples t-test, 95% CI)
- The most likely clothing types Nanto Secure and QR code labels could be used for (one sample t-test, test value = 3.5/5, 95% CI)
- The change in sustainable fashion consumption now and when DPPs are introduced (paired samples t-test, 95% CI)

IV. Results

Through the survey (N=51) for fashion consumers, it can be concluded that Nanto secure is more difficult to remove ($t(48)=3{,}463$, $p<0{,}001$) and has a higher durability ($t(47)=5{,}190$, $p<0{,}001$) compared to QR codes sewn in on 4 sides. This was the main goal of the design requirements.

For both concepts (Nanto Secure & QR code) consumers would possible not want to remove one of these two DPP's regardless of their value ($t(48)=3{,}463$, $p = 0{,}735 > 0{,}05$); consumers possibly do not find both solutions ugly ($t(49)=1{,}136$, $p = 0{,}262 > 0{,}05$); the size of both concepts are possibly not too large ($t(49) = 1{,}376$, $p = 0{,}175 > 0{,}05$); and both solutions would possibly not result in an allergic reaction ($t(49) = -0{,}401$, $p=0{,}690 > 0{,}05$).

On the other side, the QR code label showed on other aspects a significant difference. It's clearer that the QR code can be scanned compared to Nanto Secure ($t(49) = 8{,}463$, $p<0{,}001$). Nanto Secure is thicker than the QR code ($t(47) = -7{,}948$, $p<0{,}001$). Nanto Secure could annoy them more if it touched their skin compared to the QR code label ($t(49) = 8{,}463$, $p<0{,}001$). Last it's more important for Nanto Secure to be placed on the right location compared to the QR code label ($t(49) = -4{,}140$, $p<0{,}001$).

Consumers indicated in this survey that Nanto Secure could be used for jeans pants, blazers, winter jackets, coats, vests, sweaters and backpacks. According to consumers, the QR code is more versatile and can be used on every questioned clothing category except for scarfs and swimming clothing. The limitation of this survey is that it are perceived answers, where user testing and feeling such object in real life would recreate more objective results.

Furthermore, regardless of how a physical DPP tag looks like, it can be concluded through the survey that a DPP has a positive impact on the possible future consumer's sustainable fashion behavior compared to their current sustainable behavior.

V. Discussion

Looking at these results, it seems that for consumers, the current state has been made worse because of the introduction of Nanto Secure. It can be explained through a lack of relevant examples where for example this tag can be placed or how it the design would impact wearing garments.

But these downsides could be possibly be fixed by incorporating following design changes. The design of Nanto Secure allows it to be covered with a small woven label, which has not been explained in this survey. Then it would not touch the skin, can decide the facing direction (pin inwards or outwards facing) and fashion companies can decide whatever they want to display on the label. To benefit signifying it can be scanned, a small NFC logo can be woven in such labels. It's also possible to place Nanto Secure in pleats, corners or as a replacement for existing components.

VI. Conclusion

Because of the results an answer can be given to the research question:

'How to introduce a new and innovative fashion business model that aims to decrease the environmental impact of the fashion industry based on the EU eco-design directives?'

The introduction is possible by engaging with the European Commission's ESPR to reach a circular economy. Nanto facilitates these regulations by making sure that it stays scannable throughout the whole life-cycle of clothing. Innovation has been explored through circularity, feasibility, desirability and viability.

VII. Future work

The development of a framework for designing a digital product passport (DPP) in clothing has laid the foundation for further exploration. To validate and refine the framework's effectiveness, real-life use cases need to be tested and iterated upon. Conducting extensive user testing for Nanto Secure is crucial to gather robust feedback and ensure the practicality of DPP solutions for future implementation starting from 2030. This includes testing the product in various conditions, such as exposure to water, dust, oils, and heat.

Due to time constraints, some important stakeholders were not fully engaged in this study. Engaging recyclers and exploring efficient scanning and removal methods for DPP solutions is vital to support the circular economy. Collaborating with fashion companies, potentially through partnerships with fashion design students, could also yield fruitful results in incorporating DPP concepts into clothing.

Furthermore, conducting a life cycle assessment (LCA) would be beneficial to compare the environmental impact of Nanto Secure and QR codes, particularly considering the reuse factor of Nanto Secure. This assessment would help quantify the reduction in carbon dioxide equivalents and support environmentally conscious decision-making.

While the study primarily focused on material costs, it is crucial to develop a comprehensive financial plan that considers all fixed and variable costs, profit margins, and the break-even point. Incorporating these parameters into a business model would provide a more comprehensive understanding of the economic viability of implementing DPP solutions.

VIII. References

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Ontwerp van een Product Service System voor Digital Product Passport in de kledingindustrie met betrekking tot de Ecodesign for Sustainable Products Regulation van de Europese Commissie

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***Abstract* - De mode-industrie speelt een belangrijke rol bij het bijdragen aan de wereldwijde koolstofemissies en aantasting van het milieu. Er ontstaat echter een probleem wanneer essentiële product gerelateerde informatie verloren gaat zodra consumenten kleding aanschaffen, waardoor de voortgang naar een circulaire economie wordt belemmerd. Om deze uitdagingen het hoofd te bieden, heeft de Europese Commissie de integratie van digitale productpaspoorten (DPP's) voorgesteld. Dit vergemakkelijkt op zijn beurt processen voor hergebruik, reparatie en recycling.**

Deze studie richt zich op het ontwikkelen van een duurzame en niet-verwijderbare vorm van DPP's voor kleding, in de vorm van een innovatief bedrijfsmodel gericht op het verminderen van de milieu-impact van de mode-industrie. Door gebruik te maken van design thinking-methodologie, richt de studie zich op het creëren van ontwerpvereisten om het brainstormen over "oplossingen" voor dit wicked problem te vergemakkelijken.

Het resultaat is dat Nanto Secure, een fysieke oplossing voor DPP's, is ontworpen en getest. De bevindingen uit een enquête (N=51) en interview (N=2) geven aan dat modebedrijven bereid zijn om DPP's te gebruiken en benadrukken de positieve invloed van DPP's op consumentengedrag.

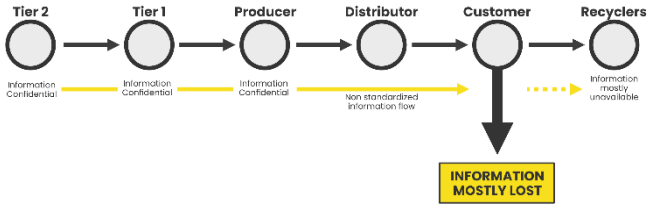
Nanto Secure toont de circulariteit (circularity), haalbaarheid (feasibility), aantrekkelijkheid (desirability) en levensvatbaarheid (viability) van de introductie van een innovatief modebedrijfsmodel dat aansluit bij de doelstellingen van de Europese Commissie om de milieu-impact van de industrie te verminderen. Nanto Secure is een oplossing van onschatbare waarde voor het behoud van DPP-gegevens gedurende de gehele levenscyclus van kleding, waardoor een circulaire economie wordt bevorderd.

***Keywords* – Digital Product Passport, Mode-industrie, Product Service System, ESPR, Design Thinking**

I. Introductie

A. Context

10% van de wereldwijde CO2-uitstoot is afkomstig van de mode-industrie, wat meer is dan de uitstoot van internationale vluchten en zeescheepvaart samen [1]. Verder is door de dominantie van de fast fashion-trend de wereldwijde kledingconsumptie in de afgelopen 20 jaar verdubbeld, terwijl de gemiddelde draagduur met 50% is afgenomen [1]. De mode-industrie heeft groei gerealiseerd, gedreven door het fast fashion-bedrijfsmodel dat de voorkeur geeft aan trendy en lage prijzen. De economische waarde ontmoedigt de meeste merken om circulaire economiepraktijken toe te passen [2]. Er ontstaat echter een probleem wanneer essentiële productgerelateerde informatie verloren gaat zodra consumenten kleding aanschaffen, waardoor de voortgang naar een circulaire economie wordt belemmerd. Zo wordt bijvoorbeeld het prijskaartje verwijderd of worden essentiële labels van kleding verwijderd zoals te zien is in figuur 1.



Figuur 1: Informatiestroom in een lineaire economie, Bron: Aangepast van [3]

B. Voorstellen van de Europese Commissie

Om deze uitdagingen het hoofd te bieden, heeft de Europese Commissie de invoering van digitale productpaspoorten (DPP's) voorgesteld. Dit vergemakkelijkt op zijn beurt processen voor hergebruik, reparatie en recycling.

DPP's maken deel uit van nieuwe Europese voorstellen zoals de Circular Economy Action Plan (CEAP) [4] en Ecodesign for Sustainable Product Regulation (ESPPR) [3], [5] om van duurzame producten de norm te maken in de EU en circulaire bedrijfsmodellen te boosten. Deze strategie maakt deel uit van de Europese Green Deal [6], die tot doel heeft de Europese Unie (EU) in 2050 klimaatneutraal te maken.

C. Wat is een DPP?

De definitie van een DPP is gehaald uit [3], [5], [7], [8]. Een DPP is een unieke productidentificatie die het hergebruik, de reparatie, het refurbishen, de herdistributie en de recycling van producten vereenvoudigt door een efficiënte tracering in de toeleveringsketen mogelijk te maken. Het dient als een hulpmiddel voor het registreren, verwerken en delen van productgerelateerde informatie tussen actoren in de waardeketen, autoriteiten, consumenten en andere belanghebbenden, met als doel de transparantie te vergroten.

DPP's bieden een uitgebreid overzicht van gebeurtenissen en transacties gedurende de levensduur van een product, waar meerdere betrokken belanghebbenden baat bij hebben. Het dient als communicatiemiddel tussen belanghebbenden, waardoor reparateurs bijvoorbeeld hun bevindingen, aanbevelingen en voortgang kunnen documenteren, waardoor vertrouwen, duidelijke communicatie en langdurige relaties worden bevorderd. Bovendien kan een DPP details van reparaties, kosten, contextuele notities en digitale versies van garantie-, service- en verzekeringsdocumentatie bevatten, toegankelijk voor relevante partijen.

DPP's zullen van 2027-2030 worden geïntroduceerd voor productcategorieën onder de ESPR, zoals speelgoed, vistuig, keramische producten, meubels en textiel, waarop dit onderzoek zich richt.

D. Onderzoeksvraag en doelstelling

Deze studie richt zich op het ontwikkelen van een robuust en niet-verwijderbare vorm van DPP's voor kleding, in de vorm van een innovatief bedrijfsmodel gericht op het verminderen van de milieu-impact van de mode-industrie.

II. Methodologie

A. Design thinking

Dit onderzoek is gebaseerd op een design thinking (DT) methodiek. DT wint aan kracht als een innovatiemethode waarmee organisaties tot baanbrekende innovaties kunnen komen [9]. Bovendien suggereert recent onderzoek dat DT een centrale rol speelt bij het stimuleren van innovatie [9], [10]. DT is gebaseerd op twee principes, divergeren en convergeren, die worden toegepast in vier verschillende fasen [11]: discover, define, develop, en deliver. De hier gepresenteerde uitgebreide samenvatting richt zich alleen op de laatste twee fasen.

B. Innovatie via de Sustainable Innovation Sweet Spot

Zoals de onderzoeksvraag suggereert, is het doel om een oplossing te creëren die innovatief is. Vier parameters worden gebruikt om tot innovatie binnen design thinking te komen [12], [13]. Het proces is gericht op het creëren van een oplossing die duurzaam, haalbaar, aantrekkelijk en levensvatbaar is. Duurzame innovatie wordt bereikt door te focussen op alle vier de aspecten van het ontwerpproces. In de context van dit onderzoek wordt circulariteit gedefinieerd in plaats van duurzaamheid.

C. Ontwerpregels voor DPP's in kledij

Het creëren van ontwerpregels van ontwerpeisen is essentieel voor de ontwikkeling van een DPP in kleding, meer specifiek op het fysieke aspect ervan. Door duidelijke richtlijnen en specificaties vast te stellen, vergroten ontwerpvereisten het algemene begrip van een DPP. De lijst met eisen is gemaakt op basis van Europese documenten [4], [5], [14], [15] en door het te analyseren door de lens van een industrieel ontwerper.

1: Niet-verwijderbaar: de DPP moet niet-verwijderbaar zijn door modeconsumenten om ervoor te zorgen dat het potentieel voor gegevensoverdracht behouden blijft. Het moet stevig aan het kledingstuk worden bevestigd met een methode die moeilijk te verwijderen is.

2: Verwijderbaarheid: De DPP moet worden gedemonteerd door recyclers, upcyclers en reparateurs om de circulariteit van de DPP-tag te vergroten. Het moet gemakkelijk te verwijderen zijn zonder het kledingstuk te beschadigen.

3: Styling: De grootte, zichtbaarheid en het ontwerp van de DPP-tag moeten minimaal zijn, zodat het kledingstuk geen onnodige massa krijgt. Het moet ook esthetisch aantrekkelijk zijn.

4: Veelzijdigheid: De tag moet compatibel zijn met verschillende soorten textiel en kleding om het proces van recycling en hergebruik te stroomlijnen en te standaardiseren.

5: Niet-beschadigend voor textiel: De tag moet mogelijke schade aan het textiel tot een minimum beperken, zowel tijdens de eerste toepassing als bij elke latere toepassing. Dit om de potentiële hergebruik van textiel te vergroten.

6: Ergonomie: Modeconsumenten zullen degenen zijn die deze DPP het grootste deel van de tijd zullen moeten 'dragen'. Daarom mag het geen irritatie of een allergische reactie veroorzaken. Bovendien moet het licht en compact zijn.

7: Circulariteit: Dit betekent dat de DPP tag zelf moet worden ontworpen met de nadruk op het minimaliseren van de milieu-impact gedurende de hele levenscyclus, van de productie tot de verwijdering aan het einde van de levensduur.

8: Indicatoren: In de hele waardeketen moeten stakeholders de DPP kunnen identificeren aan de hand van visuele aanwijzingen.

9: Kosten: Voor de functionaliteit van het product is het wenselijk dat de materiaal- en productiekosten laag zijn.

10: Robuustheid: De DPP-tag moet robuust genoeg zijn om bestand te zijn tegen water, zeep, hitte, vocht, vuil, zand en chemicaliën gedurende de hele levenscyclus van het kledingstuk.

11: Scanbaarheid: Elke stakeholders in de waardeketen moet worden uitgerust met de juiste kennis en hulpmiddelen om toegang te krijgen tot het DPP.

Deze ontwerpvereisten zijn geverifieerd door middel van korte interviews met modeconsumenten (N=22), een innovatie-ingenieur bij een Belgisch modebedrijf (N=1), een Belgisch modeverhuurplatform (N=1) en experts in hardware-ontwikkeling (N= 3).

D. Wicked problem

'Wicked problems' is een term die wordt gebruikt om problemen te beschrijven die operationeel complex zijn, geen duidelijke oplossing hebben, gedragsverandering inhouden en veelzijdig zijn [16]. Bovendien zijn ze moeilijk te definiëren en te categoriseren, er zijn geen echte 'oplossingen' voor wicked problems waar het beter is om de huidige situatie te verbeteren.

Hier is de ontwikkeling van een DPP-tag een wicked problem vanwege de complexe aard en de vele tegenstrijdige vereisten. De ontwerpregels voor het DPP benadrukken de veelzijdige aard van het probleem. Het balanceren van de behoefte aan een niet-verwijderbare tag voor consumenten met de eis van verwijderbaarheid door recyclers, upcyclers en reparateurs vormt een uitdaging bij het bereiken van materiaalefficiëntie in een circulaire economie. Bovendien moet het label stevig aan het kledingstuk worden bevestigd en gemakkelijk worden aangebracht en verwijderd zonder het textiel te beschadigen. Het moet ook klein en onopvallend zijn, maar toch zichtbaar genoeg om het belang ervan aan de consument over te brengen. Niet-verwijderbaarheid en duurzaamheid zijn belangrijk voor het bereiken van een circulaire economie, maar het is een uitdaging om een oplossing te vinden die niet-verwijderbaar blijft. Bovendien hebben verschillende stakeholders die betrokken zijn bij het gebruik van de tag tegenstrijdige wensen,

zoals consumenten die misschien geen extra labels in hun kleding willen, terwijl indicatoren essentieel zijn voor het realiseren van een circulaire economie. Deze tegenstrijdige vereisten en uitdagingen maken de ontwikkeling van een DPP in kleding tot een groot probleem.

E. Gewogen beslissingsmatrix

Elke aanpak om door wicked problems te navigeren vereist zijn eigen aanpak [16]. Hier zal een gewogen beslissingsmatrix worden gebruikt om de 11 ontwerpeisen te wegen naar belangrijkheid. Niet-verwijderbaarheid en duurzaamheid worden bijvoorbeeld 5/5 gewogen vanwege hun belang om ervoor te zorgen dat gegevens zo lang mogelijk toegankelijk blijven in kleding. De gewogen beslissingsmatrix wordt gebruikt om zowel benchmarks als gebrainstormde 'oplossingen' te vergelijken. Hieruit zullen waardevolle resultaten worden geboekt volgens de ontwikkeling van een fysieke DPP-tag in kleding.

F. Benchmarking current DPP's

1) QR codes in labels als DPP's

De huidige standaard voor het brengen van aanvullende informatie aan klanten is het tonen van een QR-code op een prijskaartje of een kledinglabel [17]. Het weergeven van een QR-code op een prijskaartje is niet wenselijk omdat ze zijn ontworpen om te worden verwijderd. Het weergeven van een QR-code op een label is complexer dan het lijkt. Onderzoek naar labelmethoden laat zien dat er twee hoofdtypen zijn: geweven en bedrukte labels.

Geweven labels, hoewel duurder, worden gezien als professioneler, duurzamer en duurzamer in vergelijking met bedrukte labels [18], [19]. Geweven labels vervagen niet gemakkelijk, zelfs niet bij intensief gebruik of wassen, terwijl gedrukte labels na 10 wasbeurten of blootstelling aan zonlicht, chemicaliën of water kunnen vervagen [19]. Geweven labels vallen minder snel af in vergelijking met bedrukte labels. Geweven labels vormen echter een uitdaging wat betreft de unieke identificatie die vereist is voor een DPP. Het productieproces voor geweven labels is niet haalbaar voor DPP's, aangezien elk label uniek geweven moet zijn, wat anders kan leiden tot afval. Geschat wordt dat de prijs voor één uniek op maat gemaakt DPP geweven label € 4,40 is, vergeleken met € 0,20 voor een partij van 1000 van dezelfde labels.

Figure 2: QR-code in label [20]

Het rechtstreeks op textiel printen van QR-codes is een alternatieve optie, waardoor er geen fysieke tags meer nodig zijn. Warmteoverdrachtsprinten (heat transfer) wordt vaak gebruikt, maar heeft nadelen zoals mogelijke allergische reacties en milieuverontreiniging [21]. Tampondruk (pad printing) is een kosteneffectieve en efficiëntere methode, maar kan na verloop van tijd vervagen, afhankelijk van het type matrijs dat wordt gebruikt [19], [22], [23].

De belangrijkste factor waarom QR-code-labels mogelijk niet geschikt zijn voor DPP's, is dat consumenten deze tags misschien graag verwijderen, er allergisch voor zijn of het irritant vinden. Daarom wordt alle tijd en geld die worden gestoken in het ontwikkelen van een DPP gemakkelijk verspild door een schaar.

G. Andere scanmethodes

Naast QR-codes zijn er andere visuele identificatiemiddelen zoals streepjescodes of serienummers. Het nadeel van streepjescodes is dat ze niet zoveel kunnen opslaan als QR-codes omdat ze eendimensionaal zijn, terwijl QR-codes tweedimensionaal zijn [24]. Waarom serienummers misschien niet de beste oplossing zijn in het geval van DPP's, is dat alleen vertrouwen op seriële codes een knelpunt kan vormen in het trackingproces, omdat elke code moet worden gescand en handmatig moet worden ingevoerd in een database of ander trackingsysteem. [24].

1) NFC als DPP's

Naast visueel scannen bestaan er andere technologieën om toegang te krijgen tot gegevens, zoals Near Field Communication (NFC) en Radio Frequency Identification (RFID). Beide zijn afhankelijk van het gebruik van radiofrequentiesignalen [25] maar het nadeel van RFID is dat het niet kan worden gescand met een smartphone terwijl NFC dat wel kan [26], [27].

Als het gaat om het implementeren van NFC-tags in kleding, is het cruciaal om het juiste type tag te kiezen. Er zijn verschillende NFC-tags op de markt verkrijgbaar. TouchLink is bijvoorbeeld een DPP die eruitziet als een ritssluiting. Maribert heeft NFC-chips in hun knoppen verwerkt. Naast NFC geïntegreerd in bestaande onderdelen, bestaan NFC-tags als waslabels, normaal of klein. De meest duurzame tags, ook wel waslabels genoemd, zijn gemaakt van PPS-polymeer. Normale NFC-tags, zonder speciale capsule eromheen, zijn ontworpen om te worden gegoten met polymeren of hars. Deze opties zijn echter niet geschikt voor circulariteit, omdat het onmogelijk wordt om de polymeer- en NFC-tagcomponenten te scheiden zonder de NFC-chip te beschadigen. Als laatste bestaan er kleine NFC-tags van 5x5 mm. Deze tags zijn water- en weerbestendig. De prijs per eenheid voor een batch van 1000 kleine NFC-tags is $ 0,36 en de leesafstand varieert van 1 tot 10 cm, afhankelijk van het leesapparaat.

Zoals TouchLink en Maribert schetsen, is dat NFC-chips een extra behuizing nodig hebben om als een DPP te kunnen functioneren. Maar vanwege circulariteitsoverwegingen moet een andere schil worden ontworpen, rekening houdend met de kansen van de benchmarks.

H. Brainstorm

Vanuit de ontwerpregels en kennis uit de benchmarks zijn vijf verschillende concepten gedefinieerd. Bijvoorbeeld, het verwerken van NFC-chips in leren patch, het herontwerpen van veiligheidsspelden en het combineren van NFC-chips in bestaande onderdelen, zoals klinknagels en jeansknopen. Het gebruik van de gewogen beslissingsmatrix om brainstormideeën met elkaar en met de benchmarks te vergelijken, bevestigde het wicked problem waar geen enkel concept uitsprong. Daarom is het doel om de brainstorm en benchmarks te combineren tot 1 enkelvoudig concept om te resulteren in een concept waarbij elke ontwerpeis minimaal een 1/2 score krijgt.

I. Conclusie brainstorm

Het gecombineerde concept gaat als volgt. Hier is de beveiligingstag geoptimaliseerd voor DPP's in de kledingindustrie om de wenselijkheid te vergroten. Het gaat om een speld die door de stof wordt gestoken, vastgezet met een vergrendelingsmechanisme. De tag is klein, licht van gewicht en kan niet worden verwijderd door consumenten, maar kan wel worden verwijderd door specifieke stakeholders door middel van de juiste kennis en tools. Kledingmerken kunnen het bedekken met een label of leren patch of het als knoop gebruiken. Styling, integratie, ergonomie en logistieke overwegingen zullen worden onderzocht in de deliver van de haalbaarheidsstudie.

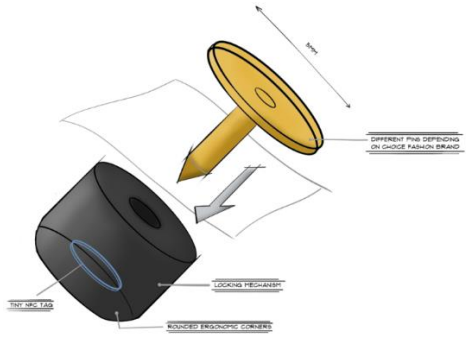


Figure 3: Gecombineerd probleem (eigen figuur)

III. DELIVER

Ten eerste is de naam van dit bedacht concept Nanto Secure, wat duidt op een robuust en betrouwbare DPP-oplossing. Het bedrijf dat Nanto Secure produceert, is Nanto. Het doel was om een naam te creëren die eenvoudig, elegant en toekomstbestendig is en leesbaar is in het Engels, Nederlands en Frans zonder rare uitspraken.

A. Nanto Secure, een circulaire DPP-tag

Het bedrijf Nanto is een Product-Service Systeem (PSS) ontworpen voor de kledingindustrie. Het biedt een tag die hergebruikt kan worden in nieuwe kleding, wat de circulariteit bevordert [28]. Om een efficiënte verwijdering van Nanto Secure te garanderen, scannen recyclers of upcyclers de NFC-tag om toegang te krijgen tot relevante DPP-informatie, waaronder de oorspronkelijke eigenaar en het bestemmingsadres voor het retourneren van de tag. Professionele handscanners die zijn uitgerust met camera's en laserrichters kunnen worden gebruikt om te scannen, samen met grote NFC-scanpads. Er kunnen automatische verzendlabels worden gegenereerd om het retourproces te vergemakkelijken. Nanto streeft ernaar partnerschappen aan te gaan met relevante instellingen om de nodige kennis, verpakkingsmaterialen en hulpmiddelen voor demontage te bieden, waardoor een gesloten kringloopsysteem ontstaat dat circulariteit in de mode-industrie bevordert.

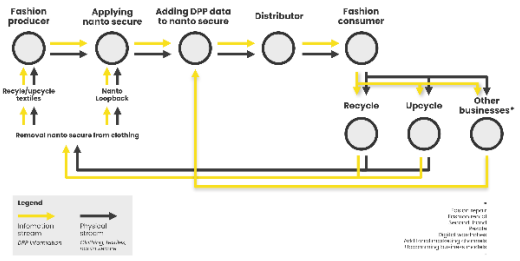


Figure 4: Informatiestroom in een circulaire economie (eigen figuur)

B. Nanto Secure, een haalbare DPP tag

De haalbaarheidsstudie omvatte het onderzoeken, benchmarken en brainstormen van bestaande vergrendelingsmechanismen, variërend van veerbelaste beveiligingspennen tot inspiratie halen uit watchbacks en beveiligingsschroeven.

Ten eerste werd de veerbelaste veiligheidspen verder ontwikkeld als een mogelijke manier om een systeem te creëren dat niet door de consument kan worden verwijderd, maar wel kan worden verwijderd met de juiste hulpmiddelen. Maar na verder prototypen en testen van dit systeem, is geconcludeerd dat een dergelijk systeem mechanisch te complex is, te zwaar zou kunnen zijn en er werd geschat dat het maken van een kleinere tag in dit onderzoek niet haalbaar zou zijn. Daarom werden andere methoden voor het bevestigen van spelden door kleding verder onderzocht, geprototypeerd, ontwikkeld in meerdere iteratieve cycli, wat leidde tot de uiteindelijk haalbare DPP-tag.

Nanto Secure is het resultaat van een uitgebreide haalbaarheidsontwikkeling. Deze samenvatting schetst de belangrijkste kenmerken en functionaliteit van Nanto Secure

Ontworpen om zowel robusst als moeilijk te verwijderen te zijn door consumenten, garandeert Nanto Secure het behoud van gegevens wanneer klanten kleding kopen. Het bestaat uit twee hoofdcomponenten: een speld die door kleding wordt aangebracht en een vergrendelingsmechanisme dat de speld aan de andere kant stevig op zijn plaats houdt. De interne componenten zijn bestand tegen water en weer, terwijl de buitenschaal is gemaakt van een speciaal hitte- en chemicaliënbestendig materiaal, waardoor de algehele duurzaamheid wordt verbeterd.

Figure 5: Nanto Secure (eigen figuur)

Dankzij de grootte van de interne componenten en het gebruik van een kleine NFC weegt Nanto Secure slechts 3,49 gram, wat vergelijkbaar is met het gewicht van een muntstuk van twee eurocent. Als vijf van dergelijke munten worden gestapeld, is de hoogte van Nanto Secure bereikt. Afhankelijk van het NFC-scanapparaat kan Nanto Secure worden gescand op een afstand van 1-10 cm, wat vrij opmerkelijk is vanwege zijn formaat.

Figure 6: Grootte van Nanto Secure (eigen figuur)

Het gebruik van een speld om DPP-gegevens op kleding te bevestigen, zorgt ervoor dat textiel niet wordt beschadigd en

dat de tag overal op het kledingstuk kan worden aangebracht. Modebedrijven die Nanto Secures gebruiken hebben de flexibiliteit om te kiezen hoe ze het in hun kleding implementeren. Ze kunnen ervoor kiezen om de pin zichtbaar te maken of zelfs hun eigen pins te gebruiken. Bovendien kan Nanto Secure discreet in kledingplooien worden geplaatst om contact met de huid van de klant te vermijden. Modebedrijven mogen Nanto Secure ook op de rand van kleding plaatsen en bedekken met hun eigen label. Een andere mogelijkheid is om de oriëntatie om te keren, waardoor het vergrendelingsdeel zichtbaar wordt, waardoor Nanto Secure als knoop of spijkerklinknagel kan dienen. Deze veelzijdigheid benadrukt Nanto Secure als een veelzijdige DPP-tag.

Bovendien is Nanto Secure ontworpen met het oog op demontage en montage, in overeenstemming met de principes van een circulaire economie. Dit ontwerp zorgt ervoor dat Nanto Secure voldoet aan de criteria voor een verwijderbare, maar niet-verwijderbare en duurzame DPP-tag.

Figure 7: Nanto Secure shell (links) en inside (rechts) (eigen figuur)

De materiaalkosten voor 1 Nanto Secure bedragen €1,33 bij een aantal van 1000. De vaste kosten, zoals de matrijs, nemen af naarmate er meer onderdelen geproduceerd worden. De prijs van één uniek geweven QR-code is € 4,40. Daarom biedt Nanto Secure een meer kosteneffectieve oplossing op basis van materiaalprijzen.

C. Nanto Secure, een wenselijke DPP-tag

Nanto Secure creëert waarde voor verschillende stakeholders door in te spelen op hun wensen en verwachtingen. Grote modemerken kunnen de voorkeur aan Nanto Secure boven QR-codelabels geven, omdat het betrouwbare gegevenstoegang garandeert, waardoor extra marketing-, verkoop- en bedrijfsvoeringskanalen mogelijk worden om de klantervaring te verbeteren. De robuustheid en verwijderbaarheid van de tag door recyclers kunnen merken stimuleren om voor Nanto Secure te kiezen, omdat ze de tags kunnen hergebruiken, waardoor de kosten worden verlaagd. Kleinschalige modemerken profiteren van de mogelijkheid om tags opnieuw te gebruiken, waardoor de investeringskosten verder dalen. Leveranciers en fabrikanten werken samen met Nanto om een circulaire economie te bevorderen door Nanto DPP's te leveren en te produceren. Softwareleveranciers zouden een duurzame en niet-verwijderbare DPP-tag willen gebruiken, zodat hun software ten koste van alles toegankelijk is. Winkeliers kunnen kleding aanbieden met Nanto Secure, zodat de gegevens intact blijven en consumenten zich geen zorgen hoeven te maken over vervagende of irriterende labels. Recyclers en upcyclers profiteren van efficiënte gegevenstoegang, wat een meer circulair recyclingproces mogelijk maakt en een naadloze integratie van tags in upcycled ontwerpen mogelijk maakt. Bestaande duurzame retailers, zoals tweedehandswinkels en modeverhuurbedrijven, profiteren van de betrouwbaarheid van Nanto Secure omdat consumenten meer transparante informatie willen [29]. Reparatiebedrijven vertrouwen op toegankelijke en bewaarde informatie in kleding voor effectieve reparaties. Ten slotte vinden toezichthouders en ngo's waarde in een betrouwbare, duurzame en niet-verwijderbare DPP-oplossing voor het volgen van de duurzame prestaties en claims van modebedrijven. Voor consumenten zal de wenselijkheid van Nanto Secure worden getest in de laatste gegevensverzameling.

D. Nanto Secure, een levensvatbare DPP-tag

Nanto, een B2B-bedrijf, biedt fysieke DPP-oplossingen aan modemerken. Key partners zijn leveranciers, fabrikanten en dataproviders. De belangrijkste activiteiten omvatten productontwikkeling, het aangaan van partnerschappen en marketing-/verkoopinspanningen. Key resources zijn fysieke componenten/materialen en expertise/kennis op het gebied van mode, circulaire economie en technologie.

De value proposition is het leveren van een naadloze en robuuste gegevenstoegang. Nanto biedt een veilige en robuuste DPP-tag die ervoor zorgt dat gegevens beschikbaar blijven gedurende de gehele levenscyclus van kleding. Bovendien kunnen modemerken profiteren van het veelzijdig ontwerp van de Nanto Secure, omdat deze op verschillende manieren kan worden toegepast om aan hun specifieke voorkeuren te voldoen. Of het nu gaat om een speld, een knoop, een klinknagel of bedekt met een label, Nanto Secure zorgt ervoor dat de tag naadloos integreert in het ontwerp van de kleding, met behoud van zowel esthetiek als functionaliteit. En het allerbelangrijkste: het is een facilitator van de circulaire economie. Ten eerste zorgt het ervoor dat gegevens niet verloren gaan nadat consumenten kleding hebben gekocht. Bovendien maakt Nanto een gesloten systeem mogelijk door ervoor te zorgen dat de tag herbruikbaar is en na gebruik kan worden teruggestuurd naar het oorspronkelijke bedrijf.

Klantenrelaties houdt in dat hulp en ondersteuning aangeboden worden aan modebedrijven die Nanto-oplossingen in hun kleding willen implementeren. Kanalen zijn onder meer directe verkoop, partnerschappen en een hergebruiksysteem via een PSS. Klantsegmenten zijn grote en kleine modemerken, upcyclers en modeconsumenten. De kostenstructuur omvat onderzoek en ontwikkeling, productiekosten, marketing-/verkoopkosten en partnerschappen /samenwerkingen. Inkomstenstromen zijn afkomstig van productverkopen, servicekosten en potentiële financieringsmogelijkheden.

E. Enquête

Nanto Secure zal alleen worden getest op modeconsumenten omdat het aantal stakeholders binnen dit onderzoek. Zij zullen degenen zijn die het het meest zullen dragen en ermee bezig zullen zijn. Hiervoor is een enquête ontworpen met Likert-schalen, variërend van 1 tot 5. De enquête meet:

- Relevante ontwerpvereisten voor consumenten van Nanto Secure versus QR-code (paired samples t-test, 95% BI)
- De meest waarschijnlijke kledingtypes waarvoor Nanto Secure en QR-codelabels kunnen worden gebruikt (één steekproef t-test, testwaarde = 3,5/5, 95% BI)
- De verandering in duurzame modeconsumptie nu en wanneer DPP's worden geïntroduceerd (paired samples t-test, 95% BI)

IV. Results

Uit het onderzoek (N=51) voor modeconsumenten kan geconcludeerd worden dat Nanto secure moeilijker te verwijderen is ($t(48)=3.463$, $p<0.001$) en een hogere robuustheid heeft ($t(47)=5.190$, $p <0,001$) in vergelijking met aan 4 zijden ingenaaide QR-codes. Dit was het hoofddoel van de ontwerpeisen.

Voor beide concepten (Nanto Secure & QR-code) zouden consumenten mogelijk niet een van deze twee DPP's willen verwijderen, ongeacht hun waarde ($t(48)=3,463$, $p = 0,735 >0,05$); consumenten vinden beide oplossingen mogelijk niet lelijk ($t(49)=1,136$, $p = 0,262 >0,05$); de omvang van beide concepten is mogelijk niet te groot ($t(49) = 1,376$, $p = 0,175 >0,05$); en beide oplossingen zouden mogelijk niet leiden tot een allergische reactie ($t(49) = -0,401$, $p=0,690 >0,05$).

Aan de andere kant vertoonde het QR-codelabel op andere aspecten een significant verschil. Het is duidelijker dat de QR-code kan worden gescand in vergelijking met Nanto Secure ($t(49) = 8,463$, $p<0,001$). Nanto Secure is dikker dan de QR-code ($t(47) = -7.948$, $p<0.001$). Nanto Secure zou hen meer kunnen irriteren als het hun huid aanraakte in vergelijking met het QR-codelabel ($t(49) = 8,463$, $p<0,001$). Ten slotte is het belangrijker dat Nanto Secure op de juiste locatie wordt geplaatst in vergelijking met het QR-codelabel ($t(49) = -4,140$, $p<0,001$).

Consumenten gaven in dit onderzoek aan dat Nanto Secure gebruikt kan worden voor jeansbroeken, blazers, winterjassen, mantels, vesten, sweaters en rugzakken. Volgens consumenten is de QR-code veelzijdiger en kan deze gebruikt worden op elke ondervraagde kledingcategorie behalve sjaals en zwemkleding. De beperking van deze enquête is dat het waargenomen antwoorden zijn, waarbij het testen en voelen van een dergelijk object in het echte leven door de gebruiker meer objectieve resultaten zou opleveren.

Bovendien kan, ongeacht hoe een fysieke DPP-tag eruitziet, via het onderzoek worden geconcludeerd dat een DPP een positieve invloed heeft op het duurzame modegedrag van de mogelijke toekomstige consument in vergelijking met zijn huidige duurzame gedrag.

V. Discussion

Door naar deze resultaten kijken, lijkt het erop dat de huidige situatie voor consumenten is verslechterd door de introductie van Nanto Secure. Dit kan worden verklaard door een gebrek aan relevante voorbeelden waar deze tag bijvoorbeeld kan worden geplaatst of hoe het ontwerp het dragen van kleding zou beïnvloeden.

Maar deze nadelen kunnen mogelijk worden verholpen door de volgende ontwerpwijzigingen op te nemen. Door het ontwerp van Nanto Secure kan het worden afgedekt met een klein geweven label, wat in deze survey niet is uitgelegd. Dan raakt het de huid niet, kan het de richting bepalen (speld naar binnen of naar buiten gericht) en kunnen modebedrijven beslissen wat ze op het label willen weergeven. Als voordeel dat het kan worden gescand, kan er een klein NFC-logo in dergelijke labels worden geweven. Het is ook mogelijk Nanto Secure te plaatsen in plooien, hoeken of als vervanging van bestaande onderdelen.

VI. Conclusion

Door de resultaten kan een antwoord worden gegeven op de onderzoeksvraag:

'Hoe een nieuw en innovatief modebedrijfsmodel introduceren dat tot doel heeft de milieu-impact van de mode-industrie te verminderen op basis van de EU-richtlijnen voor ecodesign?'

De introductie is mogelijk door in te zetten op de ESPR van de Europese Commissie om een circulaire economie te bereiken. Nanto faciliteert deze regelgeving door ervoor te zorgen dat het gedurende de hele levenscyclus van kleding scanbaar blijft. Innovatie is onderzocht door middel van circulariteit, haalbaarheid, wenselijkheid en levensvatbaarheid.

VII. Future work

De ontwikkeling van ontwerpregels voor het ontwerpen van een digitaal productpaspoort (DPP) in kleding heeft de basis gelegd voor verdere verkenning. Om de effectiviteit van het raamwerk te valideren en te verfijnen, moeten real-life use cases worden getest en herhaald. Het uitvoeren van uitgebreide gebruikerstesten voor Nanto Secure is cruciaal om robuuste feedback te verzamelen en de bruikbaarheid van DPP-oplossingen te garanderen voor toekomstige implementatie vanaf 2030. Dit omvat het testen van het product onder verschillende omstandigheden, zoals blootstelling aan water, stof, olie en hitte.

Vanwege tijdgebrek waren enkele belangrijke stakeholders niet volledig betrokken bij dit onderzoek. Het betrekken van recyclers en het verkennen van efficiënte scan- en verwijderingsmethoden voor DPP-oplossingen is essentieel om de circulaire economie te ondersteunen. Samenwerking met modebedrijven, mogelijk via partnerschappen met studenten modeontwerp, kan ook vruchtbare resultaten opleveren bij het verwerken van DPP-concepten in kleding.

Bovendien zou het uitvoeren van een levenscyclusanalyse (LCA) nuttig zijn om de milieu-impact van Nanto Secure en QR-codes te vergelijken, met name gezien de hergebruikfactor van Nanto Secure. Deze beoordeling zou helpen de vermindering van kooldioxide-equivalenten te kwantificeren en milieubewuste besluitvorming te ondersteunen.

Hoewel de studie zich voornamelijk richtte op materiaalkosten, is het cruciaal om een alomvattend financieel plan te ontwikkelen dat rekening houdt met alle vaste en variabele kosten, winstmarges en het break-evenpunt. Het opnemen van deze parameters in een bedrijfsmodel zou een beter inzicht geven in de economische levensvatbaarheid van het implementeren van DPP-oplossingen.

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Table of content

1: Introduction ____ *1*

1.1: The Impact of the fashion industry ____ **2**

1.2: European Commission's proposals ____ **3**

1.2.1: What is a Digital Product Passport? ____ 4

1.2.2: Prioritization ____ 5

1.3: Product Service Systems ____ **6**

1.3.1: Definition ____ 6

1.3.2: Link between PSS and DPP ____ 7

1.4: What is a circular economy? ____ **7**

1.5: Research question ____ **8**

1.6: Scope ____ **9**

2: Methodology ____ *10*

2.1: Design Thinking ____ **11**

2.2: The innovation sweet spot 1.0 ____ **12**

2.3: The innovation sweet spot 2.0 ____ **13**

2.4: Methodology throughout this study ____ **14**

3: Summary of Discover and Define ____ *15*

4: Develop ____ *18*

4.1: Life-cycle of clothing ____ **19**

4.2: Stakeholders of DPP's ____ **20**

4.2.1: Core Stakeholders ____ 21

4.2.2: Direct stakeholders: ____ 22

4.2.3: Indirect stakeholders: ____ 24

4.3: The development of design requirements ____ **25**

4.3.1: Design requirements: ____ 26

4.3.2: Verifying design requirements ____ 30

4.3.3: Wicked problem ____ 31

4.3.4: Conclusion design requirements ____ 32

4.4: Weighted decision matrix ____ **33**

4.5: Benchmarking ____ **35**

4.5.1: Software providers ____ 35

4.5.2: QR codes ____ 38

4.5.3: NFC ____ 45
4.5.4: RFID ____ 49
4.5.5: What about other identifications? ____ 50
4.5.6: Conclusion benchmarking ____ 52

4.6: Brainstorm ____ 53
4.6.1: Idea 1, NFC in patch ____ 54
4.6.2: Idea 2, NFC in iron-on patches ____ 57
4.6.3: Idea 3, Security pins ____ 58
4.6.4: Idea 4, Mandatory digital wardrobe ____ 61
4.6.5: Idea 5, NFC in existing parts ____ 62
4.6.6: Conclusion brainstorm ____ 65

5: Deliver ____ 68

5.1: Nanto secure, a Circular DPP tag ____ 71

5.2: Nanto secure, a Feasible DPP tag ____ 74
5.2.1: Researching pins ____ 74
5.2.2: Approach ____ 76
5.2.3: Iteration 1, spring-loaded ____ 77
5.2.4: Brainstorming other locking systems ____ 80
5.2.5: Iteration 2, snap joints ____ 88
5.2.6: Styling ____ 94
5.2.7: Bill of Materials (BOM) ____ 101
5.2.8: Production plan, assembling and disassembling ____ 102
5.2.9: Summary of feasibility study of Nanto Secure ____ 105

5.3: Nanto secure, a Desirable DPP tag ____ 106

5.4: Nanto secure, a Viable DPP tag ____ 109

5.5: Data collection ____ 116
5.5.1: Research goals ____ 116
5.5.2: Research design ____ 117
5.5.3: Data collection ____ 117
5.5.4: Data analysis ____ 119
5.5.5: Results & implications ____ 122
5.5.6: Reflection ____ 126

6: Conclusion ____ 127

7: Sustainability analysis ____ 132

8: Future work ____ 136

9: References ____ 138

10: Appendix ____ *145*

Appendix A: Prioritization ____ **145**

Appendix B: Circular Economy ____ **145**

Appendix C: Summary of Discover and Define ____ **145**

History of the fashion industry ____ 145

Benchmarking: ____ 145

Data collection 1 ____ 145

Define iteration 1 ____ 145

Define iteration 2 ____ 145

Appendix D: Life-cycle of clothing ____ **146**

Appendix E: NFC ____ **146**

Appendix F: Data sheet PPS and 316L stainless steel ____ **150**

Stainless steel: ____ 150

PPS: ____ 151

Appendix G: Snap joints parameters ____ **154**

Appendix H: Styling ____ **157**

Appendix I: Bill of Materials (BOM) ____ **157**

Appendix J: Data collection ____ **160**

List of acronyms

B2B = Business to Business

B2C = Business to Consumer

BM = Business Model

BMC = Business Model Canvas

CBM = Circular Business Model

CEAP = Circular Economy Action Plan

DPP = Digital Product Passport

DT = Design Thinking

ESPR = Ecodesign for Sustainable Products Regulation

EU = European Union

PSS = Product Service System

RQ = Research Question

1

Introduction

1.1: The Impact of the fashion industry

10% of global carbon emissions come from the fashion industry which is more than the emissions of international flights and maritime shipping combined [1]. Further, due to the dominance of the fast fashion trend, global clothing consumption has doubled over the previous 20 years, while average wear duration has decreased by 50% [1]. The fashion industry has realized growths driven by the fast fashion business model favoring trendiness and low prices. Its economic value discourages most brands from adopting circular economy practices [2]. This contributes to global warming which has resulted in a 1,1°C increase above pre-industrial levels [3]. Besides global warming, the fashion industry has an environmental impact too. For example, 79 billion cubic meters of water was used by the textile and clothing industry in 2015 [1].

When examining the consumption of textiles in Europe, it is noteworthy that it ranks fourth in terms of environmental and climate change impact, following food, housing, and mobility [4], [5]. It represents one of the top three contributors to water and land usage pressure and is among the top five for raw material use and greenhouse gas emissions. The annual average textile waste is approximately 5.8 million tons, equivalent to 11.3 kilograms per individual, with only 1% of materials used for clothing production being recycled [1], [4]. Despite this, the textile and clothing industry is an essential component of the European Union, employing over 1.5 million people and creating new business opportunities [5] For example, the collection of 1000 tons of textiles for reuse in the EU generates an average of 20 to 35 jobs [5].

This confirms that the textile and clothing industry involves unsustainable business models by relying on non-renewable resources, clothing underutilization and inadequate disposal, high greenhouse gas emissions, and exploitation of cheap labor.

1.2: European Commission's proposals

The European Commission is aiming with new proposals, such as the Circular Economy Action Plan (CEAP) and Ecodesign for Sustainable Product Regulation (ESPPR) to make sustainable products the norm in the EU and to boost circular business models. This strategy is part of the European Green Deal, which aims to turn the European Union (EU) climate-neutral by 2050 .

The Circular Economy Action Plan (CEAP), introduced in March 2020, is one of the main building blocks of the European Green Deal. The European Commission is proposing new rules so almost all physical goods on the EU market become more circular throughout their whole lifecycle. This from the design phase, production, packaging, transportation daily use, repurposing and end-of-life. The European Commission aims to reach a circular economy by [6]:

- Designing products to last longer, be easier to reuse, repair, and recycle, and to be made with recycled materials.
- Consumers will be empowered with access to reliable information about repairability and durability. Manufacturers will be required to design products that are easier to repair and to provide spare parts and repair manuals to independent repairers.
- The EU aims to avoid waste altogether and transform it into valuable resources. The European Commission will analyze waste labeling and focus on sectors such as textiles, batteries, vehicles, plastics, packaging, food, construction, and buildings, where circularity potential is high.

To fulfill the aim of the CEAP, other legislations and frameworks are put in place, such as the Ecodesign for Sustainable Products Regulation (ESPR) and EU Strategy for Sustainable and Circular Textiles. The Ecodesign for Sustainable Products Regulation (ESPR) is in its proposal stage and was published in March 2022. It closely works together with the CEAP. This framework will set guidelines on multiple characteristics such as product durability, reusability, resource efficiency and carbon footprints. The key mechanism for capturing and sharing this data is a **Digital Product Passport** solution that will provide multiple stakeholders with a detailed breakdown of the products' sustainability scores [7].

The EU Strategy for Sustainable and Circular Textiles is in the implementation stage as of March 2022 and is another key area of the CEAP. The key goal is to essentially improve the longevity and durability of textiles and to increase the ease of repair and recycling [4]. **Digital Product Passports** will be utilized as the key solution for enabling this mechanism and achieve a circular economy.

Both proposals aim to introduce a Digital Product Passport, the ESPR focusses on many more product categories including toys, fish nets, rubber tires and toys whilst the Sustainable and Circular Textiles only focusses on textiles.

1.2.1: What is a Digital Product Passport?

The definition of a DPP were extracted from [7]–[10]. A DPP is a unique product identifier that will make it easier to reuse, repair, refurbish, redistribute or recycle products by facilitate tracking it along the supply chain. The passport will also provide information about products' environmental sustainability and help public authorities perform checks and controls. The tool electronically registers, processes, and shares product-related information amongst value chain actors, authorities, consumers and others. It aims to increase transparency.

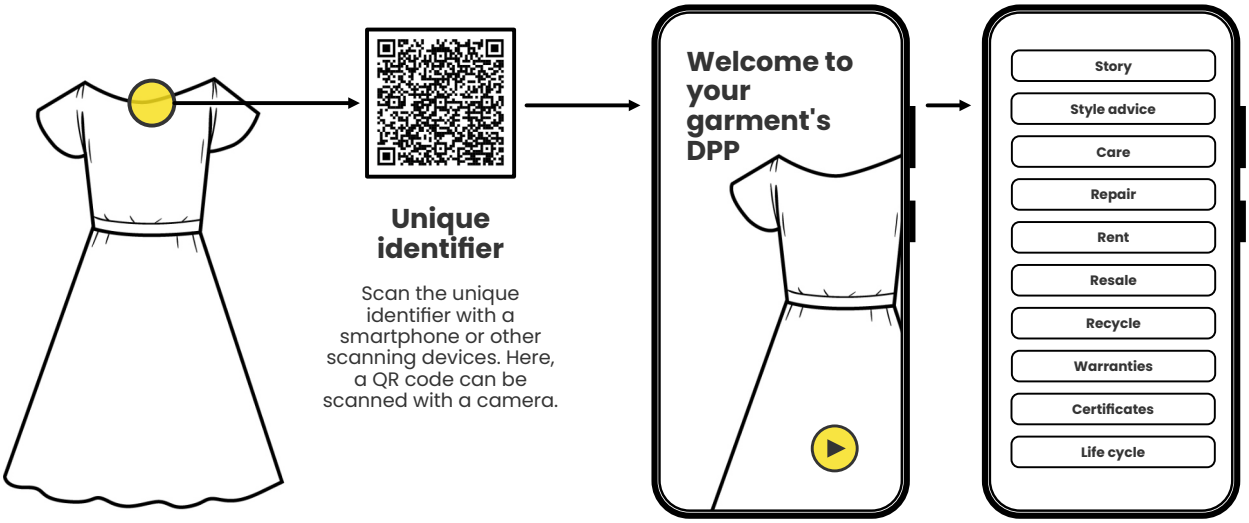


Figure 1: Example of a DPP (own figure)

The Digital Product Passport concept will evolve over time in terms of utility, but in its current form, it is largely being scoped and utilized within sustainability, recyclability and environmental initiatives, all of which fall under the circular economy. Ultimately, Digital Product Passports provide multiple stakeholders throughout the whole life-cycle of products with a full list of events and transactions that have occurred through a product's life. This will continue to scale as more businesses dive into the technology and understand its potential. A digital product passport can serve as a communication tool between various stakeholders. For example, it allows repairers to document their findings, recommendations, and repair progress, which can be shared with the customer and the original manufacturer. This transparency fosters trust and ensures clear communication, helping to manage customer expectations and build long-term relationships.

For example, details of the actual repair and cost, along with any supplementary notes to build context of why repair was required in the first instance will be part of a DPP. Furthermore, digital versions of warranty, service and insurance documentation can be stored within the passport and accessed by relevant parties.

1.2.2: Prioritization

As part of the ESPR, the European Commission did a preliminary study [11] on what product categories should get prioritization when creating DPP frameworks, which will be finally introduced in 2030. This means that exactly what data need to be captured in a Digital Product Passport is still under construction.

The study [11] analyzed what product categories, such as textiles and footwear, toys and bed mattresses have the largest environmental impact. This was calculated based on 10 different parameters including water usage, waste, material efficiency and lifetime extension. The lowest score a product category could get, is a 1. The largest a 5, meaning a large environmental impact. Therefore, the maximum score a product category could get, is 50.

The outcome of this study [11], which can be found in appendix A, suggests that the Textile and footwear industry has the highest environmental score of 43/50, 13 points higher than the second highest-scoring product groups (furniture and ceramic products). The previously mentioned Circular Economy Action Plan, the Textile strategy and the EU Industrial Strategy also identified this industry as a " key product value chain with an urgent need for action and a strong potential for the transition to sustainable and circular production, consumption and business models"[4]. Because textiles and footwear pose the largest environmental impact from these product categories, it is prioritized in creating frameworks and legislation as part of the ESPR.

1.3: Product Service Systems

1.3.1: Definition

Besides circular proposals of the European Commission, there exist other ways to reach circular economy. One of such strategies are Product Service Systems (PSS) [2], [12]. This concept will be explained through [13]–[15]. This concept adds an intangible service to tangible products . In a product-service (PSS), the usefulness of a product and its accessibility are more important than ownership. The focus is on the function, not on the ownership. Product services have great ecological potential because they help ensure that a smaller quantity of finished product is better utilized, while being processed better in the disposal phase by the manufacturer who, in principle, continues to be the owner. The implementation of a PSS not only give products a longer working life but also make them reusable. The manufacturer also stays the owner of its materials and, as a result, is less affected by fluctuations on the raw materials market. Product-service systems can mean more careful use of materials and products. In linear business models, manufacturers generate turnover by selling as many products as possible. The transfer of ownership from manufacturer to consumer involves too little inducement to design products with a long life, to allow them to be easily repaired, or make it easy to recycle their components.

Three types of PSS can be identified:

1. **Product-oriented services**: The heart of the business model is still the sale of goods, but it includes one or more additional services.
2. **Use-oriented services**: The traditional product is still a key aspect here, but the business model no longer aims at its sale. The product remains the property of the supplier.
3. **Result-oriented services**: In this business model, the supplier and customer have an agreement about a certain result, without an agreement about which specific product is needed to achieve this result.

The three PSS types can be ranked according to their circularity [16] whereas result-oriented PSS are the most circular, followed by use-oriented and then product-oriented. This is because of the shift in ownership from customer to business. But use-oriented and product-oriented PSS are more promising and feasible than results-oriented PSS for starting the transition to a circular business model [2]. Results-oriented PSSs go along radically changing existing industry practices and consumer habits, as long the focus is solely on specific results that product-service combinations could generate for consumers.

1.3.2: Link between PSS and DPP

Because of the PSS definition, a DPP as defined by the European Commission can be categorized as a PSS. First, DPP's add services to a tangible product. The service is the access to DPP information and creating additional repair/care/recycle services. The tangible product is, depending on the viewpoint, the unique identifier or the piece on clothing. Second, they both aim to reach a circular economy where products are better utilized and processed better in the disposal phase. In the context of a DPP for fashion, clothing will be better utilized by various stakeholders. For example, consumer can make more informed decisions, have access to more relevant information such as share, reuse, repair and disposal instructions. Recyclers will have detailed material information to make recycling happen more efficiently.

1.4: What is a circular economy?

A circular Economy aims to keep materials and components in use at their highest value at all times [17]. It aims to transform from the current linear economy to a circular economy is necessary to tackle global challenges like climate change, biodiversity loss, waste, and pollution. It aims to keep materials and components in use at their highest value at all times.

To illustrate the circular economy, the Ellen MacArthur Foundation [17] developed the butterfly diagram. This framework shows the continuous flow of materials in two cycles. The biological cycle on the left illustrates how the nutrients from biodegradable materials are returned to the ecosystem while rebuilding natural capital. The technical cycle on the right explains how objects are being kept in circulation as long as possible. Action in the center, such as sharing and maintaining are less material and energy intensive as the ones more at the end, such as remanufacturing and recycling.

The butterfly diagram can be found in the appendix B, as well as a description of what each technical cycle's strategies actually implies.

1.5: Research question

The problem highlighted in the image below is the loss of crucial information once customers acquire clothing [8]. Consequently, the European Commission proposes the implementation of Digital Product Passports (DPPs) to ensure the preservation of scannable information throughout the entire life cycle of garments.

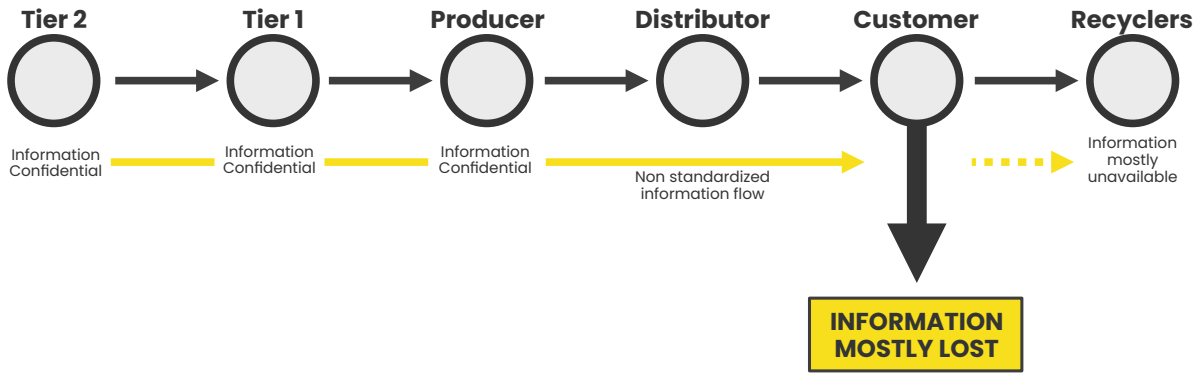


Figure 2: Information flow in a linear economy
Source: Adapted from [8]

Initially, it may appear that the research question revolves around feasibility: Is it feasible to develop a DPP solution that maintains information within clothing throughout its life cycle? However, such a solution is more intricate than initially perceived since it requires engagement with multiple stakeholders to address the problem comprehensively. Therefore, adopting a systematic approach, the aim is to develop a new and innovative business model to solve this problem. Thus, the research question (RQ) is as follows:

How to introduce a new and innovative fashion business model that aims to decrease the environmental impact of the fashion industry based on the EU eco-design directives?

Sub-research questions:

- What are the key stakeholders in the value-chain within the context of fashion DPP implementation?
- How to design a DPP in clothing which prevents to get lost?

1.6: Scope

In order to ensure the feasibility of this study, a specific scope will be established. Firstly, the focus of this study will primarily be on fashion consumers, who will be the main users of the digital product passport (DPP) and interact with it on a regular basis. Although other stakeholders in the value chain will be considered, their involvement will be limited to relevant data utilization.

Secondly, the implementation of DPPs in shoes will be excluded from the scope as it warrants a separate study in itself. The study will concentrate on various clothing items, including t-shirts, shirts, jeans pants, blazers, dresses, winter jackets, coats, vests, sweaters, scarfs, beanies, and caps.

Thirdly, the study will only encompass adult garments, excluding baby, children, elderly, and work-related outfits such as medical garments. The primary focus regarding textile types will be on woven textiles. While the study will explore circularity, a comprehensive life-cycle analysis will not be conducted due to time and resource limitations. However, an estimation of material-related costs will be provided, while a detailed financial plan will not be developed within the given time constraints.

Also, designing the interface of the DPP is out of scope, just as how data should be protected from users.

2

Methodology

2.1: Design Thinking

This research relies on a design thinking (DT) methodology to find a possible solution for the problem. DT consists of 4 distinct phases: discover, define, develop and deliver [18]. DT has been gaining momentum as an innovation method that allows organizations to reach breakthrough innovations [19] Moreover, recent research suggests that DT plays a central role in driving innovation [19], [20]. DT is based on two principles, diverge and converge which are applied in four distinctive phases [18].

Within the discovery phase, the goal is to diverge from the original problem in order to find the right problem to solve. This will be achieved by gathering as much information as possible regarding the research topic. Reading relevant papers, data, surveys and interviews are needed to discover the needed information. Next is the define phase. Once the needed information is available will it be converted to a new problem definition. The third phase, develop, several solutions to the new problem definition will be ideated. The last phase is deliver, where one or many ideas are build, tested, iterated and/or combined if necessary to eventually further refine to the final idea.

Furthermore, this study relies on 'Design 4.0', which is design for a social transformation as part of wicked problems [21]. Here, tools of human centered design and business consultancy are blended together to employ a system-oriented thinking to look at the bigger picture such as stakeholders, environment and business cases.

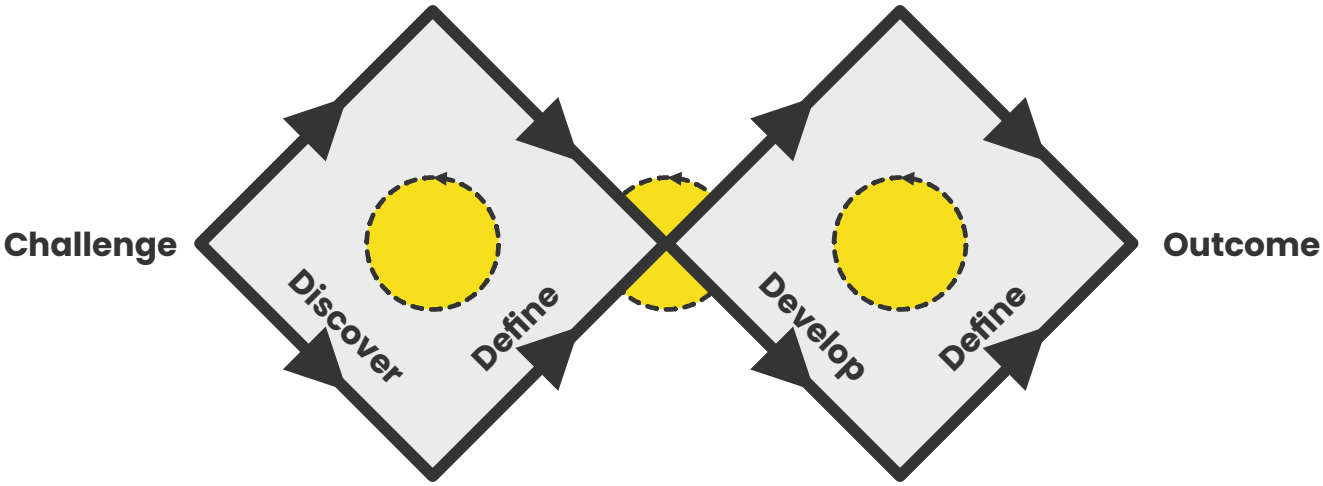


Figure 3: Design Thinking
Source: Adapted from [18]

2.2: The innovation sweet spot 1.0

Design thinking is a process that aims to create a solution that is desirable, feasible, and viable [21]–[24]. This means that the product should meet the user's needs, be possible to implement, and have a financial model. The innovation sweet spot is the trifecta of desirability, feasibility, and viability [21]. By focusing on all three aspects of the design process, it can ensure that your solution is not only desirable to the users but also feasible and viable in the long run.

Desirability is about **creating and delivering value** to customers, stakeholders or actors based on their needs [22], [23]. Testing desirability is possible by understanding preferences, expectation, pain points and gaining **empathy** with users, consulting experts within the industry, other valuable stakeholders and relevant data online. They could have a better idea how a system may work and if the solution may fit within it [23], [25].

Feasibility refers to the practicality of implementing a proposed idea. It involves evaluating whether the proposed idea can be developed within the available resources, such as **time, budget, and expertise** [22], [23], [26]. Feasibility is an important consideration when making decisions about product development and business strategy to ensure that the idea is practical and achievable [23].

Viability is analyzing and creating a unique **value proposition**. Furthermore, the potential revenue sources, stakeholder maps, cost structure, and if it is a sustainable business should be taken into account too [22], [23]

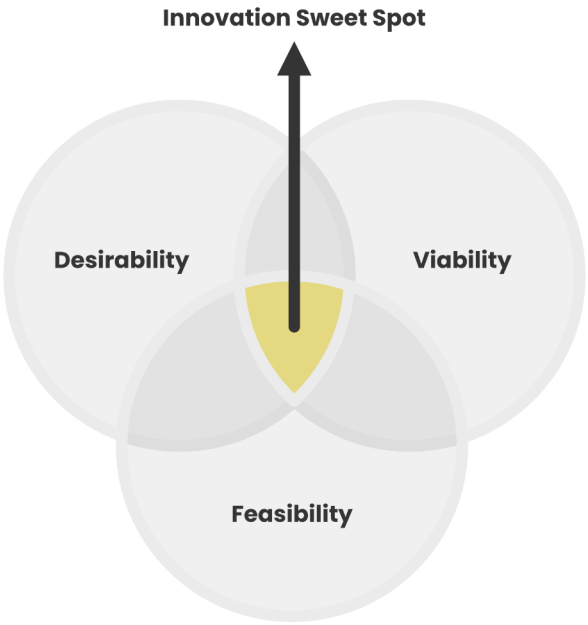


Figure 4: The innovation sweet spot
Source: Adapted from [27]

2.3: The innovation sweet spot 2.0

If solutions are introduced on the market that don't address sustainability, then product, services or a combination of both (Non-S-PSS), then those solutions lack a factor of sustainability [26], [27]. For example, Meta (the company behind Facebook, WhatsApp, Instagram) created a perfect balance between desirability, viability and feasibility because Facebook has over 1,3 billion monthly users, 5 billion videos are watched on YouTube every day, and 3h per day per person is spent on various social media platforms. The other side of the story is that 210 million people suffers from social media addictions, social media platforms run on data centers that consume immense amounts of energy, and that 50% of people use their smartphone whilst driving [27]. Because of these reasons, sustainability needs to be the fourth factor in in creating innovation[26], [27]. In this study, circularity is substituted for sustainability to accommodate the European Commission's regulations for reaching a circular economy.

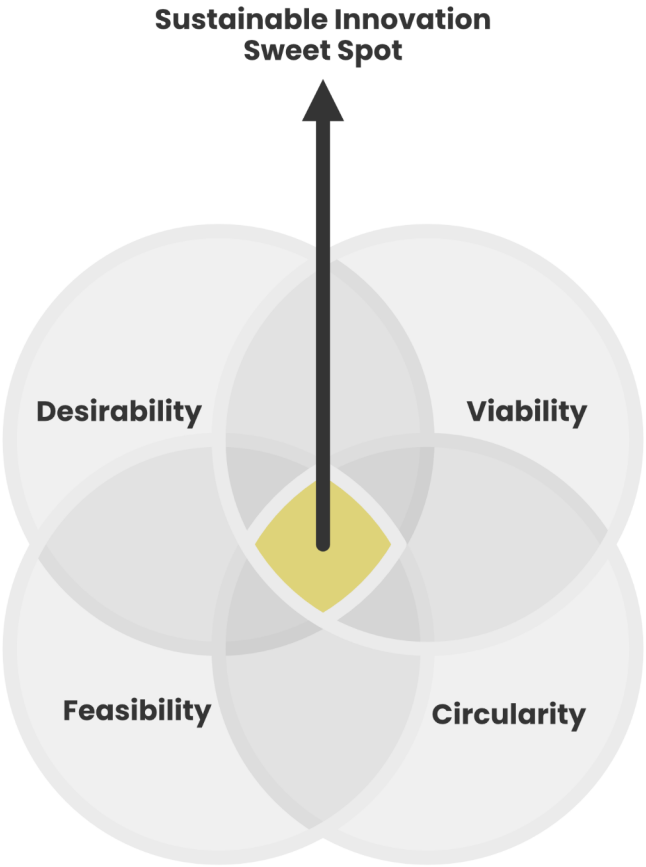


Figure 5: The innovation sweet spot 2.0
Source: Adapted from [27]

2.4: Methodology throughout this study

Throughout this study, various diverge and converge phases have been conducted. The discover and define phase, which involved a comprehensive and systematic exploration of the fashion industry and consumer engagement, will be discussed in the upcoming section. Numerous concepts were explored, ranging from the development of a fashion rental business model to the creation of sustainability awareness plug-ins. Therefore, the focus of the next part will be specifically on the contributions of the fuzzy front end to the development of a Digital Product Passport (DPP) in clothing.

The study truly begins at the develop phase, where design requirements were established to navigate the complex European legislations. It became evident that developing a DPP for clothing is a challenging and even a wicked problem. Benchmarking and brainstorming were conducted to explore potential DPP 'solutions', and a weighted distribution matrix was employed to combine the most promising aspects from the benchmarks and brainstormed ideas into a single concept. Two build-test-learn iterations were performed as part of the feasibility study. Once completed, the circularity, viability, and desirability of the concept were identified, leading to the creation of a new and innovative business model.

Finally, assumptions and hypotheses were tested through a comprehensive survey targeting fashion consumers, aiming to validate the final concept and establish its credibility.

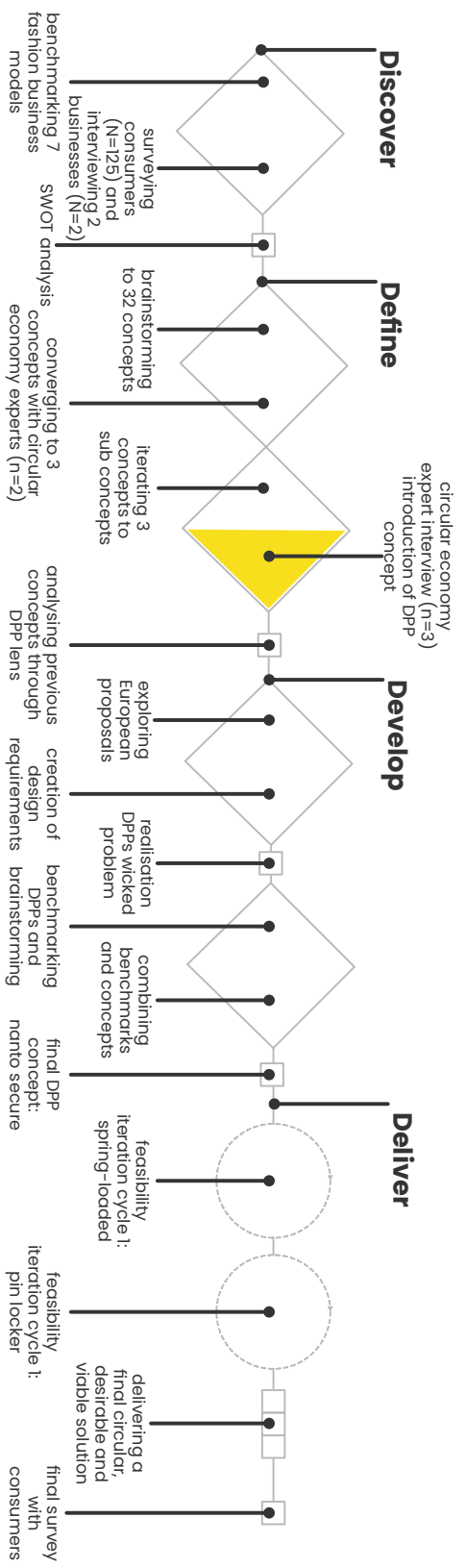


Figure 6: Methodology throughout study (own figure)

3

Summary of Discover and Define

First, before working on DPP's, the study started by understanding the fashion industry through a systematic lens. This happened by understanding the history behind the fashion industry and how it came as it is today. Also, **benchmarking** happened by researching Belgian and foreign fashion (PSS) businesses besides 'traditional' stores. These can be categorized as fast fashion, ultra-fast fashion, buying sustainable fashion, buying second-hand (product-oriented S-PSS), fashion rental (use-oriented S-PSS), peer-to-peer renting (use-oriented P-PSS), and digitization of wardrobe (result-oriented S-PSS). Studying polar or extreme cases, such as these business models, facilitates the identification of unique patterns that are critical for novel findings [28]. Second, based on these benchmarks, consumers (N=125) have been **surveyed** and businesses (N=2) have been **interviewed** to make a SWOT analysis for each business model. One fashion rental platform was interviewed and a store who sells sustainable clothing. Third, these findings provided the basis for **brainstorming** concepts in the define phase. This happened in **2 iteration cycles**. The first brainstorming cycle generated 32 different concepts. Those were rated, based on the DVFC (desirability, viability, feasibility, circularity) framework to converge to 3 concepts. During the second iteration, these were further developed and also rated based on the DVFC framework by **3 circular economy experts**. Now, the concepts from the second iteration were converged to **1 final concepts**. This will be further defined in the develop and deliver phase.

A detailed explanation of benchmarking, the first data collection and iteratively developing various concepts can be read in appendix C. This appendix is large, about 70 pages. Therefore, in this part, the most relevant conclusions are mentioned according to the development of a DPP.

During the first data collection, an interview was conducted with a Belgian fashion rental platform. Here, they are doing a pilot project implementing a DPP into their clothing to link physical items to their digital equivalent for efficient stock management and improved logistics. They conducted a pilot project with 100 items by sewing customer QR codes as labels, but this approach proved to be time-consuming and costly and they are looking for other solutions for implementing DPP's in their garments. This tells that companies are already doing DPP pilot tests to be prepared for the future, which could tell something about the opportunities DPP solutions could bring.

In the second iteration, the several iterated concepts proposed were analyzed, and a recurring theme of digitization was observed. The interview with a fashion circular economy expert made it clear that such solutions could be framed in the upcoming

DPP frameworks, which were previously lacking for fully believing in further developing such concepts. For example, Concept 21 of the first iteration, "New label rentable fashion," could benefit from DPP, which would allow for tracking along the rental cycle and improve inventory management. Similarly, Concept 2 from the second iteration could also be enhanced by the use of DPP, providing customers with valuable information about the garment's history and material composition. **However, the challenge is making sure that the DPP is accessible at all time for consumers, as labels and care instructions may fade over time or are easily removed by them.**

As a result, the implementation of DPPs introduces a new direction for the study. The research will now explore the concept of DPPs and focus on the physical implementation in clothing, considering the practical aspects of the solution.

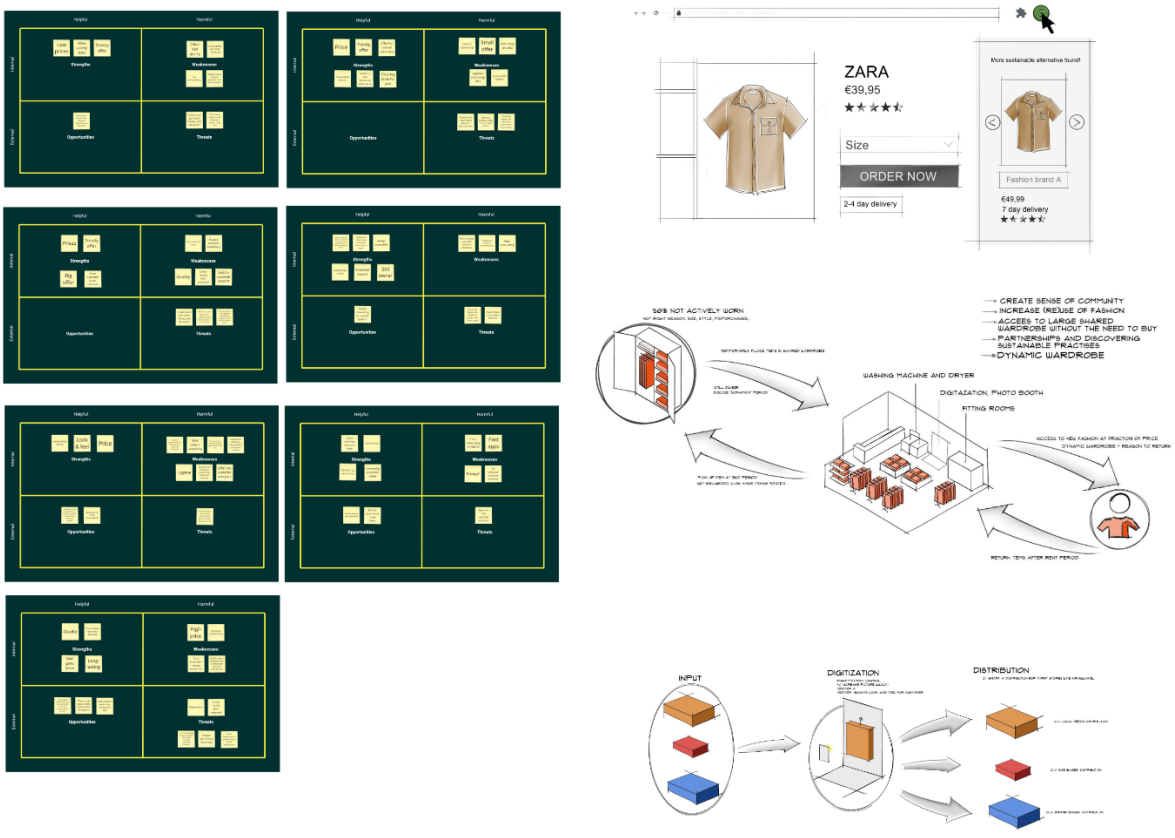


Figure 7: SWOT analysis and 3 final concepts from define (own figure)

4

Develop

The fashion DPP tag will be developed based on the 4 previously used parameters: feasibility, desirability, viability and circularity. The goal is to develop a tag that incorporates all the design requirements perfectly.

It's important to note that during the development phase, objective data has been collected by talking to key stakeholders. They include:

- Three experts within the hardware development
- One expert in ecodesign
- One innovation project engineer at a Belgian fashion manufacturer
- 22 fashion 'consumers': An alumni event, of the industrial design engineering education in Kortrijk from Ghent University was held on the 22nd of April. The organization allowed students to present their thesis' work-in-progress but it was possible to organize user tests to gain valuable insights and feedback. This will be possible in two timeframes of 2h. During the first session, potential students and their parents will visit this booth whilst alumni will visit this booth during the evening session. In total, 22 participants were shortly interviewed.

Because the encounters where sporadic, their input and expertise will be included where needed in a qualitative way. Furthermore, explanation will be backed by data from previous research.

4.1: Life-cycle of clothing

According to [29], the life-cycle of clothing can be divided in 7 distinct phases: raw material extraction, fabric manufacturing, clothing manufacturing, retailing, use, and end-of-life. A digital product passport should be implemented before clothing are in use [8]. Therefore, a DPP could be integrated from clothing manufacturing phase during the assembly. All relevant information from previous phases, such as material composition, where and by whom it was made can be uploaded to the DPP in that phase. This means that a DPP tag should be designed with assembly in mind. The image of the life-cycle of clothing can be found in Appendix D. This is right after the 70 pages long Appendix C.

4.2: Stakeholders of DPP's

Stakeholders are people, groups, or organizations who have an impact on the company's operations and performance. These may be external, such as clients, suppliers, governmental organizations, and the neighborhood, or internal, such as staff.

A possible framework to identify the stakeholders, is to frame them into 3 categories [30]. Those are **core stakeholders**. These stakeholders are crucial to the success of a project or business because they have a close and direct contact with it. They significantly affect both the ongoing success of the company or project and its day-to-day operations. **Direct stakeholders** fall into the second type. They are those who are immediately impacted by a project's or business's operations. Even though they may not be directly connected to the company or project, they have influence in a company's operation. The last category are **indirect stakeholders**. These are stakeholders who are not directly affected by the activities of a business or project, but they may still have an interest or concern.

Figure 8: Stakeholder map of Nanto (own figure)

4.2.1: Core Stakeholders

Large fashion brands: They are the primary stakeholders in the current fashion industry and would be responsible for uploading and managing the digital product passport. Examples of large fashion brands are Nike, Chanel or Hugo Boss to more sustainable oriented ones such as Patagonia. They would be required to provide information about the materials used, production processes, instruction manuals, and environmental impact of their products [7]–[10]. Furthermore, they will greatly benefit from DPP's because through additional services, they can create better customer relationships [10]. Also, they are informed if for example something gets repaired and why that happened. Because of this information, they can make their next products better.

Small scale fashion brands: In a current landscape, those are the small scaled fashion designers who release and sell fashion in small quantities. Just like large fashion brands, they should also get the same benefits as first-party fashion brands. They have the disadvantage that they don't produce in large quantities.

Upcyclers: This is different to fashion recycling. Recycling involves breaking down materials to their raw components, while upcycling involves creatively repurposing materials to create new products [17]. The addition of upcyclers as a core stakeholder is based on an interview with a fashion circular economy expert. By being part of the DPP ecosystem, fashion upcyclers can access important information about a product's materials, design, and manufacturing processes, which can help them determine how best to transform and repurpose it. This information can also help them make informed decisions about which materials to use and how to repurpose products to be more sustainable. Moreover, fashion upcyclers can also contribute to the DPP ecosystem by providing feedback and insights on the design and production processes of products. This feedback can help manufacturers and retailers make improvements to their processes to make them more sustainable and reduce waste. This is also a core stakeholders because just like large and small scale fashion brands, they also introduce 'new' clothing on the market. The expert mentioned that such stakeholders will be key to achieve a circular economy in a DPP context.

Suppliers and Manufacturers of DPP tag: For the development of a physical DPP tag, they will provide the right components and materials to make and produce the tag itself.

Data provider: They provide the software for Digital Product Passports and allow continuous operation between stakeholders. The scope of this study is not to design

the DPP interface itself, only the physicality of it. Also, there already exist several DPP software providers. This will be further researched in the benchmarking chapter.

4.2.2: Direct stakeholders:

Retailers: Retailers play a significant role in the fashion industry and would also be responsible for communicating information about the digital product passport to consumers. They would also need to ensure that the information provided by fashion brands and manufacturers is present in clothing. Furthermore, online retailers should make it possible that DPP information is available online, whilst physical retailers should make sure customers can have access to the data.

Consumers: Consumers are an essential stakeholder in the fashion industry, and they would benefit significantly from having access to a digital product passport. DPPs are a way of providing detailed information on the sustainability of a product, including its manufacturing processes and the materials used. This helps consumers to make informed decisions about the products they are buying, and to choose brands that align with their values around sustainability. It can be compared to ingredient labeling in food. Some consumers follow a strict diet, such as lactose-free, vegan or low-calorie, and only buy food with their requirements in mind. With an increasing number of consumers prioritizing environmentally friendly products [31], DPPs can serve as a valuable tool for brands to demonstrate their commitment to sustainability and differentiate themselves from competitors. Also, research has shown that sustainability is becoming a more significant factor in purchasing decisions for consumers and 33% of consumers have stopped purchasing from a brand over sustainability concerns [31].

But more importantly, consumers are the ones who will 'wear' and 'use' the DPP most of the time. Furthermore, it is also during the use phase of clothing where DPP information gets lost [8]. Therefore, a large part of this study will focus on this part of the development of a physical DPP tag.

Recyclers: Recycling clothing is 'the worst of the best' action in a circular economy [17]. They will need to efficiently scan each individual fashion item to gather essential recycling information from it. Also, being part of the DPP ecosystem, fashion recyclers can connect with other stakeholders in the fashion industry, such as manufacturers and retailers, to share information and best practices for sustainable fashion. This collaboration can lead to a more efficient and effective recycling process and help to reduce waste and pollution in the fashion industry [5].

Emerging businesses: The push towards a circular economy thanks to the European Green Deal [32], CEAP [6] and ESPR [9] with more focus on increasing the life-cycle through DPPs of products is an opportunity for new business because that can be used to create additional revenue streams and growth drivers for companies[10]. For instance, thanks to DPP information, companies can offer new repair and service functions, which could lead to better customer relationships. DPPs can be utilized as an extra channel that marketing, sales, and business operations can use to offer new services and improve the customer experience. Previous research already explored and highlighted several possible DPP enabled CBMs without knowing at the time that a DPP easily can enable implementing such CBMs.

Investors: In this phase, investors can be convinced to participate in this concept because fashion companies need to adapt to the DPP laws. Therefore, it will create an interesting opportunity for them to already jump on board of this innovation. Once the DPP has been implemented, investors in the fashion industry would be interested in the digital product passport as it would provide them with valuable information on the sustainability and social impact of the companies they invest in.

Existing sustainable retailers such as second-hand stores and fashion rental: Thanks to the introduction of DPP's, second-hand stores get a transparent view on DPP's and could redistribute them more objectively. Also sorting clothing based on brand, size or even material CO2 equivalents can create new second-hand business opportunities as defined in the discover and define phase. Also previously defined, thanks to a DPP in second-hand clothing, consumers will get relevant information such as washing instructions (which often have been removed from second-hand clothing) and when such item was put on the market to determine the possible durability. Also, as defined in previous phases, fashion rental benefits from DPPs because it already has been implemented by fashion companies in the first place, so they do not have to worry about putting it in themselves.

Repairers: A digital product passport provides repairers with comprehensive and accurate information about the clothing item, including its materials, construction, care instructions, and any previous repairs or alterations. This enables repairers to have a deeper understanding of the garment's history and specific requirements, facilitating more efficient and effective repairs. Also, repairers can quickly access relevant information about the clothing item, such as its original design, components, and assembly methods. This can significantly reduce the time spent

on diagnosing issues and searching for specific repair techniques, ultimately saving time and reducing labor costs.

4.2.3: Indirect stakeholders:

Regulators and NGOs: In the first place, the DPP is an initiative of a regulators, the European Commission. If this law becomes obligatory, then all the previously mentioned stakeholders need to follow. Once the DPP has been implemented, regulators and non-governmental organizations (NGOs) will be important stakeholders for ensuring that the information provided by fashion brands and manufacturers is accurate and reliable, and that the passport meets regulatory requirements and industry standards.

4.3: The development of design requirements

Creating design requirements are essential for the development of a digital product passport in clothing, more specifically on the physical aspect of it. By establishing clear guidelines and specifications, design requirements enhance the overall understanding and usability of the digital product passport. The list of requirements have been made because of previous knowledge, data of the European documents [3], [6], [9], [33] and by analyzing it through the lens of an industrial designer.

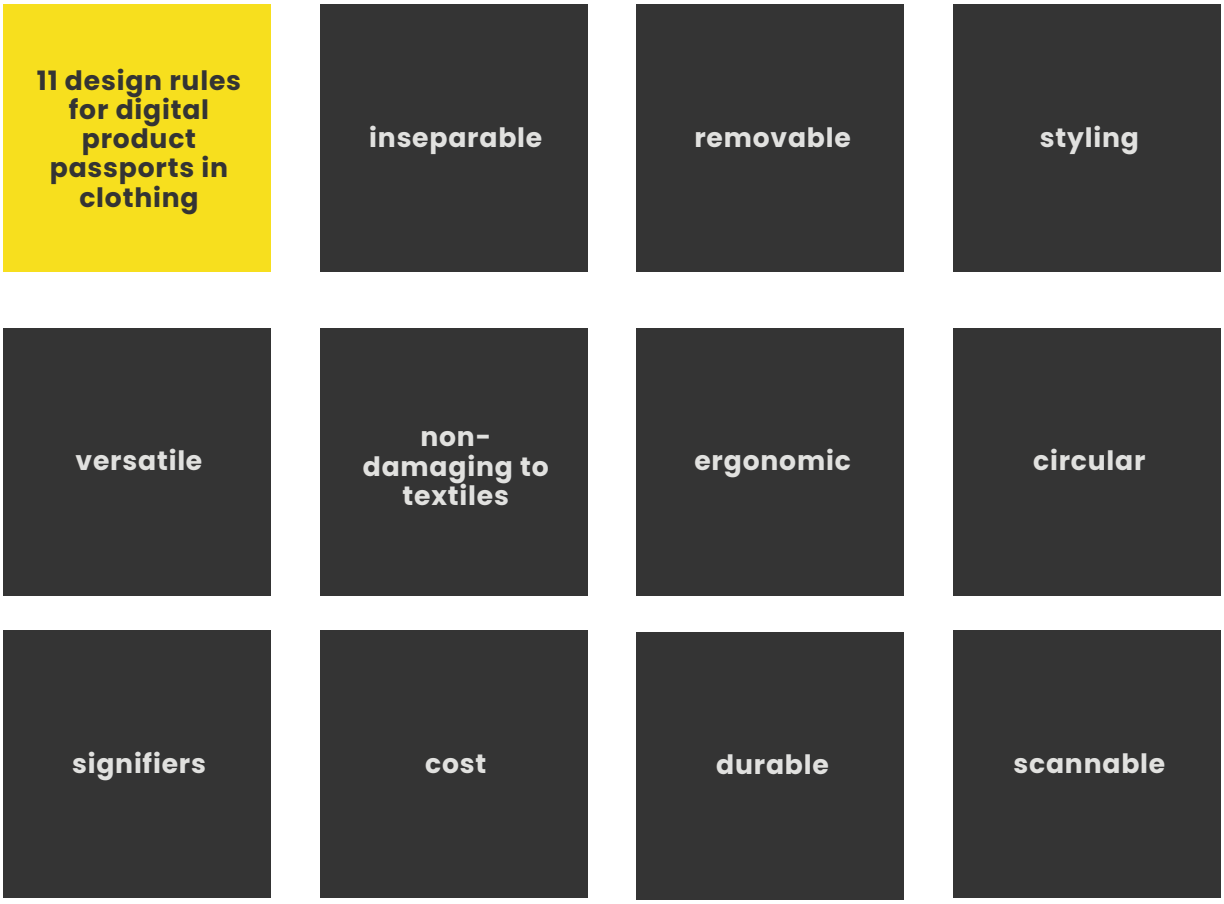


Figure 9: Design requirements (own figure)

4.3.1: Design requirements:

Non-removability/inseparability: It needs to be present throughout the whole life-cycle of the product without losing its data-carrying potential. Otherwise, the effort and benefits for a DPP are wasted. This makes the the idea of printing a unique QR code on a label that is sewn into fashion items less interesting. Some consumers like to remove labels from clothing because they are long, itchy, and not aesthetical [34]. This will be further explained in detail in the benchmarking.

Also, it's important to consider the attachment method of the tag to the garment. The tag should be attached securely to the garment using a method that is difficult to remove by consumer or by everyday wear and tear.. This will make it more difficult for fashion consumers to remove the tag without damaging the garment. Second, it's important to communicate the importance of the tag to fashion consumers and other stakeholders in the value chain. By highlighting the value and purpose of the tag, awareness can be increased and encourage stakeholders to leave the tag intact.

Removability: Removing this tag will be necessary in multiple scenarios. For example when the item needs to be repaired, upcycled or recycled. A study published in 2020 investigated the recycling process of denim (jeans). They stated that the collection and sorting of worn-out jeans is time-consuming and laborious. Jeans contain lots of different (small) parts that needs to be individually removed like labels, (leather) patches, metal parts such as rivets, zippers, and buttons. These metal and leather parts are removed but removing labels from jeans is mostly not done. Therefore, labels stay in jeans and are sent along with them. The result is that the label material contaminates the denim which may cause problems to the machinery and process. For recyclers, it’s easier to remove buttons and rippers by using gravitation. Other metal parts, such as rivets are too small and light. Therefore, special care is needed to remove them [35].

Therefore, creating an intuitive and reliable disassembling (DFD) benefits a circular economy, as of the ESPR of the European Commission.

Styling: This design requirements is about the overall size, visibility and design. A tag that is too large or obtrusive could be seen as unsightly or detract from the aesthetic appeal of the garment. Therefore, it's important to design a tag that is as small as possible, while still providing enough space to store all the necessary information. Additionally, the tag should be compact and lightweight, so that it does not add unnecessary weight or bulk to the garment. Also, a more beautiful tag could be better accepted then an ugly one.

Versatility: Creating a versatile DPP tag, which means it can be applied on different textile materials and types of garments is desirable by the European Commission because it creates standardized procedures.

Versatility is a crucial factor that significantly impacts costs in various ways. For instance, consider the scenario where a unique physical DPP must be designed for each type of textile and garment. This approach would incur higher production costs due to several factors, including expenses related to manufacturing equipment, operator training, mold creation, and machine prices. In essence, the lack of versatility would lead to increased expenses across the board.

Furthermore, versatility influences circularity too because it allows for easier tracking and tracing of the product throughout its lifecycle through 1 standardized way. By having a single physical DPP that can be used on multiple types of garments and textiles, it streamlines the process of recycling and repurposing. For example, such standardized tag can easily be scanned to determine the type of material it is made from and whether it can be recycled. If the tag is versatile, it can be easily removed from the garment and attached to a new one, ensuring that the material can be reused or recycled in a more sustainable way. This reduces waste and promotes circularity in the fashion industry.

Depending from case to case, versatility can mean that a DPP is only designed for 1 specific brand or garment type, for example swimming equipment. Of course, then this impacts the design outcome for the other requirements. In this study, the goal is to create a as versatile as possible tag.

Non-damaging to textiles: A goal of ESPR is to increase reuse, refurbishment, repair, and recycling of textiles [5], [7], [8]. Therefore, the tag should minimize any potential damage to the textile, both during the initial application and any subsequent reapplication. The solution should be removed without leaving marks. Traditional attachment methods, such as using a rivet or a jeans button to hold an NFC tag in place, causes damage to the textile. These methods require a hole to be made through the fabric, which can compromise its integrity and reduce its potential for refurbishment or remanufacture.

To address this challenge, alternative tag attachment methods should be considered that are less invasive and can be easily applied and removed without damaging the textile. Furthermore, the tag should not damage other textiles when it's for example in a washing machine. No little gaps where textiles could get stuck in or sharp edges are allowed.

Ergonomic: Irritation can arise because clothing touches the skin. Specifically the combination of tight-fitting fabrics and sweat may irritate the skin [36]. Furthermore, some people suffer from textile dermatitis from clothing made with synthetics such as rubber, nylon, rayon or polyester. This is because they don't breathe as well as natural fibers [36]. Symptoms often implies redness, scale skin, or itchy areas.

Furthermore, people can be allergic to nickel, which is referred as nickel dermatitis. Jeans buttons and other jewelry may be made from nickel. Nickel dermatitis is the most common metal allergy but people can be allergic to any metal [37]. If the solution uses any kind of metal, then hypoallergic materials such as nickel-free stainless steel, plastics (not latex), surgical-grade stainless steel, titanium, platinum, sterling silver, and 18K gold may be the solution. Creating a barrier between the material and the skin reduces the risk of an allergic reaction. For example, applying a coating limits the interaction but coating should be avoided to benefit potential recycling.

Last, it is estimated that 1/5 people are highly sensitive (HSP) [38]. This is a neurodivergent person who have a deeper system sensitivity to physical, emotional or social stimuli. As a result, they find labels annoying and always want to remove them. Thus, generally speaking, designing a physical DPP should be designed to be low stimulus.

Also, dyes and other chemicals in clothing may be another source for irritation such as formaldehyde resins. This chemical is used to make garments wrinkle-free or dirt-repellent. Dyes, glues, and chemicals used to tan or create leather could also lead to irritation. Irritation can be prevented by choosing for natural fibers, breathable applications, textiles with less dye in them and avoiding materials that stay dirt repellent, no-iron, wash and wear.

Last, the tag itself should be designed with for example no sharp edges to decrease possible irritation to the customer's skin.

Circularity: Firstly, the tag itself should be designed with ecodesign frameworks in mind, such as the Butterfly Diagram [17]. This means that the tag should be designed with a focus on minimizing the environmental impact throughout its lifecycle, from its production to its end-of-life disposal. The tag should be designed using appropriate materials and manufacturing processes, and it should be designed to be as durable and long-lasting as possible.

Secondly, the tag should be easily maintainable, repairable, and reusable. This means that the tag should be designed to be easily removed and replaced if

necessary, without damaging the garment or the tag itself. Additionally, the tag should be designed to be easily repaired, so that it can be reused multiple times over the lifespan of the garment.

Finally, the selection of the proper material for the tag is crucial in ensuring its circularity. The material should be selected based on its environmental impact, its durability, and its ability to be recycled or biodegraded at the end of its life. Recycled or biodegradable materials such as organic cotton, recycled polyester, or biodegradable plastics could be suitable options for the tag.

Signifiers: When determining whether an item possesses a Digital Product Passport (DPP), it is essential to incorporate visual indicators into the tag design. This can involve the use of vibrant colors or bold typography to attract attention to the tag. Additionally, including a recognizable logo or icon can assist stakeholders in easily identifying the DPP.

The placement of the tag on the garment is another critical consideration. To ensure ease of discovery and scanning, it is advisable to position the tag prominently in a visible, accessible, and scannable location. This could involve placing the tag on the exterior of the garment, such as on a sleeve or pocket, or integrating it into the design of a garment tag or label.

The visibility of the solution is closely linked to the effectiveness of the signifier. The more prominent and clear the signifier, the more visible it becomes. Consequently, fashion manufacturers may be less inclined to incorporate this solution into their clothing. Standardization plays a role in signification as well, with a single location and method for displaying DPP information.

The size and shape of the tag also play significant roles as signifiers. A larger tag may be more visible and easier to locate. On the other hand, a unique shape or design can help it stand out amidst other tags or labels on the garment.

These requirements have an impact on both the overall comfort of wearing the garment and its visibility, as discussed earlier. A larger tag may decrease comfort, while also influencing visibility.

Cost: An overall low 'product' cost should be considered whilst designing solutions. Material and production costs should be low whilst creating a durable object that can ensure the tag can withstand the wear and tear of the garment's lifecycle. A material should be selected based on the function of the tag. When it comes to manufacturing injection molding allows the tag to be produced in large quantities at a lower cost per unit [39].

Lowering costs can be achieved by using standardized items and processes, because they are overall cheaper than to design whole new protocols and parts. Furthermore, if such physical DPP tag could be reused over and over again (which is also beneficial for circularity), then the tag could become cheaper because companies do not need to purchase them again.

As defined in the life-cycle of clothing, such DPP tag should be implemented in clothing during assembling. This should imply that assembling such tag should be intuitive, which also has an impact on assembling cost.

In this study, only material and possible production costs are taken into account.

Durability: First, it's important to choose materials that are durable and can withstand the rigors of everyday wear and tear. This may include using materials such as plastics, metals, or reinforced fabrics that are resistant to tearing, stretching, or breaking. Additionally, it's important to choose materials that are resistant to moisture, heat, soap, washing, dirt, sand and other environmental factors that could cause damage to the tag. Second, the tag should be securely attached to the garment to prevent it from becoming detached during use. Third, the tag should be designed in a way that minimizes its exposure to potential sources of wear and tear, such as sharp edges or rough surfaces.

Scannability: Whatever the scanning technology is (QR code, serial code, barcode, NFC or RFID), it should be assured that every stakeholder within the value chain has the right tools and knowledge to access the DPP. Furthermore, scannability also involves the speed a data carrier can be found and scanned.

4.3.2: Verifying design requirements

During a conversation with an innovation engineer of a Belgian fashion company, the interviewee confirmed the validity of the design requirements and its wickedness. It was mentioned that they are also working on developing a DPP for children's clothing, but the challenge is to introduce one that covers the entire supply chain. The interviewee also highlighted the importance of introducing a tag at the bottom of a piece of clothing instead of printing a QR code on a label, which customers find unattractive and cut out, resulting in lost data. They are looking for outsourced solutions because they do not have the capacity of designing a DPP tag themselves. She suggested that multiple tags need to be developed for different types of clothing, materials and use cases. This fashion company is not afraid of a slightly more expensive solution if it secures data throughout the whole value chain. This company is intrinsically motivated because they find giving customers transparent information important.

A second-way these design requirements have been verified, is by shortly interviewing alumni (N=22) of the Industrial Design Engineering education from Ghent University. 50% of alumni said they either always or sometimes remove fashion labels from clothing. A label on the top of a garment, on the neck line, has not been seen as annoying.

4.3.3: Wicked problem

Wicked problems is a term that is used to describe problems which are, according to Plymouth University, operationally complex, lacks a singular clear solution, involves behavior change and multi-faceted [40]. Furthermore, they are hard to define and categorize, there are no real 'solutions' to wicked problems where it is better to improve the current situation. Also, wicked problems are the result of other wicked problems. Here, the development of a DPP tag is the result of wickedness of the fashion industry.

Let's examine how the design requirements highlight the wickedness of this problem:

1. The DPP needs to be non-removable by fashion consumers, but also removable by recyclers, upcyclers, and repairers to increase material efficiency in a circular economy.
2. The tag should be attached securely to the garment using a method that is difficult to remove, but also be easily applied and removed without damaging the textile.
3. The tag should be as small and unobtrusive as possible, but also be visible enough to communicate its importance to fashion consumers.
4. The tag should be designed to be low stimulus, but also be visible and aesthetically pleasing.
5. Non-removability and durability go hand in hand but can go in line with circularity if a solution becomes unremovable.
6. A perfect standardized DPP tag is beneficial for costs and circularity, but goes against the uniqueness of a brand's garment.
7. This tag will be used by different stakeholders who have contradictory wishes. For example consumers actually don't want extra labels in their clothing where adding some kind of identifier is beneficial for reaching a circular economy.

4.3.4: Conclusion design requirements

Developing these design requirements are on their own a conclusion of this study. However, the purpose now is to validate these design requirements while acknowledging that no single "solution" can completely solve the wicked problem at hand. The objective is to improve the current situation, as outlined in the benchmarking, by working towards the goals established by these design requirements.

4.4: Weighted decision matrix

In order to facilitate further brainstorming and decision-making processes, a weighted distribution matrix has been created to enable a more objective evaluation of the research. This is also created to prioritize certain design requirements. Because of its wickedness, it will not be possible to find a 'solution' that ticks of all requirements. Throughout this study, weighted distribution matrices have been utilized multiple times. Each of the 11 design requirements will be assigned a score ranging from 1 to 5, where 1 signifies a complete lack of importance and 5 denotes utmost significance. Given the nature of design requirements, a score of '1' are not applicable as these parameters are considered essential requirements. Hence, only scores of 2-5 are possible. The weights assigned to each design requirement are partially based on previous research and stakeholder input, while others have been determined by the primary researcher, supported by an explanation.

Concepts will be compared by giving a score through a 3 point Likert scale from '0' to '2' by the perception of the main researchers. This approach can be effective because it provides a simple and straightforward way to quickly evaluate and compare ideas. Too many Likert scales can cause confusion why for example something gets a score 4/5 instead of 3/5. In this stud, a score of '0' means not at all and '2' totally. A score of '1' is the middle ground. For example, if a benchmark or solution does not damage textiles, then it gets a score 2/2. If it is questionable if this signifies it can be scanned, then it could get a score of 0 or 1/2.

	Weight (/5)	Concept X's score (/2)	Weighted score
Non-removability	**5**	0	0
Removability	**3**	2	6
Styling	**3**	1	3
Versatility	**2**	2	4
Non-damaging textiles	**2**	0	0
Ergonomics	**4**	0	0
High circularity	**4**	1	4
Signifiers	**2**	2	4
Low cost	**2**	1	2
Wear and tear (durability)	**5**	2	10
Scannability	**3**	0	0
	70		33
			47,14%

Figure 10: Example weighted distribution matrix (own figure)

It's important to note that whatever the context is of where this tag will be used, other weights can be assigned to these parameters.

Weight = 5/5 for non-removability & durability: These design requirements are given the highest weight (5/5) because they are crucial for ensuring that data remains intact even after the consumer acquires the clothing. Non-removability ensures that the tag stays attached to the garment, while durability ensures that the tag can withstand wear and tear, maintaining its functionality and data storage capabilities over time.

Weight = 4/5 for ergonomics, circularity: Ergonomics is assigned a weight of 4/5 because it directly impacts other parameters. For example, if a tag is not ergonomic and easily removable, it defeats the purpose of implementing a DPP in the first place. Circularity, also rated 4/5, is important to consider as it aligns with the innovation criteria of this study. From expert interviews, two out of three experts also rated these parameters highly, emphasizing their significance.

Weight = 3/5 for removability, styling, scannability: Removability is assigned a weight of 3/5 because it has relevance to circularity. The ability to remove the tag without damaging the garment enables the tag's reuse on other clothing items, contributing to a circular economy. Styling, rated 3/5, is important as it can influence the overall acceptance of DPPs in clothing, considering that aesthetic appeal plays a role in consumer perception. Scannability, also rated 3/5, is vital for the tag to fulfill its purpose. It should be equipped with technology that allows for scanning to access relevant product information.

Weight = 2/5 for versatility, non-damaging textiles, signifiers, low-cost: Versatility is assigned a weight of 2/5 because it is desirable for the tag to be adaptable and cover various DPP solutions. However, feasibility limitations make achieving full versatility challenging, resulting in a lower score. Non-damaging textiles, also rated 2/5, is an important aspect, but other parameters take precedence. If a solution slightly damages textiles but excels in non-removability, circularity, and durability, it can still be considered. Signifiers, rated 2/5, emphasize the importance of clearly indicating which part of the garment is scannable, but education across the value chain can also contribute to raising awareness. Lastly, low-cost is assigned a weight of 2/5. While cost is important, it is not the sole determining factor in their decision-making process.

4.5: Benchmarking

As mentioned before, benchmarking will be done to benchmark current solutions based on design requirements, whereas searching for solutions where information does not get lost get prioritization. The price is calculated for a batch of 1000 items to make a more objective comparison between products.

4.5.1: Software providers

Eon

Julie Brown (head of sustainability at Eon) states that Eon[1] is a software company that wants to lower the gap between digital and physical world by connecting every item to a digital ID to make it interactive, intelligent and circular. So Eon hopes that simple products become intelligent assets that unlock circular business models. Eon developed the circular product data protocol, thus the software that other companies can use to implement in their DPP products. This software is open source. Eon wants to inspire other companies by showing use cases and concepts how to implement a physical DPP tag in clothing.

The innovation engineer of the Belgian fashion company mentioned that Eon is ahead of the DPP game with their open source software, but the company is getting criticism for being too commercially driven and not sustainable driven.

Quifactum

Quifactum[2] is a Belgian company specializing in providing DPP software to fashion companies seeking to implement DPPs in their clothing products. Their software solution brings immense value to fashion companies by effectively mapping the entire supply chain, registering each step within the production cycle, and enabling transparent communication of sustainability claims. The DPP, in this context, can be accessed by scanning a QR code on a price tag or displayed on a label.

Quifactum excels in delivering the right software solutions to fashion companies, ensuring streamlined implementation of DPPs. However, when it comes to the physical aspect of the DPP, their solutions currently lag behind as they are primarily designed to be removable. Nevertheless, this presents an intriguing opportunity where the final solution of this study can integrate Quifactum's exceptional software capabilities.

[1] Unlock the potential of your products (no date) EON. Available at: https://www.eon.xyz/ (Accessed: March 2023).

2 Quifactum (no date) quiFACTum. Available at: https://www.quifactum.com/ (Accessed: March 2023).

In addition to working with established Belgian fashion brands like Xandres and Mirabel Slabbinck, Quifactum actively collaborates with small Belgian and international brands driven by an inherent motivation to share transparent information with their customers. These companies prioritize ethical production practices, such as manufacturing in Europe, using local materials, and ensuring fair wages and safe working conditions. Transparency is of utmost importance to them, as their market competitors often neglect sustainability considerations and can offer garments at lower prices. By partnering with Quifactum, these fashion brands can effectively convey their commitment to sustainability and provide valuable information to their discerning customers.

Figure 11: Quifactum in action

Tappr

Tappr[3] is a Dutch company. Just as Eon and Quifactum, Tappr provides software to integrate DPP's in apparel, more specifically in clothing, footwear and equipment.

Compared to Eon, Tappr focusses more on DPP's and the coming European legislations. Also, Tappr's focus leans more towards an international scale, whereas Quifactum focusses nowadays more on the Belgian market.

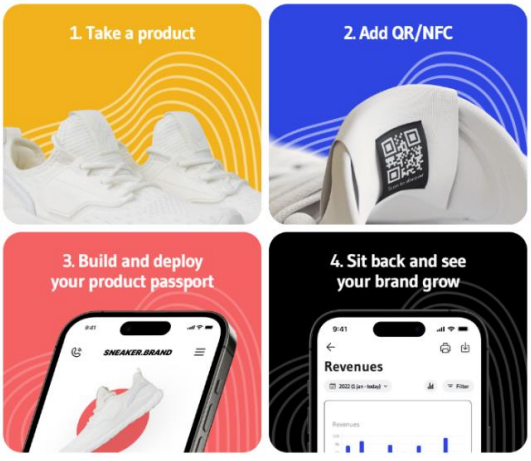


Figure 12: Tappr[3]

But just as the two other companies, they only focus on providing knowledge and software. Thus not on the physical aspect of it and as mentioned before, this is a crucial aspect of the implementation of DPP's.

[3] Digital Product Passport Platform for brands (no date) Digital Product Passport platform for brands. Available at: https://www.usetappr.com/ (Accessed: March 2023).

Conclusion software providers

It's observed that these software providers don't offer a physical DPP tag to their customers or offer ones of poor quality. This is an essential part to make sure data will be accessible in this product at all times so actors in the value chain can access it when needed.

Moreover, it is evident that the software and physical DPP solutions must work harmoniously to deliver valuable DPP data to customers. These two components are essential and complementary to each other. Consequently, the designed DPP tag will incorporate one of the three DPP software options, ensuring seamless integration and optimal performance.

4.5.2: QR codes

What are QR codes

QR codes are a quick, convenient and affordable way to monitor assets in an inventory [41]. Every device with a build-in camera can access data in a QR-code. In some way, barcodes are familiar to QR codes but whereas barcodes are 1 dimensional, QR codes are 2 dimensional which means it can store more data.

QR codes can store up to 2500 numerical characters of data such as URL's, passwords, photos,... It's still readable by a scanner if tag is slightly damaged. This is because QR codes have an built-in correction error process. But this process has its limitations and DPP information should not rely on this process to display permanent information. Lastly, it requires minimal training of operators and consumers.

Option 1: QR codes in price tags

Figure 13: QR codes in price tags (own picture)

Here, companies offer additional information regarding the garment. The main flaw is that they are designed to be easily removable once an item has been purchased. Therefore, it is strongly discouraged to use such solution for DPP information whereas it needs to be available through the whole life cycle.

Option 2: QR codes in labels sewn in on 1 side

In these options, a QR code is put on a label and sewn in on one side. These are seen as the standard for bringing additional information to a customer [42]. As stated in the design requirements, consumers remove labels, may be allergic to them and find them annoying. If it is attached to the garment by one side, then it lowers the barrier to remove it because a scissor could be used to easily remove it. Furthermore, the material should be an organic textile such as cotton and not the commonly used synthetic label materials such as satin polyester, nylon or polyester do not cause irritation or an allergic reaction [43]. Another factor that

contributes to irritation, are sharp corners, which should be avoided at all times as mentioned in the design requirements ergonomics.

Regular labels are mostly left in clothing during recycling, resulting in a mixed fiber at the end of the process [35]. Standard components such as rivets, buttons and fasteners are removed beforehand. This could result in a less effective recycling process because a multi-fiber substitute is created which is less desirable [28].

Figure 14: QR codes in labels [44]

Also, these QR code labels are not 100% DPPs. They do display transparent supply-chain information regarding this type of garment but on a batch level, meaning that every item within this batch has the same identifier. Within a DPP context, it's important that every QR code is unique because once an item is bought, the life-cycle will greatly differ from consumer to consumer.

Because of this. It's worth further investigating how unique QR codes can be applied to labels.

Researching label methods

Generally speaking, there are two types of labels, woven and printed labels [45]. Printed labels are more cost-effective because the woven labels us a higher quality material. Woven labels are perceived as more professional looking than printed ones are more often used than printed ones[45], [46]. Woven labels are more durable and last longer than printed ones [46], where the ink fades away after 10 washes or after intense use of clothing [45]. Actually, even woven labels could fade away much faster in direct sun, chemicals ore long exposure to water [47]. Contrary, woven labels do not get damaged if it is dried, washed or intensively used [45].

Figure 15: Woven label (left) [45] *and printed label (right)* [45]

Also, the plastic (printed) labels are prone to falling off more easily compared to woven labels [45] which can also be seen in the image below. Because of this information, woven labels could be a more feasible option because they don't fall off easily, are more durable, and won't fade like printed labels. Furthermore, they are softer to the touch than printed ones [46].

Printed labels are commonly used for care, manufacturer, and batch mark labels whereas woven for the brand/main, size, flag or special (side) labels [48]. Also, the exact type of materials or processes used to make these tag influences the overall degradation of information.

Figure 16: Plastic label after 7 years (own picture)

In the image below, a weaving loom is displayed. This is used to weave woven labels. Yarns, mostly polyester, are used to create the desired information. Eventually, the labels are cut off from the looms, post-treated and send to the customer. Such process is ideal for mass-production, where the same label can be woven many times. On Dutch Labels Shop[4], the price for 1000 woven, sewn-in, rectangular woven labels is €0,24/piece including tax. Important to note, is that this is the price for printing 1000 times **the same tag**. But the big sidenote for this manufacturing process, is that in a DPP context, every tag should be uniquely identified. Therefore, such manufacturing process is not feasible in a DPP context. Otherwise, each new row that is woven is an unique set of QR codes but this would increase waste, whereas only 1 label from each row is needed. Dutch Labels Shop can make 5 woven labels for a total of €22,00, which is €4,40 for 1 label.

Figure 17: Weaving loom [46]

Lastly, it is advised to make the height and width of QR codes at least 17mm for either woven or printed labels [42]. This is because the resolution would be otherwise too low to be scannable by a camera. The minimal size impacts the styling and ergonomics because smaller labels are more desired by consumer.

[4] Geweven labels (no date) Dutch Label Shop. Available at: https://www.dutchlabelshop.com/nl_be/ontwerp-geweven-labels/ (Accessed: April 2023).

Option 3: QR codes in labels sewn in on 4 sides (only cut label)

Figure 18: QR code in label, sewn in on 4 sides[5]

Considering the various remarks surrounding the use of QR codes on labels, an alternative solution for digital product passports is proposed. By sewing in these labels on all four sides and placing them on the inside of garments, a more favorable option for consumers can be achieved. This approach could eliminate the issue of a label hanging from the clothing and causing irritation. As a result, this method is preferred over sewing in labels on just one side. The same pricing as the previous option will be maintained for this alternative. This particular type of label will be utilized in the final data collection phase to facilitate a comparison with the designed solution.

Option 4: Printing QR codes on fabric

For such solutions, information is directly printed on textiles themselves. Printing QR codes directly on textiles eliminates the need for a physical tag which can result in a more desirable tag for consumers[49], [50].

Textile printing is the process where color can be applied on a specific targeted area to create various patterns and design [50]. Many different methods exists, such as block, roller, screen, and heat transfer printing but same as woven or printed QR codes, these processes are designed for printing the same information on textiles.

[5] *Unlock the potential of your products* (no date) *EON*. Available at: https://www.eon.xyz/ (Accessed: March 2023).

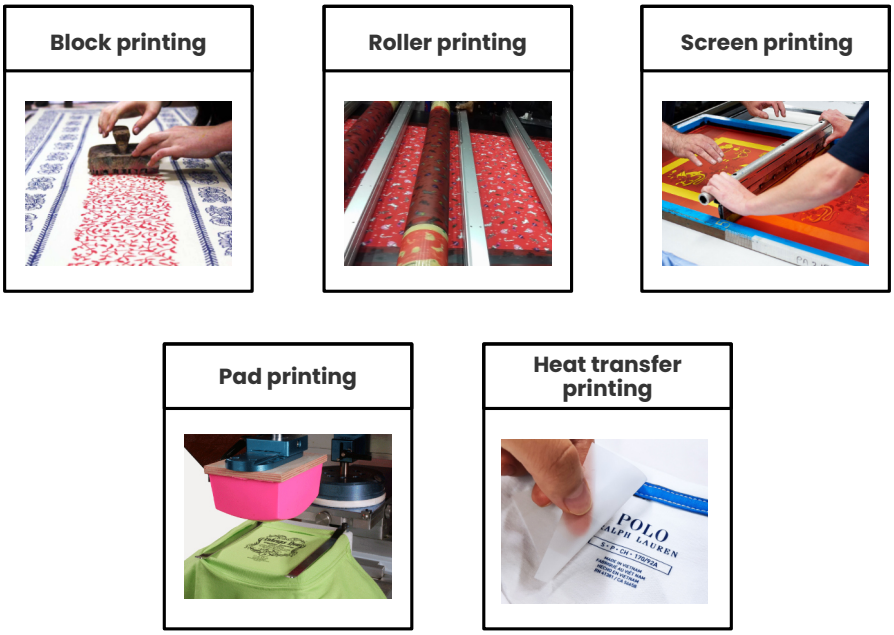


Figure 19: Printing methods (own figure)

Heat transfer and pad printing are used nowadays as a replacement of labels. Therefore, they can be called tagless labels. In the case of heat transfer printing, information (logo, size, …) is printed on transfer paper by a special inkjet printer [51]. A heat press is warmed up and presses the transfer paper on the garment for 25-45seconds. Afterwards, the film is removed and the design is 'printed' on the textile. It can be assumed that by connecting QR generator software to this printer, such as Beaconstac[6], different QR codes can be generated. It's important that this tag does not contain latex or formaldehyde, because this causes allergic reaction for some customers [43].

Figure 20: Heat Transfer labels and irritation [52]

Besides the allergic reaction, heat transfer also poses a potential threat to the environment. This method produces paper, plastic, water and oil waste [49]. Also, as seen in figure below, the quality of heat transferred labels degrade over time,

6 How to print QR codes on clothing labels: A definitive guide (no date) Beaconstac. Available at: https://blog.beaconstac.com/2021/01/qr-codes-on-clothing-labels/ (Accessed: April 2023).

which is not desirable in the context of DPP's. Also, other methods could be more cost-effective and efficient, such as pad printing [51]. On average, high-quality heat transfer label cost around $0,15 and pad printing about $0,03 per label [49], [51]. Furthermore, pad printing is faster, better adhesive, more flexible and requires less equipment and consumables [49], [51]. A reason why this may not be the best solution, depending on the type of die used, this could easily fade away over time [46], [49], [51].

Where this solution accelerates, is the potential to be applicable on clothing that touches the skin closely, such as underwear, some sports clothing,... Then, it's important for these manufacturers to include the material properties, which they will be obligatory to include, so consumers are informed about possible allergic reactions.

Observation from the researcher's wardrobe

Figure 21: Observation of heat transfer and pad printing (own figure)

4.5.3: NFC

What is NFC?

Near Field Communication (NFC), based on [53], [54] is a wireless technology that enables two devices to communicate when they are in close proximity to each other. One of the most popular uses of NFC technology is for contactless payments, where the communication between a payment device and a payment terminal requires no physical interaction. The process is initiated when a customer taps or holds their mobile device close to the payment terminal. The NFC reader and the smartphone exchange encrypted data back and forth using a specific frequency of 13,56MHz to complete the transaction, which typically takes just a few seconds. Furthermore, badges for entering hotel rooms or magnetic chips in public transport cards are other popular uses of NFC technology.

However, NFC has some limitations in terms of communication range. Depending on the type of NFC used, a user must be within a range of 10cm of the NFC receiver [54], [55]. This creates a physical barrier where the stakeholder should be near a NFC tag to initiate a transaction. This could be also seen as an opportunity in a DPP context regarding data security. Nevertheless, NFC builds on the work of the RFID set of standards and specifications.

The main benefits of using NFC technology are its convenience and versatility. Smartphones, tablets, and smartwatches can be used as handheld readers, making it easy for people to use NFC-enabled devices to complete transactions or exchange information.

NFC can be either active or passive. Regarding DPP's, passive NFC tags will be used in clothing because it doesn't require their own power supply. Another device, capable of modulating the incident field, can receive data written on the NFC tag. Modern day smartphone can read NFC (if this option is enabled in their settings) but specialized NFC readers can scan NFC tags from a further away [53].

NFC tags can be custom-coded by the manufacturer, allowing efficient use in a DPP context. For example, 1 NFC tag can be made, applied in clothing and data can be written on the go.

Choosing the right NFC tag

Many different NFC tags exist, ranging from stickers, to key chains, to wristbands. Here, relevant NFC tags are benchmarked that could be implemented in clothing.

An NFC tag should be chosen based on 10 parameters according to an online NFC warehouse[7]:

1. Compatibility
2. Available memory
3. Encryption
4. Data retention
5. Read/write cycles
6. Password lock
7. Tag positioning
8. Size/reading distance
9. Hostile environments/extreme conditions
10. Application of the tag

The technical explanation behind each parameter will be explained in Appendix E. Be aware of the fact that Appendix C is quite large.

Option 1: NFC tag suppliers

This list has been compiled to compare several tags that could have potential to be integrated in a DPP context.

Table 1: Technical benchmark NFC chips and tags (own table)




	Quantity	Price/pc incl taks	Diameter	Thickness	Operating temperature	IP	Material	Reading	Type
Laundry tag	500	1,01 €	20mm	2,5mm	=-20 - 85°C; up to 180°C	68	PPS	10cm max	NTAG213
Regular tag	500	0,84 €	13mm	1mm	=-20 - 85°C	68	PPS	10cm max	NTAG213
Mini	100	0,36 €	5mm square	0,2mm	=-20 - 85°C	?	?	8-20mm	NTAG213
Button	500	0,99 €	16mm	2,5mm	=-25 - 85°C; up to 180°C	68	PPS	10cm max	ICODE SLIX2
Regular batch	500	1,67 €	40x32mm; 25mm	4,5mm	?	?	ABS	10cm, 1,5m max	ICODE SLIX

The most durable tags, laundry and button tags[8], are made of PPS polymer (do not confuse with PSS) because this material is can withstand 70 bar for 3 minutes, can be exposed to hydrogen peroxide (5%), industrial laundry detergent (pH 10-11), neutralizing agent and perchlorethylene (100%). Furthermore, it is designed to be more heat resistance, up to 180°C as well as being IP68 rated.

7 How to choose NFC Tags (no date) Shop NFC. Available at: https://www.shopnfc.com/en/content/11-nfc-guide (Accessed: March 2023).

8 Mmstudio.si (no date) Laundry tag with NFC chip NTAG213, Rfidspecialist.eu. Available at: https://rfidspecialist.eu/store/laundry-tag-with-nfc-chip-ntag213.html (Accessed: March 2023).

Regular NFC tags[9], without any specialized 'capsule' around it, are designed so they can be molded with polymers or resin. These possibility are not suited regarding circularity, another design requirement because it will become impossible to separate the two components (polymer and NFC tag) from one another without damaging the NFC chip. The same applies for the laundry tag, it is unknow how these tags are produced but it can be assumed that an NFC chip has been molded with this polymer SPP. Therefore, it is important to design NFC solutions that are easily separatable regarding circularity but so they can still withstand harsh conditions.

The more common NFC tag material is ABS, as seen in for example hotel batches. Generally speaking, ABS is a more commonly used material and is used in for example the production of Legos.

A Chinese supplier[10] produces tiny NFC tags. They are 5x5mm, water and weather resistance. It's not specified if they are ironing-proof. For a batch of 1000 tiny NFC tags, the price per unit is $0,36. Also, depending on the reading device, the reading distance is between 1-10cm.

Option 2: TouchLink

TouchLink[11] is a fastener puller with a built-in NFC chip that reads registered information when a smartphone is brought close to it and can be linked to websites and applications.

This NFC tag design has several factors to consider. Firstly, the non-removability of the tag is dependent on how it is designed, and can be either easy or difficult to remove. Similarly, the removability of the tag depends on its design. In terms of styling, the NFC tag, which is included in an existing component, may not fit every style of clothing due to its thickness and printed logo. The solution can only be used for applications with zip-lock fasteners, such as pants, jackets, and vests. The fastener itself does not damage textiles and is ergonomically designed with a familiar use, except for its thickness due to the NFC tag. The circularity of the product is unknown, as is the cost, but it can be assumed that the fastener can

9 Mmstudio.si (no date) 13 mm size NFC disc tag with a NTAG213 chip, Rfidspecialist.eu. Available at: https://rfidspecialist.eu/store/13-mm-size-nfc-disc-tag-with-a-ntag213-chip.html (Accessed: March 2023).

10 RFID micro tags suppliers (no date) CXJ RFID Factory. Available at: https://www.cxjrfidfactory.com/rfid-micro-tags-suppliers/?gclid=CjwKCAjwx_eiBhBGEiwA15gLN5sPq7rfZlJDJTJqEhbml5H9Q-R4FvUqouGfhKndTBnhVJRmKqdEZRoCrKEQAvD_BwE (Accessed: March 2023).

11 TouchLinkTM, a Zipper Puller with Built-in NFC Chip. Available at: https://ykkasia.com/touchlink-a-zipper-puller-with-built-in-nfc-chip/ (Accessed: March 2023).

withstand significant wear and tear. However, the logo printed on the tag does not signify the possibility of scanning it.

Figure 22: TouchLink[11]

Option 3: NFC in existing parts

Maribert[12] offers 4 NFC tags that look and feel like regular buttons. They can be applied anywhere on clothing. Compared to regular buttons, they are larger (2,03 cm diameter). They don't specify the thickness of the button. From the imagery below, it's estimated that the NFC buttons thciker than regular buttons and approximate 0,6-0,9 mm thick.

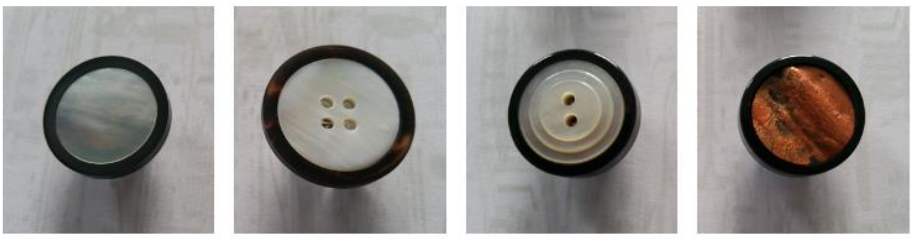


Figure 23: Maribert buttons[12]

12 NFC buttons. Available at: http://www.maribert.it/en/bottoni/nfc-buttons (Accessed: March 2023).

4.5.4: RFID

What is RFID?

Radio Frequency Identification (RFID), based on [56], is a technology to identify ID tags using radio frequency signals [56]. RFID uses a reader and a tag: the reader transmits an radio-frequency signal that powers the tag, which sends a response back to the reader with its identification data. There are three major RFID technologies that used different wavelengths:

1. Low-Frequency RFID (LF RFID)
    a. Range: up to 10cm
    b. 125-134 kHz
    c. Because of its long wavelength, it can penetrate solid materials and high water content
2. High-Frequency RFID (HF RFID)
    a. Range: up to 1meter
    b. 13.65 MHz
    c. Penetrates metal objects and medium-to-high water content
    d. Used for tracking assets in an inventory
3. Ultra-High Frequency RFID (UHF RFID)
    a. Range: up to 150meters
    b. 433 and 860-960 MHz
    c. Faster data transfer compared to LF and HF RFID
    d. Unlikely to pass metal objects and watery contents because of its short wavelength

NFC technology uses the HF RFID protocols. The NFC reader in smartphones also works in the 13.56MHz HF RFID band, so it cannot read LF and UH RFID. But NFC and HF RFID are not the same because NFC has additional protocols on top of the HF RFID. Therefore, they are not compatible. This means that this technology is not feasible in the context of DPP's [57].

Option 1: Decathlon

Nowadays, RFID is mainly used for tracking assets in a logistical context. A great example is Decathlon which is an international sport store. Decathlon has equipped almost all items in its stores with RFID tags, which results in efficiency in inventory management, theft protection, and checkout [58]. The company uses passive tags that only respond to radio waves. With the introduction of RFID tags across the entire product range, Decathlon knows exactly the inventory in its stores. When products are picked for the store and ready for shipment, the tags are activated and the item number is linked to the store in a database. This allows Decathlon to

use information in various processes. The company has achieved faster inventory of its stock through the use of RFID tags.

Figure 24: RFID tags in Decathlon garments (own picture)

As seen in the images above, this RFID label has been implemented in the label where other information is displayed too, such as a barcode, serial code and item number. This label has been designed to remove with a scissor because a dashed line indicates that.

4.5.5: What about other identifications?

For example, barcodes, or some kind of serial number are other possibilities of identifying clothing. The downside of barcodes is that they cannot store as much storage as QR codes because they are 1 dimensional, whereas QR codes are 2 dimensional [41]. Why serial numbers may not be the best solution in the case of DPP's, is that relying solely on serial codes can create a bottleneck in the tracking process, as each code would need to be scanned and entered manually into a database or other tracking system [41]. This can be time-consuming and prone to errors, especially if the clothing items are sold in large volumes. Furthermore, convincing consumers in fashion stores to manually enter this serial code may not be convenient enough and maybe will not want to access DPP information.

There are other technologies available that can improve the efficiency and security of tracking digital product passports in clothing such as the use of QR codes or NFC.

NFC vs QR codes

QR codes are more cost-effective than NFC but need to be visible to scan with a camera [41]. But QR codes doesn't offer the same degree of safety as NFC provides [54].

NFC vs RFID

Modern smartphones have a NFC chip included. This can act as a reader as receiver. Therefore, it can act as an NFC reader to read RFID but only of high-frequency. LF or UHF cannot be read by a smartphone NFC reader. Therefore, if the consumers want to access DPP data with their smartphone, it needs to be a NFC

tag [54], [57]. Another option is to include another identification, such as a QR/serial/barcode on top of NFC, but that would make the development, production and use of the DPP tag overly complicated.

In a DPP context, it is safer for the customer and their data to use NFC. As mentioned previously, it's reading distance is maximum 10cm [54], [55], for RFID it is up to 10meters [58].

QR code vs RFID

RFID's are more expensive to implement but they are better for scanning larger quantities at the same time [56].

Conclusion scanning methods

QR codes, RFID and NFC are well-integrated parts of operators, businesses and consumers' lives [41], [42], [54], [56]. Right now, NFC looks like the most promising technology because it can be used by the majority of stakeholders [54]. QR are effective for scanning 1 to 1 but may be less suitable for handling larger quantities. Also, according to benchmarking, it is questionable how QR can be uniquely produced. Therefore, this may not be the best technology as a starting point.

All of this means that the first development stage of the DPP will be focusing on implementing NFC technology in the DPP context.

4.5.6: Conclusion benchmarking

As mentioned before, current solutions will be benchmarked according to the weighted design requirements. It's worth note that no concept scored 2/2 on non-removability and durability, the most important factor to ensure that data get carried over from stakeholder to stakeholders. Second, no solution scored at least '1' on every parameter. Parameters that scored zeros should be iterated in further stages to raise them at least to a 1 to make the current problem more bearable [40]. Furthermore, current businesses only focus on how digitization methods for clothing can be used for. Not how it will be implemented. This means there's a clear gap how this should be done appropriately. This means that a new solution should be explored for new possibilities to bring DPP content to consumers, as well as other valuable stakeholders.

Table 2: Benchmarking DDP solutions (own table)

		Benchmarking							
	Weighted (x/5)	Label in price tag	QR code in label (sewn 1 side)	Printed on label, sewn in 4 sides	Printed dierectly on textile	Touchlink	Supplier: NFC Laundry tag	Supplier: NFC button /maribert	RFID Decathlon
Non-removability	**5**	0	0	0	1	1	0	1	0
Removability	**3**	2	2	2	1	1	2	2	2
Styling	**3**	1	1	1	2	2	0	1	0
Versatility	**2**	2	2	2	1	0	1	2	2
Non-damaging textiles	**2**	2	2	2	0	2	2	2	2
Ergonomics	**4**	0	1	1	2	2	0	1	1
Circularity	**4**	1	1	1	0	1	1	0	0
Signifiers	**2**	2	2	2	2	0	0	0	2
Cost	**2**	2	2	2	1	1	1	1	1
Durability	**5**	0	1	1	1	2	2	2	1
Scannability	**3**	2	2	2	2	2	2	2	0
	70	35	44	44	41	48	34	44	29
		50,00%	62,86%	62,86%	58,57%	68,57%	48,57%	62,86%	41,43%

4.6: Brainstorm

The goal is to design solutions that could tackle the problem stated in the benchmarking. This to increase designing a solution where zeros will be turned into ones and to increase the general score.

By navigating the internet, several ideas were brainstormed by the main researcher of this study. The main structure is that there are concepts about QR codes and NFC tags, each having there positives and negatives. These will be evaluated based on the previous designed weighted decision matrix.

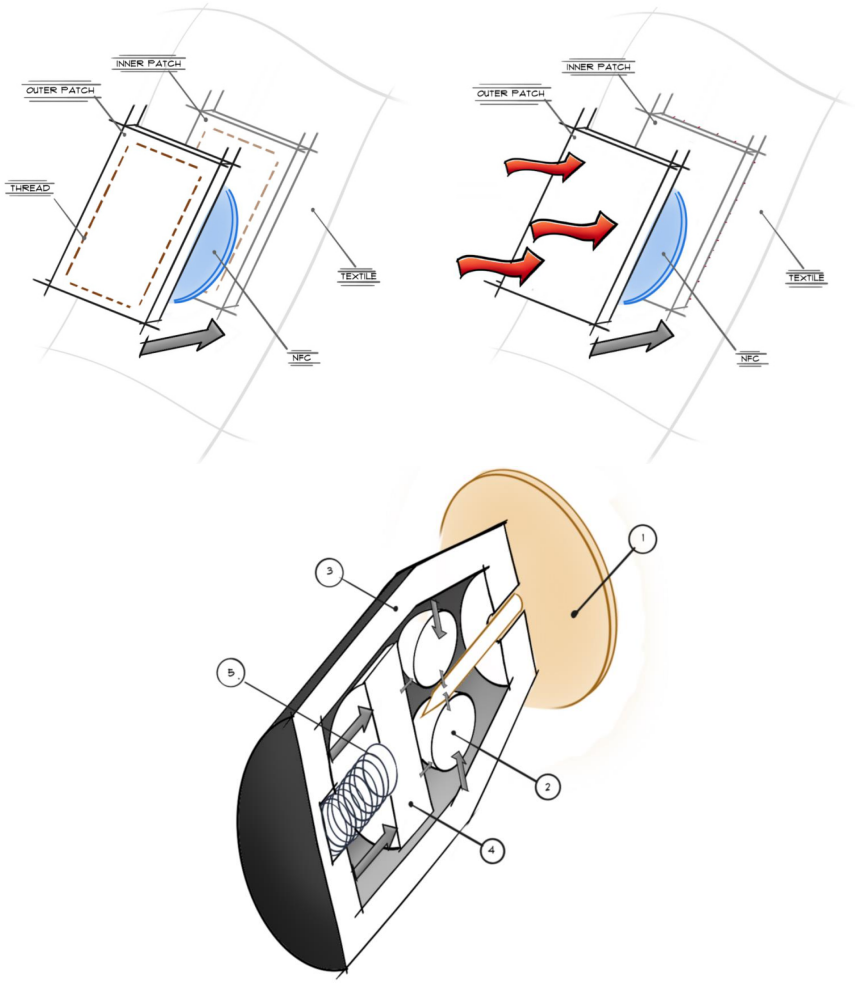


Figure 25: Selection of the brainstormed ideas (own drawings)

4.6.1: Idea 1, NFC in patch

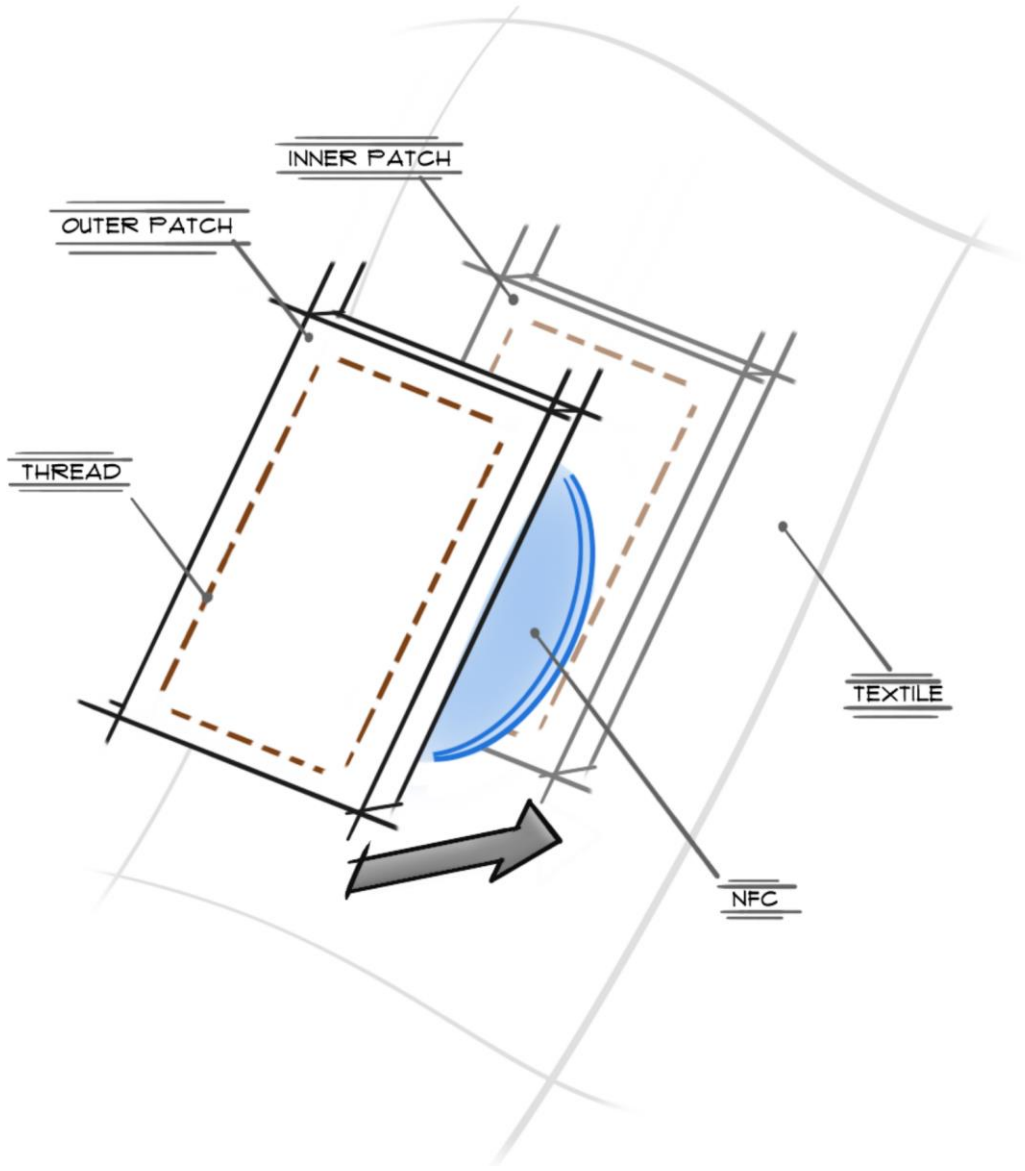


Figure 26: Idea 1: NFC in patch sewing concept drawing (own drawing)

The first idea is the implementation of a DPP tag behind a patch which is sewn in clothing. Here, its important that sewing has been done qualitativly to ensure it will remain a part of clothing throughout its whole life-cycle. Another interesting opportunity from this design is that that it's part of the garment's style and fashion brands can include their logo in the design of the patch as seen in the image below. Possible patch materials are leather, suede, denim, canvas and synthetic leather (PU).

Important with this concept is that the NFC tag is sandwiched between two patches to protect it from both sides. This could add extra bulk to the patch but that's important for durability reasons. The thickness of 1 patch is about 2mm, which has

been measured with patches in clothing the researcher had at home. From benchmarking, the thickness of a regular NFC tag is 1mm so this makes the total thickness of an NFC patch 5mm. Important to mention is that the diameter of the used NFC tag is 13mm, which has an influence on the the design.

Figure 27: Patch in synthetic leather (left, own picture) and suede (right[13])

Sewing in such patches onto textiles requires a sewing machine with a special needle whilst using a topstitch. It's recommanded to stitch 3mm from the border and sew a round the leather patch 3 times [59]. Also, the process' efficiency will be influenced by the shape of it. Squared patches may be easier to sew in then circular or shapes with lots angles [59].

A leather patch could be substituded for a vegan-leather alternative but then, the right LCA data should drive the deciscion making process. But as mentioned before, this is out of scope of this project. Another important parameter is the thread material used. The most common thread material is cotton [60]. This thread is a natural-based material but this is weaker than polyester threads, a polyester based material. Also, cotton threads are slightly more expensive [61].

Analyzing this concept through the set design requirements:

Non-removability: This tag can be removed with a seam ripper. Furthermore, if the threat has not been applied qualitativly (weak threat material, the wrong thread tension, not enough repetitions), then the patch could fall off. But this solution is not as removable with a scisccor such as labels.

Removability: This patch is removable with a seam ripper.

Styling: The design of the patch can be take into account whilst fashion designers are developing new clothing so it blends in to style of that piece. It should be noted that this concept is thicker than normal patches (2mm) which has an effect on styling.

13 RE-KÅNKEN (no date) Fjällräven.Available at: https://www.fjallraven.com/nl/nl-nl/tassen-uitrusting/kanken/kanken-rugzakken/re-kanken

Versatility: It's possible to apply this anywhere on clothing but preferably on the outside of clothing to avoid unnecessary contact with the skin.

Non-damaging textiles: Just sewing in this leather patch should not damage textiles because the needle head pushes the fibers aways.

Ergonomics: Small leather patches are found in current applications but without an NFC tag. On the other side, adding an NFC tag to this patch will eliminate the flexibility such parts.

Circularity: Depending on how the patch itself ages, it could be reused again. Leather (substitutes) are common applications in current designs. The right material should be selected based on several material properties such as the overall quality (needs to survive an extended period of time thickness and waterproofness). This is because the NFC tag needs to be protected from environmental conditions. Otherwise, a casing should be designed to protect the NFC tag, but this could make the patch way thicker as usual.

Signifiers: It's possible to add text or an NFC logo to indicate that this is scannable. As mentioned previously, this is in contrast with the styling of the tag.

Cost: Only looking at the price of a synthetic leather patch itself that can be customized according to shape (round, oval, squared) and size (2x4cm) and a quantity of 1000 pieces, then the price is €0,53/piece excl tax (21%)[14].

Table 3: Material cost NFC patch (own table)

Synthetic leather patch	0,53 €
Thread	0,00 €
Regular NFC	0,84 €
	1,37 €

Durability: Depending on material properties of the outer materials, the regular NFC tag can be protected by it, otherwise, a casing should be designed to make sure the tag survives. As mentioned before, wear and tear is also greatly impacted by the overall quality of the threat. Also, the thread should be sewn around the border for 3 times. This increases durability but increases manufacturing time and therefore, also cost.

14 Patch / Embleem PU leer (no date) Promofit. Available at: https://www.promofit.nl/patch-embleem-pu-leer?dfw_tracker=109131-266175&gclid=Cj0KCQjwmN2iBhCrARIsAG_G2i7c_ffzn9tgoBUnsxpsaW_0OSRmW-_xXXSzgyJ5r0SuT5RKf7htpTEaAl4ZEALw_wcB (Accessed: April 2023).

4.6.2: Idea 2, NFC in iron-on patches

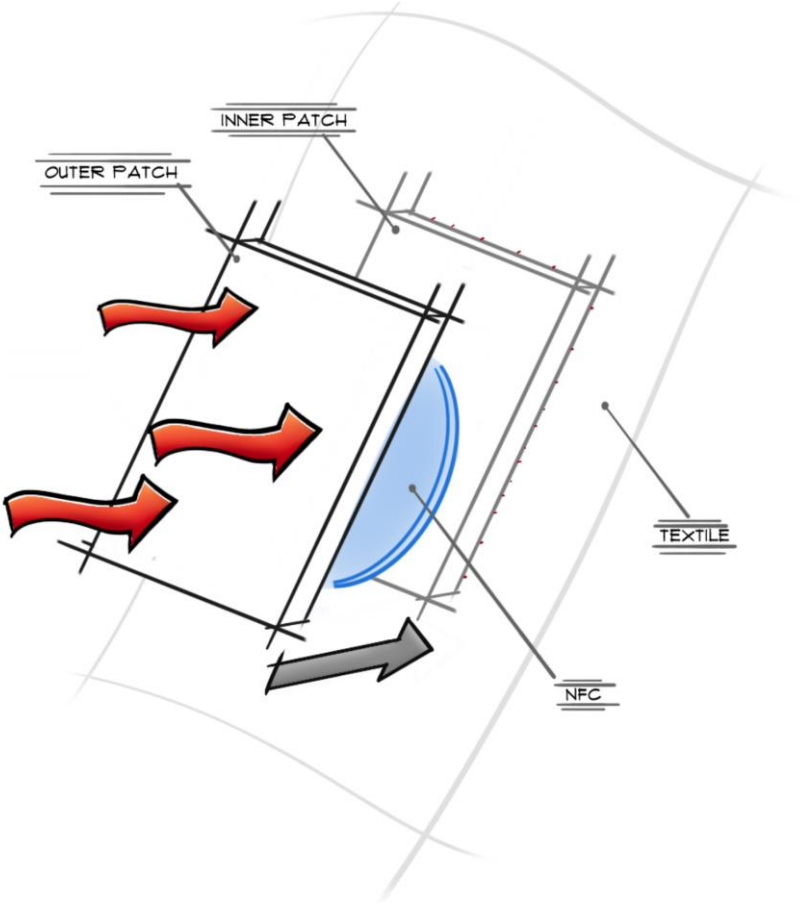


Figure 28: Iron-on method (own drawing)

Same principle as before, where an NFC is applied between the garment and the patch, but now, heat is used to melt glue which pplies the patch to clothing [62]. This solution may raise some circularity questions because heat and adhesives are used. Furthermore, removing iron-on patches can be removed by reapplying heat with an iron or by using special adhesive methods. Once removed, this patch leaves behind glue residue which is hard to remove [62]. A toothbrush, applying heat again, and wash it as many times as needed are possible ways to remove access glue. Generally speaking, using glues can be avoided by using different attachments methods.

Lastly, it is important that the NFC tag does not get damaged whilst applying 30sec of heat to the patch. Because the regular NFC tag is not designed to handle extreme heat, a laundry tag should be used, which can handle such temperatures. This means that extra bulk will need to be added to the patch.

4.6.3: Idea 3, Security pins

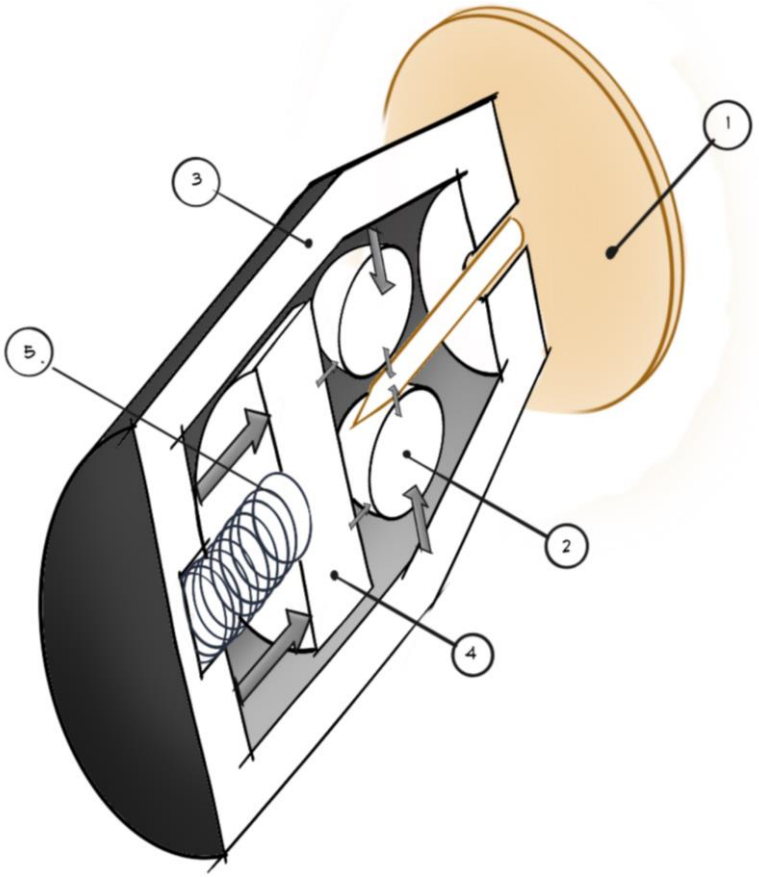


Figure 29: Idea 2: Security pin mechanical concept drawing (own drawing)

The inspiration for this idea comes from the security tags that are used in fashion stores, which are part of the EAS technology (Emergency Alert System) and include a signal transmitter that triggers EAS antennas at the entrance/exit of stores thanks to RFID technology [63]. This system notifies store staff if someone tries to steal an item, and only store staff can remove the tag due to a mechanical locking mechanism that prevents customers, especially shoplifters, from removing it. This same technology can be applied to DPP tags, but without the EAS antenna, making the tag smaller. Different mechanical locking systems for EAS tags can be found on the internet, but they share common components such as a pin that penetrates clothing and goes through a guide, which is a ferromagnet.

As seen in the mechanical concept drawing, a pin (1), which is applied through clothing is secured by a couple of small balls (2) that press against the pin because they are in a bucket (3) with angled side walls. The balls are kept in place by the guide (4), which assures the spring (5) can apply pressure.

The tag can only be removed by certain stakeholders with specialized tools, such as fashion stores, or by other stakeholders in the DPP value chain, such as recyclers

and upcyclers, who are eligible to own such devices. The detacher module works thanks to magnets. The guide is magnetic and when a strong magnet is applied, the spring compresses and the balls lose their gripping strength.

Figure 30: Detacher module[15]

Analyzing this concept through the set design requirements:

Non-removability: The security pins used in this mechanism cannot be removed by customers or shoplifters, only by store staff. This ensures that the DPP tags cannot be removed without authorization.

Removability: The security pins can be removed by certain stakeholders who have specialized tools such as fashion stores, recyclers, and upcyclers. This ensures that the DPP tags can be removed when necessary.

Styling: The smaller size of the DPP tags without the EAS antenna makes them more aesthetically pleasing to wear. The pin head itself could be customized according to the fashion brand's preference.

Versatility: The mechanical locking system used in the security pins can be adapted to different outputs, making it versatile in its application.

Non-damaging textiles: The security pins are designed to penetrate clothing without causing damage.

Ergonomics: This should be investigated. This adds extra bulk and weight to a garment. A small as possible tag should be designed with this locking mechanism.

[15] D303 Flush mount remover (no date) Alien Security. Available at: https://www.alien-security.com/security-tag-hook-detacher/

Circularity: Circularity is achieved through the removability (with the right tools) of this system. This means that this solution could be reused over and over again, as it is now done in the current security context.

Signifiers: Signifiers could be added to signify to stakeholders that this part is scannable.

Cost: Detacher modules can be found for around $300 and the individual modules for 0,66$ incl tax. Where this concept also accelerates in, is in assembling and dissembling time. Assembling takes about 5 seconds and dissembling about 4 seconds when watching explainer videos.

Durability: The durability of the security pins is not mentioned in the text.

Scannability: If NFC is used, then this tag is scannable by various stakeholders.

4.6.4: Idea 4, Mandatory digital wardrobe

What if it were possible to completely eliminate the need for adding a physical component to clothing? In general, adding nothing is preferable to adding something. One potential approach to achieve this is by introducing a system that captures information when an item is acquired through a mandatory wardrobe, similar to existing centralized systems like CoZo[16] used for sharing patient files in healthcare. This includes vaccination status, blood tests, examine results, ...

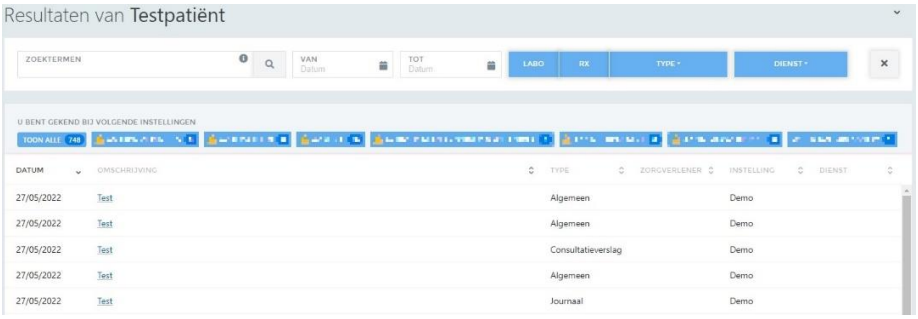


Figure 31: Example CoZo

Applying this method to DPPs in clothing can be illustrated through the following example. Suppose clothing is acquired through first-hand purchases, second-hand transactions, or fashion rentals. In this scenario, DPP information would be accessible on, for instance, the price tag. When someone acquires the clothing, the store registers this information on a central platform connected to the individual's personal account. This concept is referred to as the "mandatory digital wardrobe." However, several questions arise: Will people accept the mandatory registration of their purchases? Will they be willing to create an account and actively use the platform? Moreover, convincing established stores to participate in this platform can be challenging. To achieve a circular economy, it is essential to persuade all stakeholders to join the platform. Additionally, ensuring secure and reliable data transmission between stakeholders poses another hurdle because they all need access to this platform. Furthermore, EU reports suggest that such a solution may be allowed under Article 31 of the framework [9], which states that "where possible, the data carrier should be on the product itself to ensure the information remains accessible throughout its life cycle." In this case, the DPP would be digitally stored rather than physically attached to the product. Considering these factors, this concept will not be further developed. Nonetheless, it highlights an intriguing solution worth exploring.

[16] Medical results (no date) CoZo. Available at: https://www.cozo.be/

4.6.5: Idea 5, NFC in existing parts

As observed in the benchmarking, incorporating NFC tags into existing buttons results in a thicker-than-usual component. While reusing these solutions is possible, disassembling these parts remains uncertain, as it is presumed that the NFC tags are molded with polymers. In general, including NFC tags in existing parts presents an interesting opportunity for fashion manufacturers. They can either incorporate the tags into clothing components or add them as aesthetic pieces. Possible existing parts where NFC tags could be integrated include buttons, fasteners, zippers (TouchLink), jeans rivets, and snap fasteners. Furthermore, these parts are typically manually removed from textiles by an operator [35]. This differs from washing or other labels, where their removal depends on the specific case.

This concept focuses on the implementation of NFC technology in three components, leveraging the advantages of utilizing existing parts in the clothing manufacturing process.

The following information is based on [64], [65].

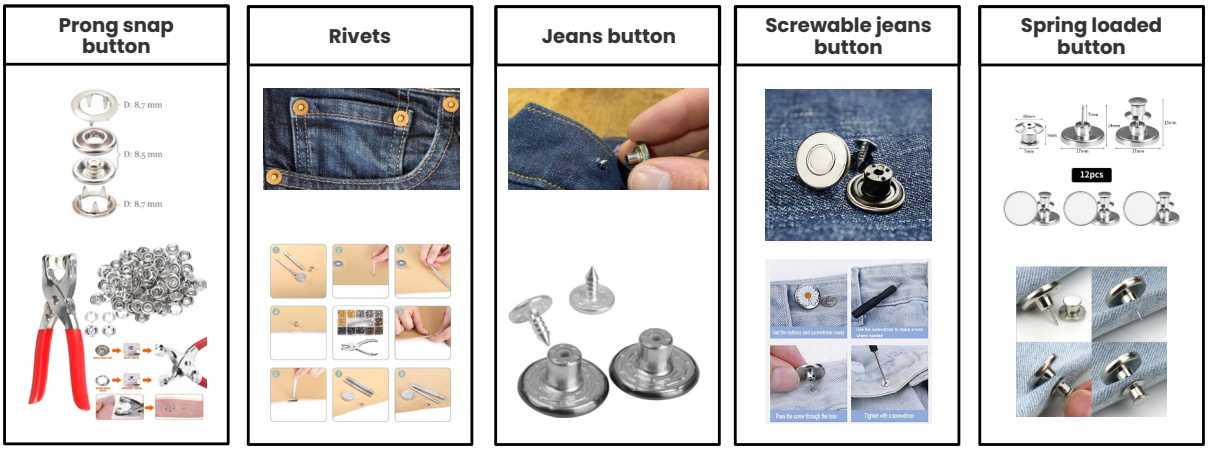


Figure 32: Schematic represenation of existing clothing parts

Idea 5.1: Prong snap button

A prong snap button[17], also known as a snap fastener, is a type of closure commonly used in clothing, bags, and other textiles. The purpose of a prong snap button is to 'click' two textiles together. It consists of two interlocking discs with small prongs, one with a socket and the other with a stud. When the prongs on one disc are pushed through the corresponding holes on the other disc and then bent inward, they create a secure and easily reversible fastening. Prong snap buttons are often

17 Prong snap button (no date) Ata Buttons. Available at: https://www.atabuttons.com/prong-snap-button (Accessed: April 2023).

made of metal, plastic, or other materials, and come in a variety of sizes, shapes, and colors. They can be applied either by using a hand fastener tool or with a manual press.

Such parts can be applied on a variety of textiles, such as cotton, denim and linen. This design accelerates in the fact that it is small and versatile, but designing an NFC within such part could not be feasible to work to work on during this study.

Idea 5.2: Rivets

In textiles, rivets are small metal fasteners used to attach two or more layers of fabric together. They are often used in areas of a garment that receive a lot of stress or strain, such as the pockets or seams, to reinforce these areas and prevent them from tearing or coming apart. The price of one rivet[18] is usually €0,06 including tax. Rivets are commonly found in denim jeans, but can also be used in other types of clothing and accessories, such as bags and belts

Rivets are typically made of brass or other types of metal, and they come in various shapes, sizes, and styles. This material should be avoided regarding the design requirements because these materials may cause an allergic reaction or irritation if it would touch the skin. This could be solved by placing it somewhere where it does not touch the skin.

Rivets are attached to the fabric by piercing a hole through both layers of fabric and then inserting the rivet through the hole. Regarding design requirements, damaging the textile should be avoided. The rivet is then secured in place by pressing it down using a tool called a rivet setter. This mechanism relies on material deformation to ensure a secure fit, which benefits the non-removability of such mechanisms. Contrary, reusing such system is impossible because the material has been deformed repentantly.

Jeans button use the same application process as rivets and can therefore be placed in this category. Important to know is that such system are recommended to be only used on durable fabrics, such as denim, leather or canvas. That's why they are usually not seen on other types of garment. The price of 1 jeans button[19] is usually €0,23/piece including tax.

Idea 5.3: Screwable jeans button

The first part is a screwable jeans button. Just as regular rivet jeans buttons, a hole needs to be pierced through the fabric, which is not desired. Instead of relying on

18 Jeans rivets

19 Jeans button

material deformation, this mechanism is secured by screwing in the button cap on the thread, which can be seen in this image. This results in a more circular part, because it could be reused over and over again. If such solution could house an NFC chip, then it's important that either a non-standard screwdriver is used to secure the button, or a cover is made for this part. As mentioned before, such system could only be used on denim, leather or canvas which makes it less versatile. The cost of a screwable jeans button[20] is €0,27 including tax.

Idea 5.4: Spring loaded button

Spring loaded buttons rely on the same principle as security pins, where ball bearing and a spring cause the pin to stay in place. Here, it's possible to easily release the pin by pulling on the cap making it possible to reapply it anywhere on clothing. This application is mainly used as a solution to tighten pants around the waist without using a belt.

This solution solves several problems the previous idea had. Firstly, it doesn't damage the textiles because the needle pokes between the fibers instead of destroying those. Second, such pins can be applied on more materials besides only denim, leather and jeans.

Adaptation to such systems should be made to make it fit within the design requirements. Firstly, reapplying this mechanism should not be as accessible to benefit the non-removability.

A spring-loaded button costs €0,47 for 1 item.

20 Screwable jeans button

4.6.6: Conclusion brainstorm

Here, it's confirmed that approaching this wicked problem and creating possible 'solutions' only tries to make the problem less worse. This is clear because the weighted scores in the weighted decision matrix still shows 0's and the total weighted scores of the brainstormed and benchmarked solutions are roughly the same. It is desirable that a concept should be designed where no zeros can be found. Therefore, a possible way to tackle this wicked problem, is to combine multiple benchmarked and brainstormed solutions together, based on the perception of the main researcher.

	Brainstorm						
	NFC in patch sewing	NFC iron-on	NFC in security pins	NFC in rivet	NFC in screw jeans button	NFC in spring loaded button	Combination 1
Non-removability	1	2	2	2	1	0	2
Removability	2	0	2	1	2	2	2
Styling	2	2	0	2	2	2	1
Versatility	2	2	2	1	2	2	2
Non-damaging textiles	2	0	2	0	0	2	2
Ergonomics	1	1	0	1	1	1	1
Circularity	1	0	1	0	2	2	1
Signifiers	0	0	0	0	0	0	1
Cost	1	1	1	1	1	1	1
Durability	1	2	2	2	2	1	2
Scannability	2	2	2	2	2	2	2
	46	42	46	43	51	45	55
	65,71%	60,00%	65,71%	61,43%	72,86%	64,29%	78,57%

Figure 33: Weighted decision matrix brainstorm (own table)

Idea 3, implementing an NFC in security pins is the only concept that has a maximum score of 2/2 with non-removability, removability and durability, three contradicting factors that contribute to the wicked problem. The two aspects were this concepts scores a 0/2 for, is for styling, ergonomics and signifiers. To increase styling of such system, it would be beneficial to design something smaller than the current security pins. TouchLink, implementing an NFC in existing parts and in a patch could be seen as other opportunities to raise the styling of idea 3. For example, it could be possible to make a smaller security pin system but the pin itself could look like a leather patch or like a broch pin.

To increase ergonomics of this security pin system, once again looking for example at TouchLink, but also (almost) every other solution could increase ergonomics. Once again, if this tag is designed to be smaller and well-integrated in clothing, then this could combined idea would at least go from a 0/2 to a 1/2 for ergonomics.

As a result, it's estimated that a score of 78,57% could be hypothetically reached if all the good aspects of the security pin system remain the same whilst incorporating the opportunities from the other benchmarks and brainstormed solutions.

Final combined concept

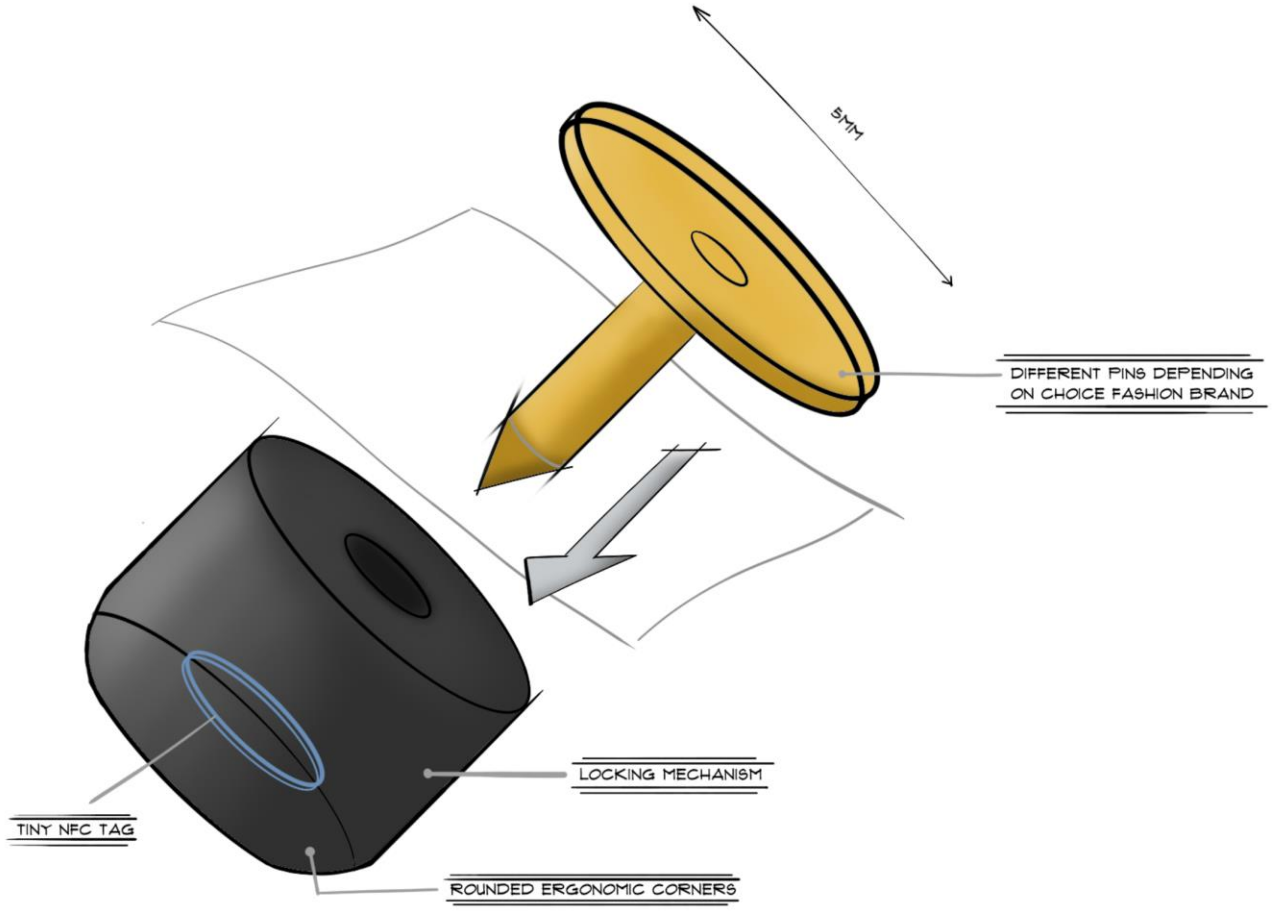


Figure 34: Conclusion brainstorm (own drawing)

The above image provides a visual representation of an optimized security tag that aims to enhance its desirability. The concept involves applying a thin pin through the fabric, similar to the ideas of using a security pin or a spring-loaded button. Importantly, this method does not damage the textile as the pin pierces between the fibers rather than through them. The pin is secured on the other side using a

locking mechanism, which can be spring-loaded or designed differently. The feasibility study in the deliver phase will explore this locking mechanism further.

To increase consumer desirability, it is crucial to design a small and lightweight solution. While the mechanism is non-removable by consumers, it can be removed by specific stakeholders with the appropriate tools. For styling purposes, the golden pin itself can display various elements such as brand logos to seamlessly blend with the design. Additionally, the solution can be reversed, with the pin head touching the skin and the black locking mechanism visible. This alternative orientation allows it to function as a button or resemble a rivet, further integrating it into clothing designs.

Clothing brands can also cover this tag with a label for aesthetic and ergonomic reasons, as shown in the accompanying image. Alternatively, a leather patch can be used to conceal the tag for aesthetic purposes.

Figure 35: Labels to cover concluded idea (own picture)

The versatility of this tag depends on its size. If it can be designed to be as small as possible, it can be suitable for various garments. However, if it is too large, it may not work well with tight-fitting clothing. The circularity aspect of this design will be explained further in the deliver phase.

While it is possible to indicate that the tag is scannable through NFC, this may conflict with its potential styling and integration into the garment's overall design. An alternative solution is to educate stakeholders about its scannability. Additionally, it is expected that a small NFC tag would have a shorter reading distance, making it less ideal for logistical purposes. Therefore, logistical partners would need devices with stronger reading capacities to scan tags from a greater distance.

Lastly, durability is an important design requirement for this tag. With the right design and material selection, it can ensure that data is not lost throughout the garment's life cycle. The feasibility study in the deliver phase will delve further into developing this durability aspect.

5

Deliver

This part explains how such physical DPP tag can be designed to be circular, feasible, viable and desirable. But before investigating each of the 4 innovation criteria, it's appropriate to give this solution a name. First, the name of the company goes as follows:

Figure 36: Nanto company logo and tag line

The name should suggest elegancy, because the solutions that Nanto provides are designed to blend in existing clothing. Furthermore, 'Nanto' looks like 'nano' which refers to the size of the solutions. Lastly, it gives a sense of future-proofness and its reading it in different languages such as English, Dutch or French should not result in any weird pronunciation. The company should convey trust, security, and durability while reflecting the circular economy principles embraced by Nanto. Furthermore, Nanto is written without capital letters in the graphic design and other images to emphasize the efficiency and volume of its products. Nanto is a company that would introduce a portfolio of DPP solutions, where in this study, 1 possible solution will be further developed using the design requirements. The name of this solution is:

Figure 37: Nanto secure logo

This refers to the fact that this solution could be the most secure solution within the product line-up. The portfolio of possible DPP solutions could look like the following, where Nanto secure is this study's focus:

Figure 38: Nanto product line-up

5.1: Nanto secure, a Circular DPP tag

Nanto secure is designed to be circular, meaning that the design allows it to be reused again to be applied in new clothing. As part of the circular economy's butterfly diagram, such reuse/redistribute objectives need a service provider [17]. That's why Nanto, the company, relies on a Product-Service System (PSS).

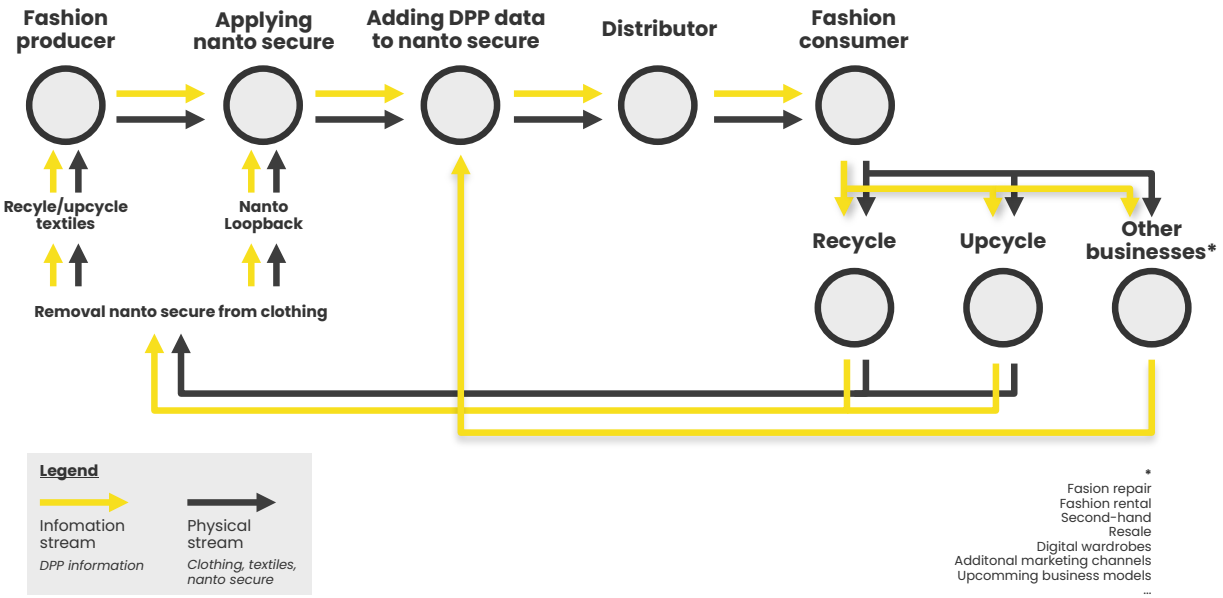


Figure 39: Information stream in a circular economy thanks to Nanto (own figure)

Specifically, it is a product-oriented PSS, whereas the fashion companies are owner over Nanto's products but Nanto is bringing additional services to the product. The service includes that this tag will be send back to business who originally acquired Nanto's products. This process is called 'nanto loopback'

To implement a successful service from 2030, a seamless and efficient process needs to be established for stakeholders who need to remove Nanto Secure, such as recyclers or upcyclers. They will be able to scan the NFC tag to access all relevant DPP information, including the original owner and the destination address for returning the tag. They can scan such NFC tags with a professional handheld scanner, as seen in the image. This device[21] is also equipped with a camera and laser aimer so it could also scan DPP's that are accessible through other information sharing methods, such as a QR code or barcode. Such device costs €604 excluding tax. It displays relevant information for such stakeholders. It's also

21 Newland MT9052 Orca III (no date) ADiVO. Available at: https://www.adivo.nl/mt9052-orca-iii-3-32gb-5-2d.html?gad=1&gclid=CjwKCAjwge2iBhBBEiwAfXDBR3AOh9-fhgwF9VdcxmwXwVOUny3RMoge8UO7OEjuPGYhlAzLDjgReRoC3mEQAvD_BwE (Accessed: April 2023).

possible to use a large NFC scanning pad[22]. Here, Nanto Secure can be easily scanned by laying garments on this reader. It's 20x20cm and because of the coil size, it can scan NFC tags from 15cm away and is compatible with Windows and MacOS. This costs €98 excluding tax and need additional software to work.

Figure 40: Handheld NFC scanner[21] (left) and NFC scanning pad[22] (right)

An automatic shipping label can be generated and printed, similar to the process for returning packages through online warehouses. To facilitate such process, Nanto should establish partnerships (SDG 17) with relevant institutions and provide them with the necessary knowledge, envelopes, cardboard boxes, and dissembling tools. By doing so, Nanto can create a closed-loop system that promotes circularity in the fashion industry while also meeting the growing demand for sustainable and transparent production processes [31]. This approach aligns with the principles of the circular economy, where waste is minimized, and resources are maximized through a collaborative approach between producers, consumers, and service providers [17].

22 NFC XL Reader (no date) ShopNFC. Available at: https://www.shopnfc.com/en/nfc-readers-writers/300-390-nfc-xl-reader-long-range-hf-reader.html#/122-model-libnfc (Accessed April 2023)


nanto
loopback

5.2: Nanto secure, a Feasible DPP tag

As mentioned in the design requirements, the non-removability and durability are two of the most important factors, which will be the main goal of this feasibility study. Besides making this tag versatile, circular and ergonomic, Nanto secure should also be cost-efficient. This can be reached by searching for standardized parts. If everything would be custom made, then it can be assumed that the price of such tag drastically increases which affects the overall desirability of fashion companies to incorporate Nanto secure in their clothing.

5.2.1: Researching pins

The following information is gathered and summarized from [66], [67].

This concept heavily relies on a using a pin to penetrate textiles. Therefore, it is important to choose the right type of needle according to the material used. For example, it is an common mistake that sewers use the wrong needle for the wrong material. For example, the needle head is too sharp or rounded. Sewing with a wrong needle can cause breaking of the fibers which is not allowed. Therefore, there are different types of needles according to the different types of fabrics.

In the context of a Nanto Secure, the material will be 'perforated' once by the needle. Nonetheless doesn't this mean that the wrong needle head can be used on materials because pressure will be applied too on the tag, which may cause the needle to break. Therefore, choosing the right needle head is needed.

A universal needle is used for cotton, felt, viscose, linen, jacquard and fleece. The stretch needle is used for synthetic, elastic fabrics like lycra, silk jersey and velvet. Because of the more rounded point, this needle pushes the fibers away without breaking the fiber. The denim/jeans needle is strong and sharp and is suited for thick, woven fabric like denim and jeans. Other materials are twill, canvas, oilcloth or plastic. The jersey or ballpoint needle is specially made for knitted fabrics, such as tricot and jersey. Besides the geometry of the needle head, also the overall thickness of what needs to be sewn through influences the sewing capacity of a needle. Needle size 60 is suited for thin fabrics, needle size 80/90 for normal thick fabrics and needle size 100/110/120 for thicker fabrics or for textiles that need a strong needle.

Furthermore, the length of the pin should also be considered. The design does not allow the needle head to stick out of the locking mechanism because this would cause major damage to the skin, as well as other textiles when it is washed in a washing machine for example. The length of the pin depends on the thickness of the material it penetrates. Therefore, it is important to inform fashion companies

about the importance of knowing the material thickness, but also the location of Nanto Secure could influence the length of the pin. For example, the section length because thicker where multiple layers of textiles are present.

Also, the pins should be made from stainless steel or a polymer to avoid allergic reactions. Furthermore, those materials are water-resistance. The price of 1 stainless steel pin is €0,02 excluding tax for a batch of 100 pins. It's also possible that companies use their own pin but they should keep in mind the limitation of this system. The mass is 0,31 grams.

5.2.2: Approach

The goal of this feasibility study is to research if a sufficient locking mechanism can be created that takes account of the design requirements. Most importantly, the locking mechanism should be non-removable by for example fashion consumers but removable by certain authorities, such as recyclers and upcyclers. Here, Idea 3 (security pins) from brainstorming could be a feasible system but it's important to make such system smaller to make it more ergonomic for consumers. An object that uses a similar system is Idea 5.4 (spring-loaded button) which is way smaller (7mm height, 10mm diameter). It's desirable to create an even smaller system. Contrary, this is designed to be easily removable which is not desirable. This means that first, the two systems will be combined so it becomes the same overall size as the spring-loaded button whilst incorporating non-removability and removability from the security pin. Such systems will be build, tested and making conclusions from each iteration cycle.

Material choice according to design requirements

This iteration should also keep in mind other ergonomics parameters, such as material chose. From the design requirements, it has been concluded that 3 type materials do not cause allergic reactions. They include natural fibers such as cotton and linen. It can be assumed that for this iteration, such materials will not be used. The second type of materials are polymers, which probably needs to be injection molded. From benchmarking, ABS and PPS are two materials often used within NFC applications. From the two, PPS will be more promising in this scenario because of its pressure-resistance, can be exposed to chemicals (hydrogen peroxide (5%), industrial laundry detergent (pH 10-11), neutralizing agent and perchlorethylene (100%)) and it is designed to be more heat resistance, up to 180°C as well as being IP68 rated. Such material properties are desirable so it could be used in versatile applications.

The last type are metals, such as nickel-free stainless steel, titanium and 18K gold. To create a cost-effective solution, titanium and 18K gold materials will not be suited for this study. Nickel-free stainless steel, or referred as 316L stainless steel is a corrosion resistance against most chemicals, salts, and acids.

Mechanical and other material properties of PPS and 316L stainless steel can be found in Appendix F.

5.2.3: Iteration 1, spring-loaded

Build 1

Because the prototypes will be made with 3D printing, it will not be possible to realistically test the release mechanism. Normally, the guide is magnetic and when a magnet is applied, the guide is attracted to it, causing the spring to compress more and releasing the balls.

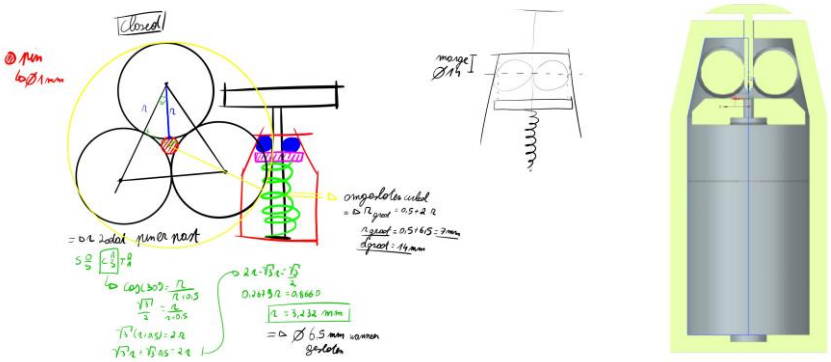


Figure 42: Calculations (left) and first CAD drawing (right) (own figure)

Total length is 32mm, which is too long to be ergonomic for consumers. The reason why it is this length, is to test the system with items who were available at that time. For example, when the compression spring was compressed, it was 15mm.

Test 1

This shell will be printed in 2 parts, because otherwise it wouldn't be possible to achieve high quality print and is inserting the materials impossible (like the spring, ball joints,...)

Because the spring didn't fit in the designed hole, a finger was used to apply pressure to the guide. The pin could not be removed using such method.

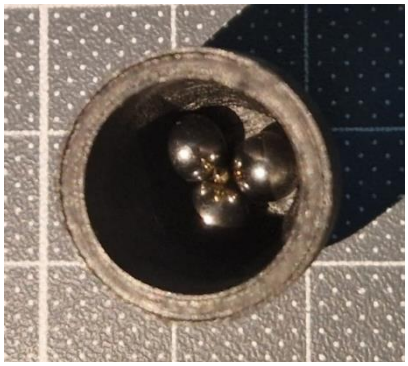


Figure 43: Test 1 (own figure)

Learn 1

In CAD, 6mm ball bearings were used to calculate the dimensions. When testing the configuration, 5mm ball bearings created more friction between the needle, the ball bearings and the sloped wall. Other diameters balls where tested too but didn't create the desired locking mechanism. If the spring size can be smaller, the overall volume can decrease.

Thanks to the design of the CAD models, it can be easily modified and tested so smaller ball joints would fit the system. Therefore, the overall size can decrease, this will be tested in further iterations.

Build 2

The proposed adjustments of Learn 1 are implemented. Important to note is that the ball bearings overlap in the CAD drawing but just as in the previous test cycle, different ball bearing sizes will be used to test the system. Also, a smaller spring was found so the overall length of the object could decrease.

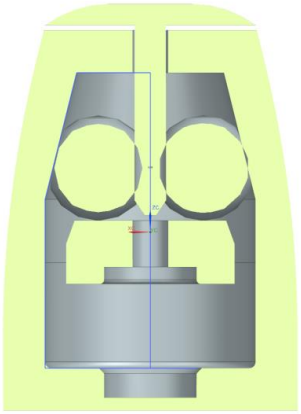


Figure 44: CAD section-view build 2 (own figure)

Lastly, the diameter guide has decreased so it creates a smaller object. Because the diameter has decreased, the ball bearings will need to be smaller. But as mentioned previously, the ball bearing diameter will be iteratively tested.

The 3 parts were printed with an FDM 3D printer, 0.1mm layer height and the print took 32minutes.

Test 2

The same testing method was applied. Because of the different dimensions, different balls were inserted and tested. Also, the spring mechanism was tested successfully.

Figure 45: Test 2 (own figure)

Learn 2

Positive, yet expected learnings are that the adjustments made to fit the compression springs was successful. Therefore, the overall size of the DPP tag has decreased. This means that this could be more ergonomic to wear compared to the previous iteration, but it's still too large and heavy because of the metal parts. Furthermore, the created locking mechanism was not strong enough. This could be caused by a low spring constant (Force = spring constant x distance), the shaft was too steep or the diameter of the ball bearings were not correct.

Build 3, 4 and 5

Next iterations concluded a steeper shaft and decreasing the length (build 3). Build 4 included the creation of guiding bars for the guide so it doesn't wobble. This was needed because when applying the spring in the system, it caused the guide to not stabilize. Build 5 designed chamfers in the guide so it could push more the ball bearings.

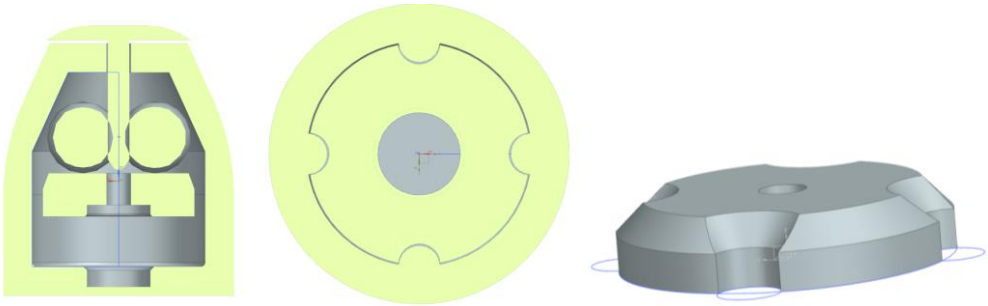


Figure 46: Build 3 (left), build 4 (middle) and part of build 5 (right) (own figure)

Test 3, 4 and 5

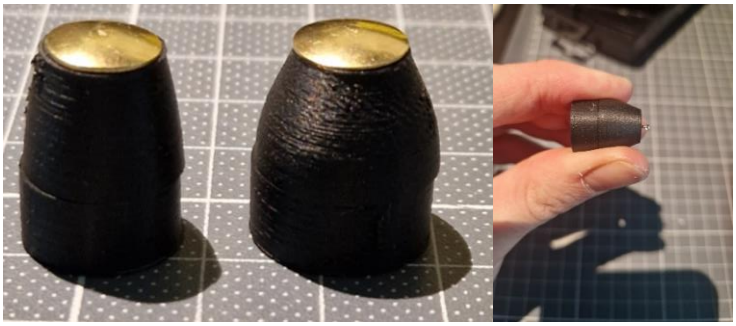


Figure 47: Test 2 (left), test 3 (middle), test 4 (right)(own figure)

Figure 48: Test 4 shell (left), inside (middle) and spring (right)(own figure)

Learn 3, 4 and 5

The locking mechanism itself gained strength over time but it can be assumed that such systems could be further engineered with the right tools and knowledge. Three iteration later and the mechanism has not decreased in size. Furthermore, it can be assumed that if such parts are produced, they could be too heavy to be worn ergonomically because of the metal parts.

Conclusion iteration 1

This mechanism has been explored but it's not feasible to further put time and money in this concept. That's why other locking mechanisms will be explored during a small brainstorm.

5.2.4: Brainstorming other locking systems

Brainstorming other locking mechanisms was done by zooming out on the problem. How could pins be securely attached to garments?

Existing pin locking systems

There are several ways how a pin could be attached to textiles [68].

Figure 49: Different locking mechanisms (own figure)

The first type is a **butterfly clutch**[23], which can be seen as the most common pin securing methods. With a price of €0,13/piece incl tax for Q=100, they can be seen as relatively cheap. They are designed to be easily attached and released, which means that on their own, they would not fulfill the design requirements. This means that an enclose system should be designed for this system, whereas the minimal height needs to be at least be larger than 7mm. Also, they are known to be less secure compared to other securing methods.

A second securing method are **rubber clutches**. They offer a better grip and are harder to remove. For a quantity of 100, their cost is[24] €0,13/piece incl tax. Compared to butterfly clutches, they are taller by 2mm, resulting in an overall height of 9mm.

A third method is a **deluxe clutch**. Actually, this uses the same mechanical principle as Idea 5.4 (spring loaded button) but is actually 1mm less heigh. The maximum diameter is still 10mm. For a quantity of 30, one deluxe clutch costs €0,26 incl tax[25].

23 Butterfly clutch

24 Rubber clutch

25 Deluxe clutch

The last method is using a **pin keeper**. This is a small cylindrical object that locks a pin in place using a tiny screw. From all the securing systems, this is the smallest one because the height is 5mm and diameter 6mm whilst still creating a strong locking mechanism. The material used is an copper-nickel alloy, which is water-resistance. Because this materials causes an allergic reaction, an enclosure should be made. Also, this method accelerates in its simplicity because it creates a strong hold with only 2 components.

This part has been purchased online through Fruugo[26], which costs €0,61 per piece incl tax for 10 pin lockers. After further inspection, the exact same item could be bought on AliExpress[27] for €0,46 for 10 pin lockers. This means that the price per unit is only €0,05 on AliExpress. Therefore, such part was purchased on AliExpress as well. The result? Both items were delivered in the same package, and even the same label on the plastic bags. The weight of 1 pin locker (shell and screw) is exactly 1,00gram

Figure 50: Pin lockers from AliExpress and Fruugo (own picture)

Conclusion

Such securing methods on their own would not fulfill the design requirements. This means that for any of these securing methods, an enclosure should be designed so it could also house an NFC tag. To create a small, lightweight and therefore ergonomic shell, it is desirable to choose the smallest locking mechanism, which is the pin keeper, as seen in table below.

Table 4: Size locking systems (own table)

	Butterfly clutch	**Rubber clutch**	**Deluxe clutch**	**Pin keeper**
Maximum diameter	10mm	11mm	10mm	6mm
Height	7mm	9mm	6mm	5mm

Furthermore, this solution accelerates in the strong hold it creates, which is desirable for keeping the pin in place throughout the whole life-cycle.

26 Fruugo pin keeper

27 AliExpress pin keeper

Idea shell 1: Elasticity plug

After a pin has been applied through clothing, the yellow part slides over it and a locking mechanism is applied. Then, the 'outer shell' is put over the yellow part. This is possible because the yellow part's material is more elastic than the outer shell. Dissembling is possible after applying pressure (purple lines) with a specialized tool, a gripper, and can happen because of the material elasticity of the material

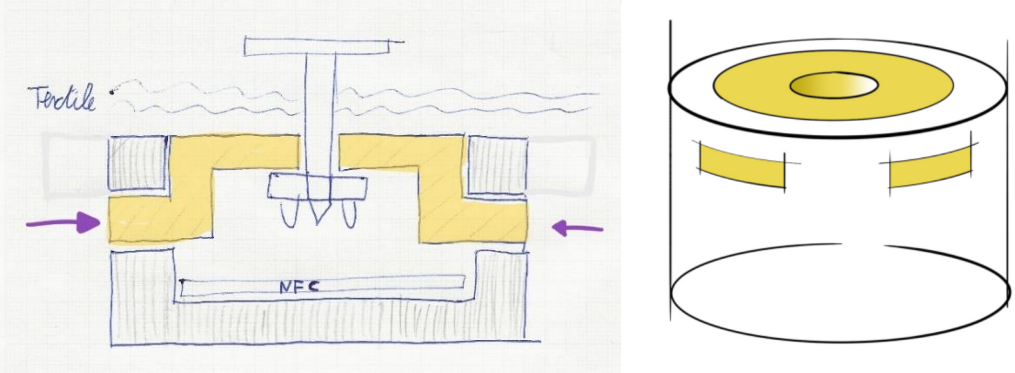


Figure 51: Cross-section view (left) and 3D view (right)

A major flaw within this design is that if enough pulling force is applied on the pin, the whole system could be easily disassembled by the consumer themselves. Furthermore, because openings are created to fit the 'legs' of the yellow part, water resistant concerns are present. A fully water tight solution would not be feasible because of the material tolerances. On the other side, this solution will be further developed in idea shell 4.

Idea shell 2: Security screw

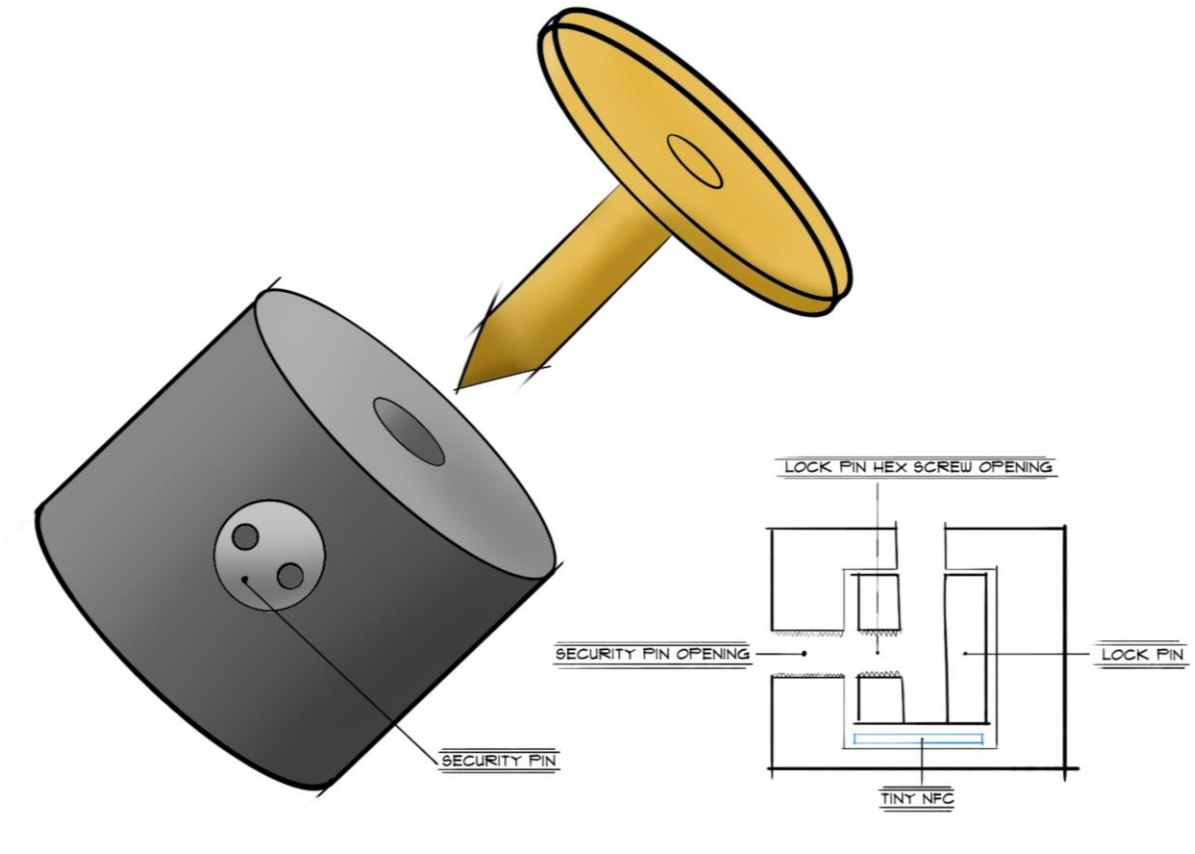


Figure 52: Security screw principle in-action (own drawing)

Figure 53: Socket head[28] (left) and spanner head[28] (right)

The access to the tiny lock pin screw is locked behind another screw, more specifically a security seal screw. Such parts are designed to be only unscrewed with a specialized screwdriver. For example, the socket head's design prevents normal hex drivers from engaging. Because of the rubber orange O-ring, such security screws seal inside components from air, gas, water and other substances. Through Zago[28], it is possible to build such parts according to the thread type, size, length, material, … Through this tool, the smallest possible screw length was selected to benefit the design of a small DPP tag. The length of the thread would be 2mm and the head itself 1.9mm, resulting in a shell thickness of 3,9mm. This is only in the direction where the security screw will be

28 Zago spanner flat head seal screw

placed. The other axis could have a smaller radius. Therefore, the overall shape of this design could be elliptical.

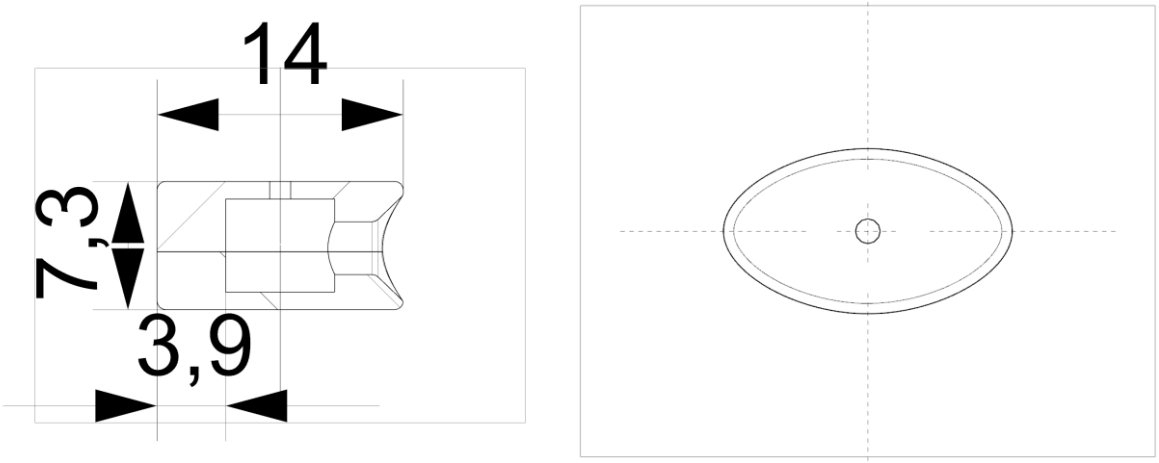


Figure 54: Idea shell 2 section view (left) and top view (right) (own drawing)

The design displayed in the images above is the result of 3 build-test-learn cycles where each part was CAD-modelled, 3D printed and tested. These CAD-models where cut in 2 so it could be easily printed, as well as easily glued together. The major conclusions from these test are that the pin locker perfectly fits in this system and that the overall size of this object could be more desirable than the previous iteration.

After this was designed, Zago reached back and concluded that the proposed length for this security screw cannot be produced by their machines. Furthermore, implementing any screw with such a small thread length results in not a secure fit which is not desirable. Furthermore, it's unknow how consumers would react to the styling of such object, where this screw is a major part. Secondly, it would also be important that this screw would not stuck out to not cause irritation to the skin and damages textiles.

This conclusion means that further developing such DPP solution is not feasible.

Idea shell 3: Watch back

Next locking mechanism is inspired on how watches can be opened and repaired but only with watch backs that have notches around the edges. To unscrew such system, a back remover tool pinches in the notches which creates grip. Such tools are needed because the watch back is designed to be as flat as possible. If it would poke out more, then possible it would be possible to unscrew such system just with someone's fingers. Therefore, it is important to redesign such piece with this

reflection in mind. This mechanism is an opportunity in a DPP context, because such system can only be removed with the right tools.

Figure 55: Watch back with notches [69] *(left) and watch back removal tool* [70] *(right)*

The redesign of such system would need to implement the facility to apply the pin locker, as well as introduce a tiny NFC tag.

The following object consist of 3 components (besides NFC, pin locker and pin). After putting the pin though the fabric, the pink part is applied on the other side. Such part is comparable to the watch frame itself with an inner thread. Then the lock pin is secured over the pin and (the green and) the red part is screwed on. This part is comparable to the watch back. Without the green 'ring' it would be possible to easily unscrew this back because enough surface area is created. On the other side, it's important that such ring does not fit tight against the two other components and that it has a high stiffness. Otherwise, it would be possible to pinch this part and is it still possible to unscrew such system.

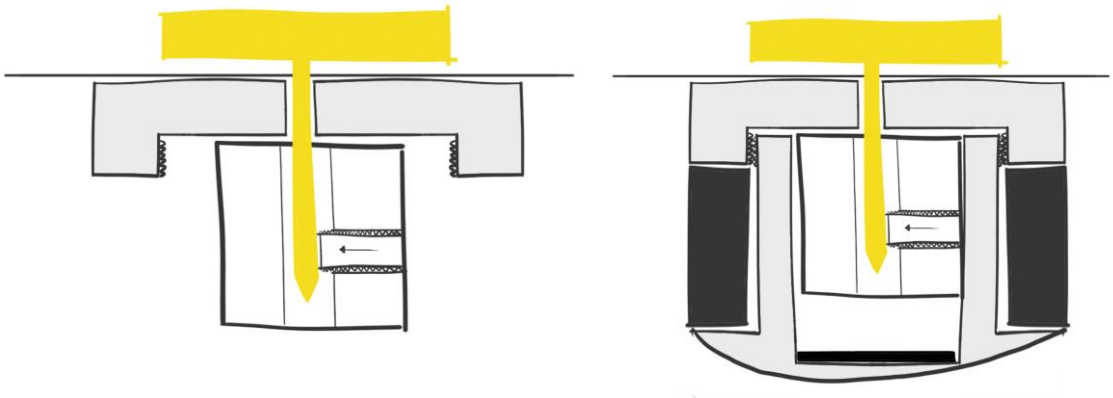


Figure 56: Application process (own drawing)

Also, if there should be spacing between the green ring and the other parts, then a small gap arises. This is not desired regarding the design requirements, because such gaps could damage textiles and could be unpleasant to touch.

Furthermore, modern watches are designed from stainless steel, which is a hypo-allergic (if no copper or nickel is part of it) and rust-free material as stated in benchmarking. They are created though a CNC milling process [71], but compared to injection molding polymers, it is slower to create 1 object and cannot produce parts in large quantities. On the other side, injection molding polymers requires the creation of a mold, which could be seen as an investment. For the sole purpose of this study, it is the purpose to create a solution which can be produced at larger quantities because DPP's needs to be versatile.

The density of the type of 316L stainless steel, defined in earlier, is 8330 $\mathrm{kg/m^3}$. This almost 5 times heavier than PPS (1690 $\mathrm{kg/m^3}$). Generally speaking, a heavier tag could drag down certain fabrics more, which does not benefit its esthetical appearance. Furthermore, a heavier tag could be seen as less ergonomic if its placed on the wrong part of clothing.

This all means that such watch-back mechanism is not in scope for this project. It could work for special collections, which are put on the market in low quantities. Then, CNC milling process and this concept could be desirable because it could look like a watch. Watches can be seen as luxurious and high-quality.

Idea shell 4: Snap joints

Generally speaking, creating an intuitive and reliable dissembling benefits a circular economy, as of the ESPR of the European Commission. Instead of using glues or welding components together, it is beneficial for a circular economy to use separatable methods [72], [73]. An example of such components are snap joints. They are simple, economical and rapid way of joining two different components together [73]. After the joining operation, the snap-fit features return to their stress-free condition. They can be designed to be inseparable or separatable.

Different type of snap joint exist but in this context, a discontinuous annular snap joint is the chosen because the lock pin itself is cylindrical. As seen in the image below, an O-ring can prevent dust, dirt, water, oils, and liquids from entering the inside components[74].

Figure 57: Discontinuous annular snap joints [74]

In Appendix G, more technical documentation such as snap joints formulas can be found. There are several technical calculation that need to be done to know if such snaps would break or not. Furthermore, the mating and separation force can be calculated too. Lastly, because 3D printing is too weak for creating snap joints at this scale, making a realistic prototype will be impossible.

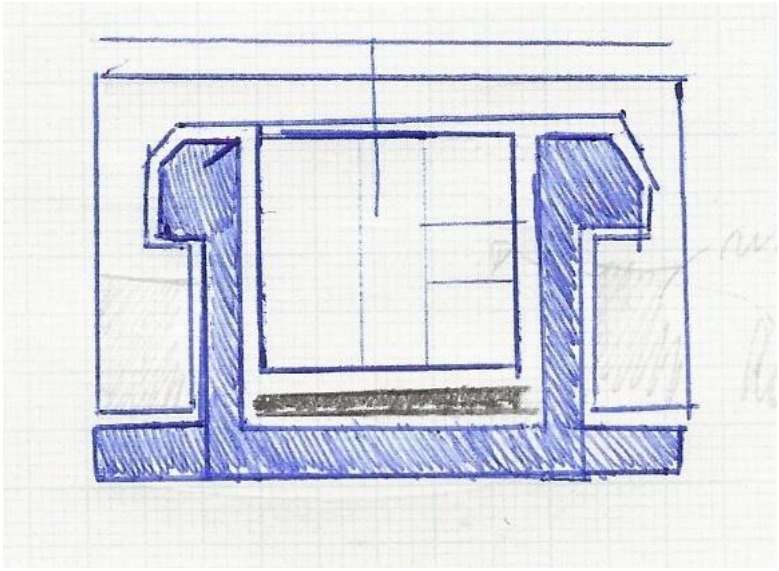


Figure 58: Cross-section view of snap joints for DPP (own drawing)

Based on the formulas found in Appendix G, it's possible to create an estimate for the permissible deflection. This means how much 1 snap joint can 'bend' before breaking. For this, a basic CAD-file needs to be drawn to create some boundary conditions. This, and further iterations will be explained in the next part of this study.

5.2.5: Iteration 2, snap joints

Build 1: CAD drawing

As mentioned before, a mini NFC and pin locker will be designed into the frame of Nanto. A section view, 3D view and the snap joint part can be seen in image below. One leg is missing so it would be possible to apply the tiny screw in the pin locker. A second iteration of this part will be made so it would be more easily removable.

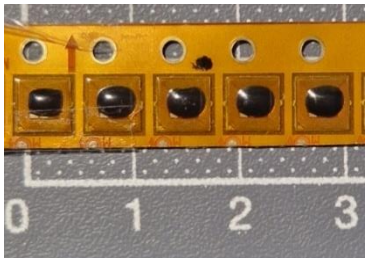


Figure 59: Tiny NFC (own picture)

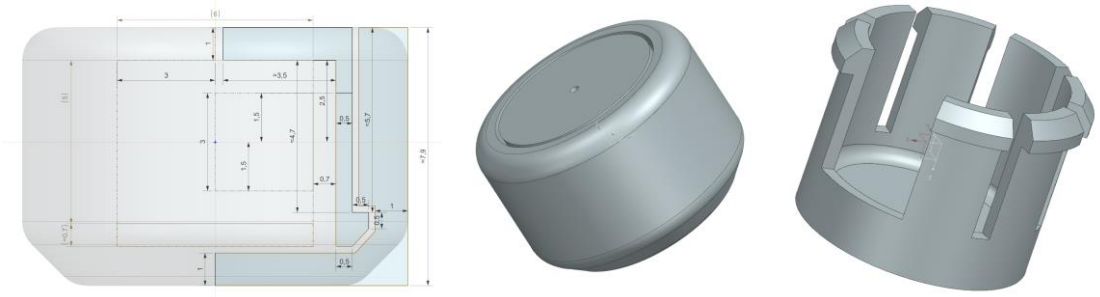


Figure 60: First version Snap joints shell

Build 2:

Thanks to the design changes made in build 2, it would be possible to separate both parts by using for example an industrial spatula. Just as before, there is 1 joint leg missing to facilitate application and removal of Nanto Secure. Furthermore, the entrance side angle is 100°, making it two separatable pieces. Normally, it would be possible to calculate the joining and separation force, but for SPP polymer, certain values are unknow from the technical documentation. Therefore, only the permissible deflection (y) can be calculated. This is an important parameter to calculate because it determines how much 1 leg can bend before it breaks. The higher the permissible deflection, the less likely it will become that 1 leg will break. Therefore, an overall greater permissible deflection is desired. This CAD drawing has been redrawn to facilitate further leg joint calculations.

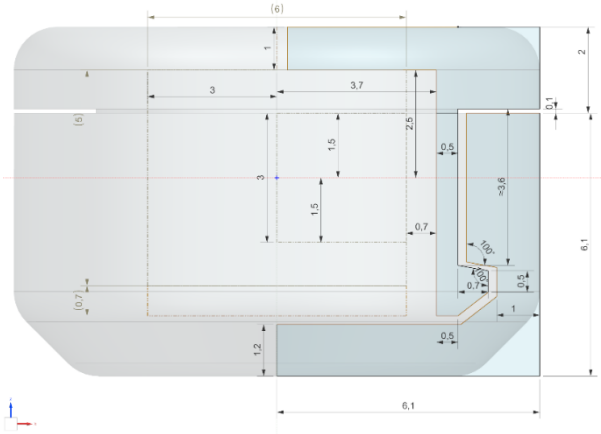


Figure 61: Second iteration cross-section view (own figure)

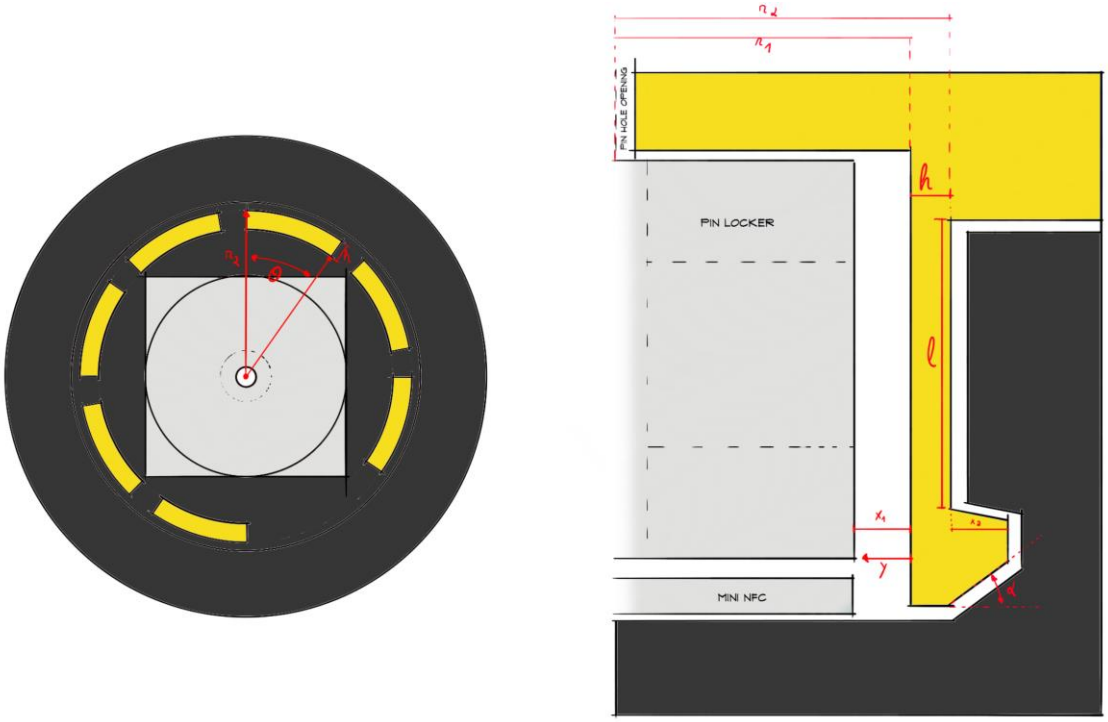


Figure 62: Schematic representation of calculating snap joint parameters (own drawing)

The following equation explains why it's better that the permissible deflection (y) should be greater than the distance between the pin locker and the snap joint legs (x_2). By designing such pieces that way, it will become impossible for a leg to snap. Furthermore, $x_1 < x_2$ so there would be enough space for the leg joint to bend. Combining these reflections creates following equation:

$$x_1 < x_2 < y$$

For this iteration, the following dimensions are known:

$$l = 3{,}6mm$$
$$\varepsilon_{max} = \max strain\ SPP = 3\%$$
$$h = 0{,}5mm$$
$$r_2 = 3{,}7mm + h$$
$$r_1 = 3{,}7mm$$
$$\theta = 30°$$

Test 2: Calculations

In Appendix G, the formulas can be found that were used to calculate K(2) and the permissible deflection (y). Here the type of design is a cross section constant over the length, and the shape of the cross section is a ring segment.

$$y = \frac{K(2) * \varepsilon_{max} * l^2}{r_2}$$

$$y = \frac{4{,}9 * 0{,}03 * (3{,}6mm)^2}{(3{,}6mm + 0{,}5mm)} = 0{,}30mm$$

Learn 2

Design changes will be made to increase the y-value to make a more secure system.

Build 3: CAD drawing

The following design changes will be made to permissible deflection (y) larger. First, the shape of the snap joint leg itself will change so the cross section will not be constant over the length, but decreases one-half. Because of this, a factor of 1,64 is introduced in the formula, which results in a larger permissible deflection.

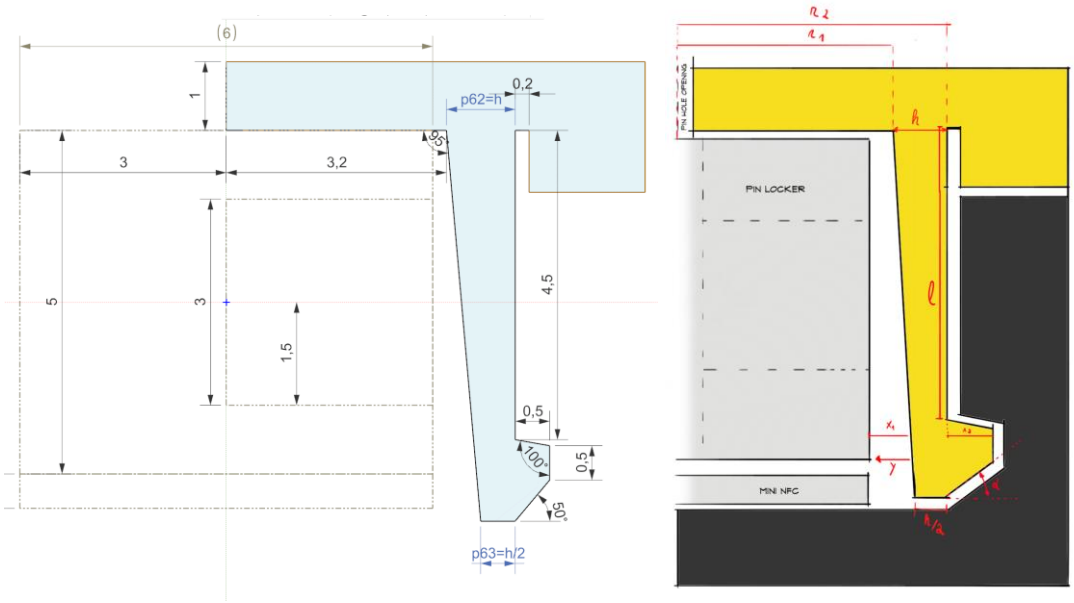


Figure 63: Schematic representation of iteration (own figures)

As seen in the CAD drawing and schematic representation, the length has increased from 3,6mm to 4,5mm by making a cutout.

Test 3: Calculations

A different K(2) is the result of a different inner and outer radius ratio.

$$y = 1{,}64 * \frac{K(2) * \varepsilon_{max} * l^2}{r_2}$$

$$y = 1{,}64 * \frac{3{,}00 * 0{,}03 * (4{,}5mm)^2}{(3{,}2mm + 1mm)} = 0{,}71mm$$

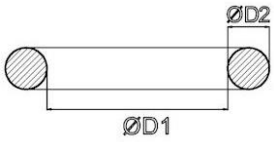
Learn 3

The y-value has drastically increased to a more desirable outcome. It is more desirable to create a higher y-value but there are many more other valuable parameters that could have been calculated, such as the mating and separation force.

Build 4: Final CAD

In the next iteration, O-rings[29] are added in a groove between the two components. This should prevent liquids and other harmful substances to enter the tag. O-rings exist in various sizes which influence the overall size of the tag. Normally, the tiny NFC tag is water and weather resistance, just like the pin locker but it's better to keep the inside free from outside conditions and substances.

Table 5: O-ring[29]

	D1	D2	€	Mass
	10,00mm	1,00mm	10 units: €0,11/u incl tax; €0,09/u excl tax <250: €0,02/u incl and excl tax	1,00gram

Furthermore, radii are added to the bottom of the snap joints to decrease the likeness to fail when applying mating or separation force. Also, it's possible to create an industrial styling but it's of course restricted by the functional result of all these phases. To combine styling and ergonomics, an external chamfer and radii are added to create a sense that such product is less thick as it actually is. When everything is assembled, the height is 7,8mm thick, which is about as thick as thick as a modern day smartphone [75].

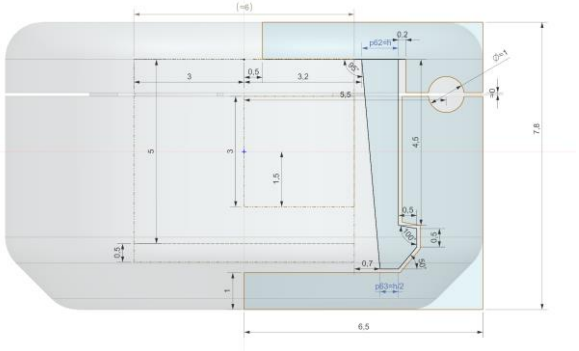


Figure 64: Final CAD cross-section

29 O-ring 10x1 mm NBR 70 Shore A (no date) technirub. Available at: https://www.technirub.nl/o-ringen-en-o-ring-snoeren/o-ringen-nbr-70-shore-a/o-ring-10x1-mm-nbr-nitril-70-shore-a.html (Accessed: April 2023)

***Test 4*:**

A looks-like model is 3D printed without certain snap joint characteristics because the used printer (FDM with PLA filament) cannot print a realistic result at this scale. Though 3D printing is less strong than injection molded parts [39], it's unexpected that these legs were quite strong compared to previous iterations (are not included in this study). This is mainly because of the sloped leg joint face and the edge blends.

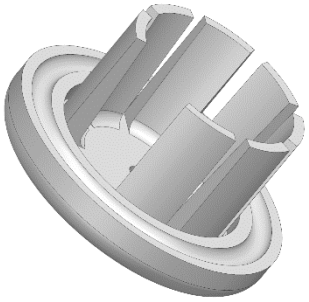


Figure 65: Looks-like model inside (own figure)

Learn & reflection 4

This marks the end of iterating and developing a locking mechanism and shell. For the current constraints, the smallest possible tag is created. From benchmarking pin locking mechanisms, the smallest, yet most secure option was chosen but when looking at the final outcome's cross-section view, the locking mechanism takes up 64,1% of vertical space and 46,1% of horizontal space. Therefore, the question arises if a smaller locking mechanism would still fit a snap joint shell? The answer is maybe. This is because there is a limit to how small snap joints can be. The snap joint legs (=l) and permissible deflection (=y) are proportional, meaning that the smaller snap joint legs, the lower the permissible deflection will be. This means that the x2-value needs to decrease and it is unknown what the impact of that will be on the mating and separation force. As a result, if a less heigh locking mechanism is found, then using snap joints for connecting the two halves needs to be further calculated.

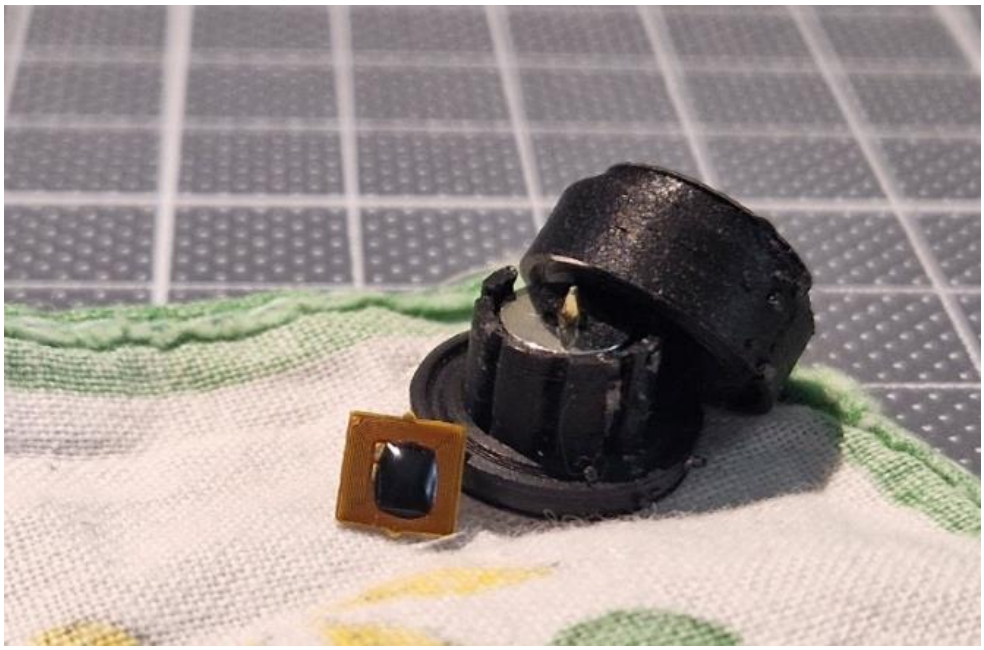


Figure 66: Nanto secure disassembled (own picture)

This study has focused on avoiding glues or molding parts together to benefit a circular economy [73] and has therefore used snap joints to connect two halves. Using snap joints are also beneficial to the design requirements, because the parts to need to be separated and dissembled for recycling or other scenarios and generally speaking for circularity reasons.

The mass of the current shell can be calculated by multiplying the volume by the density of SPP (1,69$\frac{gram}{cm^3}$). The volume is measured in the CAD model itself and is for the inner part 0,26$cm^3$and 0,42 cm^3 for the outer part. The outcome of adding the volumes and multiplying it by the density of SPP is 1,15gram. Therefore, the mass of the full outcome can be calculated:

Table 6: Mass of Nanto Secure (own table)

Component	**Mass**
SPP shell	1,15gram
Pin locker	1,00gram
Pin	0,31grams
Tiny NFC	0,03grams
O-ring	1,00gram
	3,49grams

Now, the tags height is 7,8mm and diameter is 13,0mm. When looking at the benchmarked table, a regular NFC tag is also 13,0mm in diameter but with a 1mm thickness. Therefore, if 8 regular NFC tags are stacked it is as heigh as the current prototype. To put the size of this tag more in perspective, the size of Euro coins can be used. A coin of €0,02 weights 3,06grams, is 1.67mm thick and has a diameter of 18,75mm. This means that if 5 two cent coins would be stacked on top of each other, the DPP tag would perfectly fit within it. Also, the weight of the DPP tag and the 2 eurocent coin are almost the same.

Figure 67: Render of Nanto Secure next to a stack of 5 coins (own render)

5.2.6: Styling

As probably seen in previous iterations, a basic industrial design has been given to the tag. Because the overall dimensions of the tag are final, it's time to explain the process.

'The Principles of Design' is a list of 11 fundamental elements of what makes a composition more visually pleasing [76]. Those include balance, unity, contrast, emphasis, repetition, pattern, rhythm, movement, proportion, harmony and variety.

Imagine a tag without any styling, as seen in the images below. It lacks movement, proportions, balance and harmony. A tool to create the right proportions, balance and harmony is to use the golden ratio [77]. The ratio has been used throughout history by philosophers, architects, and designers to create eye-catching, pleasing designs and structures [77]. The ratio itself is 1:1,6180... This means that if the height of 1 part of the shell is for example 1mm and the other 1,6180mm. In the current context the height of the cap is 1,9mm and of the shell 5,9mm. The calculated ratio is 1:3,2052, which is too large to create a balanced and proportional styling. Besides styling, such sharp corners are not ergonomic and even may cause damage to textiles, which are all not desirable. Because of this, a new iteration is made.

Sadly enough, the height of both pieces cannot be lower because of the mechanical limitations snap joints have. Therefore, a chamfer and edge blends are introduced to bring the ratio closer to the golden ratio. Furthermore, adding edge blends is beneficial for ergonomics too.

Another important factor to take into consideration in the styling is CMF, which stands for color, material, and finishes. The material already has been decided, which is SPP. A surface finish determines how glossy a material is, ranging from high gloss (SPI A1-3) to matte finish (SPI D1-3) [78]. In this context, a SPI-D2 matte finish is chosen because SPI A, SPI B and even SPI C could easily show scratches, which is not desired in the context of a durable DPP tag because the perception of reliable tag could decrease. It's possible to injection mold different colors, but for simplicity, only black and white/grey materials will be produced. Pictures of SPI sample carts can be found in the Appendix H.

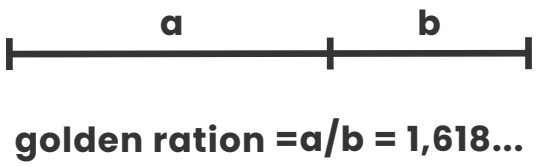


Figure 68: Golden ratio
Source: Adapted from [77]

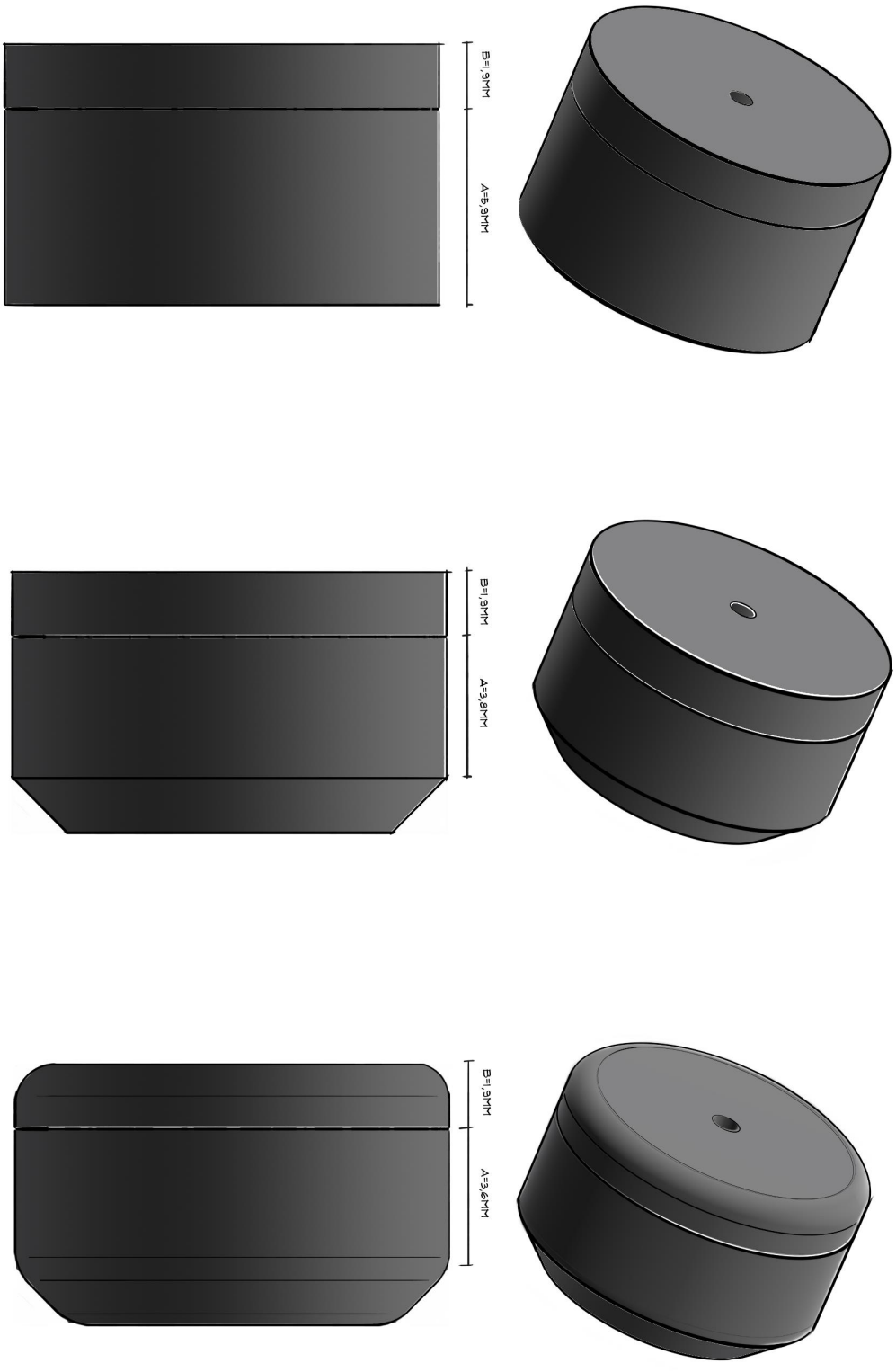
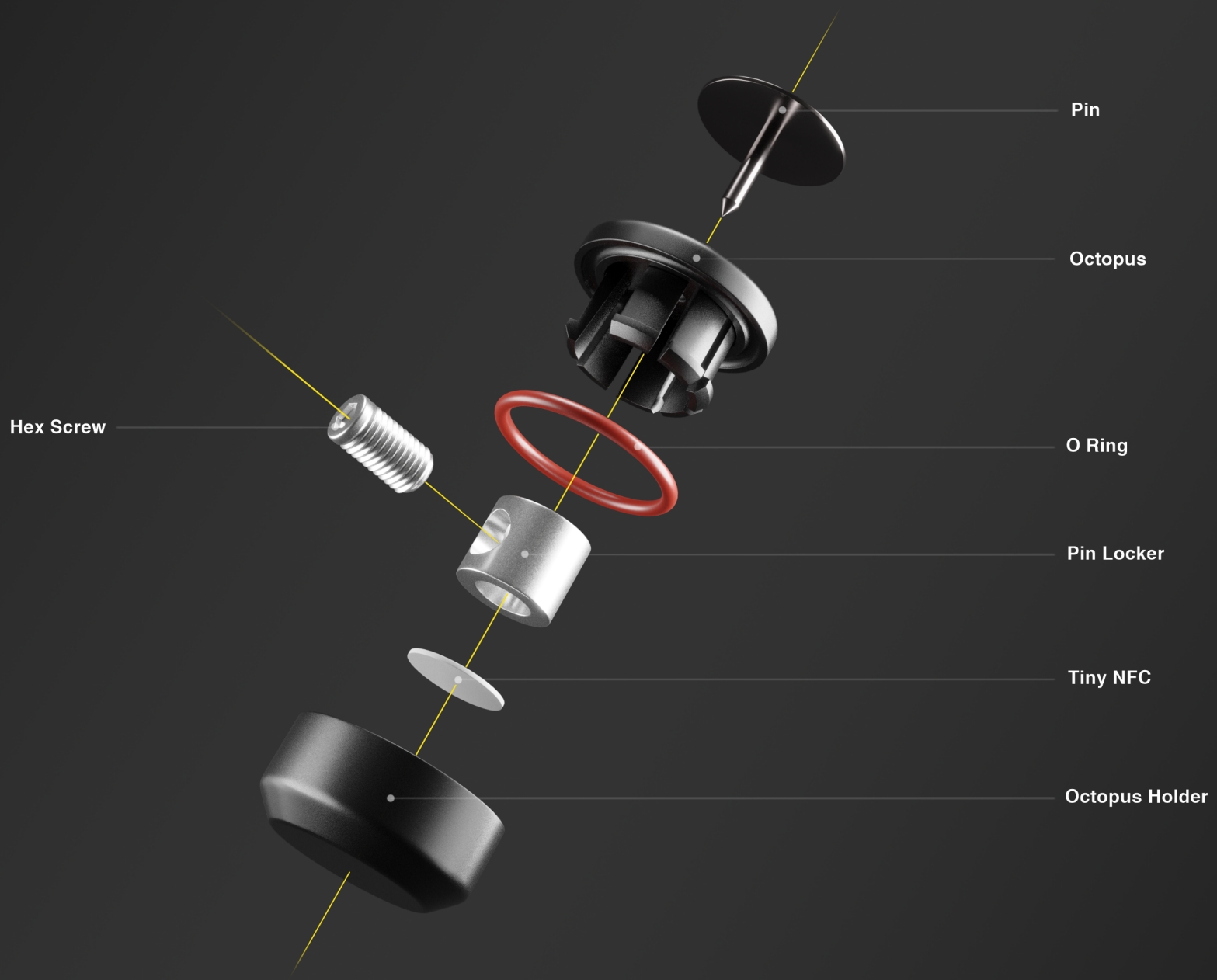


Figure 69: Styling progress (own drawing)

This visualization demonstrates the appearance of the internal components when assembled. It is evident from this depiction that the removal of one leg is necessary to securely fasten the hex screw to the pin, thus establishing a reliable system.

Figure 70: Orthographic front render (own render)


Pin
Octopus
Hex Screw
O Ring
Pin Locker
Tiny NFC
Octopus Holder

The following illustrations showcase various pin options. The initial set of pins in the top row are standard Nanto pins, which are utilized in calculating the material costs for Nanto secure. Conversely, the remaining pins displayed are imaginative concepts that have not yet been prototyped. The second row presents a more discreet alternative for outward-facing pins. Additionally, it is possible to create a pin with a head resembling and feeling like a button, as exemplified in the third and fourth rows. Naturally, companies have the freedom to provide their own pins for usage. Apart from serving as a functional garment component, Nanto secure's opposite side could also be utilized as a button or other decorative element.

Figure 71: Possibilities of pins

Nanto secure can also be molded with other pigments, the image below illustrates a possible white shell but also a different pin. Different pins can be used which are more or less prominent.

5.2.7: Bill of Materials (BOM)

The Bill of Materials is a list which contains components and their cost, quantity and level [79]. For 1 Nanto secure, the unit cost is:

Table 7: BOM Nanto Secure (own table)

Component	Amount	€/unit excl tax
Octopus	1	€0,42
Octopus holder	1	€0,44
Pin locker	1	€0,07
Pin	1	€0,02
Tiny NFC	1	€0,36
O-ring	1	€0,02
		€1,33

All the costs, except for the SPP inside and outside components were already explained in previous parts. The cost of these two items were calculated using Protolabs software. Here, they calculate the cost of the mold for three possible scenarios: Prototype mold with 1 cavity, on-demand manufactured mold with 1 cavity, on-demand manufactured mold with 8 cavities. The higher amount of cavities in a mold, the more parts can be produced. As seen in Appendix I, the more cavities in a mold, the higher the mold price. But it's important to keep in mind that such calculations are estimates and not exact prices. Also, it is unknow how tax could be calculated in this scenario, that's why just the part price of €0,44 and €0,42 are taken in account for the BOM.

Also, this BOM only displays part prices and does not incorporate the fixed cost of the mold. Including this would actually be part of the financial plan of Nanto which is not in scope for this project.

Table 8: Materials in Nanto Secure (own table)

Component	Material
Octopus (holder)	SPP polymer
Pin locker	Stainless steel
Pin	Stainless steel
Tiny NFC	Copper wire, FPC
O-ring	Rubber (nitril)

5.2.8: Production plan, assembling and disassembling

Because assembling would happen in Belgium, production and supplier locations near Belgium are preferred to keep traffic cost and emissions as low as possible. After assembling, it will be distributed to the fashion companies who want to implement Nanto secure in their clothing.

Table 9: Supplier location (own table)

Component	Supplier
Octopus (holder)	Belgium (Stock Plastics)
Pin locker	China (AliExpress)
Pin	Netherlands (Deurhuizen)
Tiny NFC	China (CXJ RFID Factory)
O-ring	Netherlands (technirub)

As mentioned before, no more local supplier of pin lockers were found. Therefore, AliExpress will be the supplier at this moment.

The assembling and disassembling process was tested 3 times, and the average assembling time is 26,5 seconds and disassembling time 29sec. Important to know is that this was done by the main researcher of this study who is familiar with this object and how to handle it, but this would be expected in a DPP future where Nanto secure has been purchased by fashion companies. They'll get the following (dis)assembling steps and it is assumed that they will become more trained the more they engage with it. Also, due to missing online information surrounding the SPP polymer material, the mating and separation force could not be calculated. This force of course also has impact on the (dis)assembling time and performance.

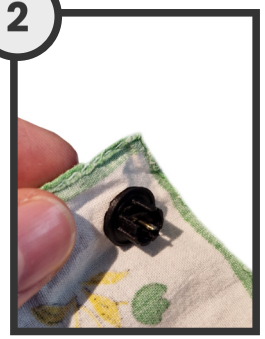
How to assemble nanto secure?

parts: pin, octopus, pin locker, pin locker hex screw, octopus holder
tool: hex screwdirver (1mm)

1

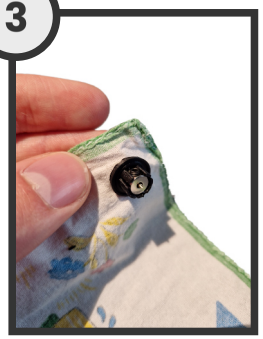
Take the right garment which needs a nanto secure.
Stretch the fabric if needed and apply the pin through the fabric.
By stretching it a bit, it makes sure the pin passes in between the fibers and does not cut them through.

2



Turn the garment inside out.
Apply the Octopus over the needle.
Make sure that the missing leg is facing toward a direction where it would be possible to use the hex screwdriver.

3

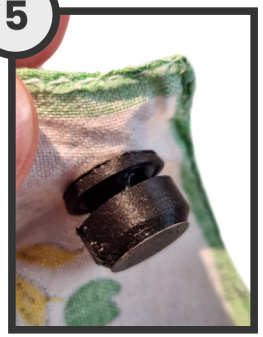


Apply the lock pin over the pin, where the hex screw is facing toward the leg joint opening.
If applied faulty, then use gravity to release the lock pin from the pin. Then reapply again.

4

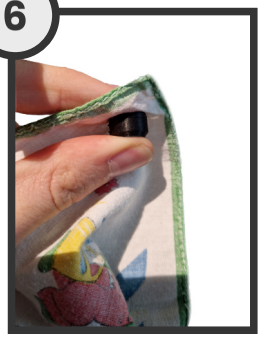
Take the hex screwdriver and screw the hex screw tightly.
It's important to apply pressure to the pin head and the lock pin so the pin head is tightly locked to the textile. This will ensure a secure fit.

5



Take the Octopus holder and push it over the Octopus.

6



If the operator hears a click sound, meaning that joining the two parts has been done successfully.

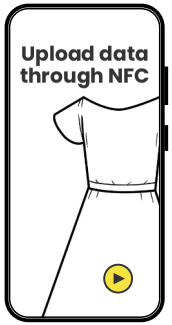
Test

separation force by trying to take both halves apart

sharp edges to avoid damaging textiles and human skin

NFC chip reading and data readability

Upload data through NFC



How to disassemble nanto secure?

tools: hex screwdirver (1mm) and spatula

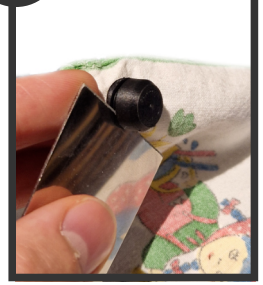
1

Use a handheld NFC scanner to find nanto secure (or any other DPP). If the tag will not be reused in that context (for example recyclers), a shipping label can be printed out.

2

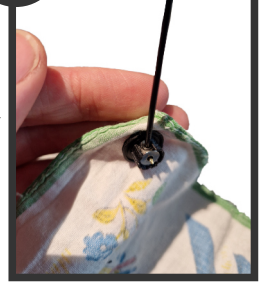
Navigate to Nanto Secure

3



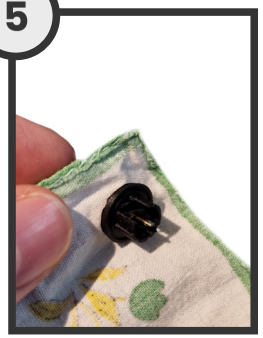
Use the provided spatula to separate both components from one another. This is possible thanks to the momentum created.
After one of the components has risen for about 1,5mm, it is possible to use your hand to safely remove the cap.
Store it away

4



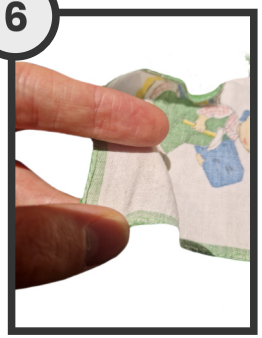
Take the hex screwdriver and unscrew the hex screw
It's important to not fully unscrew it because it is a tiny screw. Only a 45° turn is enough.
Remove the pin locker

5



Remove the Octopus. Afterwards, remove the pin from the fabric

6



It's normal that a small hole is visible. If the pin was applied correctly in the first place, then it's possible for woven fabrics to make the hole disappear. Stretch and apply friction to the fabric. This should reposition the fibers.

Collect all the components and put them in envelopes that nanto provided. After a lot of components have been collected, the box can be send to nanto.

5.2.9: Summary of feasibility study of Nanto Secure

Extensive feasibility development have been done. In this part, it will be summarized how this solution works.

Nanto Secure is a Digital Product Passport that is designed to be difficult to remove by consumers and also to be durable. This to make sure that data does not get lost whenever a customer acquires clothing. Nanto Secure consists of 2 main parts. The first part is a pin, that is applied through clothing. The second part locks the pin in place so nobody should be afraid of losing DPP information. All the internal components are water and weather resistance and the outer shell is made from a special heat-and chemical resistant body to increase durability of this item.

Because a pin is used to secure DPP data to clothing, it doesn't damage the textiles and could be applied anywhere on clothing. Fashion companies, who will buy DPPs from Nanto, will be able to choose how to implement Nanto Secure in their clothing. They can chose to make the pin visible or even use their own pins. It's also possible to place Nanto Secure in pleats of clothing so it would not touch a customer's skin. Fashion companies could also place Nanto Secure on the edge of clothing and decide to cover it with their own label, as seen in the image below. Another possibility is to reverse the orientation so for example to make the locking part visible. Then Nanto Secure can be used as a button or a jeans rivet. This all means that Nanto Secure is a versatile DPP tag.

Furthermore, Nanto Secure is designed with disassembly and assembly in mind to make sure that it's fits in the criteria of a circular economy.

Next parts will further elaborate on the viability of Nanto and desirability of Nanto Secure.

5.3: Nanto secure, a Desirable DPP tag

Nanto and Nanto Secure can effectively cater to the desires and expectations of stakeholders by focusing on value creation. By combining various assets and resources, businesses can deliver offerings that accurately meet the wants, needs, and desires of their customers. Value creation serves as the key mechanism through which businesses can effectively address stakeholder requirements and provide them with desirable solutions [80].

The created value for certain stakeholders actually has been partially explained in for example the development of a circular and feasible DPP tag. Here, it will be summarized and expanded upon, based on [3], [7]–[10].

Generally speaking, Nanto Secure is a DPP solution that assures data to be available throughout the whole life-cycle of clothing. This has different implications and benefits for each stakeholder.

Consumers: They are the main scope of this study. Therefore, a separate study will be dedicated to them called Data collection 4.1.

Large fashion brands: These customers of Nanto would choose Nanto Secure over other solutions, such as the QR code in labels because it assures them that data will remain in clothing throughout the whole life-cycle of clothing. By choosing for Nanto Secure, it assures that consumers have permanent access to extra channels that marketing, sales, and business operations can use to offer new services and improve the customer experience.

Furthermore, these brands can choose for Nanto Secure because of its versatility. It can be used as a pin, a button, rivet or can be covered with a label on the edge of clothing or with a patch. Also, because this tag is designed to be durable and removable by for example recyclers, these businesses are assured that the tag will be send back to them so they can reuse it again. This could also bring down the price of a tag. Last, Nanto is a B2B company so these brands should not worry about producing it themselves, only assembling it into their garments and uploading the right data.

The example below shows a company that incorporated a pin in their design. By giving this stakeholder the tools (=Nanto Secure), they can start designing DPP clothing with Nanto Secure in mind and place it in clothing so it seamlessly blends into it.

Figure 72: Versatility of Nanto Secure

Small scale fashion brands: The same value is created for these businesses as for large fashion brands. Where Nanto benefits these brands extra, is because of its relative lower material cost (€1,33) compared to a unique woven QR code labels, which cost €4,40 per tag. Furthermore, because Nanto is a PSS, these small scale fashion brands get to reuse these tags, which in terms also lower the investment costs.

Suppliers and Manufacturers: By working together, delivering and producing Nanto DPP's, these partners can work together to create a circular economy.

Data provider: By creating a durable and non-removable tag, data providers are assured their software can always be used.

Retailers: By offering clothing with Nanto solution within it, it assures to consumers that this data will remain in clothing at all cost. Therefore, they should not worry about purchasing clothing where the DPP easily fades away, is annoying, causes allergic reaction,..

Recyclers: With Nanto Secure, recyclers are certain that data can be read from clothing. This means they can create a more efficient recycling process, which benefits a circular economy. The trade-off for this benefit, is that they only can remove it with specialized tools, that Nanto will provide.

Upcyclers: The same value as for recyclers is created but on top of this, the tag can easily be assembled and also anywhere on clothing. Upcyclers could take the design of Nanto as an opportunity to incorporate it nicely into the design.

Existing sustainable retailers such as second-hand stores and fashion rental: Second-hand stores benefit from Nanto Secure because transparent information is available in clothing. Consumers want more transparency in clothing [31] and if labels are removed from clothing [34], then it could scare of potential second-hand buyers. Fashion rental places have the opportunity to show relevant information to their customers to motivate them into renting fashion, which has been identified as a barrier in fashion rental in the define phase.

Repair businesses: Same as before, ensuring that information is accessible in clothing and has not been removed or faded away is a necessity for repair businesses. This information is essential for details such as its original design, components, and assembly methods.

Regulators and NGOs: A secure DPP solution will benefit them tracking the sustainable performance and claims of fashion companies.

5.4: Nanto secure, a Viable DPP tag

This part focusses on the business model surrounding the DPP tag. Actually, the viability of Nanto has been mentioned across the deliver and define phase of this study. For example, the value created (in de desirability part) could be framed into the viability. Also, the explanation why Nanto relies on a PSS is also part of the viability of this study. Therefore, this part will only focus on the business model and branding.

Nanto is a B2B company that delivers physical DPP solutions to fashion brands. This means that they will acquire DPP tags through Nanto. It's comparable to other fashion suppliers, such as delivering buttons, zippers and thread to fashion brands.

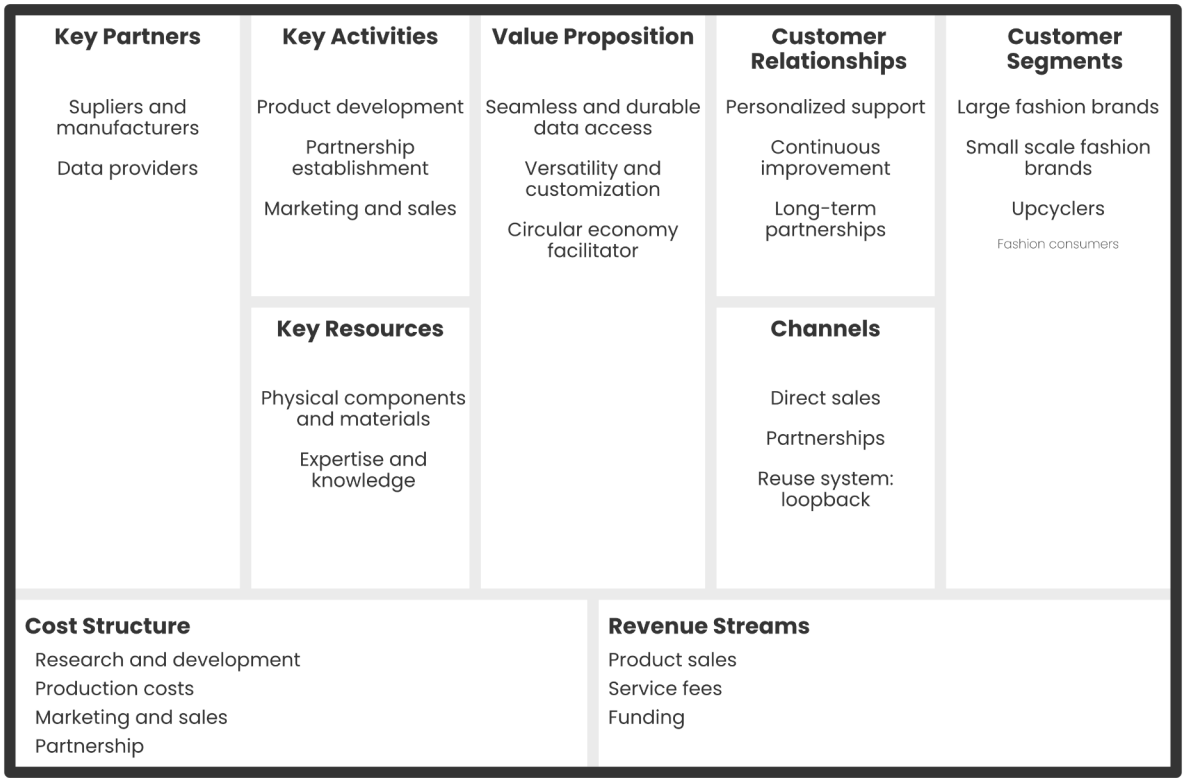


Figure 73: Business model canvas Nanto

Key partners

Suppliers and manufacturers: Partner with suppliers and manufacturers to source the necessary components and materials for Nanto Secure.

Data providers: Collaborate with existing DPP software providers to ensure Nanto Secure is compatible with it to create seamless operation and continuous data access. Data providers, such as Quifactum, Eon and Tappr need physical solutions to access their database.

Key activities

Product development: Design, develop, and produce Nanto Secure with durable and reusable features.

Partnership establishment: Build partnerships with fashion brands, upcyclers, suppliers, manufacturers, and data providers to create a comprehensive ecosystem. Another part of this is educating these stakeholders about how to assemble and disassemble Nanto products.

Marketing and sales: Promote the benefits of Nanto Secure to potential customers and educate them about the value it brings to their products.

Key resources

Physical components and materials: Secure the necessary components and materials to manufacture the DPP tags. For Nanto Secure, the BOM can be found at the end of the feasibility study.

Expertise and knowledge: Employ a team with expertise in fashion, circular economy, and technology to support the development and implementation of Nanto Secure. Knowledge will come from certainty in the EU legislations, as well as further understanding the supply-chain of the textile industry.

Value proposition

Seamless and durable data access: Provide a secure and durable DPP tag that ensures data remains available throughout the entire lifecycle of clothing.

Versatility and customization: Nanto Secure offers a flexible design that can be applied in various ways and customized based on fashion brands' preferences.

Circular economy facilitation: Enable a closed-loop system by ensuring the tag is reusable and can be returned to the original business after use.

Customer relationships

Personalized support: Nanto provides personalized assistance and support to fashion brands during the integration process. This by creating a strong partnership with them.

Continuous improvement: Seek feedback from customers and stakeholders to improve the functionality and effectiveness of Nanto Secure. On its own, Nanto Secure can gather feedback from various stakeholders on how to improve the tag itself.

Long-term partnerships: Creating long-term relationships with fashion brands, upcyclers, recyclers, repairers and data providers to ensure the circularity and growth of the DPP ecosystem.

Channels

Direct sales: To fashion brands through online platforms, industry events, and direct communication.

Partnerships: Collaborate with fashion brands, upcyclers, suppliers and manufacturers, to leverage their existing networks and distribution channels.

Reuse system: Send back Nanto Secure to the original owner through mail

Customer segments

Large fashion brands: Target well-known fashion brands seeking a reliable and durable DPP solution to enhance their products and customer experience.

Small scale fashion brands: Offer them a cost-effective DPP solution to differentiate themselves and meet circularity goals.

Upcyclers: Work with upcycling businesses to incorporate Nanto Secure into their design process and repurpose clothing effectively.

Fashion consumers: Though they will not be responsible for assembling Nanto Secure in clothing, it is important to keep track and take ergonomic requirements in mind whilst Nanto is designing DPP products. In fact, a DPP not desired by fashion consumers could cause a consumer to not buy that item.

Cost structure

Research and development: The existing Nanto portfolio needs to be updated time over time after receiving feedback through the DPP system itself. Furthermore, allocate resources to research and development for upcoming DPP's.

Production costs: Cover the material and mold costs associated with manufacturing of Nanto Secure. These can be found in the BOM.

Marketing and sales: Invest in marketing and sales efforts to promote Nanto Secure and acquire new customers.

Partnerships: Allocate resources to establish and maintain partnerships with various stakeholders.

Revenue streams

Product sales: Generate revenue through the sales of Nanto Secure DPP tags to fashion brands and upcyclers.

Service fees: Charge service fees for additional support, customization, and data integration

Funding: Several organizations exist that grant fundings to circular business/product development such as Belgium Builds Back Circular[30], which also specifically identified DPP's as possible funding projects. It grants fundings ranging from €100 000 to €1 000 000. The European Commission[31] is also currently granting funding to DPP projects.

Examples

The following pages include extra marketing & illustrative examples.

30 https://www.health.belgium.be/nl/tweede-projectoproep-voor-bbbc

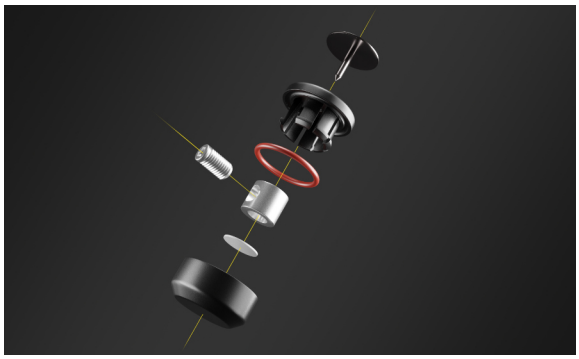
31 https://hadea.ec.europa.eu/calls-proposals/digital-product-passport_en

#E1E1DF | #343434 | #F7DF1E

nanto
empowering circular fashion

nanto

nanto
secure



nanto secure ensures fashion DPP readability throughout the whole life-cycle, suited for blazers, jackets, coats and vests. The design allows it to be reused again

nanto portfolio

nanto
secure

nanto
slim
to be announced

nanto
thin
to be announced

Example of possible partnership

nanto

FJÄLL RÄVEN

Example of possible partnership

nanto

patagonia®

5.5: Data collection

5.5.1: Research goals

The main objective of this data collection is to address the research question (RQ):

How to introduce a new and innovative fashion business model that aims to decrease the environmental impact of the fashion industry based on the EU eco-design directives?

Nanto Secure could facilitate the implementation of these regulations to reach a circular economy. Therefore, this part of the study will only focus on fashion consumers, the ones who will eventually wear and use the DPP's most of the times.

Whilst addressing wicked problems, it is important to note that finding 'solutions' will not fully cover the problem and where the goal is to make the current state more bearable [40]. To test this, the solution, Nanto Secure, will be measured alongside the current standard for bringing DPP information to consumers, which is putting a QR code on label. To be precise, the label that is sewn in on 4 sides and put on top of the garment on the inside is chosed because it a bit more difficult to remove than sewing it in on 1 side.

The following hypothesis may help answer these sub-research questions:

- H0a: The paired population means for current fashion behavior and DPP fashion behavior are **equal**
- H1a: The paired population means for current fashion behavior and DPP fashion behavior are **not equal**
- H0b: The paired population means for concept 2 (QR code) and concept 1 (Nanto Secure) are **equal**
- H1b: The paired population means for concept 2 (QR code) and concept 1 (Nanto Secure) are **not equal**
- H0c: The average rating a concept received for a type of garment is **equal** to 3,5.
- H1c: The average rating a concept received for a type of garment is **not equal** to 3,5.

5.5.2: Research design

Testing the design requirements will happen through a quantitative survey aimed towards fashion consumers. Fashion consumers are reached through a survey which has been send by email to participants from the first survey of this study (data collection 1.2) who were interested in participating in further research. Furthermore, a survey link was shared with friends and family and was shared on Instagram.

5.5.3: Data collection

The survey is designed in Dutch. The survey questions can be found in Appendix J. All questions are designed with Likert scales from 1 (totally disagree) to 5 (totally agree) to facilitate quantitative data analysis.

The structure of the survey goes as followed:

- Introduction
- Current behavior
- Explanation of DPP and scope study
- C1 (Nanto Secure)
- C2 (QR code in label, sewn in 4 sides)
- Possible future behavior once DPP is introduced

C1 gets one additional question compared to C2, which can be seen in the table below.

Table 10: Data collection 4.1 structure concepts (own table)

	Clothing categories	**Design requirements**	**Location on clothing**
C1 (Nanto Secure)	Yes	Yes	Yes
C2 (QR code label)	Yes	Yes	No

The clothing categories are: t-shirt, shirts, jeans pant, blazer, dress, winter jacket, coat, vest, sweater, scarf, beanie, cap, sport clothing, swimming clothing, and backpack. This tells something about how participants perceived the concepts for each type of clothing. Testing in real life would create more validate result but this could be a study on its own.

Relevant design requirements were implemented:

- Removability 1: The ease of removal with household items (scissor, seam picker,…)

- Durability: The ease of damaging the tag so it becomes unreadable
- Removability 2: The need for removing the tag regardless of DPP value
- Styling: How ugly the tag is
- Ergonomics 1: Volume, the tag is too big
- Ergonomics 2: Thickness, the tag is too thick
- Ergonomics 3: Irritating if tag would touch the skin
- Signifiers: Clear that this tag can be scanned
- Ergonomics 4: Allergic reaction
- Ergonomics 5: Irritating if tag would be placed on wrong location

Participants could indicate on a picture of a few items where they would want to place the tag. This tells something about the perceived use cases of C1 (Nanto Secure)

Last, questions about current behavior besides how their behavior would change after a DPP would be introduced regardless how a physical tag would be implemented. Once again, this is more of perceived value because such measures have not been introduced yet. The variables go as followed:

1. Variable 1: The influence of transparent information
2. Variable 2: Engaging with second-hand
3. Variable 3: Engaging with reselling clothing
4. Variable 4: Engaging with fashion rental
5. Variable 5: Engaging with self-repairing clothing
6. Variable 6: Engaging with letting clothing be repaired by someone else
7. Variable 7: Comparing clothing based on sustainability measures

5.5.4: Data analysis

The survey was made in Qualtrics but it was forgotten to make questions mandatory. Therefore, the respondent frequency for answers fluctuates between 47 and 51.

Gender	Frequency	Percentage
Male	16	31%
Female	35	69%
Age		
16-26	33	66%
27-42	6	12%
43-58	10	20%
59-68	1	2%
Unspecified	1	2%
	51	

Figure 74: Sample composition

Data is analyzed in SPSS, the statistical software.

For the third hypothesis (c), a one sample t-test is used to measure both concepts. A test value of 3.5 is chosen for clothing categories because this answer it means somewhere between 'neither yet, neither no' and 'possible yes'. Using a higher test value may not be suited in this context because of the limitations of a survey. Testing such concepts would more valid in real-life situation than through a virtual survey.

For the second hypothesis (b), a paired-samples t-test is used to compare the means of the two concepts. A 95% confidence level is used.

There is a significant difference between concept 2 and 1 for six out of ten variables:

- **Removability 1**: There is a significant difference between concept 2 (M= 3,76, SD=1,071) and concept 1 (M3,06, SD=1,144) (t(48)=3,463, p<0,001). This result implies that consumers will have a harder time removing the concept 1 (Nanto Secure) with household items compared to the second concept.
- **Durability 2**: There is a significant difference between concept 2 (M= 3,92, SD=0,986) and concept 1 (2,77, SD=1,153) (t(47)=5,190, p<0,001). This result

implies consumer can make the QR code tag unreadable more easily then concept 1 (NFC tag)

- **Ergonomics 2**: There is a significant difference between concept 2 (M=1,65, SD=0,699) and concept 1 (M=3,86, SD=1,227) (t(47) = -7,948, p<0,001). This means that consumers think that concept 1 (NFC tag) is thicker than the QR code.
- **Ergonomics 3**: There is a significant difference between concept 2 (M=2,80, SD=1,309) and concept 1 (M=3,86, SD=1,010) (t(49) = 8,463, p<0,001). This means consumer think concept 1 (NFC tag) could annoy them more if it touched their skin.
- **Signifiers**: There is a significant difference between concept 2 (M=4,72, SD=0,730) and concept 1 (M=2,36, SD=1,266) (t(49) = 8,463, p<0,001). This means that its more clear they can scan the QR code than the NFC tag.
- **Ergonomics 5**: There is a significant difference between concept 2 (M=3,37, SD=1,334) and concept 1 (M=4,08, SD=0,886) (t(49) = -4,140, p<0,001). This means that it's important that concept 1 (NFC tag) is located on the right position of clothing so it could not annoy consumers.

For 4 out of 10 variables, no significant difference has been found:

- **Removability 2**: There is no significant difference between concept 2 (M=2,29, SD=0,979) and concept 1 (M=2,33, SD=0,966) (t(48)=3,463, p = 0,735 >0,05). This means that consumers would possible not want to remove one of these two DPP's regardless of their value.
- **Styling**: There is no significant difference between concept 2 (M=2,52, SD=1,287) and concept 1 (M=2,32, SD=0,891) (t(49)=1,136, p = 0,262 >0,05). This means that consumers possibly do not find both solutions ugly.
- **Ergonomics 1**: There is no significant difference between concept 2 (M=2,82, SD=1,304) and concept 1 (M=2,52, SD=1,035) (t(49) = 1,376, p = 0,175 >0,05). This means that the size of both concepts are possibly not too large.
- **Ergonomics 4**: There is no significant difference between concept 2 (M=2,30, SD=1,182) and concept 1 (M=2,36, SD=1,120) (t(49) = -0,401, p=0,690 >0,05). This means that both solutions would possibly not result in an allergic reaction.

For the first (a) hypothesis, the current and future behavior are tested through a paired samples t-test. A 95% confidence level is used.

1. There is a significant difference for variable 1 (t(46) = -4,883, p < 0,001), the influence of transparent information in the decision making of fashion

shopping before (M=2,77 , SD= 1,146) and after the introduction of a DPP (M=3,57, SD= 0,827)

2. There is a significant difference found for variable 2 (t(48) = -2,949, p<0,05), the influence on second-hand consumption before (M=2,67, SD=1,477) and after the introduction of a DPP (M=3,39, SD=1,115).
3. There is a significant difference for variable 3 (t(48) = -7,637, p<0,001). This parameter tells if consumers would be engaged to resell clothing now (M=1,80, SD=1,099) and after the introduction of a DPP (M=3,16, SD=1,007).
4. There is a significant difference for variable 4 (t(47) = -8,321, p<0,001), the influence on fashion rental consumption before (M=1,00, SD=0,00) and after the introduction of a DPP (M=2,40, SD=1,162)
5. There is no significant difference found for variable 5 (t(48) = -1,615, p > 0,05), the influence if consumer do repair clothing themselves now (M= 3,06, SD=1,329) and if they would repair it themselves after the introduction of a DPP (M=3,45, SD=1,119).
6. There is a significant difference for variable 6 (t(47) = -2,944, p<0,05), the influence on consumers letting clothing repaired by someone else now (M=2,88, SD=1,362) and after the introduction of a DPP (M=3,31, SD=1,291)
7. There is a significant difference for variable 7 (t(48) = -5,818, p<0,001), the influence on comparing clothing before (M=2,80, SD=1,040) and after the introduction of a DPP (M=3,98, SD=1,010)

Al the data output can be found in Appendix J of this study, which is all the way at the end of the manuscript

5.5.5: Results & implications

For current fashion consumption, compared to how it would change according to the introduction of a DPP, 6 out of 7 variables showed a significant difference between their variable before and after consumption. Therefore, H0a can be rejected. This means that there is a significant difference between the current sustainable fashion consumption and future sustainable fashion consumption when a DPP will be introduced. Thus, it can be said that a DPP in clothing is desirable for reaching more circular behavior.

For C1 (Nanto Secure), there is a significant difference in the mean score for 7 categories: jeans pants, blazers, winter jackets, coats, vests, sweaters and backpacks ($p<0,001$). The null hypothesis for these variables can be rejected. For the others, the null hypothesis can be accepted.

For C2 (QR code), there is a significant difference in the mean of 13 categories, thus except for scarfs ($p=0,05$) and swimming clothing ($p>0,05$). This means that for the 13 variables, the null hypothesis can be rejected. For the others, the null hypothesis can be accepted.

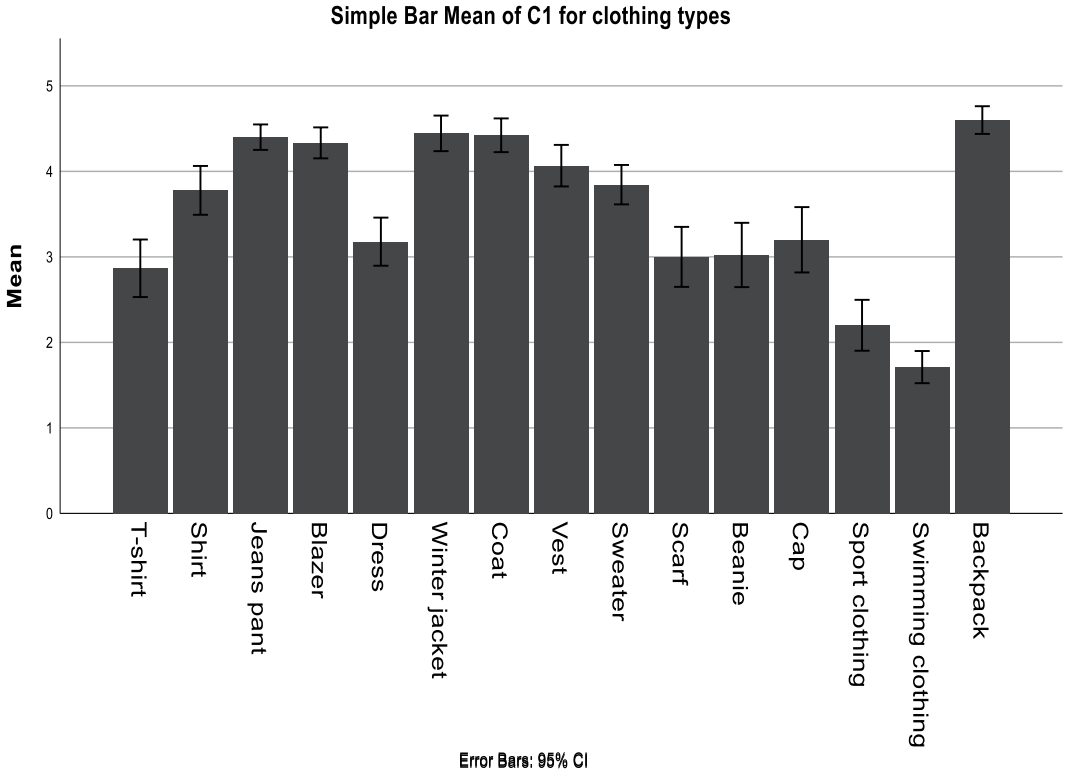


Figure 75: Result C1 (Nanto Secure) clothing types

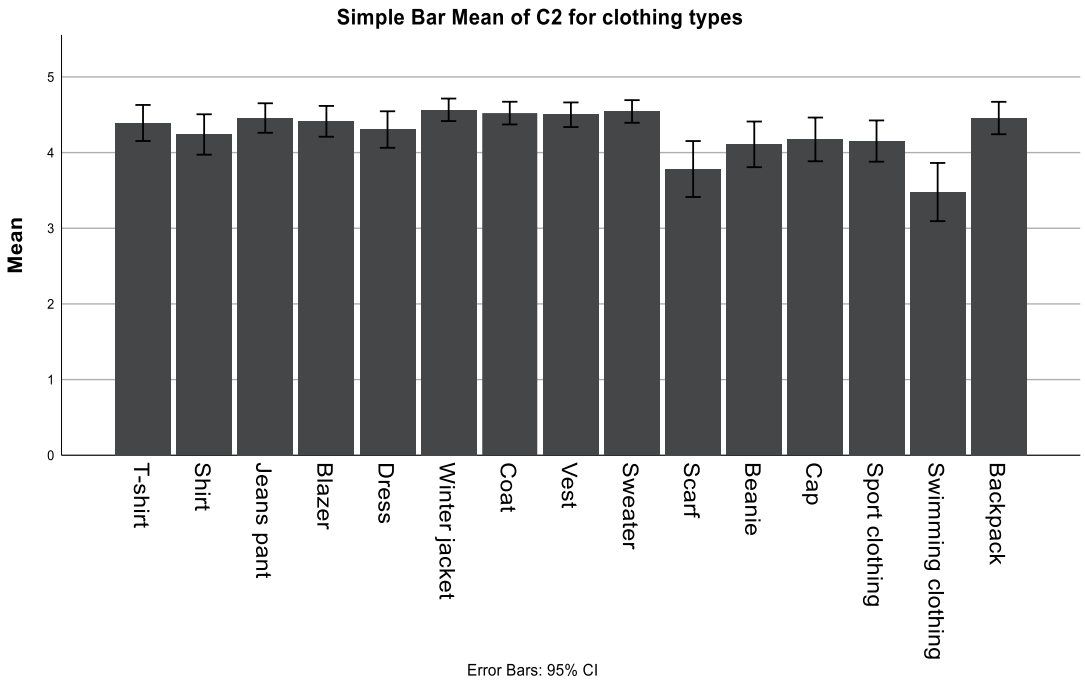


Figure 76: Results C2 (QR code) clothing types

To answer the second hypothesis, further analyzing the results is needed. For 4 variables, both concepts showed no significant difference in their means (removability 2, styling, ergonomics 1, and ergonomics 4). This means that consumers would possibly not want to remove one of these two DPP's regardless of their value; consumers possibly do not find both solutions ugly; the size of both concepts are possibly not too large; and both solutions would possibly not result in an allergic reaction.

Two other variables are in favor for Nanto Secure (removability 1, and durability 2). This result means that consumers will have a harder time removing Nanto Secure with household items compared to the QR code label; and that Nanto Secure is more durable than the QR code label. These were also the important weighted scores from the design requirements. This has also been a priority in the development of a feasible DPP tag.

The remaining 4 variables are in favor for the QR code (signifiers and ergonomics 2,3, and 5). This result means that it is more clear that the QR code can be scanned compared to Nanto Secure; Nanto Secure is thicker than the QR code; Nanto Secure could annoy them more if it touched their skin compared to the QR code label; and that it's more important for Nanto Secure to be placed on the right location compared to the QR code label.

Important side note with these results, is that C1 (Nanto Secure) is a new, unfamiliar concept so it can be assumed that people would rather indicate the middle answer

because they simply would not know it. So for them, these answers are also assumption and should be analyzed as perceived values. Also, when Nanto Secure was explained to the fashion consumers, only 1 use case of it was explained to make it not too long. This means that only the 'pin' mode, and not that it could be covered with a small label, a leather patch or could be used as a button were not explained.

Looking at these results, it seems that for consumers, the current state has been made worse because of the introduction of Nanto Secure. But the 4 variables that were in favor for the QR code could be seen as an opportunity to make Nanto more desirable. Therefore, some suggestion can be made for each variable:

- Signifiers: Adding a small NFC label on top of the label would better signify that it is scannable. Furthermore, education consumers that such part is scannable (marketing, information in web shop or in-store,...) are other ways to signify that such parts can be scanned
- Ergonomics 2: In the explanation of Nanto Secure, only 1 possible option has been shown how it could be worn, and that is with the tag itself facing inwards. It has not been tested in the survey how this variable would change if the tag would be facing outwards or if it could be covered with a patch, as seen in this image, or as used as a button. Then it would not touch the skin, can be facing outwards and fashion companies can decide whatever they want to display on it. Of course, in such label, a small NFC logo can be woven.
- Ergonomics 3&5: This goes hand in hand with the proposed suggestion in ergonomics 2. Placing the tag behind something, whilst still making it accessible, could remove the need for touching the consumer's skin. Furthermore, placing it in pleats, corners or as a replacement for existing components have been suggested by consumers at the end of the questions.

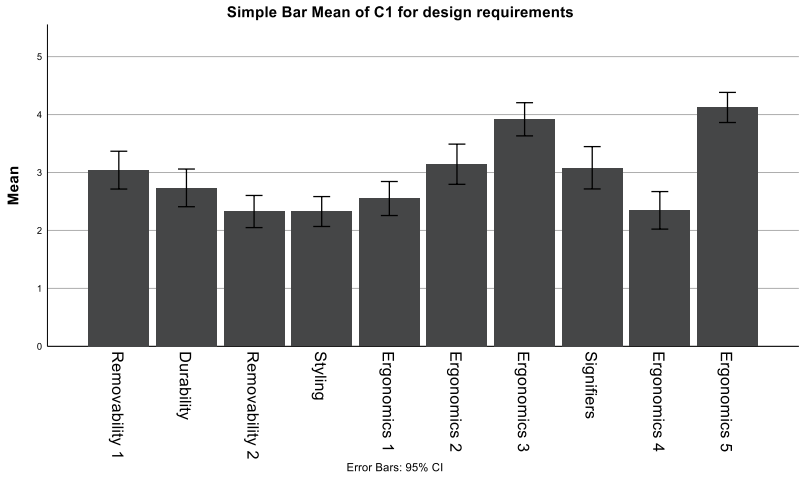


Figure 77: Result C1(Nanto Secure) for design requirements

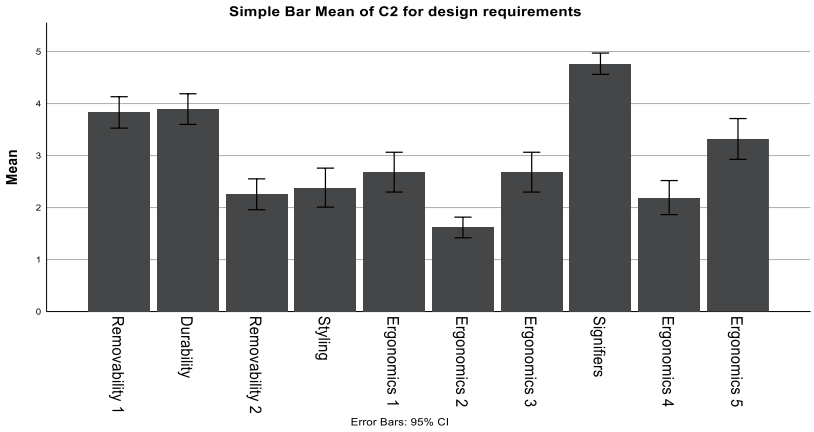


Figure 78: Results C2 (QR code) for design requirements

Based on the data analysis of the comparing the means of current fashion behavior compared to future DPP behavior, it can be said that the null-hypothesis can be rejected and the alternative can be accepted. DPP's would make future fashion consumers more circular-minded.

Feedback consumers

At the end of the survey, after all the questions were asked, people could give some general remarks. Here people mentioned they would prefer the NFC tag over the QR code but the location is the determining factor. Furthermore, it would be preferrable if the NFC tag is more incorporated in the design of existing parts. Generally speaking, consumers acknowledged the wicked problem when trying to think of solutions.

People could leave behind a comment for each of the concepts. For concept 1, the NFC tag, the most popular comments are:

1. The tag should not be too heavy and should not affect the falling or hanging of the clothes.
2. It would be useful if the tag could be incorporated into a hem or pocket so that it does not interfere the user.
3. It is important that the tag does not touch the skin directly and does not damage the textile during washing.
4. It would be nice if the tag doesn't stand out, but remains scannable.
5. The back of the tag should not be too thick on thin fabrics such as T-shirts and shirts.
6. Not all consumers have access to NFC/QR and this can cause problems for the elderly.

For concept 2, the QR code, these are the most popular comments:

1. Make sure stitching doesn't irritate, not itch or bother. More permanent solutions, such as embroidery causes irritation too.
2. Not useful for people who can't use QR codes.
3. The tag should be neutral and should not fundamentally alter the garment.
4. Some people prefer to cut out the tag and keep it elsewhere.
5. The QR code should not be fade away.

Location on clothing

The results of the heat maps can be found in the attachments of this study.

5.5.6: Reflection

Overall, the study provides insight into the influence of a DPP on fashion consumption and highlights some concerns related to the implementation of NFC tags on clothing. The solution (C1 NFC tag) may not shine in every category but the flaws in the design can be seen as opportunities in further iteration in it.

6

Conclusion

The design requirements can be seen as a first step in creating a framework for introducing DPP's in clothing. It extend further on existing European Commission proposals, where the emphasis lays on the non-removability of such identifiers. These design requirements have been weighted to create a desired scope in this study, but important to note is that these weights can be changed according to the specific needs and context of the use case. Here, the emphasis laid on non-removability and durability. Furthermore, the development of a DPP in clothing can be seen as a wicked problem. This is because contradictory facets are observed in the requirements, which makes creating 'solutions' for it difficult because it's complex, multi-faceted and involves behavioral change [40].

A possible future standard for accessing DPP information is by putting a QR code on a label. In this case, it has been studied that such label should be sewn in on 4 sides and put on the inside on top of the garment. This is to lower the removal threshold compared to labels that are sewn in on one side. But research concluded that companies who are currently including QR codes labels in clothing are actually not product-specific DPPs but batch-related DPPs because the identifier (here QR code) needs to be unique for every single item. In this case, the identifier is the same across the batch. Within a DPP context, it's important for reaching a circular economy that every QR code is unique because once an item is acquired, the life-cycle will greatly differ from product to product. Furthermore, using a QR code on a label creates challenges within the design requirements. First, the ink on a printed identifier could fade away over time due to active wear and tear, water and UV radiation [45]. To reach a circular economy, it's important that information does not get lost during the use phase of clothing. Generally speaking, woven labels are more durable and won't fade like printed labels [45], but the manufacturing process does not a allow to weave unique QR code labels [46] without drastically increasing the price of the label.

Also, through interviewing a fashion rental platform and clothing manufacturer, it is concluded that they are willing to implement a DPP in their clothing for various reasons and are currently looking for outsourced solutions on how to do it. They mentioned that sewing in each individual QR code label is time-consuming, which drive up costs. Also, labels are not desired by consumers because they are big, itchy and they would possible remove those. This means that current fashion companies are looking for outsourced solutions besides QR codes in labels.

Nanto Secure is the first DPP that is designed with the design requirements in mind whilst keeping the wickedness in mind. Nanto Secure is designed to try making the current situation more bearable because it's impossible to find a solution that

covers the whole problem [40]. Nanto Secure offers a robust solution for securely attaching and preserving DPP data on clothing. Its design ensures durability and prevents data loss when customers acquire clothing. Comprising two main parts, Nanto Secure includes a pin that can be applied anywhere on the clothing, without causing damage to the textiles. The pin is secured in place by a lock pin, providing certainty that the DPP information will not get lost. The inner components are water and weather-resistant, while the outer shell is constructed from a special heat and chemical-resistant material, enhancing its overall durability. Furthermore, every Nanto Secure is identical thanks to the implementation of a tiny NFC chip. Only the data written on it will be different. This is in contrast to the QR code label, where every label is unique and drives up production cost. The cost to produce 1 Nanto Secure is €1,33 and for 1 customer QR code €4,40.

The company that would produce Nanto Secures is Nanto, which is a B2B company. Fashion companies purchasing DPPs from Nanto have the flexibility to choose how they implement Nanto Secure in their clothing. They can opt to make the pin visible or even use their own pins. Nanto Secure can be placed in clothing pleats to avoid direct contact with the customer's skin. It can also be positioned on the edge of clothing and covered with the company's label. Alternatively, the orientation can be reversed, enabling the locking part of Nanto Secure to be visible and used as a button or jeans rivet. This versatility makes Nanto Secure a highly adaptable DPP tag. This versatility of Nanto Secure extends to its compatibility with various clothing materials and placements. Fashion designers have the freedom to position it intuitively and even use it as a replacement for buttons. Importantly, the pin design ensures that applying Nanto Secure does not break the fibers of woven fabrics, as it gently pushes the fibers aside instead of cutting through them. This consideration further enhances the functionality and practicality of Nanto Secure as a reliable and sustainable attachment method for DPPs.

Moreover, Nanto Secure has been designed with the principles of the circular economy in mind. The study focused on avoiding the use of glues or molded parts that hinder recyclability [73]. Instead, snap joints were employed to connect the two halves, enabling easy disassembly and separation for recycling or other circularity-driven purposes. Additionally, the choice of polymer and the inclusion of an O-ring enhance its durability, protecting against water, oils, sand, dust, and UV radiation. Disassembly of Nanto Secure requires specific knowledge and tools, ensuring that only the appropriate stakeholders can perform it. Furthermore, Nanto operates as a Product Service System thanks to Nanto Loopback. It facilitating the return of Nanto Secure to the original owner after removal, promoting reuse and increasing the tag's circularity [17].

Second, through a survey with 51 fashion consumers, it can be concluded that Nanto Secure is more difficult to remove and has a higher durability compared to QR codes sewn in on 4 sides. For both concepts (Nanto Secure & QR code) consumers would possible not want to remove one of these two DPP's regardless of their value; consumers possibly do not find both solutions ugly; the size of both concepts are possibly not too large; and both solutions would possibly not result in an allergic reaction. On the other side, the QR code label showed on other aspects a significant difference. It's clearer that the QR code can be scanned compared to Nanto Secure. Nanto Secure is thicker than the QR code. Nanto Secure could annoy them more if it touched their skin compared to the QR code label. Last it's more important for Nanto Secure to be placed on the right location compared to the QR code label. Looking at these results, it seems that for consumers, the current state has been made worse because of the introduction of Nanto Secure. But these downsides could be possibly be fixed by incorporating following design changes. The design of Nanto Secure allows it to be covered with a small woven label. Then it would not touch the skin, can decide the facing direction (pin inwards or outwards facing) and fashion companies can decide whatever they want to display on the label. To benefit signifying it van be scanned, a small NFC logo can be woven in such labels. It's also possible to place Nanto Secure in pleats, corners or as a replacement for existing components.

Consumers indicated in this survey that Nanto Secure could be used for jeans pants, blazers, winter jackets, coats, vests, sweaters and backpacks. According to consumers, the QR code is more versatile and can be used on every questioned clothing category except for scarfs and swimming clothing. The limitation of this survey is that it are perceived answers, where user testing and feeling such object in real life would recreate more objective results.

Furthermore, regardless of how a physical DPP tag looks like, it can be concluded through the survey that a DPP has a positive impact on the possible future consumer's sustainable fashion behavior.

Because of these findings and research, an answer can be given to the research question:

How to introduce a new and innovative fashion business model that aims to decrease the environmental impact of the fashion industry based on the EU eco-design directives?

The answer is yes. First, the European Commission is aiming with its ESPR to reach a circular economy in Europe. Nanto facilitates these regulations by making sure that it stays scannable throughout the whole life-cycle of clothing. Circular innovation has been researched through circularity, feasibility, desirability, and viability thanks to the design requirements.

7

Sustainability analysis

The purpose of this study is to develop a new business model that addresses the environmental impact of the fashion industry. This has been achieved by engaging with the European Commission's proposals, such as the Ecodesign for Sustainable Product Regulation (ESPR) and Circular Economy Action Plan (CEAP). The study focuses on the creation of Digital Product Passports (DPPs) to preserve and provide data within products, thereby supporting the transition towards a more circular economy. The outcome of this study is Nanto Secure, a solution that ensures the scannability of DPPs throughout the entire lifecycle of clothing. This study has prominently focused on developing sustainable innovation by focusing on 4 parameters: desirability, feasibility, viability and sustainability. In terms of this study, sustainability has been substituted with circularity whereas this the goal set by the European Commission.

By providing consumers with reliable and transparent information about the garments they'll engage with, Nanto Secure contributes to achieving SDG 12. The introduction of DPPs aims to establish a circular economy, where consumers can make informed choices. Furthermore, DPP's facilitate creating additional repair and care services on top of creating reliable recycling information and distributions.

Moreover, SDG 17 emphasizes the importance of partnerships to achieve sustainable development goals. Implementing DPP legislation to drive circular economy goals requires engagement from all stakeholders. In the case of Nanto Secure, strong partnerships are necessary, particularly with recyclers or upcyclers who can return the tags to the original owners. These partnerships enable the efficient functioning of the circular system and promote collaboration towards shared sustainability goals.

While the study primarily focused on the creation of DPPs, it highlighted an important consideration: European documents did not specify whether all clothing items should possess individual product-specific DPPs or if batch-specific DPPs would suffice. The finalization of DPP frameworks would shed light on this matter, including whether certain clothing types would be excluded from DPP regulations and if DPP information should be accessible at the product or batch level. Such decisions had implications for the production cost of woven QR code labels. Product-specific QR code labels were estimated to cost €4.40 per label, while batch-specific QR labels were projected to be more affordable at €0.20 per label. It is essential to acknowledge that consumers often found these labels bothersome, unattractive, itchy, and sometimes removed them. Such actions are undesirable in the context of DPPs, where data preservation within clothing is crucial for efficient data transfer. Nevertheless, if product-level DPPs becomes the norm for specific

clothing types, Nanto Secure remains an appealing option for clothing companies seeking to incorporate reliable DPPs.

The study delved deeply into future legislations, actively engaging with them. Nanto Secure had been meticulously designed for clothing that was required to include DPPs. However, it raises questions about existing clothing in the market. Should there be incentives for digitizing these items? Do current fashion companies possess relevant data about their previous collections, and could it be seamlessly linked to their current inventory? The European Commission acknowledges the common loss of data once consumers acquired clothing, but the challenge remained: how can the physical product be accurately connected to the corresponding digital data? One possible solution could be the implementation of AI to facilitate the linkage of current clothing in the market to their digital data. The responsibility for adding this information could lie with the consumer, but if AI could successfully link current clothing to a comprehensive database, recyclers and other relevant stakeholders could also access batch-related information. On the other hand, adding DPPs at consumer level would benefit stakeholders to write relevant use-related information to that garment, such as original purchase cost, repairments, resold,...

Another important consideration revolves around ensuring accessibility to relevant DPP information for all stakeholders. It is crucial that fashion consumers, including those without access to digital scanning methodologies, can still access DPP information. While the European Commission's proposals lean towards digitization, it raises a concern for older individuals who may not possess smartphones or the ability to use such technologies. Maybe it would be possible for them to print out relevant DPP information.

In terms of accessibility, Nanto Secure presents a potential solution that benefits visually impaired individuals. By simply holding their phone over clothing, they can utilize NFC technology to scan Nanto Secure. Once scanned, their smartphone will audibly read out all the necessary information, empowering them to make clothing choices based on their preferences. Moreover, this technology allows them to effortlessly identify DPP clothing in their wardrobe by scanning their smartphone over the garments. By offering alternate ways to interact with DPP information, Nanto Secure not only meets the requirements of those who are visually impaired but also assures inclusivity and accessibility. It creates opportunities for those who might not have access to conventional digital scanning goods and allows them to fully engage in the advantages provided by DPPs by utilizing technology and audio-based feedback.

In the evaluation of Nanto Secure's suppliers, it is important to acknowledge that several suppliers and manufacturers are based in China. Transparent communication regarding these production locations is essential. However, it is crucial to note an interesting observation made during the research process. Initially, efforts were made to explore local suppliers, and a potential Dutch manufacturer for the lock pin was identified. Surprisingly, it was discovered that despite the appearance of sourcing from different locations, both the Dutch supplier and AliExpress ultimately shipped the lock pin from the same source in Shenzen, China. This finding highlights an important realization: had the lock pin been ordered solely from the Dutch store, the assumption of locally produced items may have been made. However, by acquiring it from AliExpress as well, it became evident that both items originated from the same Chinese source. This experience underscores the need for thorough investigation and transparency in assessing the true origin of products. It serves as a reminder that relying solely on the information provided by a single supplier may not present an accurate representation of the production location. These realization are also the first steps to prove the importance of DPPs, to thoroughly investigate the sources and communicate it transparently to the potential stakeholders.

8

Future work

The development of a framework for designing a digital product passport in clothing has provided a starting point for further exploration. Real-life use cases should be tested and iterated upon to validate and refine the framework's effectiveness.

In order to gather more robust feedback, conducting extensive user testing Nanto Secure is essential for the development of DPPs in clothing. While sporadic feedback has been collected on the prototype, conducting comprehensive user tests would provide valuable insights and ensure the creation of practical DPP solutions that can be effectively utilized from 2030 onwards. This also implies testing it for an extended period of time in various conditions, such as exposing it to water, dust, oils and heat.

Additionally, due to time constraints, certain important stakeholders were not fully engaged in this study. It is crucial to reach out to recyclers and investigate efficient scanning and removal methods for DPP solutions to support the circular economy. Collaborating with existing fashion companies to incorporate DPP concepts into their clothing, potentially through partnerships with fashion design students at universities, could also be a fruitful endeavor.

Furthermore, conducting a life cycle assessment (LCA) would be beneficial to compare the carbon dioxide equivalents of Nanto Secure and QR codes. It would be particularly interesting to consider the reuse factor of Nanto Secure in the assessment, as it can contribute to reducing environmental impact.

While this study focused on material costs, it is important to develop a comprehensive financial plan that takes into account all fixed and variable costs, profit margins, and the break-even point. Incorporating these parameters into a business model would provide a more holistic understanding of the economic viability of implementing DPP solutions.

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10 Appendix

Appendix A: Prioritization

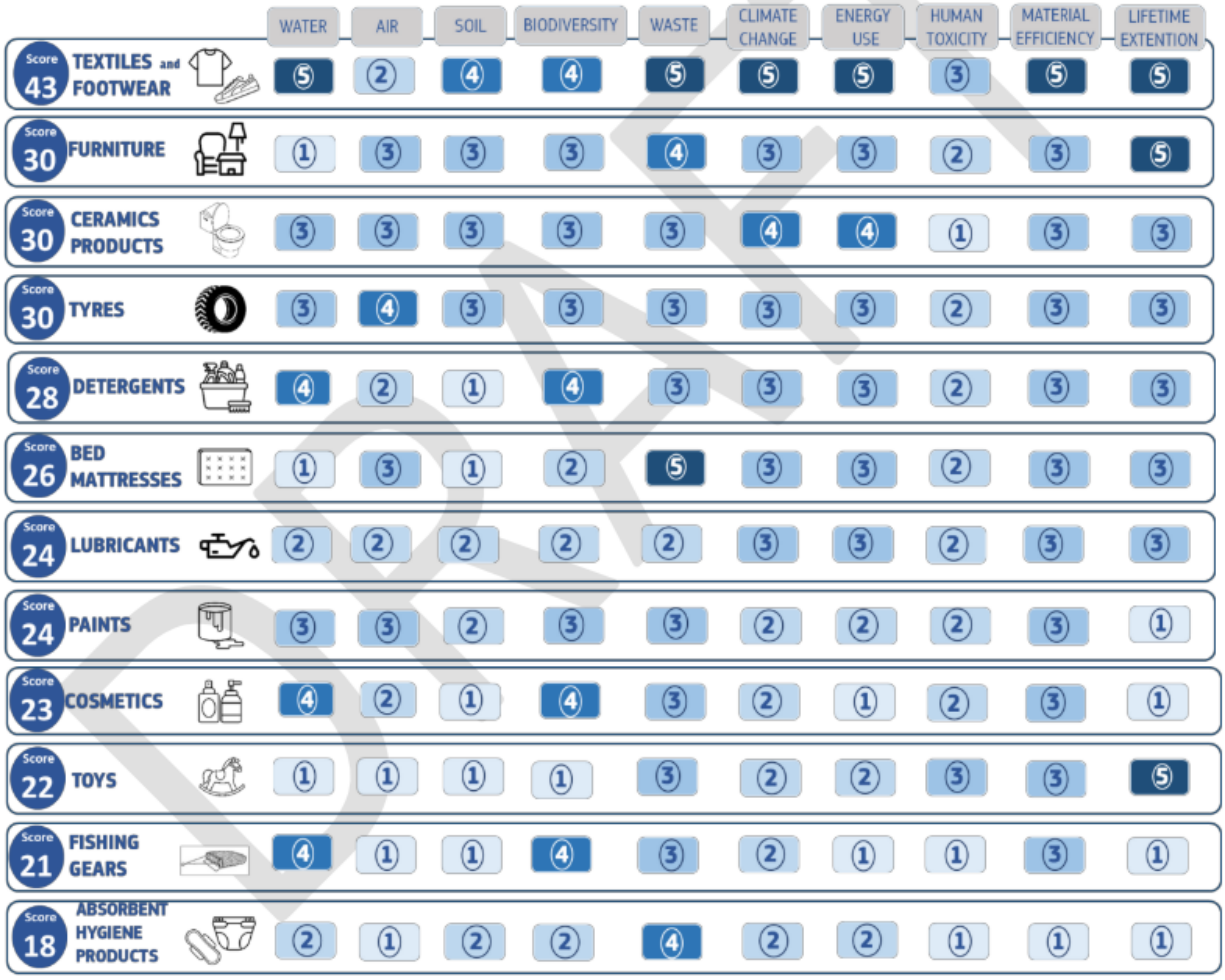


Figure 79: Environmental assessment by the European Commission for 12 ESPR product categories [11]

Appendix B: Circular Economy

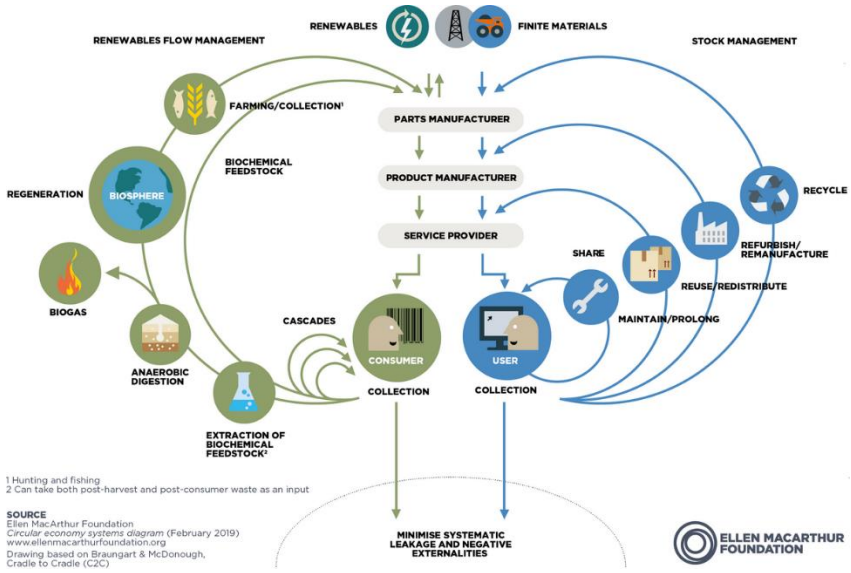


Figure 80: The Butterfly Diagram, visualizing the circular economy [17]

Sharing: Products made of non-biodegradable materials, such as metals, operate within a technical cycle. The most effective methods in this cycle is **sharing** products. This means that the value of an object is preserved and its usage length is increased. It may not be appropriate for all product categories but it will increase the use of a product.

Examples of sharing systems are AirBnB, where people can share living spaces, to shared wardrobes in the fashion industry.

Maintaining: The second most effective method is maintaining the original quality of an object so it is protected from failure or decline. Maintaining is important for products which are suffering from wear and tear. An example in the fashion industry, are services that enable consumers to properly clean, store and repair clothing.

Reusing: Like sharing and maintaining, this strategy keeps the products as much as possible in its original form. In the fashion industry, reusing businesses include services where people can sell and buy second-hand clothing.

Redistributing: Here, a product is allocated from its intended market to another market. An example in the Belgian second-hand fashion industry is the Kringwinkel. If a second-hand fashion item has not been sold by a certain time, it is redistributed to another Kringwinkel store.

Refurbishing: This is the first strategy that involves returning products to their original, good working condition by repairing and/or replacing components,

updating specifications, and improving cosmetic appearance. Refurbishing in the fashion industry could mean repairing and cleaning clothing to their original condition.

Remanufacturing: Compared to refurbishing, this action involves more intense work effort to reuse a product again. It can be achieved by re-engineering components so the level of performance is improved or even updated compared to the original.

Recycling: When a product cannot be remanufactured or refurbished, then recycling can be the right strategy. Recycling involves bringing a product back to its basic materials and to reprocess them again into new materials and products. Recycling needs to be avoided because the time and energy invested in making that product in the first place, is lost.

Appendix C: Summary of Discover and Define

History of the fashion industry

Sir Walter Rodney wrote in 1973 the book "How Europe Underdeveloped Africa" and it explains the impact of colonization on the African continent. Colonization means the centuries-long process by which Africa became the way it is today [81]. Europeans entered with the express purpose of resource and labor exploitation (=slavery). Because of this, Europe could industrialize quickly thanks to these mined labor and resources from their colonies. Eventually, colonies became independent countries and during the mid-20th century, when the cold war was peaking, these countries were expected to participate in a global market economy. They have been participating in this, but on a basis of exploitation. Therefore, Sir Walter Rodney stated that "there would be no economic prosperity or development of the First World, without the continued underdevelopment of the Third World".

Before the Industrial Revolution, fashion was primarily made by hand, and people would commission tailors and dressmakers to create bespoke garments. There were no standard sizes, and stores were not yet prevalent [82]–[84]. During the first industrial revolution in the 1800s, the sewing machine was invented and patented. This created an innovation in the production of textiles. It dramatically brought down the price of garments as well as increased production [83], [84]. This led to the rise of ready-to-wear clothing, which was produced in large quantities. The fashion industry is also the first major industry that lacks locally produced raw materials, so clothing manufacturers had to rely on foreign countries [82]. Therefore, during this time people where enslaved in the US for their free labor on cotton plantations. Meanwhile, textile factories in the North employed unskilled workers in poorly regulated working environments. All of this replaced the local dressmakers [82]. Eventually, regulations came in place in the early 20th century when a major textile factory in New York City caught on fire and killed 146 workers [82], [84].

The third major event, after colonization and industrialization is globalization and free trade which was prevalent during the 20th century [82], [84]. Free trade meant that import and export tariffs were dropped and goods became cheaper. Also, multinational companies started outsourcing production because countries in high-wage countries (The Global North) became too regulated and expensive to produce clothing. The Global South (low-wage countries) was cheaper and less regulated and started producing over there [84]. This enabled the Global North's overconsumption. Victor Lebow is an American retail economist and stated "Our enormously productive economy … demand that we make consumption our way

of life, that we convert the buying and use of goods into rituals, that we seek our spiritual satisfaction, our ego satisfaction in consumption… we need things to be consumed, burned up, replaced and discarded at an ever accelerating rate".

This has led to the current state fashion, called fast fashion. It core principle is created by the founders of Zara, H&M, Primark and more in the early 2000s [84], [85]. It states that this new business model allows 'poor' people in the Global North to access fashion from the catwalks. Because of this, fashion consumers want the latest fashion for the cheapest price because it gives consumers high but temporary satisfaction.

Benchmarking:

Benchmarking existing business models is a way to compare what's already there [86]. It can create a holistic overview which enables systematic thinking[20], [25].The internet will be navigated to find several fashion business models. A selection needs to be made because not every business can be analyzed. According to Eisenhardt (1989), studying polar or extreme cases facilitates the identification of unique patterns that are critical for novel findings (Saha et al., 2021). Polar cases are for example S-PPS compared to non-S-PSSs. Also, the goal is to have a fashion business model of each of the three PSS.

***Fast Fashion*:**

Cheaply made clothing, produced in large volumes based off a business model which produces large profits but requires a quick turn over of goods. Fast fashion waters down trends taken from the catwalk and turns them over quickly for large profit often at the expense of people and the environment [1], [2], [84], [85].

Fast fashion business models offer low prices for customers, the garments have a short manufacturing timeline, can be treated as disposable (designed with planned obsolescence) [84] and offer extremely trendy clothes. This in terms of micro trends which means that items will remain trendy for short periods of time and therefore, causing the consumer to consume more [1], [2], [84], [85].

The figure below illustrate that fast fashion business models plan, design and product develop products in 1 week and produce and deliver those in 1 more week [87]. The total fast fashion cycle duration is approximately 2 weeks compared to 34 to 61 weeks for other fashion business models like a global hybrid fashion company and a US lifestyle brand.

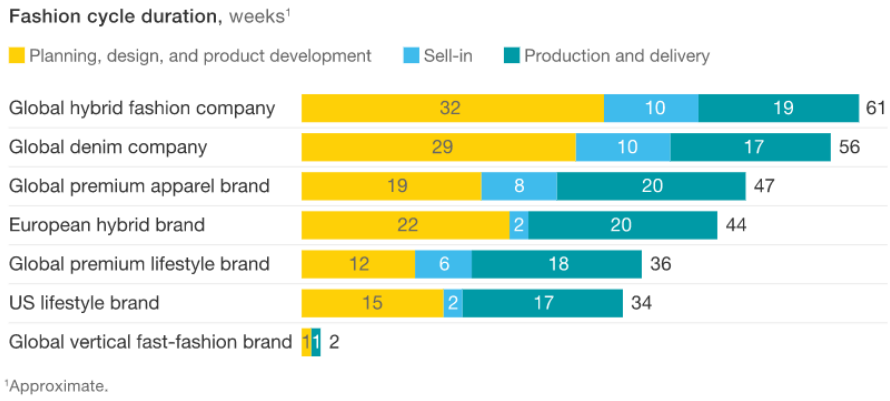


Figure 81: The duration of an end-to-end fashion cycle [87]

Examples of fast fashion businesses are Zara, H&M, C&A, Primark, New Balance, Forever 21, Pull & Bear, Decathlon, Urban Outfitters, Adidas, Nike, …

Fast Fashion is therefore and extreme case compared to other, more sustainable businesses and was selected in this study. It has also been selected because of its dominant position in the current market.

Ultra-fast fashion:

This term is used to describe an unsustainable business model that involves designing, producing and selling clothing at a higher pace than fast fashion, often in a matter of days instead of weeks. Ultra-fast fashion mostly operate online and just like fast fashion, it design fashion for micro trends but at even lower prices, lower quality items, copying from high-end brands, using low-cost labor and outsourcing production to countries with lower wages[88]–[90]. This is possible due advancements in production technology and that the global supply chain allows quick production and distribution of fashion. Just like fast fashion business models, it encourages excessive consumption waste.

Ultra-Fast Fashion companies often send a small batch of clothing to online influencers. The items that are received positively from the influencer and their community are then mass produced[89]. Because trends come and go, production needs to be fast, ultra-fast. This at a cost for factory workers in low-wage countries [90]

This business model is chosen because it's an extreme case. Example of this business models are Shein, ASOS and Boohoo.

Buying second-hand:

Every fashion item that already has been worn by someone and reused by someone else can be seen as second-hand [91]. This business model is a product-oriented PSS. The tangible part are the pre-owned clothing items and the intangible

service include collection these items, analyzing and distributing it. This business model is chosen because of its raising popularity [2]. Examples of these stores within a Belgian fashion landscape are the Kringwinkel and Think Twice.

This business model is chosen because of its popularity and it is a product-oriented PSS.

***Buying sustainable fashion*:**
Clothing brands within this category sell sustainable fashion based on following the butterfly diagram from the Ellen MacArthur Foundation. Besides this framework, the 9R framework can be implemented too in this context [92]. On a single axis, it shows certain actions from linear economy to circular economy strategies.

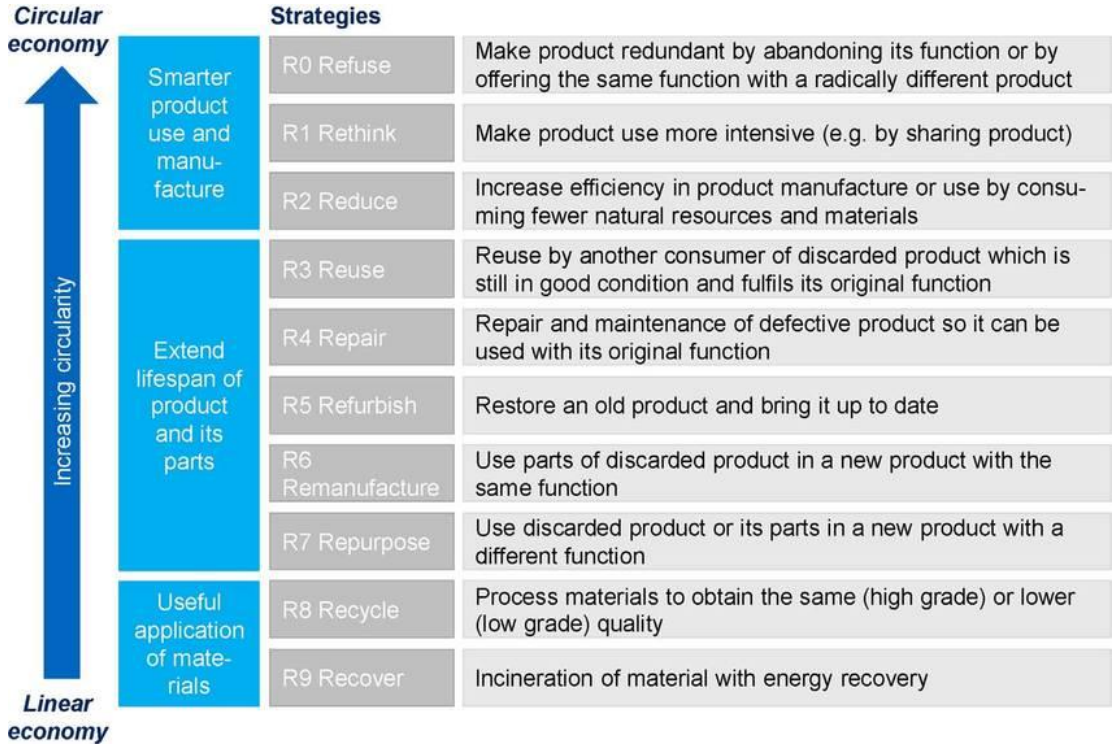


Figure 82: 9R framework [87]

For example, if a brand design clothing long-lasting clothing, secure a safe and fair working environment, use sustainable materials, then they fit in this category. It's a broad category but Veja, Fjallraven and Patagonia are therefore seen as sustainable brands. The Belgian sustainable fashion retailer is a store that offers multiple sustainable brands according to their sustainable and fair mindset.

The reason why to implement this category is that the lack of ownership being a key barrier for access-based services [2]. Here the consumer owns a sustainable product.

***Fashion rental*:**
This business model is comparable to regular fashion stores or web shops but instead of a consumer buying cloths, the consumer rent them out for a limited time. Fashion rental promotes longer lifecycle and efficient use of resources, through promoting access to high-quality items without ownership, whereby products become the capital assets rather than a commodity [2], [93].

Fashion rental is an use-oriented PSS, more specifically a product sharing or pay-per-service unit because provider is owner of clothing and enables this rental service. They concluded that female participants between 20 and 59 were able to imagine renting clothes and signing up for a subscription-based rental model. The largest driver for consumers is sustainability-related motives and the largest barrier was that renting (everyday) clothing is seen to be too expensive. Furthermore, concerns for liability in case of damage and the desire to own clothes rather than renting was determined to be a barrier too. When looking at what type of clothing female consumers would like to wear, garments for special occasions (94%) was the most popular one. 48% would use rental services for business clothing but only 32% had an interest in renting everyday clothing.

The main business' side driver is to increase sustainability by making the fashion market more circular and increasing the intensity of use for each garment. The offered rental clothing could come from dead stock or purchasing entirely new clothing at fairs and markets. The main described barriers is a high customer acquisition, complicated inventory management and making the business model profitable while still offering attractive rental prices to customers. Also, only 20-30% of new customers stayed longer than two to three months thus, not leading to a return on the acquisition investment. Another barrier are significant challenges in inventory management. For example, overstock and seasonal items take up space which increase carrying cost without generating revenue and decreases trust. Furthermore, 15-30% of new additions can be seen as flops or hot picks. The remaining 40-70% is the gray mass. Flops and gray mass generate additional costs because they are less likely to be rented out and increase carrying cost [93].

Online platforms, such as Dress in Belgium, send rentable fashion to consumers by mail whilst at Lena fashion library in the Netherlands, consumer can rent items in a physical 'store'.

This business model has been chosen because it is a use-oriented PSS, which a second type of PSS.

***Peer-to-peer renting*:**
This business type is a mix of fashion rental and buying second-hand fashion. Business that operate within this idea offer customers a platform to have access to tools to make it accessible to lease out your owned fashion items. This means that, instead of reselling items in customer's wardrobe, they can offer it for rent to other people. Therefore the name 'peer-to-peer' renting. This business model seems promising because it solves the logistical problems within fashion rental platforms.

The only business that could be found which operates within this business model is Tulerie. They claim that customers who participate with this system and therefore, rent out their fashion and/or wear hired fashion, can generate income by increasing the wear of your owned fashion

- How it works for hosts:
    - Hosts make a list of the items they wish to rent out (rental period, rental price,...)
    - Accept requests
    - Send it
    - Clean it up and receive money
    - Repeat
- How it works for borrowers:
    - Browse cabinets offered by lenders
    - Make a request
    - Carry the items
    - Return items by mail
    - Repeat

Just like fashion rental business models, this is a use-oriented PSS but with more of a community scope, which has been seen as an important factor in a sharing economy [12].

***Digitization of wardrobe*:**
These application offer tools to take pictures of items in someone's wardrobe. It digitizes them and generate new outfits based on the weather, schedule,... It is a result-oriented PSS because the result, new outfits and inspiration, are created. This business model introduces a new aspect to the benchmarking, which is digitization of clothing. Whering, Stylebook and Smart Closet are examples of such applications.

Besides being the last type of PSS (result-oriented), this business model was chosen because of digitalization aspect.

Benchmarking

Every business model has a definition. Now, there are three different ways to benchmark them according to circularity. The first way is using the 9R framework, which has been explained before. Here a clear definition is given for each of the 9 circular strategies.

- R0 Refuse
- R1 Rethink
    - Digitization of wardrobe
- R2 Reduce
- R3 Reuse
    - Buying second-hand
    - Fashion rental
    - Peer-to-peer renting
- R4 Repair
- R5 Refurbish
- R6 Remanufacture
- R7 Repurpose
- R8 Recycle
- R9 Recover
- No category
    - Fast fashion
    - Ultra-fast fashion

The last category that needs to be placed somewhere, is 'buying sustainable fashion'. Depending on how fashion companies handle this, it can be placed for example in R5 if they restore an old product and sell it again. Besides that, this framework doesn't include social and fair measures, which is an important sustainable factor for for example Veja.

Below, benchmaring the 7 business models are benchmakred on the butterfly diagram. Just as in the 9R framework, no definition for (ultra-) fast fashion fits within one of the categories. Here, placing 'buying sustainable fashion' depends on the individual brand.

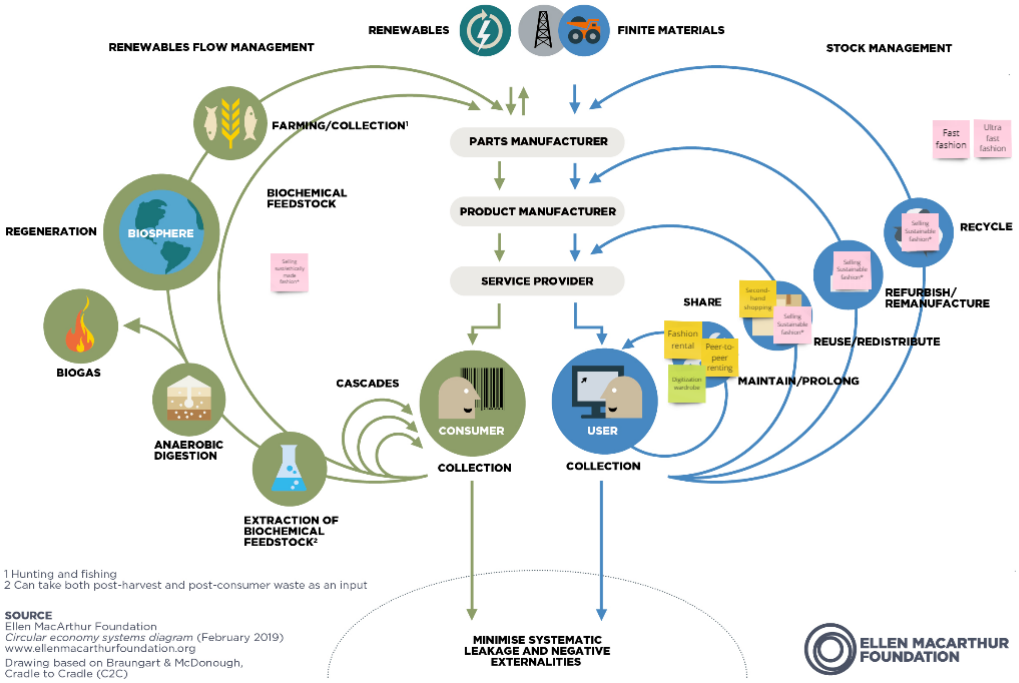


Figure 83: Circular economy benchmarking

The last way to benchmark circularity, is by analyzing the type of PSS. These three types can be ranked according to their circularity [16] whereas result-oriented PSS are the most circular, followed by use-oriented and then product-oriented. Thus, 'digitization of wardrobe' is the most circular, then 'fashion rental' and 'peer-to-peer renting', and lastly 'second-hand shopping'. The three other categories are no PSS and therefore, don't fit in this benchmark.

In future stages of this study, a solution will be designed. According to its description, it also will be placed somewhere on one of the three benchmark axis to analyze if the solution would be more circular.

Because these benchmark only tell something about circularity, and not desirability, viability and feasibility, a new study will be performed to further enrich the problem definition.

Data collection 1

***Data analysis*:**

Survey

Variables	Frequency	Percentage
Gender		
Male	42	33,30%
Female	83	65,90%
Non-binary	1	0,80%
Education (highest degree)		
High school (12-18 y.o.)	11	8,70%
Graduate	12	9,50%
Professional bachelor	34	27,00%
Academic bachelor	12	9,50%
Academic master	55	43,70%
PhD	2	1,60%
Residency		
Urban	35	27,80%
Suburban	31	24,60%
Rural	60	47,60%
Age		
17-26	39	30,95%
27-42	15	11,90%
43-58	55	43,65%
59-68	15	11,90%
69+	2	1,59%

Figure 84: sample composition survey

The age group are made, based on the generation. The categories are based on Beresford Research.

Open questions and multiple choice answers, like for example what consumers like and don't like about a business model, will be analyzed qualitative. For example, many answers for what customers liked about fast fashion business models is price. Many participants framed this differently, some just say 'price' whilst others mentioned 'affordability', 'low prices', 'attractive prices', 'not expensive',... Therefore, some interpretation is needed whilst analyzing and reporting these qualitative results. Where possible, the frequency of answers will be placed next to the result. As mentioned previously, this is exploratory research. The goal of this data phase is to develop a competitor and SWOT analysis for each of the 7 business models (whilst understanding the current (sustainable) fashion consumption).

Data analysis is performed using the SPSS data software, not to confuse with the other SPSS definition stated in the introduction, which is Sustainable Product Service System. Besides SPPS, Excel is used too.

Interview

As mentioned previously, 2 business models were interviewed. Those are a Belgian fashion rental platform called The Belgian fashion rental platform, and a sustainable fashion store called The Belgian sustainable fashion retailer.

The Belgian fashion rental platform interview:

The Belgian fashion rental platform is an online rental platform for Belgian and Dutch designers, where every day as formal and occasional items are offered. They make impact by increasing the wear if an item.

Customer's profile is mainly in Brussels and Flanders and would like to start in the Netherlands too. For The Belgian fashion rental platform, growing into the Netherlands would logistically does not have a lot of impact because their main headquarters is in Antwerp, close to the Dutch border. The marketing possible needs to change a bit according to the Dutch fashion mindset but nowadays, there are marketing problems too for their current B2C BM in Belgium. Why the marketing is difficult to do, is because it is a fairly new concept which implies educating customers first. They need to test for certain possible persona's to know what trigger works for whom, how to reach them. They don't have the budget now to invest in campaigns for each possible fashion 'persona'.

Now The Belgian fashion rental platform is searching for investors to launch new marketing campaigns because budget is needed to create brand awareness. The expected a quicker B2C grow because the The Belgian fashion rental platform team doesn't currently have someone which huge amounts of B2C background.

In November 2022, The Belgian fashion rental platform released besides a subscription model, a flexible/pay-per-use model. This has been positively received by the customers as well as the general audience. The Belgian fashion rental platform states that it is a lower threshold to convince new customers to test The Belgian fashion rental platform instead of fully committing to a subscription model. Eventually, it would be better in the end if those customers are convinced to start a subscription for The Belgian fashion rental platform. For consumers, it is also way more practical hiring it once without starting a subscription, especially if it is for an occasional outfit. And withing The Belgian fashion rental platform's values, it is better to hire something, even if it just for once instead of buying it.

It is confirmed that countries such as the Netherlands, United Kingdom and the United States are way more ahead of the fashion rental practices then in Belgium.

There are 3 main operational costs. The first is washing and repairing cost. The Belgian fashion rental platform works with external company to do those actions. The items are once a week washed by their partner. Accessories and transport items (backpacks, purses) are checked by The Belgian fashion rental platform themselves on for example damage and they clean themselves. The second main cost are transport costs, this is a fixed cost for sending it to the customer and back is €10. Based on The Belgian fashion rental platform's date, items are send back on average after 6 weeks. For one-time rental, this is a sperate cost the customer needs to pay. The last cost is packaging.

Costs not directly linked are sales and marketing, rent of their place, cost of employees,...

The Belgian fashion rental platform doesn't buy the offered items from fashion suppliers. Therefore, agreements with fashion companies are made to offer their garments for rent. Because of this, The Belgian fashion rental platform doesn't have full power to decide for themselves what items they'll put on their platform. The control The Belgian fashion rental platform has is that they have the option not to make something available for their audience. This came in handy when they noticed that certain delicate materials, such as silk, came back fully damaged because it is too delicate. Then The Belgian fashion rental platform has to pay for those items to the original fashion owner. Also, for example white dresses do not perform well because customers are afraid they'll damage it.

Therefore, The Belgian fashion rental platform confirms that some items are not designed to be hired but to be sold. Some items are, and those are the ones that are performing well like these pants, jackets, purses,.. But the silk and white items not. But these parameters should also be implemented within a fashion sales business. It comes down to how many times someone wears an item and how to care for those. If those are not well designed for items which will be sold, then it certainly does not imply for rental items. For example, customers would have the same problem if they bought a silk shirt and it is completely damaged after one wash, then the same problem would happen in a fashion rental context.

Some brands specifically design rental items for The Belgian fashion rental platform. 'A E S A E R T' is a purse brand designed for very special occasions. The purses that are designed for occasional wear can serve to be sold.

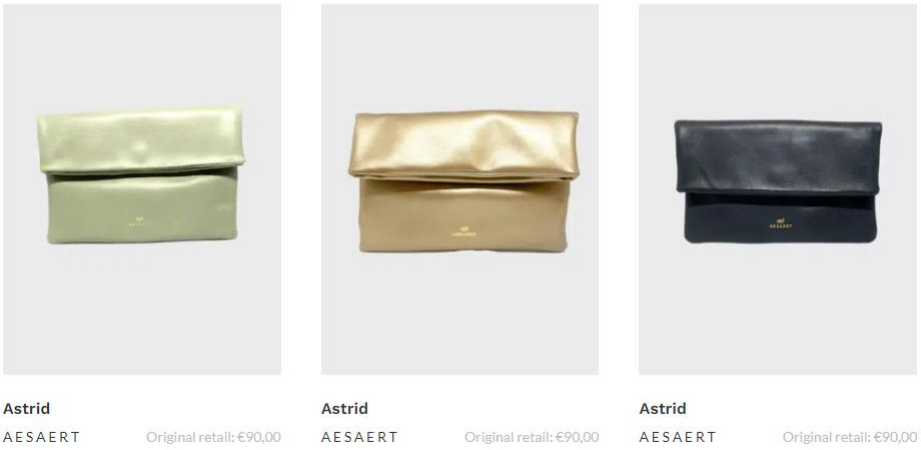


Figure 85: Fasion designed for rental

Another brand that specifically designed for The Belgian fashion rental platform is Leonie Vlaar Slow Fashion. These are upcycled and therefore, unique items. The Belgian fashion rental platform has supported the design process and gave valuable input to Leone Vlaar regarding properties they have to keep in mind whilst designing for rent. For example, combining two materials should still enable proper washing, other care, reuse,...

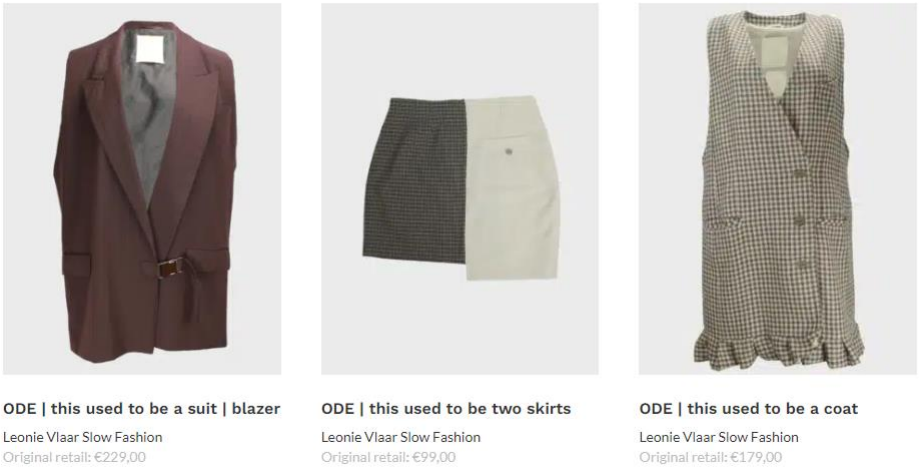


Figure 86: Upcycled collection at The Belgian fashion rental platform

Generally speaking saying, it is difficult to really pinpoint the 'hot picks', 'grey mass' or 'flops' for specific brands, colors, materials,... But pants, jackets, shirts are items that are most popular on The Belgian fashion rental platform's fashion platform. It doesn't happen that The Belgian fashion rental platform needs to tell to fashion partner that they need to pick up their clothing.

If The Belgian fashion rental platform continues to grow, then it possibly will mainly become a supply chain warehouse BM. Therefore, the first project The Belgian fashion rental platform does with Thomas More, is to link physical items to its digital

equivalent to following it throughout its logistical process. For example, an items comes back to The Belgian fashion rental platform, they scan it, it goes to washing company, comes back, scans back and indicated it is washed,... This can create a more dynamic stock that doesn't need to be organized according to brand. When The Belgian fashion rental platform knows how long each item is in each phase, then they can calculate the costs more objectively. Based on this data, they can make operational changes. For example, washing these items two times a week instead of 1.

To test the digitization of the physical fashion items, they did a pilot project with 100 of their current items and they individually sewed in a customer QR code as a label. But this is time-consuming which makes the costs rise. Also, The Belgian fashion rental platform's current software could not be integrated with the software used for scanning and digitizing these items. Therefore, a better integrated system is needed for smoother and time-efficiency. This needs investments in a digitized project.

Now, the The Belgian fashion rental platform employees are well aware of their current collection. Nowadays, they have the digital and physical collection. In these are different and are accessed in different ways. The digital collection is accessed through The Belgian fashion rental platform's platform whilst the physical collection is displayed in a physical location in Mortsel (Antwerp). Therefore, if these items where digitized, then it would mean that The Belgian fashion rental platform knows where each item is located, either online or in the physical store.

Quifactum now provides the software and technology of digitization of those items and Thomas More, a University College in Flanders, has now started a project enabling those fashion companies transitioning into digitization.

Now, two physical tags could be used for digitization, a QR code printed on a label or an RFID (NFC) tag. RFID (NFC) is more expensive but the QR code needs to last long time, cannot fade when washing, time-consuming when sewing in,... So no ideal solutions has been found yet.

The main motivations for the first customer segment for The Belgian fashion rental platform are mainly because of sustainability motivations, the need for having lots of different clothing is sustainably solved by offering a wide variety for rent instead of buying it, and do not feel guilty anymore because they otherwise would have bought something through fast fashion.

Another customer segment are customers like journalists, people who are attending events, needs to present on a podium,... For them it is convenient to rent

something new for once and let their company pay for it. Because of this system, they don't need to buy new items each time and can wear something different every time.

The last customer segment are the ones who chose for fashion rental because of economic reasons. For this segment, it is more attractive to rent an expensive purse instead of buying it so they get the opportunity to wear it something nice too.

Two categories can be identified when looking at the reason why customers have regret using The Belgian fashion rental platform before. Firstly, there are the customers who are still customers and those who are not customers anymore. Whenever The Belgian fashion rental platform is sending a fashion item to a customer, they also receive a small paper that customer can fill when they are sending back that item. On this little paper, The Belgian fashion rental platform is asking the reasons behind why they're sending back this item. From this, The Belgian fashion rental platform knows that the biggest pain point are the sizes. Now, it happens that a fashion item is too tight, too big, too large,... This feedback is also send to the original fashion producer.

Because of this, The Belgian fashion rental platform is starting a pilot project with Shavatar. The customers will need to do some basic body measurements and needs to answer a few question. Based on this information and the given measurement table provided by the fashion item supplier, a better size indication can be given to the customer. Generally speaking for every online business, returning an item is a cost for the company and a time lost for the customers. This means that all of this needs to be avoided.

The second reason what people don't like about The Belgian fashion rental platform, are the size ranges. There is way to less availability for the small and plus-sized sizes. A third reason why people stopping using The Belgian fashion rental platform in the beginning, was because there wasn't enough fashion items provided.

The Belgian fashion rental platform is also implementing Contourlab. This start-up provides fashion consumer support fashion customers styling their outfit. This can only be done in their physical store but could easily be implemented online.

The Belgian fashion rental platform would benefit the European Union's regulations aiming towards fashion producers. The European Commission is aiming to introduce regulations that would tax fashion businesses more if they produce a lot of fashion waste. Therefore, the Commission would propose that these producers

stay in ownership of the clothing and therefore, responsible for the end-of-life of clothing.

The Belgian sustainable fashion retailer Interview:

This interview was shorter than the interview with The Belgian fashion rental platform. Therefore, the data analysis of this interview is way shorter and limited. The mail goal of The Belgian sustainable fashion retailer is to raise customer awareness about the impact of the fashion industry.

An important factor is storytelling. The Belgian sustainable fashion retailer, does implements this strategy in several ways to communicate their message about sustainable fashion to their customers and the wider community.

One of the ways in which The Belgian sustainable fashion retailer applies storytelling is by emphasizing the origin and production methods of their garments. The Belgian sustainable fashion retailer collaborates with various sustainable brands that are committed to ecological and social sustainability and provide transparency about their production processes. The Belgian sustainable fashion retailer shares these stories and information about the brands and products on their website, social media, and in physical stores, giving customers a better understanding of the background of the clothing they are purchasing.

The Belgian sustainable fashion retailer also showcases their commitment to sustainability in their store design and visual merchandising, using eco-friendly materials and displays to communicate their values to customers.

Just as The Belgian fashion rental platform, the fashion rental company, The Belgian sustainable fashion retailer sends back information to the original sustainable manufacturer so they can make these garments better.

An important factor how The Belgian sustainable fashion retailer attracts new customers is by their physical stores in several Belgian cities. This physicality is necessary for staying profitable but to also create better customer relationships.

Generally speaking, then don’t see second-hand stores like Think Twice or the Kringwinkel as competitors. Their BM is aimed towards a different customer segment but they all serve the same purpose to decrease the environmental impact of the fashion industry.

Because The Belgian sustainable fashion retailer is dedicated to supporting ethical and sustainable fashion methods that have a beneficial influence on both people and the environment, The Belgian sustainable fashion retailer believes that fair fashion is crucial. Making sure that the clothes they sell is created in a fair and

ethical manner is one of The Belgian sustainable fashion retailer' top priorities. They work with companies whose supply chains stress openness, justice, and social responsibility to make sure that employees are treated with respect and that their fundamental human rights are upheld. By collaborating with these companies, The Belgian sustainable fashion retailer advocates for just and moral manufacturing methods and works to end injustice and exploitation in the fashion sector.

Results & implications:

Many more SWOT data exist from other research but here, data is included only from the interview and survey.

Competitor analysis Fashion rental from The Belgian fashion rental platform's perspective

Not every parameter from the competitor analysis can be answered by the company itself. The parameters that can be answered are the following:

1. Most and least popular channels?
    a. Social media and news articles are the most popular channels
2. Best and worst feature, for those who have and have not used this BM before.
    a. The best features are sustainability motivations, not committing in buying fashion, wide variety of options decrease the need for buying new fashion and this system is great if a customer needs to rent something just for once instead of buying it for that special occasion
    b. The worst features are items are the wrong sizes and the lack of variety in sizes,
3. Most and least popular product category for those wo have and not have used this BM before
    a. Items for everyday use, formal items, accessories, purses are the most popular
    b. Specific colors and materials are less desired by customer

SWOT analysis fashion rental from The Belgian fashion rental platform's perspective

1. Strengths
    a. Promoting reuse of clothing
    b. Because this is a small company, their workflow is more flexible. For example, they can do quick and small tests with possible new customers segments to enhance their current offer.
    c. Recurrent income is generated through subscriptions.
    d. The newly introduced flexible plan is positively received by their customers and attracts new customers into trying The Belgian fashion rental platform for the first time

e. The Belgian fashion rental platform is the pioneer in fashion rental platforms in Belgium
f. The Belgian fashion rental platform doesn't need to buy fashion items, therefore, there is almost no acquisition cost.
g. Because this is an online platform, The Belgian fashion rental platform has objective data what their customer segment is, what items are the most and least popular
h. Wide range of designer clothing and accessories available for rental
i. Partnerships with upcycling companies or fashion designers who develop clothing specifically for The Belgian fashion rental platform creates an unique catalogue for consumers
j. Having the chance to wear items who are normally out of budget for certain customers.
k. Wide variety of fashion items to rent so the urge of always having something new in the wardrobe is solved
l. Convenient online platform for browsing and booking rentals

2. Weaknesses
    a. Fashion rental is a new concept, this makes marketing expensive because they need to educate consumers first. Some customers may be biased first and don't like the fact that someone else wore it. They don't have the budget to launch marketing campaigns for each of the possible customer segments. All of this hinders customer acquisition.
    b. The Belgian fashion rental platform doesn't have full control over what items are offered on the platform.
    c. Certain materials are not suited for fashion rental, such as silk, because they get damaged too easily
    d. Certain color do not perform greatly because customers are afraid they may damage it
    e. Customers are not eager to rent shoes, it is also harder to clean.
    f. Storing shoes in the warehouse takes up lots of space because a lot of volume if shoe boxes are stacked
    g. Always need to refresh and update catalogue to satisfy customers
    h. Limited availability of certain sizes and styles may limit appeal to a wider range of customers
    i. Relatively high rental prices may deter budget-conscious consumers
3. Opportunities
    a. Expansion into neighboring markets, such as the Netherlands.
    b. Partnership with local designers to offer unique and exclusive rental options.

c. Investigating more fashion rental uses like for weddings or proms.
d. They are looking for B2B streams they can jump on board with, for example rental for tv shows, movies, … because then they can make bigger deals then with B2C.
e. The digitization of fashion items are beneficial for future logistical reasons
f. Reducing the amounts an item is send back to The Belgian fashion rental platform is cost-efficient for them and time-saving for the customer
g. Helping customers styling outfits in a fashion rental context can benefit this CBM

4. Threads
    a. Not finding proper investors can cause the company to go bankrupt if the B2C growth starts to stagnate or decrease.
    b. Changes in government regulations and tariffs that may affect the company's ability to import and rent out designer clothing and accessories.
    c. Competition from other fashion rental companies, both locally and globally

Competitor analysis from The Belgian sustainable fashion retailer' perspective

1. Most and least popular channels?
    a. The most popular channel is the physicality of the stores
2. Best and worst feature, for those who have and have not used this BM before.
    a. The best features is that consumers know they are buying fair and sustainable
    b. The worst feature may be the price for certain customer segments.

SWOT analysis from The Belgian sustainable fashion retailer' perspective

- Strengths
    - Creating a strong customer relationship
    - Making customers aware about sustainable fashion consumption
    - Giving feedback to fashion producers
    - Physical store locations in multiple Belgian cities
    - Emphasis on transparency in production and supply chains
- Weaknesses
    - Higher prices compared to fast fashion retailers
- Opportunities
    - Growing demand for sustainable and ethical fashion

- The information stream from customer, to The Belgian sustainable fashion retailer, to fashion manufacturer is an interesting opportunity regarding digitization of fashion items.

- Treats
  - Competition from other sustainable and fair fashion brands
  - Shifting consumer preferences and trends

Customer's perspective result

Table 11: Competitor analysis part 1

DC 1.2	N=126				Who have used		Who have not used	
	% of customers have heard	% of customers have used	Most popular chanels	Least popular channels	Best feature	Worst feature	Best feature	Worst feature
Fast fashion	92,9% (N=117)	96% (N=121)	Shop in the streets Social media Online webshop	App store Digital newspaper Email	Prices Wide veriaty sizes Trendy offer	Quality Sustainability (generally) Transparancy	/	/
Ultra fast fashion	61,6% (N=117)	20% (N=25)	Social media Online webshop Friends/family	Shop in the streets Email Digital/physical newspaper & App store	Prices Trendy offer Big offer	Environmental impact Factory workers/conditions Quality	Nothing Low prices More accessible (sizes, financial)	Environmental impact Quality Factory workers/conditions
Buying second-hand	99,2% (N=125)	65,6% (N=83)	Shop in the streets Friends/family Social media	Email Digital/physical newspaper App store	Sustainability (reuse) Look & feel Price	Quality (usage marks, smell, too damaged) Availability of sizes Too low prices = overconsumption	Sustainability (resue) Price /	Hygiene Resource unclear Offer
Buying sustainable fashion	79,4% (N=100)	56,3% (N=71)	Shop in the streets Online webshop Friend/family & social media	App store Email Digital/physical newspaper	Quality Sustainability 'Feel-good' factor	High price Occasional greenwashing (no transparancy)	Sustainable (general) Quality Long lasting	Expensive Once obtained = get bored of item Doesn't offer my style
Fashion rental	50,0% (N=63)	8,7% (N=11)	Friends/family Social media Shop in the street	App store Email Digital/physical newspaper	Price Trendy offer For special occasions	Lack of ownership Small offer Returning	(reuse) Access to new fashion at lower price Cleaning	Logistics (returning etc) Lack of ownership Hygiene
Peer-to-peer renting	2,4% (N=3)	0,0% (N=0)	/	/	/	/	Sustainability (reuse) Financial reward Still owner	Not in control over when it's rented out Complex to orginize Time-consuming
Digitization wardrobe	15,1% (N=19)	3,2% (N=4)	Social media Friends & family App store & Search engine	Onle webshop News on TV /	Great overview what you have Experimenting /	Time-consuming Paid /	Generating new outfits Overview Optimizing wardrobe	Time-consuming Privacy No personal creativity involved

Table 12: Competitor analysis part 2

DC 1.2	Who have used it		Who have not used it		Who have used it				Not used
	Most popular uses	Least popular uses	Possible most popular uses	Possible least popular uses	% don't use it anymore	% have regretted using it	Biggest reasons regretting it	% wardrobe	% don't want to use it
Fast fashion	Everyday use Seasonal fashion Accessoires & shoes	Underwear Sport items Verkleedkledij	/	/	23,1% (N=28)	57% (N=69)	Quality Sustainability (generally speaking) Guilt	42,33%	/
Ultra fast fashion	Accesories Everyday use Badkledij	Watches & jewerly Designer fashion Shoes, formal fashion & seasonal fashion	/	/	48% (N=12)	72% (N=18)	Quality Sustainability (generally speaking) Guilt	12,00%	84,2% (N=85)
Buying second-hand	Everyday use accessories Verkleedkledij	Badkledij Formal fashion & watches & jewelery Designer fashion	Verkleedkledij Everyday use Transport items		4,8% (N=4)	16,9% (N=14)	Lower expectation onces wearing Lower quaity than expected tempted by lower prices and not wearing it anymore	18,66%	39,5% (N=17)
Buying sustainable fashion	Everyday use Shoes Seasonal & transport items	Sport items Watches & jewerly Designer fashion	Everyday use Shoes Formal fashion	Verkleedkledij Watches & jewelery Badkledij	5,6% (N=4)	9,9% (N=7)	Lower quality than expected Mispurchase	23,71%	12,7% (N=7)
Fashion rental	Formal fashion Verkleedkledij	Everyday use Designer fashion	Formal fashion Designer fashion Verkleedkledij	Shoes Watches & jewelery Accessories, transport items	0,0% (N=0)	0,0% (N=0)	/	2,71%	33,9% (N=39)
Peer-to-peer renting	/	/	Formal fashion Verkleedkledij Designer fashion	Shoes Watches & jewelery Transport items	/	/	/	/	66,7% (N=84)
Digitization wardrobe	/	/	/	/	0,0%	50,00%	Paid Not using anymore	/	65,5% (N=80)

SWOT analysis from customer's perspective

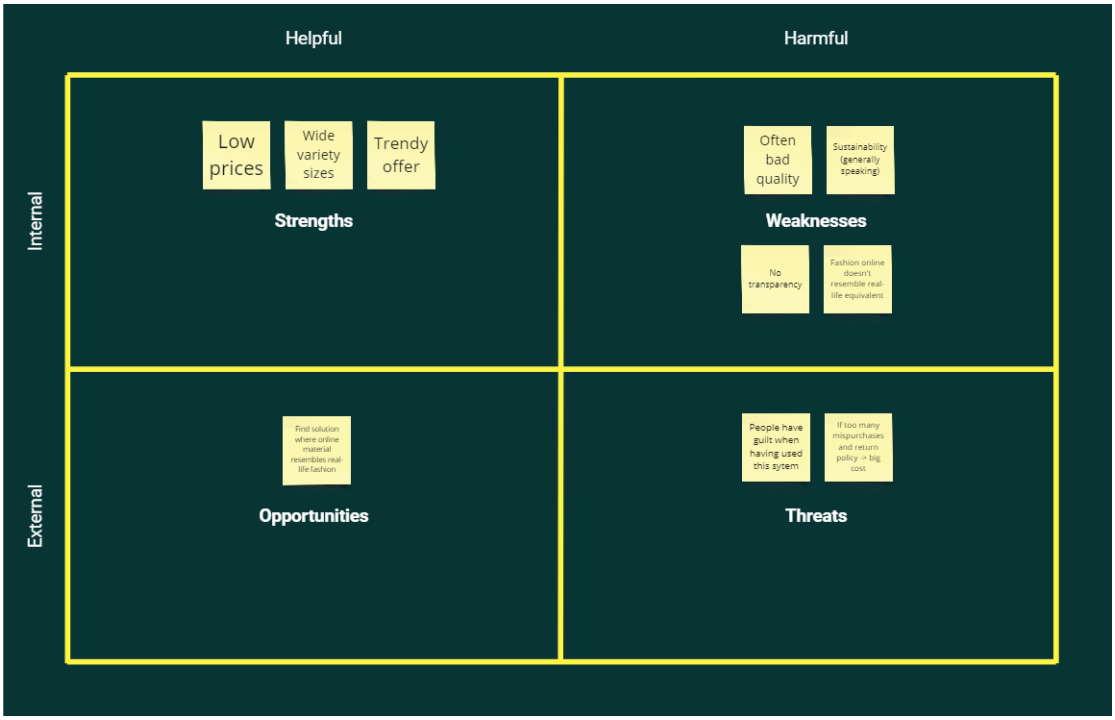


Figure 87: SWOT of fast fashion

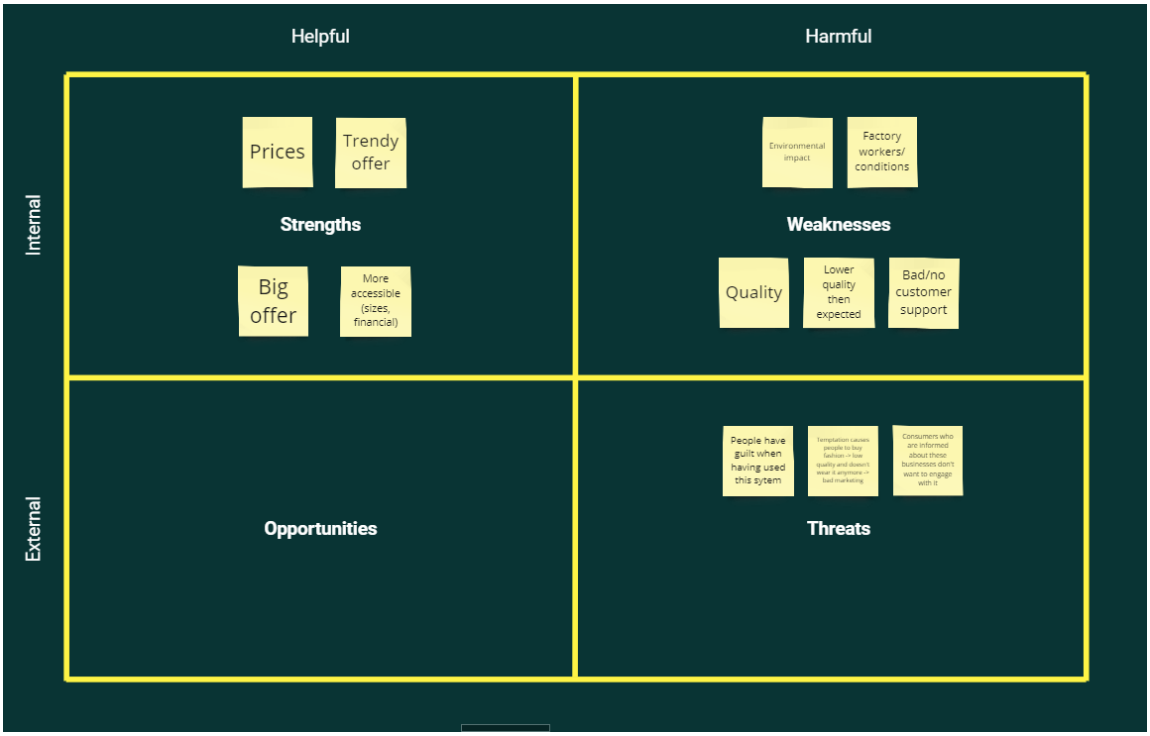


Figure 88: SWOT of Ultra-fast fashion

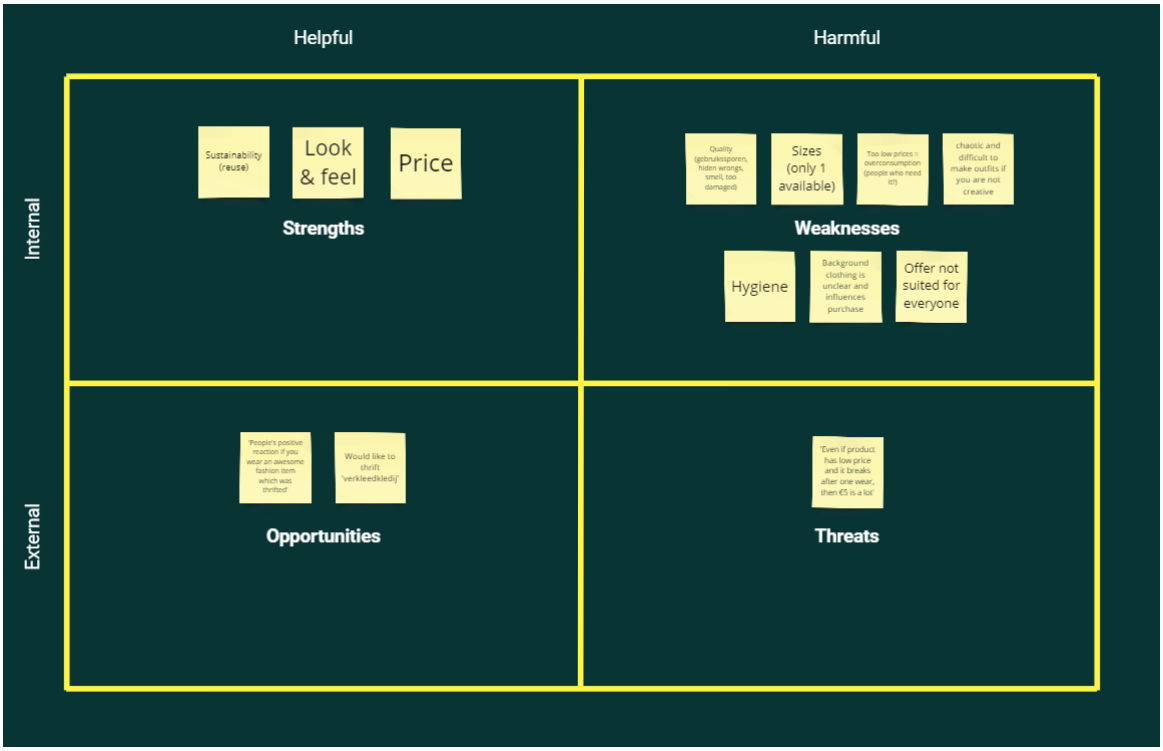


Figure 89: SWOT of second-hand shopping

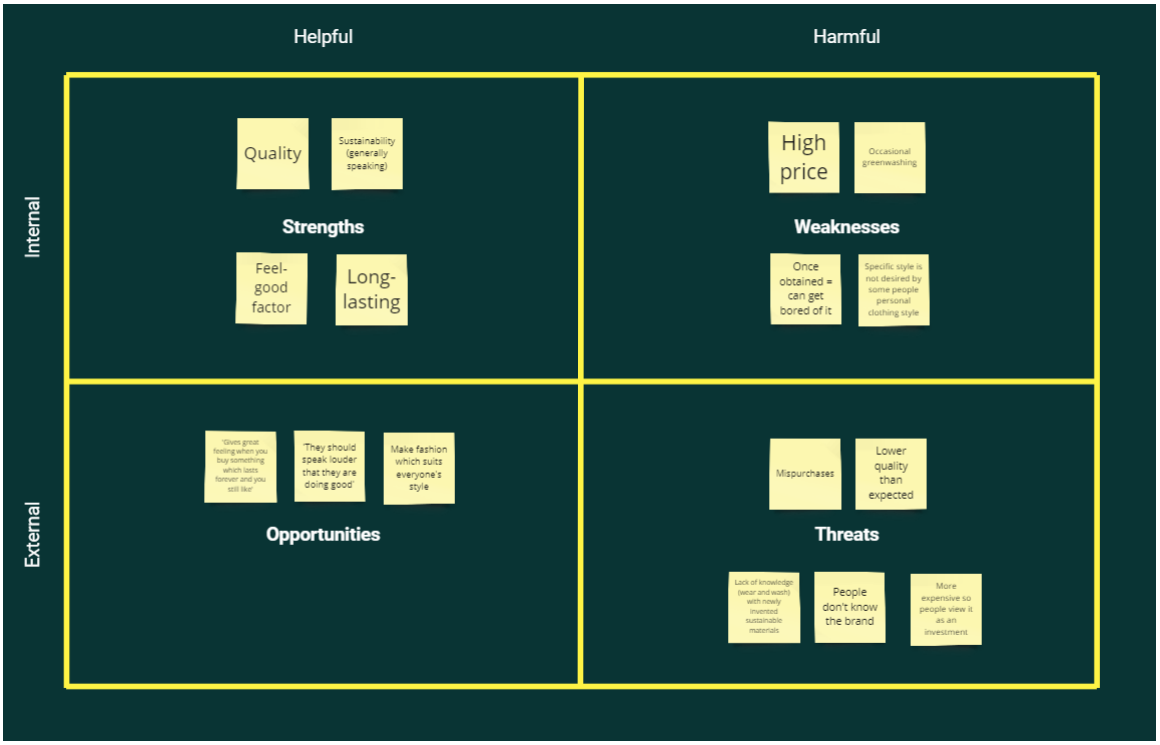


Figure 90: SWOT of buying sustainable fashion

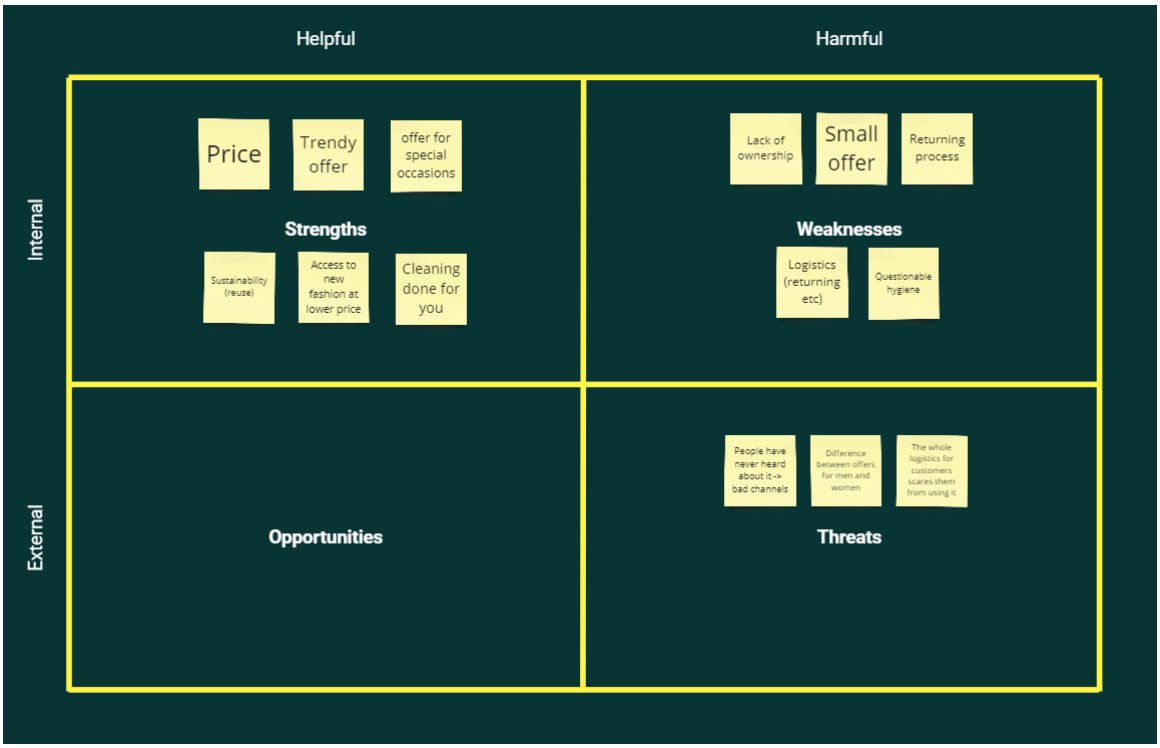


Figure 91: SWOT of fashion rental

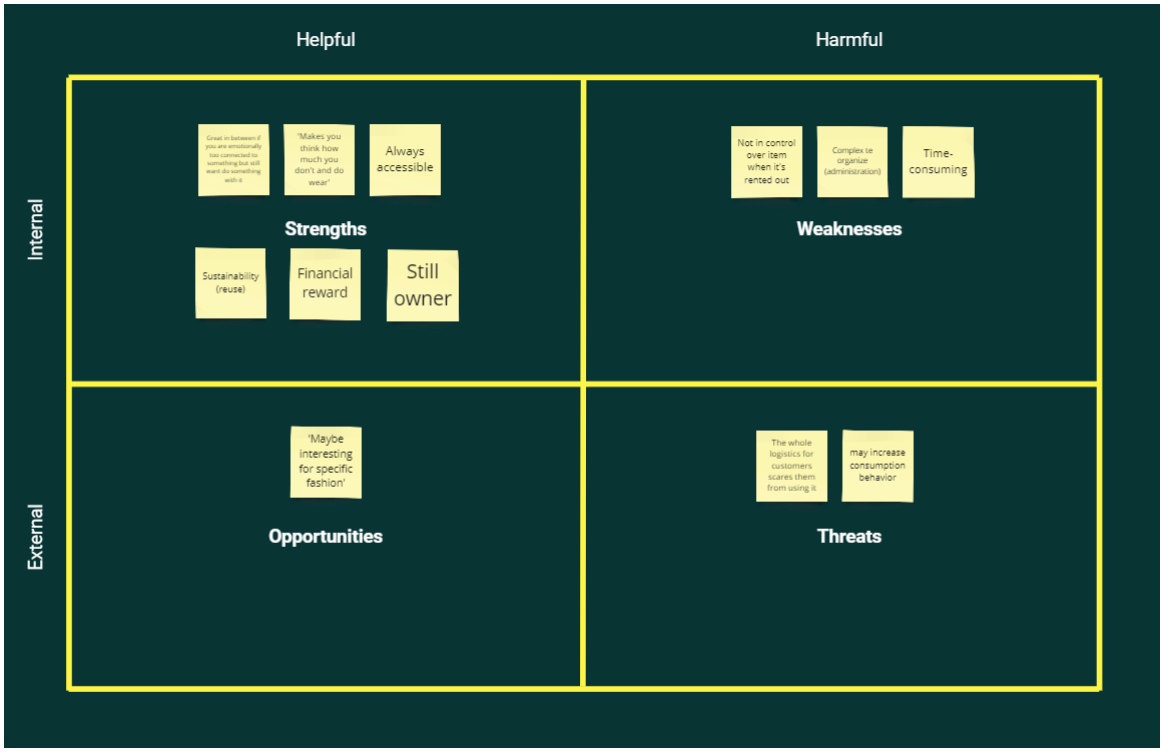


Figure 92: SWOT of peer-to-peer renting

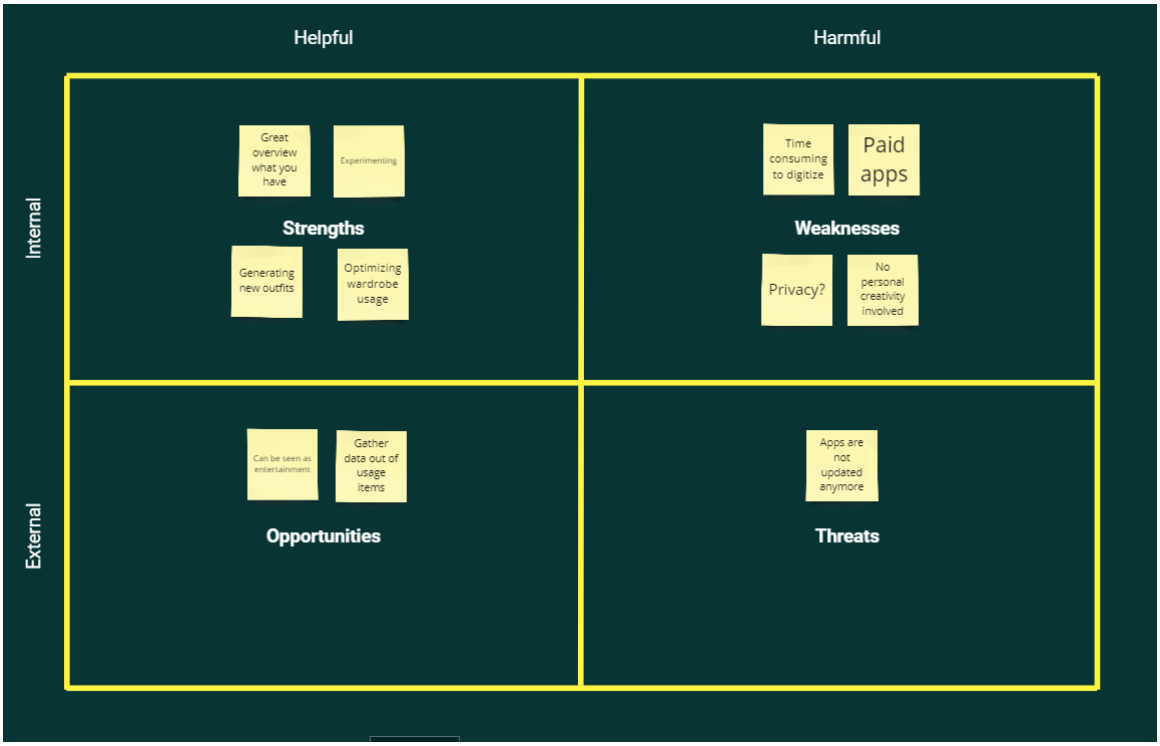


Figure 93: SWOT of digitization of wardrobe

***Reflection*:**

During the survey, it maybe would have been better to ask for percentage ranges instead of a fixed percentage. Also, it would have been interesting if product passport data would have been integrated with the fourth question of the general fashion consumption of consumers (what factors are important regarding fashion items). Also, only 2/7 businesses are interviewed.

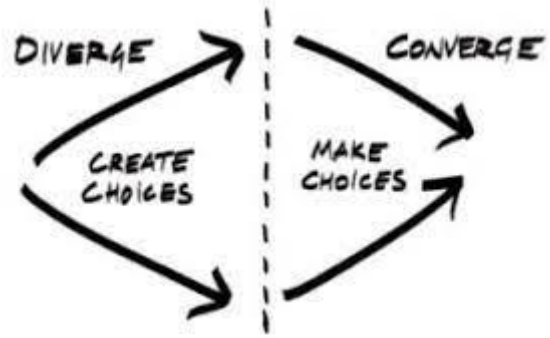
Generally speaking, more data in the SWOT analysis from the customer's perspective would have been expected whilst now. This doesn't mean that the results are useless.

Define iteration 1

The SWOT analysis and competitor analysis forms the basis of the problem definition which marks the end of the define phase of DT. Now, the next DT phase starts: develop. The goal is to diverge and converge as many times needed to eventually converge to 1 final solution regarding the research question.

Diverge 1: From SWOT to 32 concepts

From the SWOT analysis and the competitor analysis, several solutions can be developed. They have been designed by the main researcher. The goal is to develop 30-40 small concepts without already judging these concepts if they are good or bad. After this, objective converging will happen to go to 1 or a few ideas that will be further developed in a next iteration.



The majority of the ideas come from the SWOT analysis and competitor analysis. In total, 35 concepts were developed. Some of these are still broad, systemic ideas whilst some of them are already quite specific. Also, not every concept will be explained, otherwise, this paper would be too long and the left-out ideas did not directly had an influence on the final idea.

Concept 1: Rental service

Making a service for physical fashion stores so they are enabled to offer a rental service besides selling fashion. This could be a separate corner where they lease out items or design tools that can enable fashion stores to offer rent.

Feasibility: Implementing this service would require investment in the necessary infrastructure, such as a rental inventory management system and customer tracking system.

Desirability: Offering a rental service in physical fashion stores can increase customer engagement and satisfaction. Customers can try out different styles and experiment with their looks without committing to buying the items. This is confirmed by the SWOT from renting fashion. Additionally, this service can attract

new customers who prefer rental over buying and help retain existing customers who may be looking for more sustainable consumption options.

Viability: It can provide an additional revenue stream for fashion retailers and help reduce inventory costs by repurposing items that would otherwise be unsold. However, the success of this business model would depend on factors such as the rental pricing strategy and inventory management.

Circularity: By offering a rental service, physical fashion stores can contribute to a more circular economy by extending the lifecycle of fashion items and reducing textile waste. This service can also promote sustainable consumption and reduce the environmental impact of fast fashion.

Concept 4: Sustainable fashion social media

This concept would establish an social media experience for sustainable clothing like second-hand, swapping, renting, upcycling,... For example, customer uploads outfits and people on the platform can give feedback on that outfit.

Feasibility: From a technical standpoint, the platform would need to have image uploading capabilities, user authentication, and a system for displaying and managing feedback. The technical challenges would be designing an intuitive user interface and ensuring the platform is secure and scalable.

Desirability: There is a potential demand for a platform like this, as many people struggle with deciding what to wear or whether a certain outfit looks good on them. This idea comes from the weaknesses of second-hand shopping, where stores are chaotic and making outfits is difficult if someone is not creative. By providing a space where users can receive feedback and validation from others, the platform could help users feel more confident in their clothing choices.

Viability: The platform could generate revenue through advertising or data collection. However, the costs of developing and maintaining the platform, as well as acquiring and retaining users, could be significant. It could be possible for partnerships with sustainable clothing sources that link clothing to the app.

Circularity: The platform could encourage users to swap or resell clothing items they no longer want or need, reducing waste and promoting circular fashion. Additionally, the platform could prioritize featuring sustainable and ethical fashion brands.

To enhance the concept, AI technology can provide more accurate and personalized feedback to users. Finally, integrating sustainability and ethical fashion practices can be integrated more deeply into the platform's features and

branding, such as highlighting eco-friendly materials or providing information on a brand's labor practices.

Concept 5: Digital twin based on 3D scanning

Here, an online service offers customers a 'digital twin' of their body, allowing them to try on digital clothing and receive feedback on fit and sizing. This concepts goes one step further then an existing solutions, where customers answers questions to estimate their size.

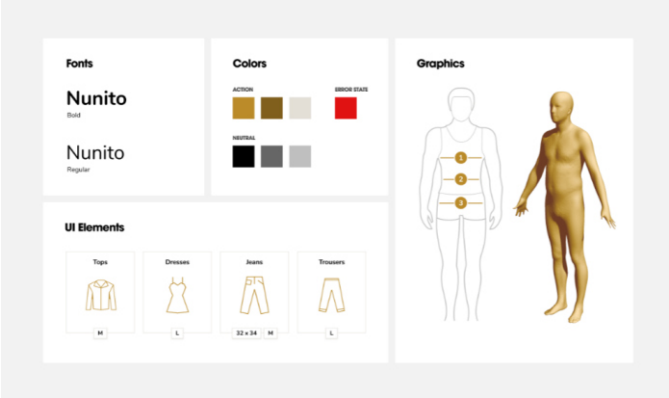


Figure 94: Example Shavatar

Feasibility: The service would require advanced 3D scanning technology to create the digital twin, as well as a user-friendly interface for customers to try on digital clothing and receive feedback. The technical challenge would be developing accurate algorithms that can provide precise feedback on fit and sizing.

Desirability: There is a clear need for a service like this, as many online shoppers struggle with finding the right size and fit when purchasing clothing online. This has been confirmed by The Belgian fashion rental platform. By providing a service that offers personalized feedback and recommendations, customers can save time and money by avoiding returns and exchanges.

Viability: One possibility is to offer the service to online retailers as a plug-in, with a percentage of every purchase made through the tool serving as a revenue stream.

Circularity: The service could encourage customers to purchase more sustainable and ethical fashion items by highlighting eco-friendly materials or brands. Additionally, the service could promote circular fashion by offering recommendations for wardrobe items that can be paired with multiple outfits, reducing the need for excess clothing.

To enhance the concept, AI can provide more accurate and personalized feedback to customers based on their body type and style preferences.

Concept 6: Digital twin customer based on measurements

This concept is closely related to the previous one but isn't less intrusive as 3D scanning an entire body. Here, consumers measure parts of their body. These measurements makes a digital estimate of their body. The FDVC are mostly the same.

Concept 7: Show fashion virtually on digital twin

Once a digital twin has been made of a customer, virtual garments can be placed on this virtual body. Realistic clothing physics simulate how an item will fit according to size and style.

Feasibility: Here, the challenge would be to 3D model and digitize clothing to realistically display them. Furthermore, it needs a digital twin of a customer to operate.

Desirability: Customers may feel more confident in their purchase decisions if they can see how the garment will fit on their body type.

Viability: Fashion companies may pay for this service whenever an item is purchased/rented out through this system.

Circularity: same as for concept 5

Concept 8: Physical peer-to-peer renting

Here, a (pop-up) store would be established where people can bring fashion items to be displayed like in a regular store, and other people can hire or rent those fashion items.

Feasibility: It would require a space to display the clothes, as well as a system to track inventory and transactions. The technical challenge would be building a user-friendly online platform that can facilitate peer-to-peer renting.

Desirability: There is a clear need for a service like this, as many people have clothing items that they no longer wear or need, but that are still in good condition. This has been confirmed in the SWOT from peer-to-peer renting. By offering a peer-to-peer rental service, people can earn extra income or points to rent other clothes. Renting also promotes sustainability by reducing the need for fast fashion, and giving people access to a wider range of clothing items without having to purchase them. Additionally, people who rent clothes can save money and have the opportunity to try out new styles without committing to purchasing them.

Viability: To determine the viability of this service, we would need to consider its potential revenue streams and costs. One possibility is to charge a percentage of the rental fee as a commission. The service could also generate revenue through

advertising or partnerships with sustainable fashion brands. However, the costs of setting up and maintaining the store, as well as acquiring and retaining customers, could be significant.

Circularity: The store could only accept clothing items that are in good condition and made from sustainable materials. Additionally, the store could educate customers on sustainable fashion practices, such as buying high-quality, timeless pieces that can be worn multiple times. But most importantly, this idea promotes reuse of clothing that is still in great condition.

To enhance the concept, the renting process should be designed more seamless and user-friendly, such as a mobile app that allows customers to easily browse and rent clothing items. Partnerships with sustainable fashion brands or designers to offer exclusive collections or collaborations would be possible too. Finally, the store's offerings can be expanded by including other products, such as accessories or home goods for rent. This could attract a wider range of customers and create a more comprehensive sustainable lifestyle brand.

Concept 9: Color palette

The concept would introduce a plug-in that gives style advice to customers of online web shops by determining what their color palette is.

Feasibility: The plug-in would require an algorithm that can analyze uploaded photos and determine the user's color palette. This algorithm could be based on existing color analysis techniques or could be developed specifically for this plug-in.

Desirability: By offering personalized style advice based on the user's color palette, customers can make more informed fashion choices and feel more confident in their purchases. Additionally, online webshops can benefit from this service by providing a more personalized shopping experience for their customers.

Viability: One possibility is to charge a fee for the plug-in, either as a one-time purchase or as a subscription service. Alternatively, the plug-in could be offered for free to customers, but the online webshops would pay for the service as a way to differentiate themselves and provide a better shopping experience.

Circularity: The plug-in could encourage customers to make more sustainable fashion choices by recommending items that complement their existing wardrobe or that are made from sustainable materials.

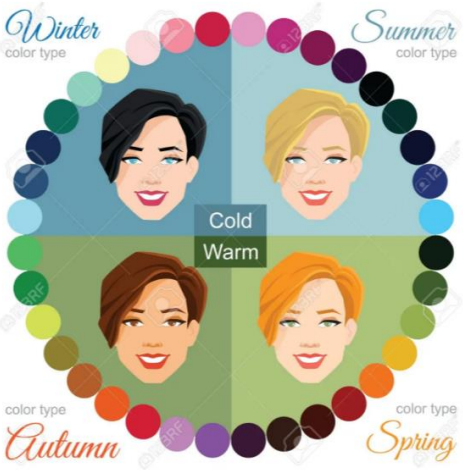


Figure 95: Color palette

Concept 10: Optimal renting storage room

Here, the goal is to design fashion rental storage spaces more optimally by addressing the issue of inefficient use of space caused by for example large shoe boxes or other large items.

Feasibility: The challenge would be in designing a system that optimizes storage space while still allowing for easy access and organization of the clothing items. This could involve utilizing vertical space, implementing innovative storage solutions, and incorporating technology such as automated retrieval systems or inventory tracking systems.

Desirability: There is a clear need for more efficient and sustainable storage solutions in the fashion rental industry. This has been confirmed by the interview with The Belgian fashion rental platform. By designing spaces that are optimized for storage, rental companies could offer more items for rent.

Viability: Designing and implementing a more efficient storage system could involve investment costs, such as new storage technology or renovating existing storage spaces. However, rental companies could potentially offset these costs through storing more items in a smaller space, thereby reducing rental costs.

Circularity: By increasing the rental capacity, more items can be offered for rent. A bigger offer could engage more customers in rental services.

Concept 11: Rentable fashion

This concept builds on the thought that garments in fashion rental are not initially designed to be rented out but to be sold. This could be a reason why renting fashion for everyday use has not been widely accepted yet. This mindset was confirmed by The Belgian fashion rental platform.

Feasibility: For example, designing an underlayer specifically for rental fashion is could work, as it can be made from materials that are easy to clean and maintain. Maybe modification to current items can be made to increase the potential to start renting.

Desirability: This concept can be desirable for both consumers and fashion companies. Consumers who are hesitant to rent clothing due to hygiene concerns may be more willing to try it if clothing was designed to be rented out. For example, an underlayer that creates a barrier between their skin and the rented clothing could increase the potential to rent fashion.

Viability: If garments can be designed with renting in mind, then fashion companies could create recurrent income on items.

Circularity: This concept promotes rentable rented clothing instead of buying new items. It can also reduce waste by extending the lifespan of clothing and by using materials that are easy to clean and maintain.

Concept 13 : Digitizing fashion

When customer buys new fashion (online/offline), it adds to digital wardrobe (no need to take pictures yourself). This concepts assumes that extra product related information is provided, such as digital images, production, color, material, … when someone bought an item. All this information is added to someone's digital wardrobe. This concept is based on 'digitization of wardrobe' but items already have been digitized by the fashion companies.

Feasibility: This concept can be feasible as it only requires fashion companies to provide extra product information in digital format. The ability to use AI to provide personalized style advice and suggest solutions for wear and tear is also feasible. However, it may require a significant investment in technology and infrastructure to create a seamless user experience.

Desirability: The concept of having a digital wardrobe that automatically updates with new purchases and provides additional product information can be highly desirable for fashion consumers who want to keep track of their wardrobe in an organized way. This has been confirmed in the SWOT of the digitization of a wardrobe. It also enables them to easily access and view their clothing collection from anywhere, at any time.

Viability: The concept can be made viable by monetizing the additional services that can be provided to users, such as personalized style recommendations based on their digital wardrobe. Fashion companies can also benefit from this concept as it enables them to collect valuable data on consumer preferences and behavior.

Circularity: Consumers are provided with more information about the products they buy, allowing them to make more informed and sustainable choices. It also encourages the reuse and repurposing of clothing items by making it easier to keep track of one's wardrobe and identify pieces that can be mixed and matched. The ability to suggest solutions for wear and tear can also extend the lifespan of garments, reducing the environmental impact of fashion.

Concept 16 : Smart closet

Someone's wardrobe alerts them if they 'ignored' an item for too long, which can suggest them to wear them again. Notifying users is based on for example the weather or season, for example, a notification would not be sent during summer to wear a winter coat.

Feasibility: Existing technology such as mobile applications or wearable devices with sensors that track clothing usage can be used to implement this technology.

Desirability: It can help users make better use of their wardrobe and encourage them to wear items they may have forgotten about. It can also help reduce clothing waste by promoting the use of existing items in someone's wardrobe.

Viability: The concept could monetized by offering premium features such as personalized styling suggestions based on individual preferences, fashion trends, or weather forecasts.

Circularity: It encourages users to make better use of their existing wardrobe and reduce the need to buy new clothing. It can also promote sustainable fashion by providing personalized styling suggestions based on eco-friendly and ethical fashion brands.

Concept 17 : PSS box for men

This concept introduces a PSS aimed towards men but offering rentable clothing for certain situations. For example if they want to go on a date, a party, dress up fancy to go to the beach, wedding,...

Feasibility: It could be feasible to offer a rental service for fashion items and other accessories needed for certain occasions.

Desirability: The concept of renting a box of fashion items can be desirable for people who don't have the time or resources to shop for a date night outfit. It can also appeal to people who want to try out new styles without committing to a purchase. The desirability can be created from online fashion influencers who may promote this new service.

Viability: If rental fees and the cost of the items in the box are set appropriately, then this business could be viable. Additionally, marketing efforts need to be directed towards the target audience to ensure that the service reaches the right people. This has been confirmed by The Belgian fashion rental platform

Circularity: The rental model is a circular business model as it encourages the reuse of fashion items instead of buying new ones. It can also promote sustainable practices by encouraging people to borrow instead of buying clothes that may only be worn once. The rental box can include eco-friendly and sustainable fashion items, promoting circularity and sustainability. The service can also partner with local businesses such as restaurants or entertainment venues to offer exclusive deals or discounts to users of the rental service.

Concept 18 : PSS parfum

This concept can be part of the previous one. Here, a reusable parfum bottle can be shipped to the customer to add a fragrance to the outfit.

Figure 96: Reusable parfum bottle

Concept 20: Environmental plug-in

Plug-in that shows environmental impact of clothing a customer is planning to buy.

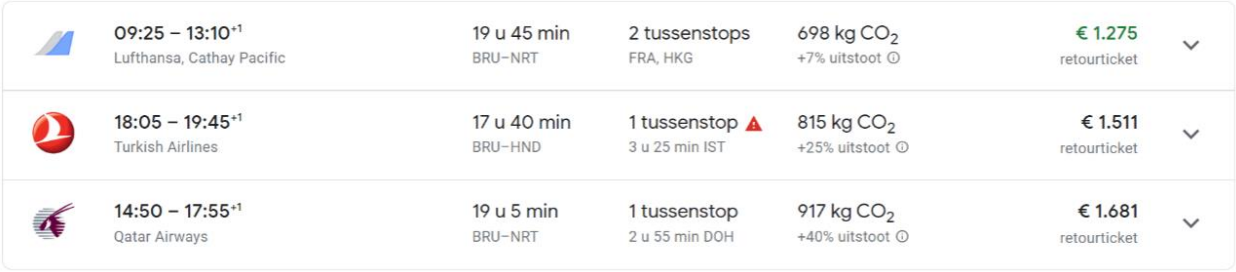


Figure 97: Google Flight shows CO2 emmissions

Feasibility: Developing a plug-in that shows the environmental impact of clothing could be challenging because companies may not offer transparent information. But generally speaking, programming and implementing a plug-in itself should be feasible.

Desirability: Consumers are increasingly concerned about the environmental impact of their purchases, which has been confirmed from the SWOT analysis. Therefore, developing a plug-in that shows the environmental impact of clothing can be desirable so consumers can make more informed decisions.

Viability: This solution could be open-source and donation driven.

Circularity: By showing the environmental impact of clothing, the plug-in can contribute to circularity by encouraging consumers to make more sustainable choices. If consumers can see that a particular piece of clothing has a high environmental impact, they may be more likely to choose a more sustainable option instead.

Concept 21: New label rentable fashion

Physical rental stores phase the problem that the carboard tag get lost and therefore, they are looking for more permanent solutions. For example, they could implement a QR code, RFID or NFC tag in clothing. These digital tags could contain all the necessary information that was previously displayed on the cardboard tag, such as size, brand, and price. Customers could scan the code with their phone to access this information. In addition, these digital tags could also be used to track the item's rental history and ensure that it is returned to the correct location. The platform could use this data to analyze which items are in high demand and adjust their inventory accordingly.

Feasibility: Implementing digital tags in clothing items is could be feasible. QR codes, RFID tags, and NFC chips are all widely used technologies that can be integrated into the rental platform.

Desirability: Customers would likely appreciate the convenience of being able to access information about an item without having to deal with a physical cardboard tag they'll lose. It could also improve the rental platform's efficiency and accuracy.

Viability: The cost of implementing digital tags would need to be considered, as well as any potential security concerns. However, the potential benefits could outweigh the costs.

Circularity: Digital tags could also promote circularity by making it easier to track and reuse items, reducing the likelihood of items being discarded or lost.

Figure 98: Possible solutions

Concept 22 : Company merch

Now, companies offer their employees some company specific merch such as branded shirt and pullovers. But a company's branding can change. Therefore, would it be possible to design fashion that can easily replace that part of the fashion instead of producing a new item?

Feasibility: The process of creating such merch would involve designing the item with a detachable logo/name component that can be easily removed and replaced.

Desirability: The solution would offer greater flexibility and cost-effectiveness. Companies can simply replace the logo/name component instead of having to order a whole new set of merch with the updated design.

Viability: The viability of this concept would depend on the cost of producing the interchangeable logo/name parts and the willingness of companies to adopt this new approach to their merch. It may also require some education and training for employees to ensure that they understand how to remove and replace the logo/name component.

Circularity: This concept promotes circularity by reducing waste and extending the life of company merch. It also allows for the reuse of the clothing item itself, rather than having to dispose of it entirely and order a new one.

Concept 23 : Dynamic rental subscription

This was one of the ideas someone proposed in the survey. What if fashion rental membership is dynamic? So it goes down if someone doesn't use it

Feasibility: Technically speaking, this should be possible.

Desirability: Initial desirability is created from that answer from the survey.

Viability: Calculations needs to be done to make sure this system creates enough revenue and profit.

Circularity: If a dynamic plan can motivate new customers in rentable fashion, then it could increase reuse of items.

Concept 24 : Clothing exchange box

A 'clothing swapping box' would be introduced on several locations in the country. For example, next to a park, school, train station or commercial district. Here, everybody could voluntarily donate clothing and people who need it can take it. This idea is inspired from existing projects in for example London (image below).

Figure 99: Clothing exchange box

Concept 25 : Distribution second-hand

This concept would create a better data-driven second-hand clothing distribution. Now, customers find those stores chaotic and a pity that items are only available in 1 size, color, … This has been confirmed in the SWOT analysis. This can be solved by efficiently distributing items according to local demand, similar items in 1 store,…

Feasibility: This concept could be feasible as it requires logistical enhancements and digitization of clothing.

Desirability: The concept is desirable as it can provide a better shopping experience for customers who are looking for specific types of clothing items. It can also help the thrift store to sell more items by making them easier to find.

Viability: This concept can be financially viable for the thrift store as it can increase the sales of items that might have otherwise been overlooked. It can also help the store to attract more customers who are looking for specific types of clothing items.

Circularity: This concept promotes circularity in the fashion industry by encouraging the reuse of clothing items. By organizing the items in the store more efficiently, the concept can make second-hand shopping more accessible, convenient and reduce the need for new clothing production.

Concept 26: Greenscreen garments

Here, parts of clothing are made green, just like a greenscreen. Whenever a customer is taking a picture, an app can place new imagery on that location.

Figure 100: Examples of greenscreening

Concept 27: Clothing investment app

From the SWOT analysis of buying sustainable fashion, customers have indicated that they view these items as an investment. But what if buying sustainable fashion can be turned into an investment app like in the financial world. This application could help customers visualize that they can wear that item many times, in certain occasions and how much the cost per wear is.

For example, certain items will only be worn during certain weather events just like snow boots. Whenever someone wore it during that weather, the price per wear goes down. It's a visual cue for someone to see that their investment pays of or not.

Concept 28: Plug-in shows similar, more sustainable items

This concept introduces a plug-in for web browsers that consumers can enable whenever they are shopping online. It will show the most sustainable alternative based on image recognition/AI and the given description.

Feasibility: AI tools and image recognition tools are getting more popular over time. Therefore, showing similar, more sustainable items on webstores could be feasible.

Desirability: The concept of a plug-in that promotes sustainable fashion consumption is desirable as it appeals to consumers who are environmentally conscious and want to make responsible choices. It also provides a solution for consumers who may not have the time or resources to research sustainable fashion brands or find similar items in sustainable stores.

Viability: The concept is viable as it can be implemented as a browser extension or an app that integrates with existing online fashion platforms. Sustainable fashion brands can also partner with the plug-in to increase their visibility and attract customers. The plug-in can generate revenue by charging a fee to brands that want to be featured.

Circularity: The plug-in can encourage the adoption of circular practices such as renting, swapping, or buying second-hand. It creates more awareness and informed-decision making.

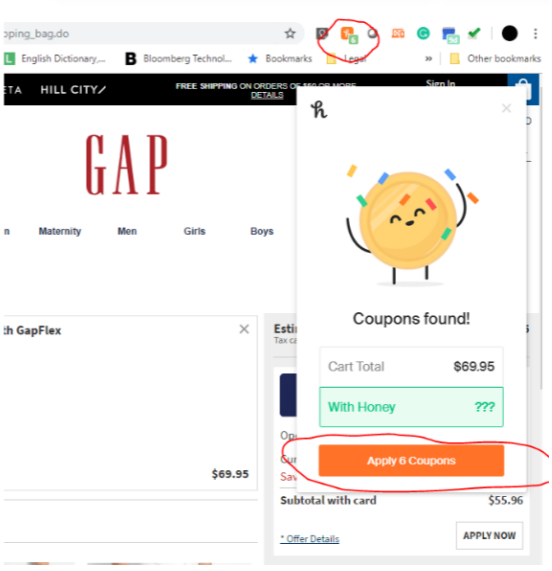


Figure 101: Honey plug-in, shows coupons

Converge 1: From 35 concepts to 3 concepts

Research goals

The goal is to converge these several ideas to the most promising ones. The idea is to diverge again from these most-promising concepts based on feedback generated from the first converging phase. The goal of the second converging phase is to go to 1 final concept. This will be build and tested in March and April.

It's important that the concepts are framed correctly and clearly to enhance further designing.

Research design

Ideas will be assessed based on the 4 main introduced parameters (feasibility, desirability, viability and circularity). One more parameters will be introduced and this is 'intuition'. Intuition in terms of business and product development refers to the ability to make decisions based on instinct, experience, and subjective judgment rather than relying solely on data and analysis. It involves tapping into one's inner knowledge and trusting one's gut feeling. Intuition is often used when making decisions under uncertainty or when there is incomplete information. While intuition can be a valuable tool in decision-making, it should be balanced with data-driven analysis to ensure the best possible outcomes. That's why the other parameters are taken into account to balance out this subjective parameter.

Rating the concepts will be done online, through Microsoft Teams, in a timeframe of 2h with the 3 original researchers of the study (Casper Van Herzele, Fatima Khitous, Francesca Ostuzzi). Fatima's input focus is mainly on business model development (viability) and circularity whilst Francesca's expertise lays within circularity and feasibility. A longer session was not possible due to agenda scheduling conflicts. Therefore, this meeting is in need of an efficient way of analyzing every concept. It's a limitation that no external experts where invited. In further data collection, outside perspectives will be taken into account.

The session started by explaining the purpose of this meeting. Then, the 5 parameters were explained and the rating system. After this, participants were informed about the 'voting mechanism'. Every concept will be quoted separately by every participant based on the 5 different parameters as mentioned previously. To facilitate a quick decision-making process, a 3 colored dot system will be used to score 5 parameters. Each colored dot represents a different meaning: green for safe and good ideas, orange for innovative but risky concepts, and red for ideas that are too risky. The purpose of this system is to enable a quick assessment of the ideas. In the context of this thesis, ideas with more green dots should be prioritized as they are more likely to succeed based on the 5 parameters, even though they

will still require further refinement and divergent thinking in the next phase. In contrast, ideas with lots of yellow/red dots are not necessarily bad, but will require more time and resources compared to green ideas. Furthermore, while green dot ideas are generally safer and more likely to succeed, it's important not to dismiss orange and red dot ideas outright. These ideas may be innovative and provide a competitive advantage, and should be carefully evaluated to determine if the risks are manageable. In some cases, taking a risk may be necessary to achieve the desired outcomes.

Figure 102: Meaning voting system

When the participants were briefed by the quoting system, 1 concept at a time was explained. After a concept was explained by the main researcher, each participant rated each concept based on the 5 parameters and there is room for explanation and feedback. This was all done on Miro.

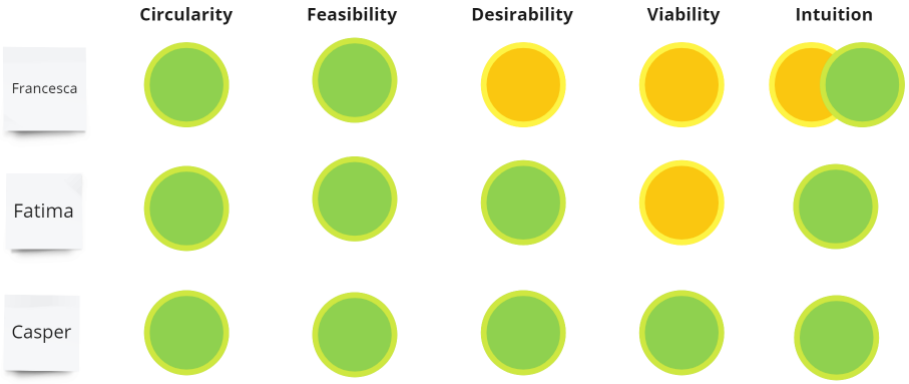


Figure 103: Example of rating system in-action

Data collection

Only 15 out of 32 concepts have been analyzed due to time constraint. Not every concept could be analyzed during the 2h time window. Because of this, only 10 concepts were quoted during the online meeting whilst 5 more concepts were rated afterwards. Selecting concepts during and after the meeting were based on

the intuition of the main researcher and their uniqueness (some had too similar traits).

Data analysis

Data analysis is done in Excel. The concepts can be categorized according to similar traits. For example, there are 4 concepts in total (C5, C9, C20 and C28) which build on the concept of designing a plug-in a web browser that helps customers make more informed decisions. Other categories included 'Designing fashion for PSS', 'Physical store', 'Digitizing fashion', 'Applications', 'Making hiring services more efficient', 'Other'.

The data will be analyzed through a weighted decision matrix. For every parameter (circularity, feasibility,…) the amount of times a green, orange or red dot was placed has been counted. Afterwards, the 5 parameters were weighted, meaning that not every parameter plays a significant role in the decision making. As a result, the results for parameter 'intuition' will remain the same whilst for the 4 other parameters, the number will be multiplied by 2 because they are the main parameters of this study. The equation below illustrates this.

$$Total\ Weighted = 2 * (Circularity + Feasibility + Desirabilty + Viability) + 1 * Intuition$$

The maximum amount 1 color can received through a weighted way, is 28. Ideas will be selected based on the ranking of the total amount of green votes because they are the safe and good ideas.

	Concept 1					
	Circularity	Feasibility	Desirability	Viability	Intuition	Weighted Amount
Green	3	2	1	0	2	14
Orange	0	1	2	2	1	11
Red	0	0	0	1	0	2

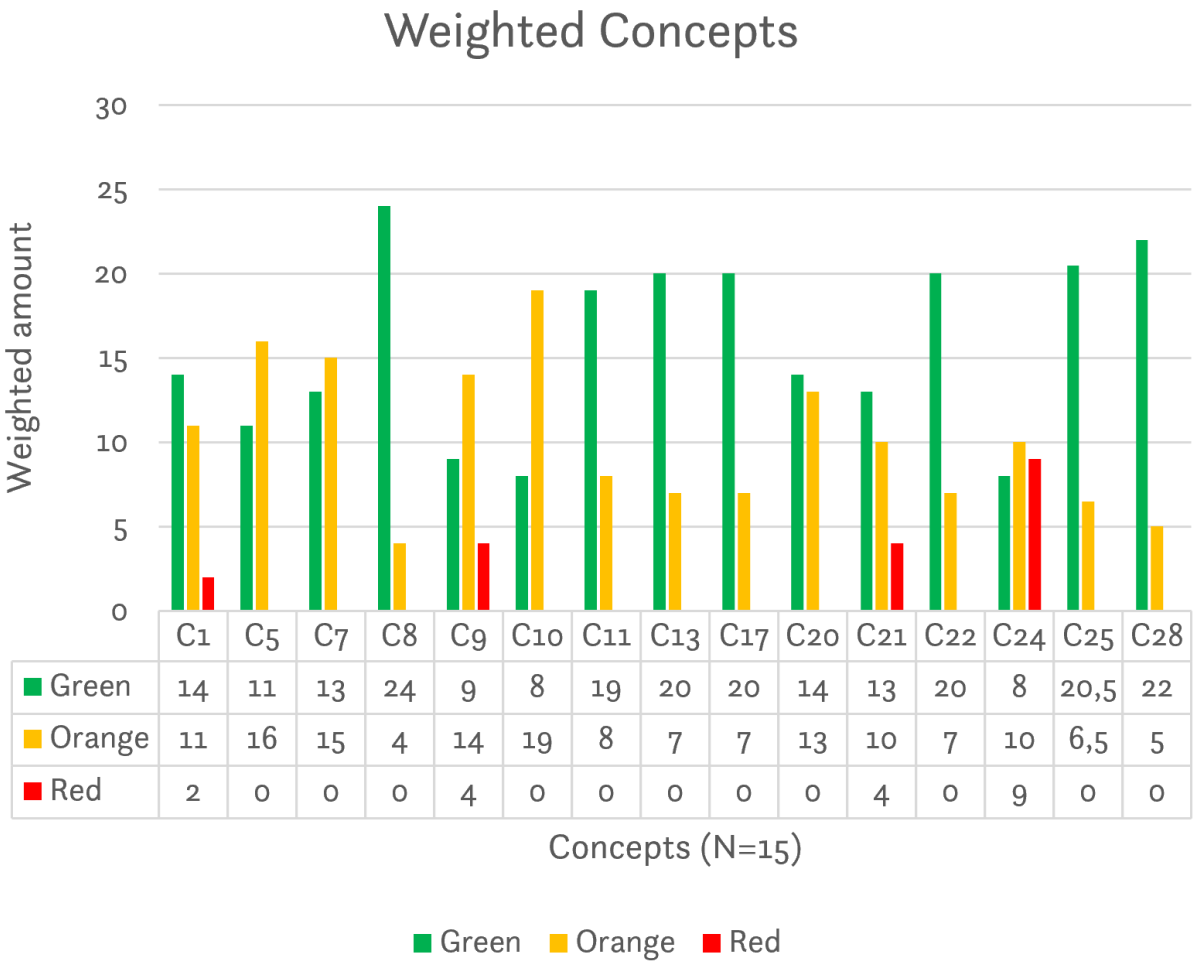
Figure 104: Example weighted matrix

This equation will be used for the 14 other concepts too. Also, sometimes, the participants couldn't agree if a rating was 'fully green' or 'fully orange, then they placed 2 dots. In data analysis, this was calculated as for example 0,5 green vote and 0,5 orange vote.

Results & implication

The ranking, based on the amount of green votes go as followed:

1. C8 (Green = 24/28)
2. C28 (Green = 22/28)
3. C25 (Green = 20,5/28)
4. C13, C17 and C22 (Green = 20/28)
5. C11 (Green = 19/28)



	C1	C5	C7	C8	C9	C10	C11	C13	C17	C20	C21	C22	C24	C25	C28
Green	14	11	13	24	9	8	19	20	20	14	13	20	8	20,5	22
Orange	11	16	15	4	14	19	8	7	7	13	10	7	10	6,5	5
Red	2	0	0	0	4	0	0	0	0	0	4	0	9	0	0

Figure 105: Weighted Concepts (N=15)

As mentioned previously, the concepts can be categorized in 5 categories.

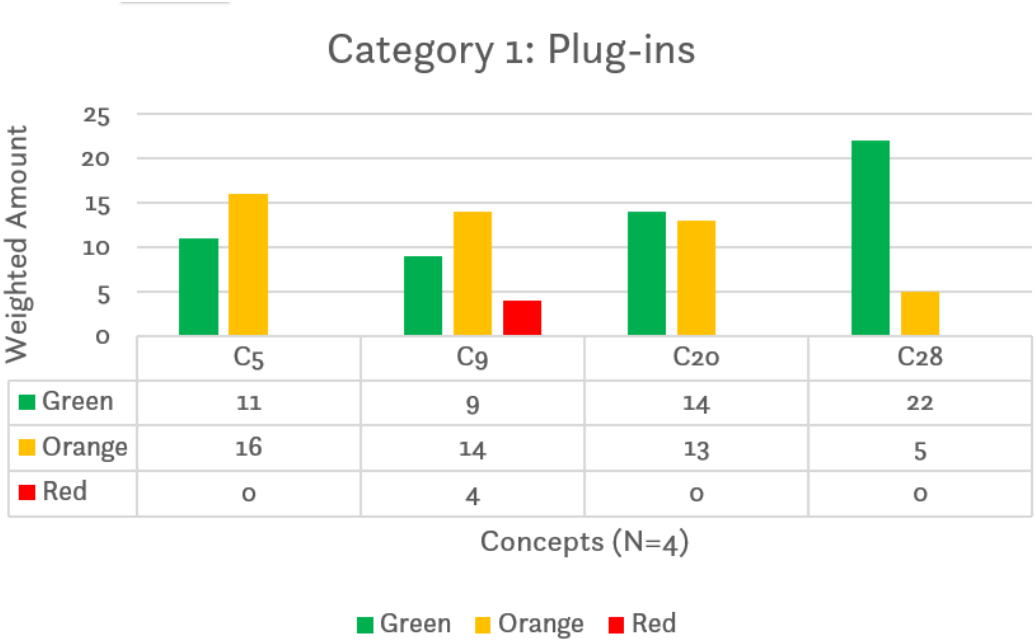


Figure 106: Category 1: Plug-ins

C28, a concept that shows more sustainable/circular alternatives, with the power of AI whenever they are shopping online, was received positively (22/28 green votes). Here, the question arose if this create possible rebound effects, where people will actually engage and buy more fashion. But approached effectively, this concept could enable consumers to more sustainable living. For example by making filter so consumers can search by rental service, or local production… Because of its potential and possibility to design, this concept will be further developed.

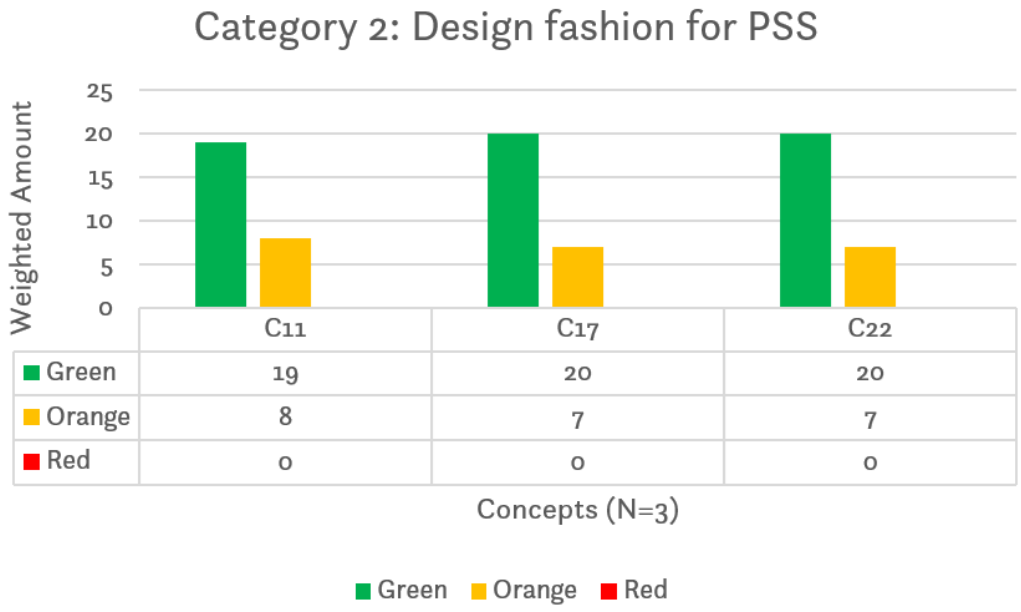


Figure 107: Category 2: Design Fashion for PSS

Starting with C11, designing fashion that is made to be hired and used in a PSS. Generally speaking, the participants were intrigued by the confirmed hypothesis that current fashion items are not designed with renting businesses in mind. Feedback included narrowing down to 1 specific product category like skiing equipment, or looking at specific parts of a product that needs modifications (share bike infrastructure in cities or Cambio). Another pathway that's possible within this concept, is to explore design parameters and frameworks for fashion designer who want to design rentable fashion. This could be the industry standard reference material/guide to design if they want to do some PSS with their fashion. As promising as these two ideas are, It has been decided to not elaborate on these ideas. This is because it will be time-consuming to find the right specific product to redesign and at this moment, this study has not been focusing on specific items, rather more on system. Also, the main researchers feels like to be more of a fashion designer, rather then an industrial designer working on this project. In the long term, when someone does not feel great on working on something, then they will be less motivated and dedicated working on a project.

C17, design of a PSS for men. Participants mentioned that looking at current male fashion influencers and their followers creates interesting opportunities regarding PSS. Here, the community of the influencers can be targeted. But the participants' main concern is that further designing could eventually lead to a non-sustainable PSS. Therefore, engaging customers through smart marketing is key asset of development. For example, looking at event-specific clothing such as parties or weddings and offering a fashion rental service aimed directly at men and those event has great potential. The reasons why this concept will discarded is because it heavily revolve on engaging customers through marketing. As a product designer, the focus lays on different aspects then pure marketing.

The last concept, C22, is the one with the second most green votes (22/28). This solution tackles the issue of changing company clothing. Feedback included that this concept can be extended to conferences, fairs, festivals. Here, the organization may produce merch every year related to the branding like tote bags, pens, notes,... Also, this concept may not relate too much tackling the fast fashion problem. Another reason why the future of this thesis will not focus on tackling this problem is because it may not be technical enough for an industrial designer to develop. There is potential in developing this concept but not as part of this research.

Overall, the 3 solutions within this categories all have rather high green scores compared to other categories. The reason behind this could be because the one

of the participants background are PSS and that studying existing PSS is part of this study.

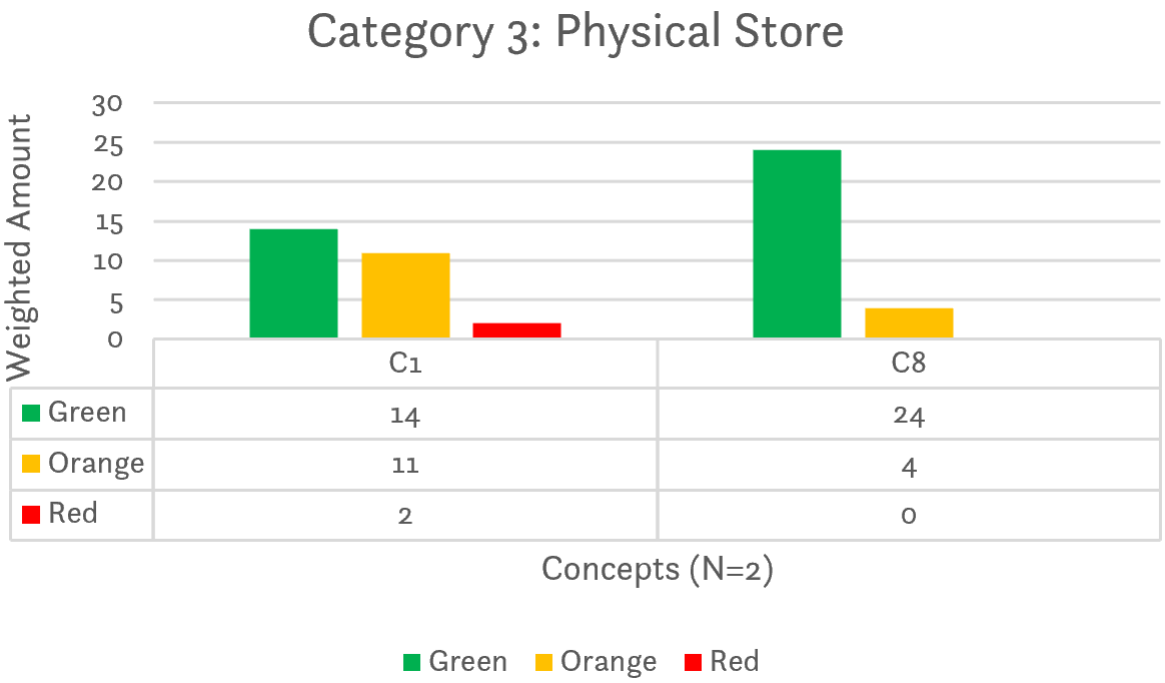


Figure 108: Category 3: Physical Store

C8, opening a pop-up store where everybody can place unworn items that are displayed for rent besides for sales is the concept with the most green votes (24/28). Generally speaking, the participants liked the seasonal aspect, as well as the circularity. There could be many reasons why someone does not use clothing anymore, for example when it's not their style anymore, grown out of it or want to try something new without buying something new. They liked the fact that it's still a physical store where people can go to and that customers, who temporarily donate clothing to this store are still owner which can overcome a possible barrier for sharing businesses. Because of this, C8 will be further developed besides C28.

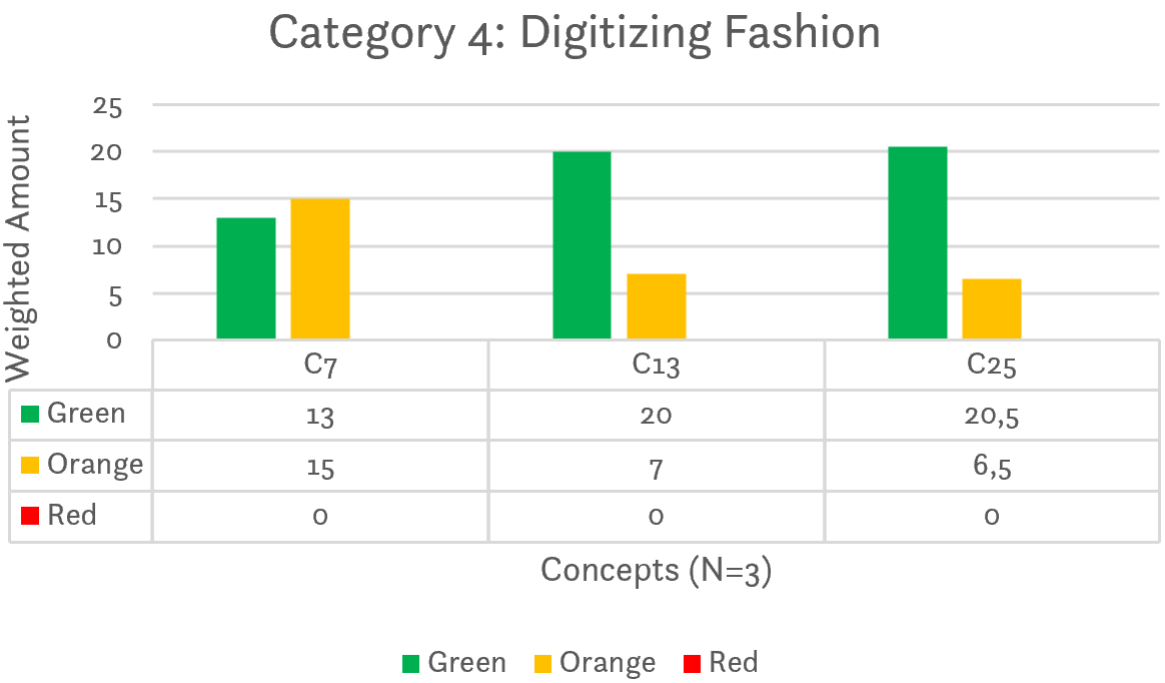


Figure 109: Category 4: Digitizing Fashion

C13 (green votes = 20/28) involves some opportunities within digitizing fashion. If digitization helps enabling circular consumption, then this this may be the road to go for. This concept can easily be combined with C25 (green votes = 20,5/28), where second-hand clothing will be distributed more efficiently. Here, participants liked the fact that a new value proposition was created, based on previous research. Therefore, digitizing fashion will be one of the concepts that will be further developed.

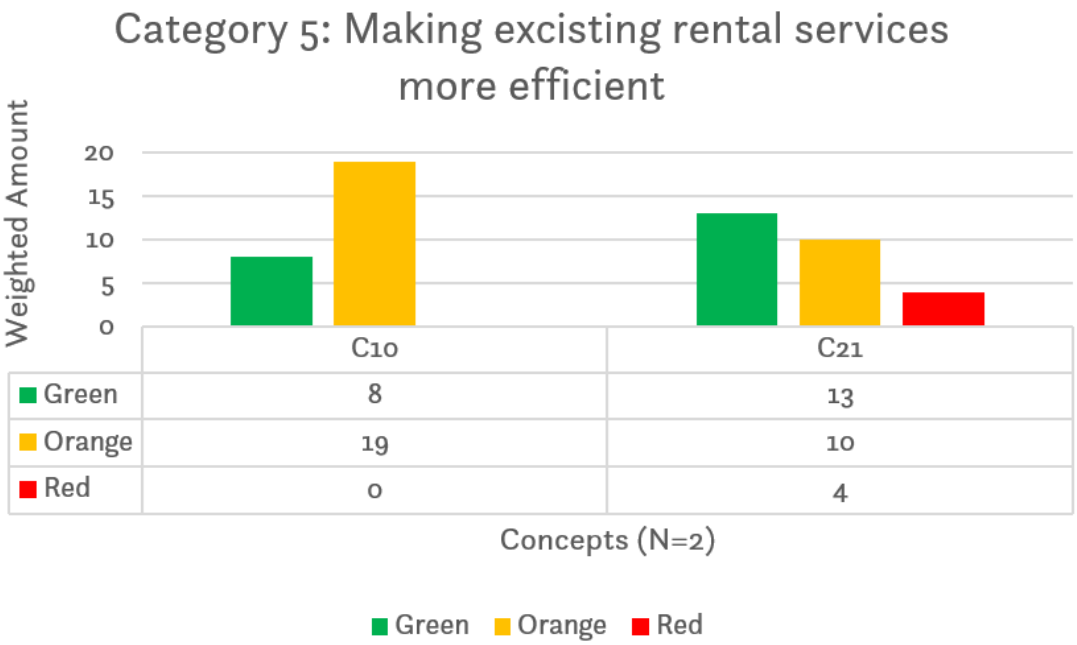


Figure 110: Category 5: Making existing rental services more efficient

After analyzing the results, 3 concepts will be further developed: C28, C8 and C13. These three concepts are vastly different from one another, where one focusses on developing a plug-in for web-browsers, another on digitizing fashion in a second-hand context and the last one by creating a new rental value proposition.

Reflection

<u>During the data collection:</u>

Participants where nicely surprised about the vast amount of concepts and the diversity between some of those. Because of this it took longer than expected to assess the concepts based on the 5 parameters. Therefore, the main researcher needed to already eliminate concepts that needed to be assessed. This means that not every concept has been analyzed because of time constraints.

Also, it would have been interesting to weight each of the participants votes too. For example, the main researcher's vote, who has been developing these concepts, could have been weighted too. For example, the two other participant's votes could have been multiplied by two whilst the main researcher's vote could have stayed the same.

Table 13: Reflection

	Expected	Unexpected
Positive	• The 3 colored dot method was a quick and intuitive way to analyze the concepts. Participants had an easy time understanding the meaning behind the three colors.	• The participants were familiar enough understanding the 5 criteria. This saved time so more resources could be used analyzing the concepts. • The participants were positively surprised about the diversity of the concepts.
Negative	• Not every concept could have been analyzed. The 2 hours were not enough to explore all the ideas. It was somewhat expected that not every concept could be covered. In total 15 out of 32 concepts have not been rated. • No other outside perspective from experts has been taken into account. The participants where fully involved within this thesis and this may have led to limited results.	• The participants expected a template. This was created during the session which took some time.

Define iteration 2

Based on the feedback and available time, the 3 concepts were further developed. For each (sub)concept, a drawing was made to further develop these concepts. This in a time period of 2 weeks.

Also, each concept will be analyzed through the desirability, viability, feasibility, and circularity parameter based on the current information. Not every input can be objectified yet, that's why a second converge phase will take place but more on that later.

Concept 1

A physical (pop-up) 'fashion experience' would be established where customers can voluntarily and temporarily donate their (seasonal, unused) fashion items for others to rent. Customers remain the owners of their garments and are financially rewarded when these are rented out. This reward can take the form of discounts for sustainable brands, vegan restaurants, or other environmentally-friendly options. Therefore, strong partnerships needs to be established for offering this reward. Compensation is a strategy in a sharing economy [12]. The goal is to guide and inspire customers to sustainable sources and away from (ultra-) fast fashion. By extending the use of garments, this idea promotes circularity. Customers are encouraged to adopt environmentally friendly practices, and the local community benefits from a shared wardrobe. A local scope is an important finding in the sharing economy [12]. This concept meets the need for access to a larger wardrobe without the commitment of purchasing items. It also appeals to customers who are environmentally-conscious and looking for a more sustainable option in their local area. Furthermore, it may create a sense of community and belonging to a sustainable movement.

The solution is a use-oriented PSS, just as fashion rental and peer-to-peer renting.

Feasibility: This concept is based on the sharing economy model [12] and requires resources to establish a physical pop-up shop.

Desirability: From the competitor analysis, 65,8% of customers surveyed would like to engage with fashion rental. Therefore, this concept could be desirable as it offers customers access to a larger wardrobe without committing to purchasing items, appeals to environmentally-conscious individuals, and promotes a sense of community and belonging.

Viability: The use of financial rewards can also incentivize customers to participate and promote the concept further. Additionally, the use of partnerships to provide rewards can make the concept financially sustainable.

Circularity: This concept promotes circularity by extending the lifespan of garments and encourages sustainable practices. Additionally, the local community benefits from a shared wardrobe, reducing waste and contributing to a circular economy.

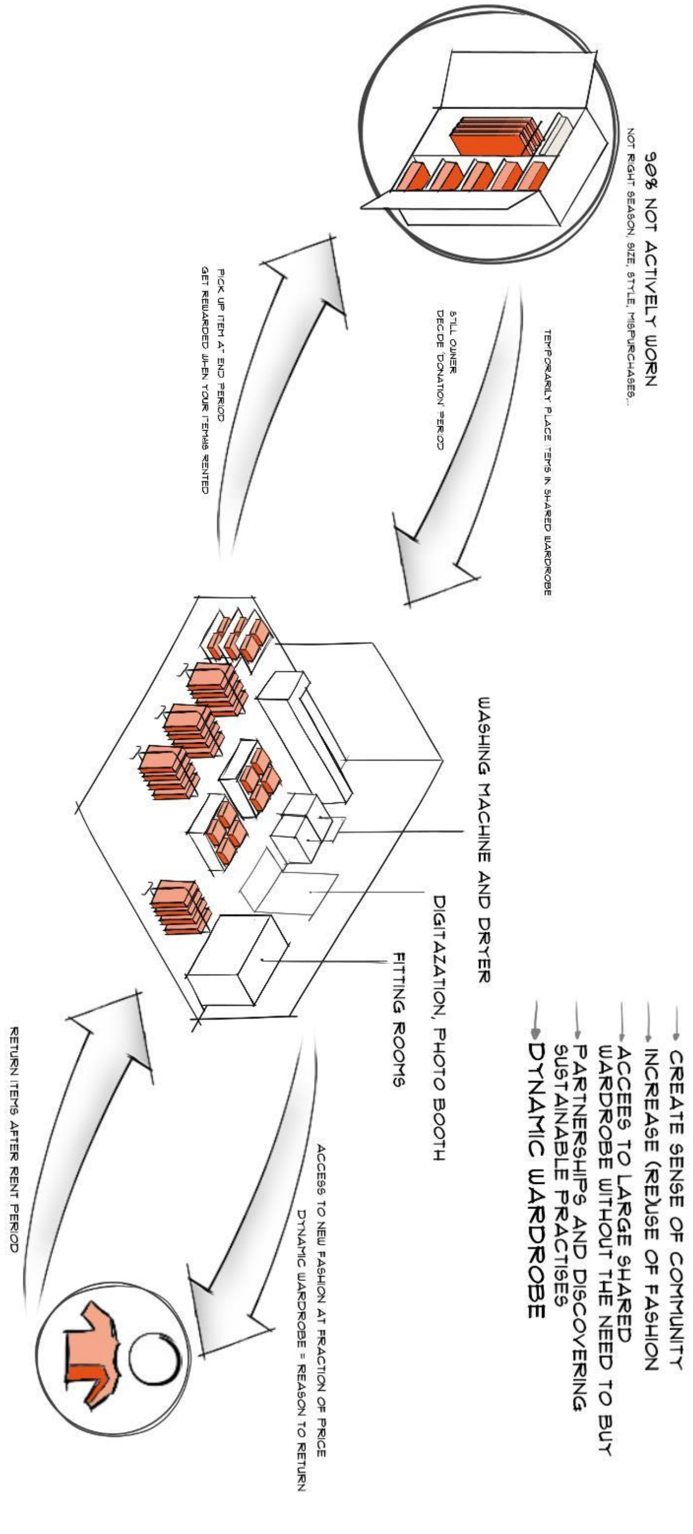


Figure 111: Concept drawing 1

Concept 2

This concept aims to streamline the distribution system of second-hand fashion chains by digitizing the new input and uploading it to a database. AI will smartly distribute the new input to existing thrift shops based on similar and/or the same items. This makes the shopping experience for customers more pleasant as there is a bigger chance the same item in different sizes are available which is now a weakness of second-hand shopping. Additionally, digitizing the input before distribution allows thrift shops to sell second-hand fashion items on a webstore, making the concept even more appealing to customers. Overall, the implementation of AI for existing thrift shops adds a layer of convenience and efficiency to the system. Here, the challenge would be to digitize all these items. Therefore, the developed solution would be focusing on that.

Feasibility: Digitizing the new input and uploading it to a database is technically feasible with the help of AI. However, the challenge of digitizing all the items would require a significant investment in time and resources.

Desirability: The concept could be desirable for customers as it streamlines the shopping experience by making it more convenient and efficient. From the SWOT, customers lack the variety in clothing options and sizes. Customers can easily find the same item in different sizes and can also shop online, which is a major convenience factor.

Viability: This idea adds a new value creation to existing thrift shops by making their inventory more accessible to customers. Additionally, the webstore feature could potentially increase sales for thrift shops, making it a financially viable option.

Circularity: The concept promotes circularity by making it easier for customers to access second-hand fashion and extending the lifespan of these items. It also encourages a shift towards a more sustainable and circular fashion industry.

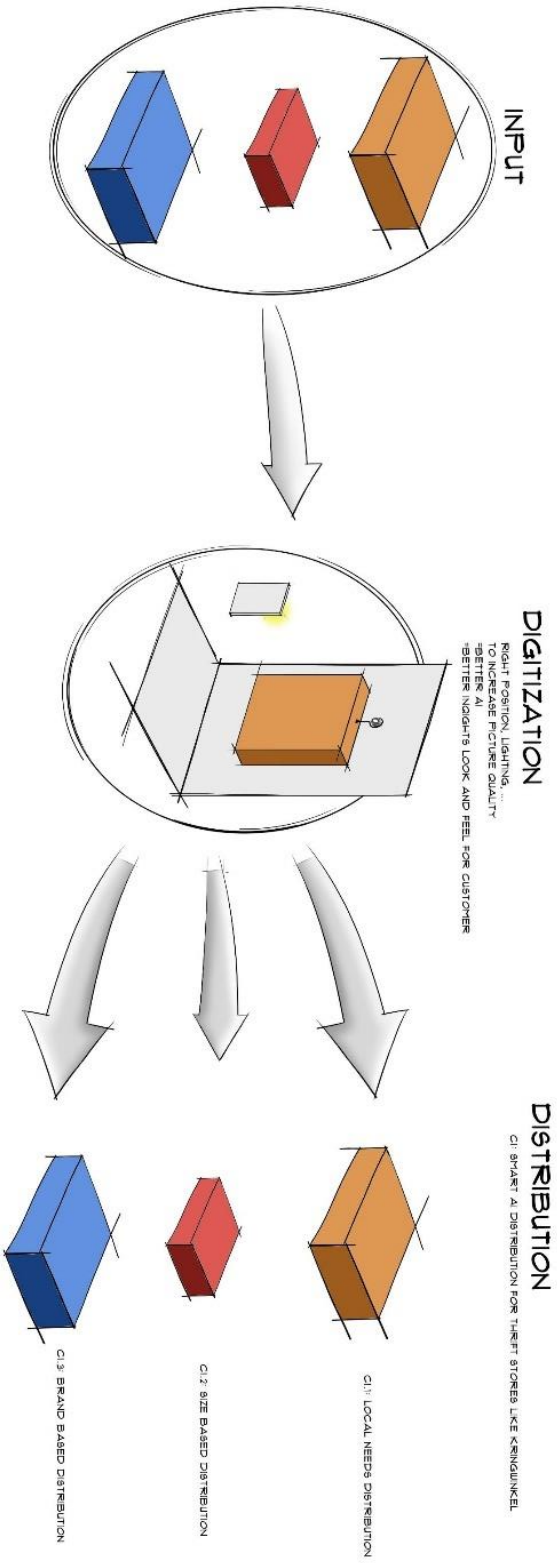


Figure 112: Concept drawing 2

This concept has sub-concepts too that were developed because of the opportunities digitization can bring.

C2a-c

Concept C2a-c is basically the previously explained idea but only focusing on distributing second-hand clothing according to size, brand, style and local needs.

C2d

Once second-hand clothing is digitized, customers can scan this information, by for example a QR code sewed in fashion, and access relevant information. For example, they saw a nice dress but it's too large, then they scan that QR code and the AI detects a similar dress but for example in another second-hand store or in a fashion rental place.

C2e,f

Here, the focus would be on the digitization process itself. Concept 2e focusses on creating a service that easily scans and digitizes items for second-hand stores. There is clearly a need for such solution by looking at the Kringwinkel (large Belgian second-hand chain) web shop.

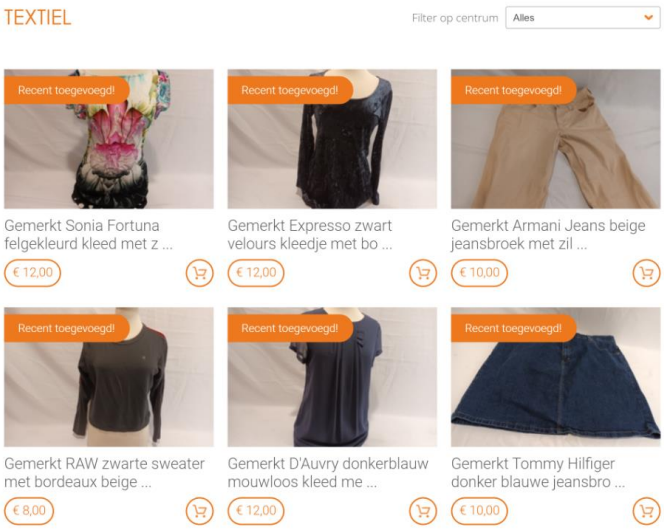


Figure 113: Digitization of second-hand clothing

Concept 2f focusses on creating the right tools for customers to digitize their own clothing.

C2g

This sub-concept only focusses on how to distribute these items, based on size and look or brand based. This idea may be a decentralized solution, where second-hand items come in the logistical center, are digitized and then distributed/sold to existing second-hand stores who are looking for specific items, sizes, look & feel, brands,...

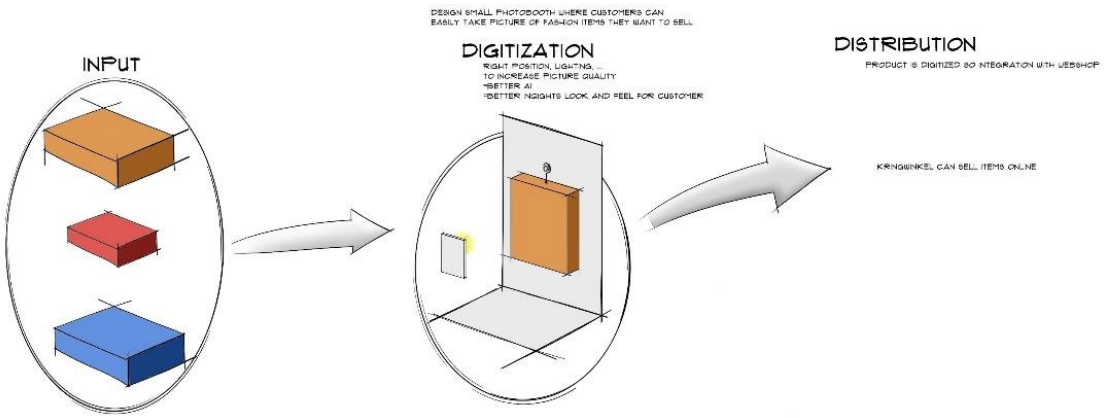


Figure 114: Concept C2g

C2h

Instead of people digitizing items themselves to sell on second-hand platforms such as Vinted or Facebook Marketplace, a new service digitizes I for them and is in charge of selling it. The original owner only needs to pay a small fee for it.

C2i

A problem second-hand shoppers have, is the lack of essential care instructions. Therefore, an AI app scans an item and the material and generates the proper wash and care instructions

C2j

Once second-hand items are digitized, it can be displayed on a screen in the store. It's an inventory of what's available in this store. With the introduction of AI, it can help customers find a similar item but for example in a different size or color in that store or another second-hand store of that brand.

Figure 115: Touchscreen displays store's inventory

Concept 3

This concept involves creating a plug-in for web browsers that helps customers find the most sustainable equivalent to non-sustainable (ultra-) fast fashion items they are interested in purchasing. The plug-in would use a database of sustainable fashion items, ranging from second-hand items, to local production and fashion rental. Using this tool makes it easier for customers to make informed decisions while online shopping. Furthermore, it is a tool for sustainable brands to reach a wider audience and to promote their products. By addressing these customer needs, this concept has the potential to be an effective tool in engaging consumers in the circular economy fashion movement.

Feasibility: This concept is highly feasible as it is relatively easy to create a plug-in for web browsers and integrate it with a database of sustainable fashion items. However, the challenge lies in the creation and maintenance of an up-to-date database of sustainable fashion items, as it requires continuous research and updating.

Desirability: It addresses the growing demand for sustainable fashion and helps consumers make informed decisions while online shopping. It also helps sustainable brands to reach a wider audience and promote their products, which can lead to increased sales and brand awareness.

Viability: It aligns with the goals of the circular economy and promotes responsible consumption. It has the potential to generate revenue through partnerships with sustainable fashion brands.

Circularity: The concept promotes circularity by encouraging consumers to choose sustainable fashion items over non-sustainable options. By increasing the demand for sustainable fashion, it can help reduce waste and the environmental impact of the fashion industry.

Figure 116: Concept 3: Plug-in

Converge 2:

Research goals

The goal from this phase is to eventually go to 1 final concept in a period from 2-3 weeks. This will be achieved by making a weighted distribution matrix of the (sub) concepts. Another goal is to introduce external experts in from this point on.

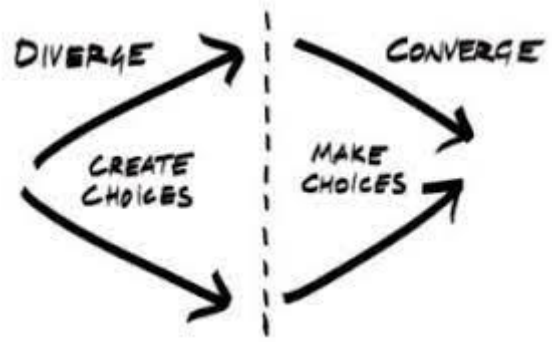


Figure 117: from 3 concepts --> subconcepts --> 1 final conept

Research design

From the first method, several lessons have been learned. The most important factor to take into account is to introduction and input of experts within the (Belgian) circular economy.

The most important factor whilst doing an interview, is to gather relevant data in a limited time. Not only is the reseracher's time limited, but also the expert's time. Therefore, a suggestion was made to the experts if they would like to have an interview or if they would like to give their opinion through a survey.

The different concepts will be analyzed and compared, based on a weighted distribution matrix. The same 5 parameters as the previous data collection is used, so the DVFC plus intuition framework.

Data collection

The interview process goes as followed. Firstly, the experts were e-mailed to ask their consent to participate in this research. If interested, they'll answer for their preferred way of giving their input, through a short survey or longer online/physical interview. In reality, no expert wanted to give their input through a survey so all the data has been collected through interviews. That's why there is no survey made.

The interview would take between 30-45min. It will go as followed:

1. GDPR form:
    a. The participants are asked to fill in a GDPR form.

2. Introduction of the researcher
    a. Here, the researches introduces himself and explains his background and the purpose of the education (industrial design engineering).
3. Introduction about the thesis: problem, research question, and briefly past work.
    a. The participant gets more background information about which work has been done in the past.
4. Explanation of the 5 parameters and the way how they will be rated. Now, the experts can give a score from 1 to 5 where 1 means “totally not agree” and 5 “totally agree”. In this phase of the interview, there is time for discussion and feedback.
    a. During in-person interviews, the sketched concepts where printed out as a visual representation. A template has been made in excel. Firstly, the experts were asked to rate the importance of each of the 5 parameters (DVCFI) on a scale from 1 to 5. Here, 5 means that this parameters is very important to the expert whereas 1 means the contrary. When a concept will be explained, the participants will be asked to rate each individual parameter from a score from 1 to 5. For example, when a concepts gets a score 5 on circularity, it means it involves full circularity. 1 means that it isn’t circular at all.
    b. The general weighted score is multiplied by the given score for each concept. This generates the specific weighted score for each parameter of each (sub)concept. The total score is generated when all the specific weighted scores are added up.
    c. Additional notes and more explanation of each concept will be written out in Microsoft Word.
5. Explanation of the 3 concepts and subconcepts and scoring each of the parameters.
6. Closure

Data analysis Interview 1: Circular economy expert 1:

Circular economy expert 1 has studied materials engineering, more specifically in metals. She has worked at Arcelor Metal for several years. Since January, she started working at the circular economy department at the city of Ghent. Now, her focus is on the buildings and how to make the waste streams circular.

The interview took part in the town hall of Ghent. Though there was a reservation made for a room, this was not available at the time. Therefore, we had to move to the a shared workplace where. This means that there was less privacy and more

distraction. For example, a speed dating session was taken place. As a result, the interviewing conditions where not ideal.

Table 14: Weighted parameter Circular economy expert 1

Criterea	Weighted
Feasibility	4
Viability	4
Desirability	5
Circularity	5
Intuition	3,5
Total score	**107,5**

Circular economy expert 1 was the most excited about the last concept, which also reflects in the highest intuition score. Generally speaking, there was no time to get feedback from every concept. Therefore, the goal was to get at least feedback and weighted scores for each main concept, then sub-concepts could be possible.

Feedback concept 1:

Her first remark was about repair and insurance. What happens if something breaks, doesn't return it or it needs to be repaired? These are the same questions customers have answered in the very first survey. But benchmarking the current state of rental fashion services conclude that these PSS can include some type of insurance. This means that, if the final concept would conclude the development of a an altered rental fashion service, this should be a priority.

Circular economy expert 1 was doubting the viability value of this idea. First of all, hiring a physical place is expensive and employing someone too. Secondly, a cost-benefit analysis should be made to better understand this parameter. For example, balancing out the financial reward for the added value of a fashion item is difficult to predict. It's difficult to predict if financial rewarding the user's input would increase the input of the shared wardrobe, and therefore make this wardrobe more interesting for people to use.

When talking about desirability, she saw more potential for renting out specific fashion items. An example she gave are formal outfits, dresses or suits people only wear for example weddings. This is in line with previous results.

Table 15: Total weighted score concept 1 Circular economy expert 1

Criterea	Weighted	C1 algemeen	
		Score	Weighted score
Feasibility	4	5	20
Viability	4	2	8
Desirability	5	3	15
Circularity	5	4	20
Intuition	3,5	2,5	8,75
Total score	**107,5**		**71,75**
			66,74%

Feedback concept 2:

a-c: Her main doubts with this concept is if the time and resources is beneficial in terms of viability and desirability. For her, it seems like a lot of work to not get a lot back.

d: If this input has been digitized and AI is introduced, she saw potential that users could go second-hand shopping more efficiently. Regarding circularity, she mentioned transporting items has an environmental impact too.

h: All the traffic would hold back the circularity. Her intuition would say that she would bring it to a Kringwinkel then engaging with this system.

Table 16: Total weighted scores concept 2 Circular economy expert 1

Criterea	Weighted	C2.a-c		C2.d		C2.ef		C2.g		C2.h		C2.i		C2.j	
		Score	Weighted score	Score	Weighted score	Score	Weighted score	Score	Weighted score	Score	Weighted	Score	Weighted	Score	Weighted score
Feasibility	4		0	4	16		0		0	4	16		0		0
Viability	4		0	2,5	10		0		0	2	8		0		0
Desirability	5		0	4	20		0		0	2	10		0		0
Circularity	5		0	3	15		0		0	2	10		0		0
Intuition	3,5		0	3	10,5		0		0	2	7		0		0
	107,5		0		71,5		0		0		51		0		0
					66,51%						47,44%				

Feedback concept 3:

When discussing this concept, Circular economy expert 1 came up with the idea where webshops could implement a new filter (besides size, color, material, …) that gives consumers recommendation what to buy. This can be done based on a simple questionnaire, previous personal fashion purchases, …

She also mentioned there is an opportunity to include filters within this plug-in according what's important to the user. For example a distance filter would benefit the transparency. Knowing where the distribution center is, how much CO2 is emitted will increase the needed informed decisions for the customer.

Table 17: Total weighted score concept 3 Circular economy expert 1

Criterea	Weighted	C3.a	
		Score	Weighted score
Feasibility	4	4	16
Viability	4	3,5	14
Desirability	5	3,5	17,5
Circularity	5	3,5	17,5
Intuition	3,5	4	14
	107,5		79
			73,49%

Generally speaking, she could better imagine the more well-defined concepts, C1 and C3. C2 (digitization) is more abstract and therefore, she had difficulties really understanding the concept and seeing the implications.

Data analysis Interview 2: Circular economy expert 2:

Circular economy expert 2 is an expert in the circular economy, but focusses more on the fashion industry. He's working on several circular initiatives such as supply-chain transparency, digital product passport for textile companies, created a tools library and opened a clothing upcycling lab.

For him, desirability gets the highest score because if desirability is high, then feasibility will become easier. This implies on for example the acceptance of new regulation and CBM's to stakeholders. The need for circularity needs to come from a demand in society, for example through regulation that will come in place.

Table 18: weighted parameter Circular economy expert 2

Criterea	Weighted
Feasibility	2
Viability	4
Desirability	5
Circularity	4
Intuition	3
Total score	**90**

Feedback concept 1:

This is a great concept if this store would acquire dead stock too. It's also a concept that more or less already exists. If this would be further developed and tested, there would be a chance that the final solution looks a lot like the current alternatives.

Table 19: Total weighted C1 Circular economy expert 2

Criterea	Weighted	C1 algemeen	
		Score	Weighted score
Feasibility	2	3,5	7
Viability	4	3	12
Desirability	5	4	20
Circularity	4	3,5	14
Intuition	3	3,5	10,5
Total score	**90**		**63,5**
			70,56%

Feedback concept 2:

A-c: This concept adds a new value proposition to existing second-hand stores like the Kringwinkel. If this concept is designed with increasing generally speaking sales in mind, then circularity is not achieved. Consumers should not be motivated to buy more, they should by responsibly.

J: Introducing such displays in stores is a mature technology, meaning that introducing this in second-hand stores would be not a huge problem. Studies have showcased that the introduction of such displays in fashion stores have increased sales by 4%, but this strategy does not align with circularity.

This concept would be possible once a new European legislation would be introduced from 2027, the so called Digital Product Passports (DPP). Spoiler alert, but this legislation will be explained in detail in the next chapters. But the key takeaways are that every garment on the European market should be equipped with a unique identifier, such as a QR code, RFID or NFC chip. This digital passport contains useful information that can be scanned by every stakeholder in the value chain.

Because of this legislation and this proposed idea, he came up with the idea to create a new kind of upcycle center or clothing 'experience', where instead of people going shopping to find new clothing, the bring their existing clothing to this experience. The DPP is scanned and possibilities are generated for what to do with this item. Maybe it is repaired or combined into something new someone can bring home. Maybe it taken back to the original manufacturer and repurposed into something new. This concept would solve the problem of textiles, whereas consumer throw it away or donate it too easily. Second-hand stores or recyclers need to invest a lot because the consumer itself is too lazy to repurpose clothing

themselves. That new 'experience' will be a meeting place that is focused around the key principles of a circular economy.

The DPP framework will be developed in the coming years. The final implementation will be in 2027 and estimated to be integrated in society from 2030. Whatever the solution would be, if this thesis would focus on developing solutions within the DPP context, then in the coming year, a valuable network with necessary stakeholders can be created. Viability wise, developing a DPP concept needs to be done smartly. For example, creating partnerships with existing platforms or fashion manufacturers to deliver valuable data can create value.

Because of this input, concept c2j has been quoted based on the possibilities a DPP can bring.

Table 20: Total weighted C2 Circular economy expert 2

Criterea	Weighted	C2.a-c		C2.d		C2.j	
		Score	Weighted score	Score	Weighted score	Score	Weighted score
Feasibility	2	4,5	9	4	8	3	6
Viability	4	3	12	2,5	10	3,5	20
Desirability	5	3	15	4	20	5	25
Circularity	4	2	8	3	12	5	20
Intuition	3	3	9	3	9	5	15
			53		59		86
			58,89%		65,56%		95,56%

Feedback concept 3:

Introducing a plug-in for existing platforms can be easily developed and implemented. He believes that this solution should be automated, and not manually activated by a consumer to achieve as much needed transparency as possible.

Table 21: Total weighted C3 Circular economy expert 2

Criterea	Weighted	C3.a	
		Score	Weighted score
Feasibility	2	4	8
Viability	4	4	16
Desirability	5	3	15
Circularity	4	3	12
Intuition	3	2	6
			57
			63,33%

Data analysis Interview 3: Circular economy expert 3

Circular economy expert 3 works for the city of Ghent for the economy department with a specialty in circular economy. He studied Biomedical engineering and Political Sciences. Now, he's focusing on cleantech, health tech, shipping and the port of Ghent. For him, it is important to think about a whole products lifecycle. For example, now homes are getting isolated but removing, reusing and recycling once it is at the end of the life-cycle will be hard because it has not be designed to be removed, reused,...

Feasibility is important, but not as important as other parameters. Transitioning is achievable through funding and legislation of the EU. For him, viability is the most important factor, possibly due to his position at the economy department.

Table 22: Weighted parameter Circular economy expert 3

Criterea	Weighted
Feasibility	3
Viability	5
Desirability	4
Circularity	4
Intuition	4
Total score	**100**

Feedback concept 1:

This concept's logistical costs will be high but is certainly feasible. It will be harder to create a viable business because it's a new and unknown service. It's important to focus on a target group desirability wise, for example the local scope or offering special occasion wear. This concept has a high chance to succeed in an urban context but then it's important to look at cultural factors too such as including hijabs in the collection too. This will affect desirability of the service.

Table 23: Total weighted C1 Circular economy expert 3

Criterea	Weighted	**C1 algemeen**	
		Score	Weighted s
Feasibility	3	5	15
Viability	5	3	15
Desirability	4	3	12
Circularity	4	2	8
Intuition	4	3	12
Total score	**100**		**62**
			62,00%

Feedback concept 2:

A: Feasibility wise, this concept is easily implementable. Social workers can be the operators who need to be educated, set-up digitization of garments and hand-in data to that item. In terms of viability, it's mostly manual labor but AI can be used to fill in other data such as the material and color. Based on circularity, this concept does not add much for a circular economy. It would be possible to create a successful business case around this concept.

J: This concept would be interesting if the software would be implemented as an application for smartphones. Then the investment of this touchscreen would be unnecessary. It's possible for consumers to convince buying second-hand clothing if this service would be in-place.

Table 24: Total weighted C2 Circular economy expert 3

Criterea	Weighted	C2.a-c		**C2.j**	
		Score	Weighted s	Score	Weighted s
Feasibility	3	5	15	3	9
Viability	5	2	10	4	15
Desirability	4	5	20	3	12
Circularity	4	3	12	3	12
Intuition	4	4	16	3	12
			73		60
			73,00%		60,00%

Feedback concept 3

Some companies may not want to grant access to data, therefore, partnerships with sustainable brands that do want to share data is needed. It has a high desirability score because consumer do want to engage with more sustainable clothing. It may be possible that legislation wise, this concept would be difficult to implement. Based on circularity, if this increases sales, then its not circular. If consumers are redirected towards for example fashion rental, then a more circular solution is created.

Table 25: Total weighted C3 Circular economy expert 3

Criterea	Weighted	C3.a	
		Score	Weighted s
Feasibility	3	3	9
Viability	5	5	25
Desirability	4	5	20
Circularity	4	2	8
Intuition	4	3	12
			74
			74,00%

Results & Implications

Three different circular economy experts rated several ideas based on desirability, viability, feasibility and intuition. In the total weighted distribution matrix below contributes every experts for the same amount. But 2 out of 3 experts' focus was not on the fashion industry. That's why this expert's opinion will weigh more than the other ones. When viewing the final distribution matrix, C2j is the highest scoring concept (M=77,78%, SD=25,14%). It's important to keep in mind that one of the experts rated this concept with DPP regulations in mind. The second highest scoring concept is C3 (M=70,27%, SD=6,02%).

Table 26: Weighted Distribution Matrix Iteration 2

		Max score	C1	%	M	SD
C1	Nele	107,5	71,75	66,74%		
	Jan	90	63,5	70,56%	66,43%	4,29%
	Wouter	100	62	62,00%		
		Max score	C2a-c			
C2	Nele	107,5				
	Jan	90	53	58,89%	65,94%	9,98%
	Wouter	100	73	73,00%		
		Max score	C2d			
	Nele	107,5	71,5	66,51%		
	Jan	90	59	65,56%	66,03%	0,68%
	Wouter	100				
		Max score	C2h			
	Nele	107,5	51	47,44%		
	Jan	90			47,44%	/
	Wouter	100				
		Max score	C2j			
	Nele	107,5				
	Jan	90	86	95,56%	**77,78%**	25,14%
	Wouter	100	60	60,00%		
		Max score	C3			
C2	Nele	107,5	79	73,49%		
	Jan	90	57	63,33%	70,27%	6,02%
	Wouter	100	74	74,00%		

Circular economy expert 2 believes in the possibilities DPPs will bring. Furthermore, some of the proposed concepts will be possible due to the implementation of DPPs. His solution has potential but it's not the challenge an industrial designer may want to solve. But this solution is a possible business case for the development of a DPP.

Upon analyzing the concepts from iteration 1 and 2, as well as previous research, a recurring theme is observed: digitization is always present and considered as part of the solution. Throughout the whole study, digitization has been received as not

feasible because the right knowledge was lacking. Thanks to the interview with Circular economy expert 2, it was clear that such solution could be framed in the upcoming DPP frameworks.

The best example is concept 21 of the first iteration “New label rentable fashion”, which was an idea that came because of the interview with a Belgian fashion renting platform. The company is currently testing a pilot project to sew QR codes into 100 rentable fashion items. The aim of adding DPP in fashion rental is to track it along the rental cycle and improve inventory management. However, sewing QR codes manually is time-consuming and not practical. Other solutions like NFC or RFID tags are more expensive. Therefore, they are looking for other DPP solutions for their rentable fashion. Although the goal was not to develop such concepts in detail in that phase, it’s clear that there is a need for such solutions within existing companies. The reason why such concept was not further developed in the next iteration, was because the DPP frameworks were missing.

Analyzing concept 2 from the second iteration creates several interesting reflection when viewing such concepts through a DPP lens. Firstly, Concept 2a-c could benefit from DPP as it would allow for more accurate tracking of the size, brand, and style of second-hand clothing. The distribution of second-hand clothing will happen more efficiently ones DPP’s are fully integrated. What misses in such context, is HOW it will be scanned. Thus meaning that operators should know what to scan, how to scan and know what to do according to such physical solution. By using DPP, thrift shops could more easily access information about the items they receive and distribute them more efficiently.

Concept 2d could also be enhanced by the use of DPP. In a DPP context, clothing will have for example a QR code with information about the garment's history and material composition, customers can access valuable information about the item they are interested in. This information could include washing and care instructions. What is lacking here, is making sure that this DPP will be accessible to second-hand consumers because often, labels and care instructions and therefore, also possible QR codes on labels, will be cut away or have faded away over time. Therefore, it is important that this data should be accessible at all cost throughout the whole supply chain so every actor within the value chain of DPP’s can access data.

Concepts 2e and 2f would greatly benefit from DPP’s, because it can be accepted that high-quality pictures of the original item will be put inside the DPP. This means that creating a solution to easily digitize items would become redundant once a DPP will be introduced.

Therefore, the implementation of DPP measurements creates a new direction for this study. The research will from now on explore what DPP's are, but also focusing on HOW it will be implemented in clothing, so looking at the physicality of the solution.

Reflection

During the interviews with experts, some concepts were more challenging to understand when the researcher explained them. Thankfully, the sketches were easy to understand and a must-have in this scenario. Also, experts had an easier time understanding concepts that were more tangible and concrete. This was the case for the sustainability plug-in (concept 3).

Appendix D: Life-cycle of clothing

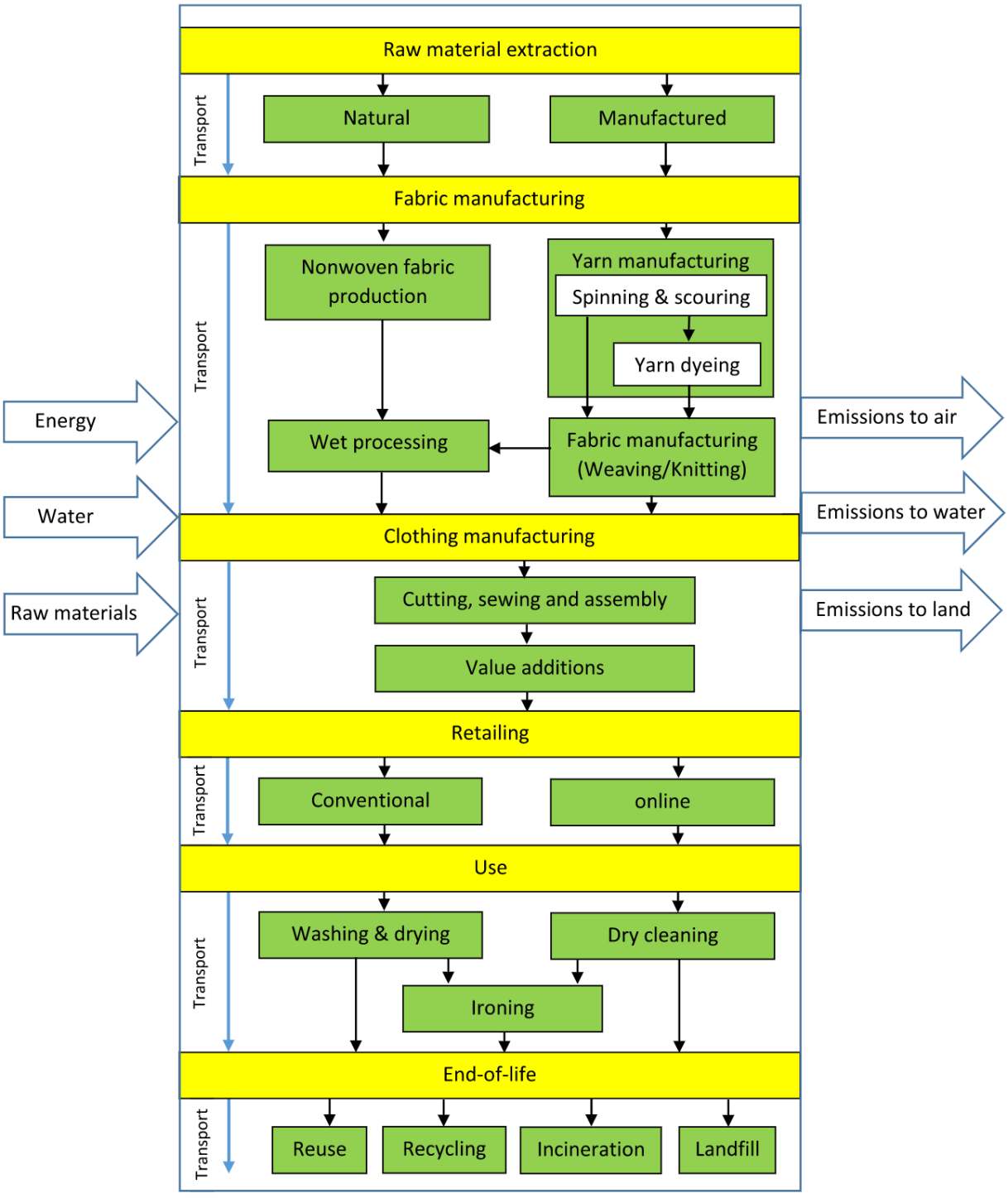


Figure 118: Life-cycle of clothing [29]

Appendix E: NFC

Choosing the right NFC tag

1. Compatibility
    a. DPP's should be scannable with an smartphone. NTAG or ICODE chips can be read by it.
2. Available memory
    a. As seen in the image below, the memory capacity of some common NFC chips will be too low to store relevant DPP information such as instruction manuals, replacement components with their up-to-date price,… Therefore the most suited way to display DPP information to customers are through an URL or serial number programmed on the chip. They contain mainly between 40-140 characters. For this application, NTAG210 and NTAG213 chips are suitable. Furthermore, tags with less memory are less expensive.
    b.

IC	Frequency	Memory	Protocol	Brand	Reading
TK4100	125Khz	64bit			1-10cm
T5577	125Khz	363bit		Temic	1-5cm
MIFARE 1K	13.56Mhz	1K byte	ISO14443A	NXP	1-5cm
MIFARE 4K	13.56Mhz	4K byte	ISO14443A	NXP	1-5cm
NTAG213	13.56Mhz	180byte	ISO14443A	NXP	1-5cm
NTAG215	13.56Mhz	540byte	ISO14443A	NXP	1-5cm
NTAG216	13.56Mhz	888byte	ISO14443A	NXP	1-5cm
Ultralight EV1	13.56Mhz	1024byte	ISO14443A	NXP	1-5cm
ICODE SLI	13.56Mhz	1024bits	ISO15693	NXP	5-20cm
ICODE SLIX	13.56Mhz	1024bits	ISO15693	NXP	5-20cm
DESFIRE EV1 4K	13.56Mhz	4K	ISO14443A	NXP	1-5cm
Higgs 3	840-960Mhz	512bit	GEN2 6C	NXP	3-4m
Monza 4D	840-960Mhz	512bit	GEN2 6C	NXP	3-4m

3. Encryption
    a. Certain NFC chips exist that can be encrypted so not everybody could scan it. If encryption needs to happen on the tag itself, then NTAG413 or MIFARE Ultralight C is suited. But data can be protected though other ways that are not locally coded on the tag itself. For example, tokenization or two-way authentication could be implemented.
4. Data retention
    a. NFC chips do not store data eternally and depend from chip to chip. For NTAG21X series, MIFARE chips, data retention is 10 years. Certain NFC tags' data retention is 25 years (MIFARE DESFIRE EV2), 50 years (ICODE SLIX, ICODE SLIX2, ICODE DNA) or even 200 years (ST25TA)
5. Read/write cycles
    a. Data on common NFC tags can be read or programmed up to 100 000 times. These tags include the NTAG21X series and ICODE series. Some chips go up to 1 million reads.
6. Password lock

    a. This means that a password should be known to rewrite the data, not to read it. This means they are still readable. NTAG21X series and ICODE SLIX2 chips supports this feature.
7. Tag positioning
    a. The most important factor whilst considering NFC/RFID in any application, is that no metal can be between the chip and the reader, otherwise, the tag is not readable. Tag positioning regarding DPP's is an important factor because it refers to the design requirements styling, versatility and ergonomics.
8. Size/reading distance
    a. The reading distance of a NFC chip depends on several factors [59]. The first one is the overall quality of the tag itself and the reader. The following factor is the interference of metal and electromagnetic signals may prohibit sufficient scanning. Therefore, the material surrounding the NFC should be chosen wisely so it doesn't insulate the magnetic field. The following factor is the reading distance designed by the NFC manufacturer and the last parameter is the size of the antennas. How smaller the tag, how the closer the reading device should be brought to scan the tag.
9. Hostile environments/extreme conditions
    a. This is yet another important design requirement. The NFC tag should be protected from these harsh environments to assure it doesn't break. It's also a possibility to design a casing for a NFC tag that can survive these conditions. NFC tags exist with an IP rating of 66, 67 or 68; survive in extreme temperatures up to 230ºC; weather resistance; resistance against shocks, vibrations, falls; liquids, sanitizing, corrosive liquids; resistance against industrial/domestic washing and ironing.
10. Application of the tag
    a. Stickers are the most common ones. Perforated exist too where a screw or nails can hold them in place. Other applications such as key rings, bracelets, ID badges, etc.

Material properties ABS and SPP

Omschrijving	Norm	Eenheid	Waarde
Treksterkte	DIN 53455	N/mm	75
Rek tot breuk	DIN 53455	%	3
E-Modulus	DIN 53457 (23 °C)	N/mm^2	3500
Buigsterkte	DIN 53452	N/mm^2	-
Slagsterkte	DIN 53453 (23 °C)	Charpy	-
Shore of kogeldruk hardheid	-	Shore °D	91
Wrijvingscoëfficiënt	-	-	-

Figure 119: Mechanical properties SPP

Omschrijving	Norm	Eenheid	Waarde
Treksterkte	DIN 53455	N/mm	41
Rek tot breuk	DIN 53455	%	45
E-Modulus	DIN 53457 (23 °C)	N/mm^2	2100
Buigsterkte	DIN 53452	N/mm^2	70
Slagsterkte	DIN 53453 (23 °C)	Charpy	37
Shore of kogeldruk hardheid	-	Shore °D	78
Wrijvingscoëfficiënt	-	-	0,6

Figure 120: Mechanical properties ABS

Appendix F: Data sheet PPS and 316L stainless steel

Stainless steel:

From:
https://www.matweb.com/search/DataSheet.aspx?MatGUID=1336be6d0c594b55afb5ca8bf1f3e042&ckck=1

Physical Properties	Metric	English	Comments
Density	8.00 g/cc	0.289 lb/in³	

Mechanical Properties	Metric	English	Comments
Hardness, Rockwell B	79	79	
Tensile Strength, Ultimate	560 MPa	81200 psi	
Tensile Strength, Yield	290 MPa	42100 psi	
Elongation at Break	50 %	50 %	in 50 mm
Tensile Modulus	193 GPa	28000 ksi	
Izod Impact	150 J @Temperature -195 °C	111 ft-lb @Temperature -319 °F	
	150 J @Temperature 21.0 °C	111 ft-lb @Temperature 69.8 °F	
Charpy Impact	103 J	76.0 ft-lb	V-notch, 30°C

Electrical Properties	Metric	English	Comments
Electrical Resistivity	0.0000740 ohm-cm	0.0000740 ohm-cm	at 20°C
Magnetic Permeability	1.008	1.008	at RT

Thermal Properties	Metric	English	Comments
Specific Heat Capacity	0.500 J/g-°C @Temperature 0.000 °C	0.120 BTU/lb-°F @Temperature 32.0 °F	
Thermal Conductivity	14.0 - 15.9 W/m-K	97.0 - 110 BTU-in/hr-ft²-°F	
Melting Point	1375 - 1400 °C	2507 - 2550 °F	
Solidus	1375 °C	2507 °F	
Liquidus	1400 °C	2550 °F	
Maximum Service Temperature, Air	870 °C	1600 °F	Intermittent
	925 °C	1700 °F	Continuous Service

Component Elements Properties	Metric	English	Comments
Carbon, C	<= 0.030 %	<= 0.030 %	
Chromium, Cr	16 - 18 %	16 - 18 %	
Iron, Fe	61.9 - 72 %	61.9 - 72 %	As Balance
Manganese, Mn	<= 2.0 %	<= 2.0 %	
Molybdenum, Mo	2.0 - 3.0 %	2.0 - 3.0 %	
Nickel, Ni	10 - 14 %	10 - 14 %	
Phosphorus, P	<= 0.045 %	<= 0.045 %	
Silicon, Si	<= 1.0 %	<= 1.0 %	
Sulfur, S	<= 0.030 %	<= 0.030 %	

Figure 121: Material properties of stainless steel

PPS:

Technical Data Sheet

Ryton® R-4-02

polyphenylene sulfide

Ryton® R-4 and R-4-02 40% glass fiber reinforced polyphenylene sulfide compounds provide a good combination of mechanical and electrical properties with outstanding chemical resistance, even at elevated temperatures.

General		
Material Status	• Commercial: Active	
Availability	• Asia Pacific • Europe	• Latin America • North America
Filler / Reinforcement	• Glass Fiber, 40% Filler by Weight	
Features	• Chemical Resistant	• Good Electrical Properties
Uses	• Automotive Applications	
RoHS Compliance	• RoHS Compliant	
Automotive Specifications	• FORD ESF-M4D388-A3	
Appearance	• Black	
Forms	• Pellets	
Processing Method	• Injection Molding	

Physical	Typical Value	Unit	Test method
Density / Specific Gravity	1.69		ASTM D792
Molding Shrinkage			
Flow : 3.20 mm	0.20	%	
Across Flow : 3.20 mm	0.50	%	
Water Absorption (24 hr, 23°C)	0.020	%	ASTM D570

Mechanical	Typical Value	Unit	Test method
Tensile Strength			
--	152	MPa	ASTM D638
--	140	MPa	ISO 527-2
Tensile Elongation			
Break	1.1	%	ASTM D638
Break	1.0	%	ISO 527-2
Flexural Modulus			
--	14500	MPa	ASTM D790
--	14000	MPa	ISO 178
Flexural Strength			
--	207	MPa	ASTM D790
--	200	MPa	ISO 178
Compressive Strength	270	MPa	ASTM D695
Poisson's Ratio	0.38		

Impact	Typical Value	Unit	Test method
Notched Izod Impact			
3.18 mm	80	J/m	ASTM D256
--	8.0	kJ/m²	ISO 180/A
Unnotched Izod Impact			
3.18 mm	350	J/m	ASTM D4812
--	20	kJ/m²	ISO 180

Hardness	Typical Value	Unit	Test method
Rockwell Hardness			ASTM D785
M-Scale	104		
R-Scale	122		

Thermal	Typical Value	Unit	Test method
Deflection Temperature Under Load			ASTM D648
1.8 MPa, Unannealed	265	°C	
CLTE			ASTM E831
Flow : -50 to 50°C	2.0E-5	cm/cm/°C	
Flow : 100 to 200°C	1.5E-5	cm/cm/°C	
Transverse : -50 to 50°C	4.0E-5	cm/cm/°C	
Transverse : 100 to 200°C	8.0E-5	cm/cm/°C	
Thermal Conductivity	0.32	W/m/K	
UL Temperature Rating	200 to 220	°C	UL 746B

Electrical	Typical Value	Unit	Test method
Surface Resistivity	1.0E+16	ohms	ASTM D257
Volume Resistivity	1.0E+16	ohms·cm	ASTM D257
Dielectric Strength	20	kV/mm	ASTM D149
Dielectric Constant			ASTM D150
25°C, 1 kHz	3.90		
25°C, 1 MHz	3.80		
Dissipation Factor			ASTM D150
25°C, 1 kHz	2.0E-3		
25°C, 1 MHz	2.0E-3		
Arc Resistance	125	sec	ASTM D495
Comparative Tracking Index (CTI)	PLC 4		UL 746A
Comparative Tracking Index	175	V	IEC 60112
Insulation Resistance [1] (90°C)	1.0E+11	ohms	

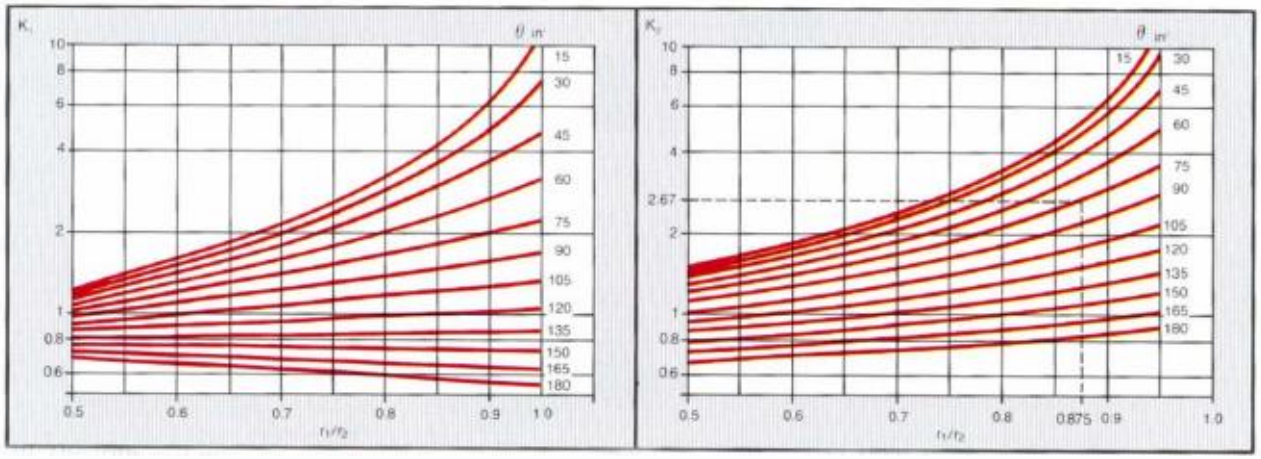
Appendix G: Snap joints parameters

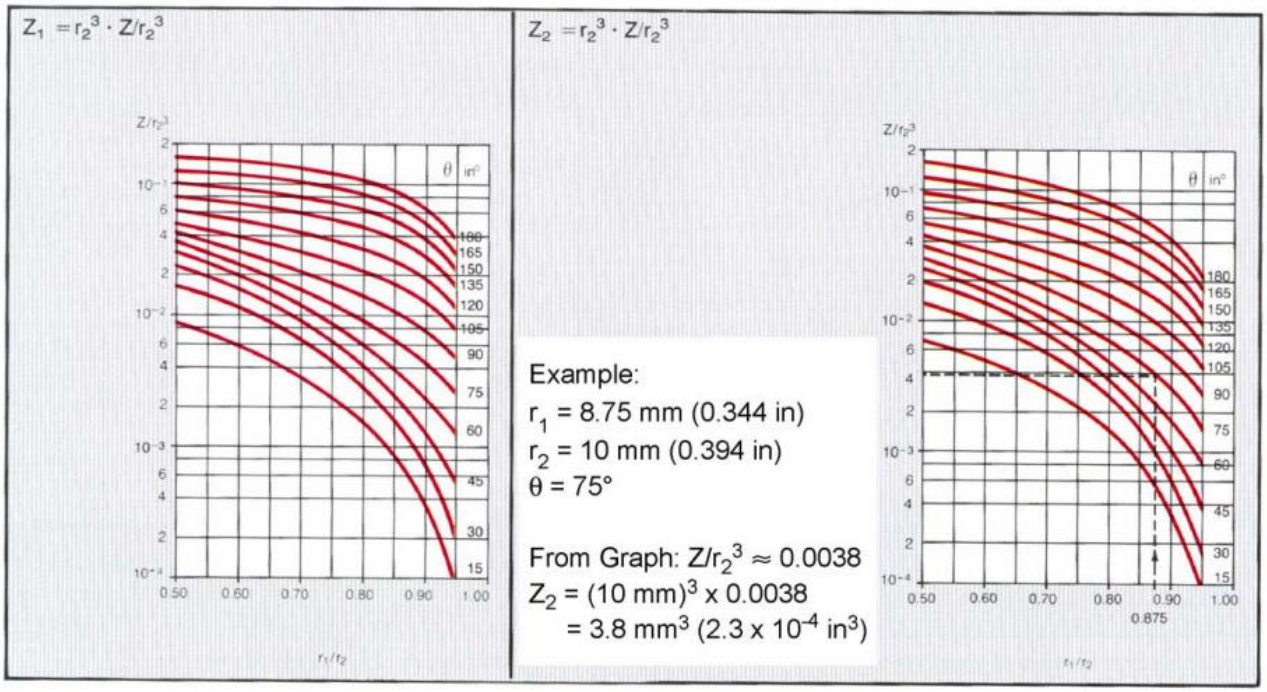
All information, formulas and graph are from [72]

Table 27: Snap joint formulas

Type of design \ Shape of the cross section	A Rectangle	B Trapezoid	C Ring segment	D Irregular cross section
(Permissible) deflection 1 Cross section constant Over the length	$y = 0.67 \cdot \frac{\varepsilon \cdot l^2}{h}$	$y = \frac{a + b_{(1)}}{2a + b} \cdot \frac{\varepsilon \cdot l^2}{h}$	$y = K_{(2)} \frac{\varepsilon \cdot l^2}{r_2}$	$y = \frac{1}{3} \cdot \frac{\varepsilon \cdot l^2}{c_{(2)}}$
(Permissible) deflection 2 All dimensions in direction y, e.g., h or Δr, decrease to One-half	$y = 1.09 \cdot \frac{\varepsilon \cdot l^2}{h}$	$y = 1.64 \cdot \frac{a + b_{(1)}}{2a + b} \cdot \frac{\varepsilon \cdot l^2}{h}$	$y = 1.64 \cdot K_{(2)} \cdot \frac{\varepsilon \cdot l^2}{r_2}$	$y = 0.55 \cdot \frac{\varepsilon \cdot l^2}{c_2}$
(Permissible) deflection 3 All dimensions in direction z, e.g., b and a, decrease to one-quarter	$y = 0.86 \cdot \frac{\varepsilon \cdot l^2}{h}$	$y = 1.28 \frac{a + b_{(1)}}{2a + b} \cdot \frac{\varepsilon \cdot l^2}{h}$	$y = 1.28 \cdot K_{(2)} \cdot \frac{\varepsilon \cdot l^2}{r_2}$	$y = 0.43 \cdot \frac{\varepsilon \cdot l^2}{c_{(2)}}$
Deflection force 1,2,3	$P = \overbrace{\frac{bh^2}{6}}^{Z} \cdot \frac{E_s \varepsilon}{l}$	$P = \overbrace{\frac{h^2}{12} \cdot \frac{a^2 + 4ab_{(1)} + b^2}{2a + b}}^{Z} \cdot \frac{E_s \varepsilon}{l}$	$P = Z_{(4)} \cdot \frac{E_s \varepsilon}{l}$	$P = Z_{(4)} \cdot \frac{E_s \varepsilon}{l}$
Subscript numbers in parenthesis designate the note to refer to.				

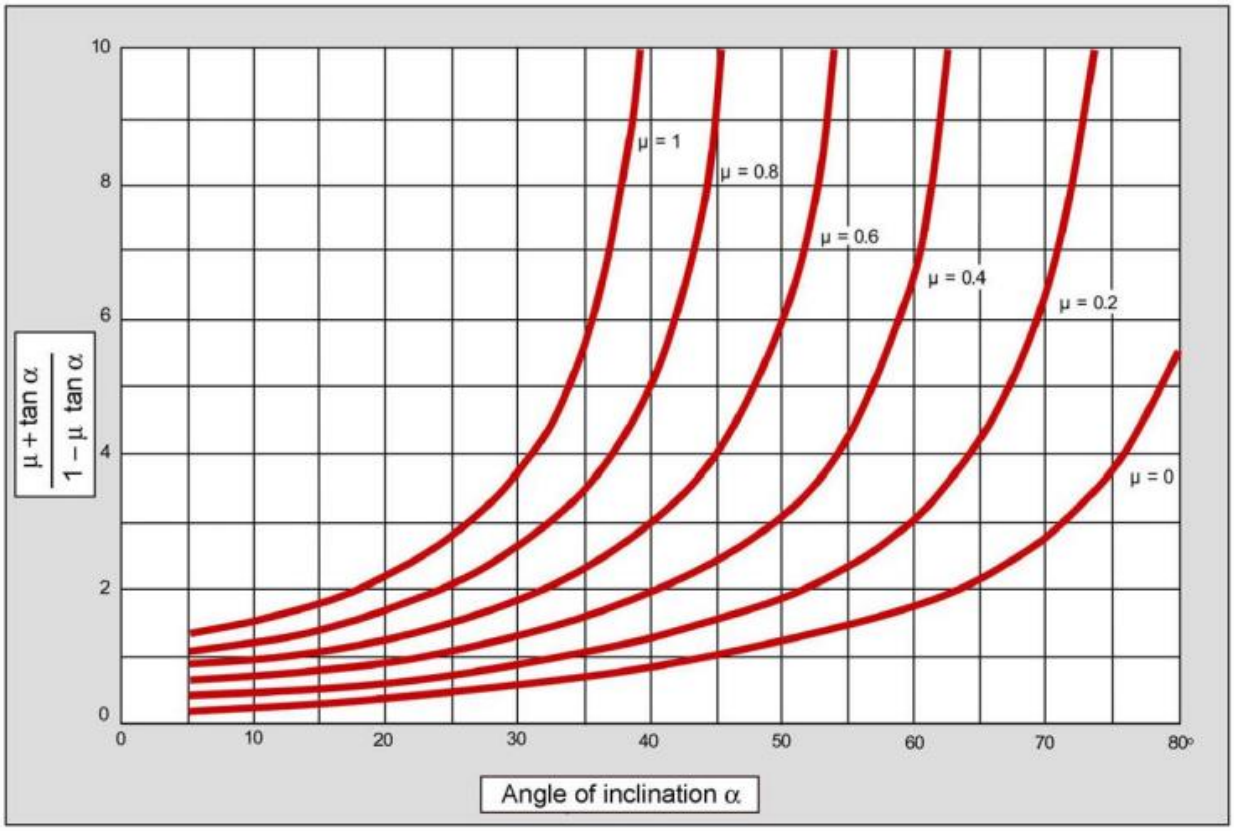
- y = permissible deflection
- b = width at root
- c = center of gravity (i.e., distance between outer fiber and neutral fiber)
- E as absolute value = percentage/100
- E = permissible strain in the outer fiber at the root
- l = length of arm
- K = geometric factor
- h = thickness at root
- Es = secant modulus
- P = permissible deflection force
- Z = section modulus
- Z = I c; where I = axial moment of inertia





Mating & separation force:

$$W = P \bullet \tan(\alpha + p) = P \frac{\mu + \tan\alpha}{1 - \mu \tan\alpha}$$


10
8
6
4
2
0
0
10
20
30
40
50
60
70
80°
μ = 1
μ = 0.8
μ = 0.6
μ = 0.4
μ = 0.2
μ = 0
$\frac{\mu + \tan \alpha}{1 - \mu \tan \alpha}$
Angle of inclination α

Appendix H: Styling

SPI finishes from [78]

Appendix I: Bill of Materials (BOM)

From Protolabs (United States)

Total price inside:

Part price inside:

Total price outside:

Part price outside:

Appendix J: Data collection

Survey itself

Default Question Block

Mijn naam is Casper Van Herzele en ik ben momenteel bezig met het afronden van mijn thesis. Hierin heb ik gezocht naar oplossingen om de impact van de kledingindustrie op onze planeet te verminderen. Ik zou het enorm waarderen als je de tijd zou willen nemen om mijn uitleg goed door te lezen en de vragen eerlijk te beantwoorden. Het invullen van de vragenlijst duurt ongeveer 15 minuten en het is van groot belang om de concepten en uitleg goed te begrijpen.

Ik wil je graag verzekeren dat alle informatie die je verstrekt vertrouwelijk zal worden behandeld. Alvast hartelijk bedankt voor je medewerking!

Met vriendelijke groeten,
Casper

Current behavior

(Deel 1/4) Beantwoord volgende vragen. Deze gaan over je huidige modeconsumptie.

	1: Helemaal van niet	2: Meestal niet	3: Noch ja, noch neen	4: Meestal wel	5: Helemaal van wel
Mijn aankoopproces van nieuwe kledij wordt beïnvloed door bijvoorbeeld waar het geproduceerd is, door wie, in welke omstandigheden,...	○	○	○	○	○
Ik koop tweedehands kledij	○	○	○	○	○
Ik verkoop kledij	○	○	○	○	○
Ik huur kledij	○	○	○	○	○
Ik repareer kledij zelf	○	○	○	○	○
Ik laat kledij repareren door iemand anders	○	○	○	○	○
Ik vergelijk kledij tijdens het kledingshoppen op basis van duurzaamheid	○	○	○	○	○
Ik vind een label in kledij, met wasinstructies, de merknaam, de maat, en waar het geproduceerd wordt, nuttig	○	○	○	○	○

Introductie DPP

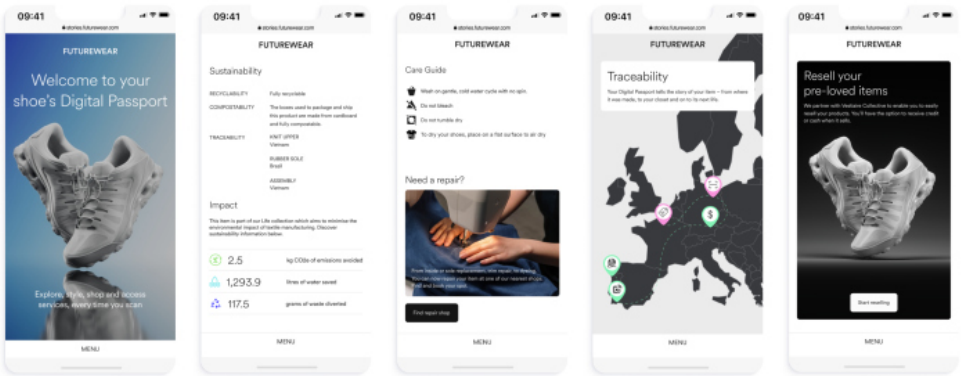
Een **Digital Product Passport (DPP)** is als een ingrediëntenlabel voor producten. Het bevat informatie over de duurzaamheid en de productieprocessen van o.a. kledij (wat hier van belang is). Dit helpt consumenten om geïnformeerde beslissingen te nemen over de producten die ze kopen en merken te kiezen die in lijn liggen met hun waarden omtrent o.a. duurzaamheid. DPP's kunnen ook helpen om greenwashing te identificeren, de productwaarde te beschermen (welk product is echt of vervalst), de ecologische voetafdruk van een product te achterhalen en recyclage-info raadplegen. Door transparantie te bieden over de duurzaamheid van een product kunnen merken het vertrouwen van hun klanten opbouwen en een positieve reputatie in de markt vestigen.
Door de introductie van een DPP zullen kledingbedrijven dichter bij hun klanten kunnen staan. Ze kunnen hieraan ook extra services koppelen zoals het aanbieden van correcte reparatieonderdelen, bijvoorbeeld schoenzolen, knopen, garen, ...

Consumenten kunnen een DPP scannen door middel van een QR-code (aangebracht in kledij) of door hun smartphone tegen een speciaal ontworpen tag te houden (NFC tag).

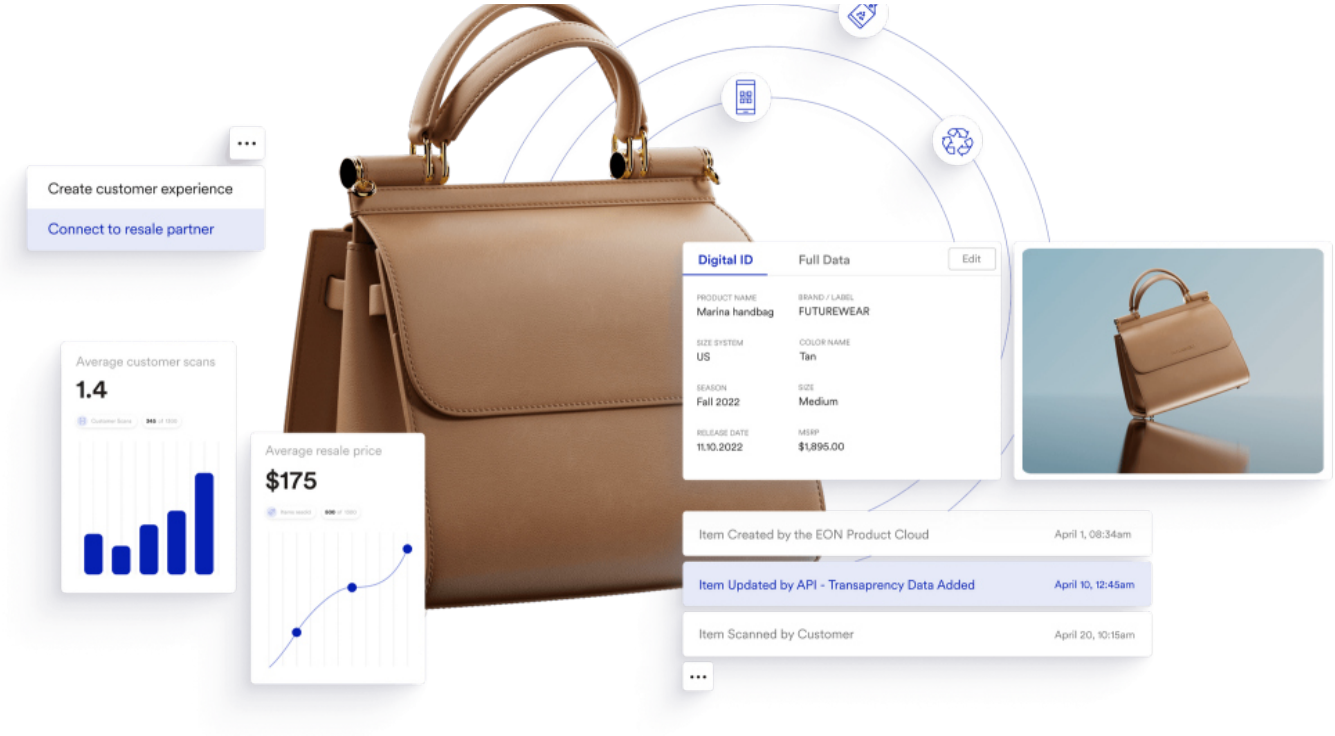
Het is belangrijk dat de DPP niet enkel toegankelijk is voor consumenten, maar ook voor recylagecentra. Dankzij DPP's kunnen ze achterhalen wat de exacte materialensamenstelling is om zo een efficiëntere recyclage te garanderen. Ook moeten bepaalde stakeholders, zoals kledingherstellers of tweedehandswinkels bepaalde data kunnen aflezen en toevoegen, bijvoorbeeld om zo correcte vervangstoffen te vinden bij de reparatie of hergebruik ervan. Daarom is het belangrijk dat deze tag garantie biedt dat het **leesbaar** blijft doorheen de hele levenscyclus van een kledingstuk.

Fun fact: DPP's gaan geïntroduceerd worden vanaf 2027 en worden op dit ogenblik vastgelegd door de Europese Commissie.

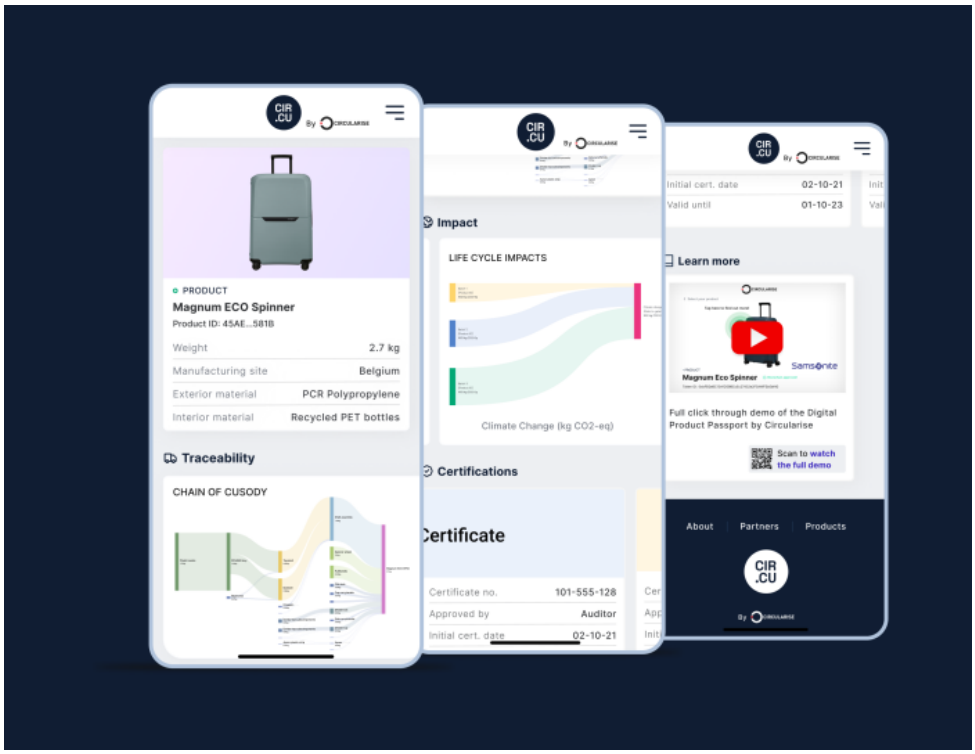
Voorbeeld van een DPP voor schoenen:



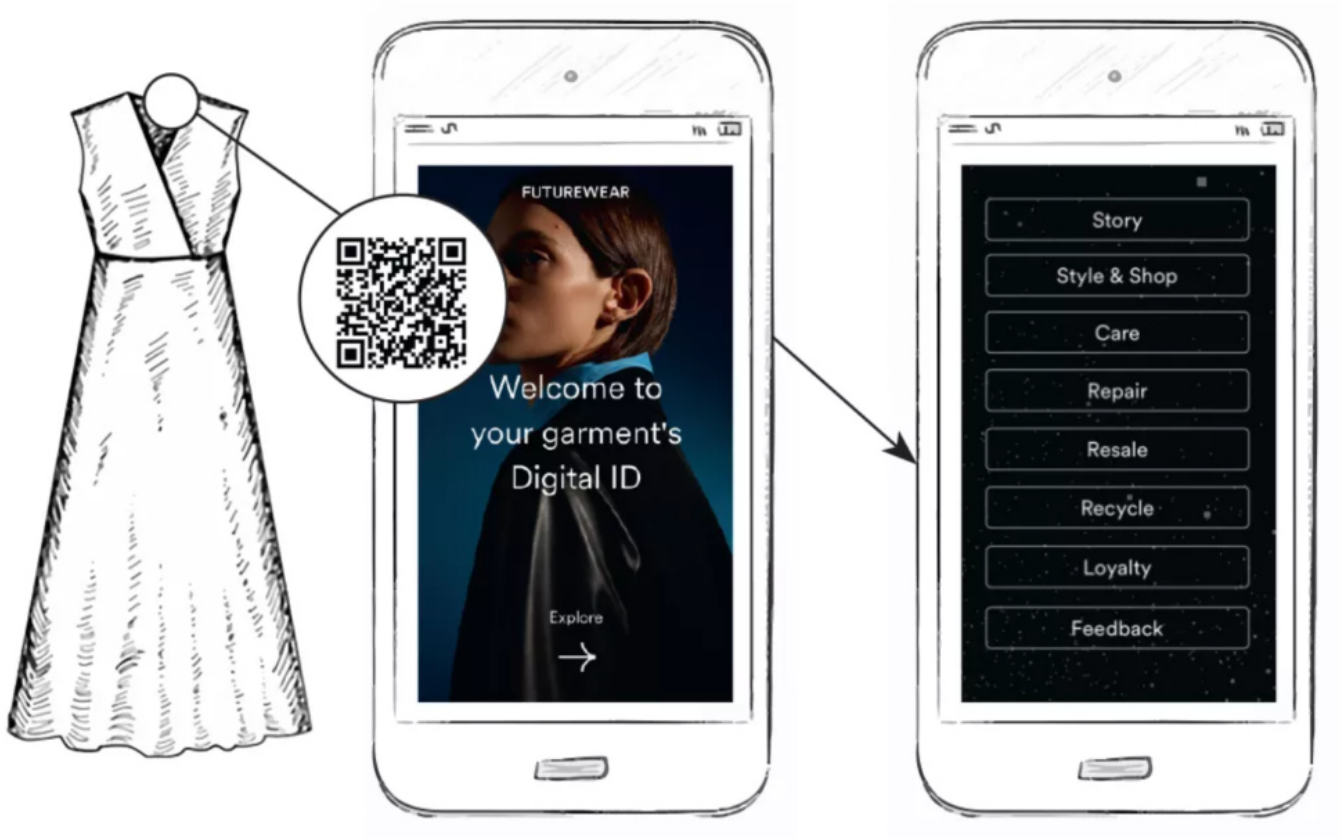
Voorbeeld van een DPP voor een handtas:



Voorbeeld van een DPP voor een koffer:



Voorbeeld van hoe je een DPP kan scannen:



This is what a garment's digital ID looks like. You can find it on the tag of your item (if it was produced by a brand that uses the technology).

A scan of the QR code with your phone will take you to a microsite with various resources, including care instructions, styling tips, and nearby repair shops.

Eisen DPP

Tijdens mijn thesis heb ik me gefocust op de fysieke uitwerking ervan, dus zekerheid kunnen bieden dat data leesbaar blijft doorheen de hele levenscyclus van kledij (van productie tot verkoop, van gebruik tot recyclage,...) alsook op welke manier je een Digital Product Passport (DPP) als consument kunt gaan scannen. Denk maar bijvoorbeeld aan een QR code in een label verwerken of een NFC tag.
Iedere moderne smartphone kan NFC lezen en deze technologie wordt veel gebruikt in bijvoorbeeld batches voor hotelkamers, OV-chipkaarten en bankkaarten.

Concept 1

(Deel 2/4) Concept 1: Met deze oplossing blijft de belangrijke data van jouw kledingstukken veilig en beschermd gedurende de hele levenscyclus ervan. Het is onmogelijk voor consumenten om het te beschadigen of te verwijderen, en het is bestand tegen water, vuil, hitte en UV-straling.

De oplossing is eenvoudig te gebruiken met NFC-technologie. Houd simpelweg je smartphone tegen de tag en het digitale paspoort van het kledingstuk wordt weergegeven.

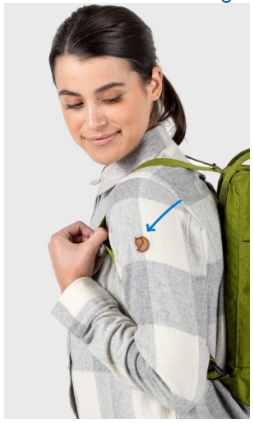
De tag is slechts 7mm dik, dat zijn vijf 1eurocentjes op elkaar gestapeld, en kan overal op het kledingstuk worden bevestigd alsook op verschillende materialen.

Er wordt een pinnetje door textiel aangebracht en aan de andere kant vastgezet. Hierdoor kunnen kledingontwerpers de ideale positie kiezen, zodat het past bij het ontwerp van het kledingstuk en de gebruiker niet hindert. Het is de bedoeling dat pinnetje en omhulsel permanent in kledij aanwezig blijven. Hieronder zie je hoe het op kledij kan aangebracht worden:





Bovendien kunnen ontwerpers verschillende ontwerpen kiezen voor het pinhoofd zoals hun eigen logo, een mooie broche, of aan bestaande onderdelen van kleding zoals knopen of klinknagels. Dit zorgt ervoor dat de tag mooi aansluit bij het ontwerp van het kledingstuk.



Deze tag is alleen te plaatsen door fabrieksarbeiders en kan alleen worden verwijderd door bepaalde belanghebbenden (zoals kledingmakers, stomerijen en recyclers). Als consument hoef je je dus geen zorgen te maken dat je het per ongeluk zult verwijderen of beschadigen.

De tag is ook gemaakt van hypoallergeen materiaal, wat betekent dat het geen irritaties of allergische reacties veroorzaakt. Dit is van cruciaal belang omdat de tag niet kan worden verwijderd.

Met deze oplossing kun je met een gerust hart genieten van duurzame mode zonder je zorgen te maken over beschadiging of verlies van belangrijke informatie over je kledingstukken.

belangrijke informatie over je kledingstukken.

Deze tag zou geschikt zijn voor volgende kledingstukken:

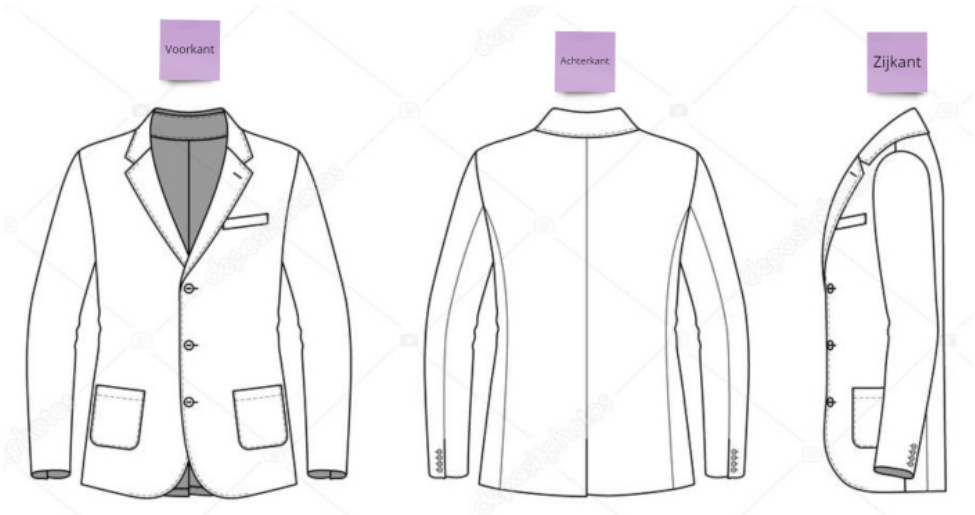
	1: Totaal niet	2: Waarschijnlijk niet	3: Noch ja, noch neen	4: Waarschijnlijk wel	5: Helemaal wel
T-shirt	○	○	○	○	○
Hemden	○	○	○	○	○
Jeansbroeken	○	○	○	○	○
Blazers	○	○	○	○	○
Jurken	○	○	○	○	○
Winterjas	○	○	○	○	○
Mantel	○	○	○	○	○
Vestje	○	○	○	○	○
Sweaters	○	○	○	○	○
Sjaal	○	○	○	○	○
Muts	○	○	○	○	○
Pet	○	○	○	○	○
Sportkledij	○	○	○	○	○
Zwemkledij	○	○	○	○	○
Rugzakken	○	○	○	○	○

Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet.

	1: Totaal niet	2: Waarschijnlijk niet	3: Noch ja, noch neen	4: Waarschijnlijk wel	5: Totaal wel
Ik zou deze tag gemakkelijk kunnen verwijderen met items die ik thuis heb liggen (schaar, naadplukker/tornmesje)	○	○	○	○	○
Ik zou gemakkelijk deze tag onleesbaar kunnen maken met items die ik thuis heb liggen	○	○	○	○	○
Ik zou deze tag willen verwijderen, ongeacht de waarde ervan	○	○	○	○	○
Ik vind deze tag lelijk	○	○	○	○	○
Ik vind deze tag te groot	○	○	○	○	○
Ik vind deze tag te dik	○	○	○	○	○
Het zou me storen mocht deze tag mijn huid aanraken	○	○	○	○	○
Het is duidelijk dat ik deze tag kan scannen	○	○	○	○	○
Deze oplossing zou voor een allergische reactie kunnen zorgen stel dat het mijn huid zou aanraken	○	○	○	○	○
Ik zou me ergeren aan deze tag stel dat deze op de foutieve locatie wordt geplaatst	○	○	○	○	○

Je kan op iedere kledingstuk 1 keer de ideale positie aanduiden (met je vinger of klikken met je muis) waar je deze tag zou willen plaatsen. Je krijgt telkens de voorkant, zijkant en achterkant van een kledingstuk te zien.

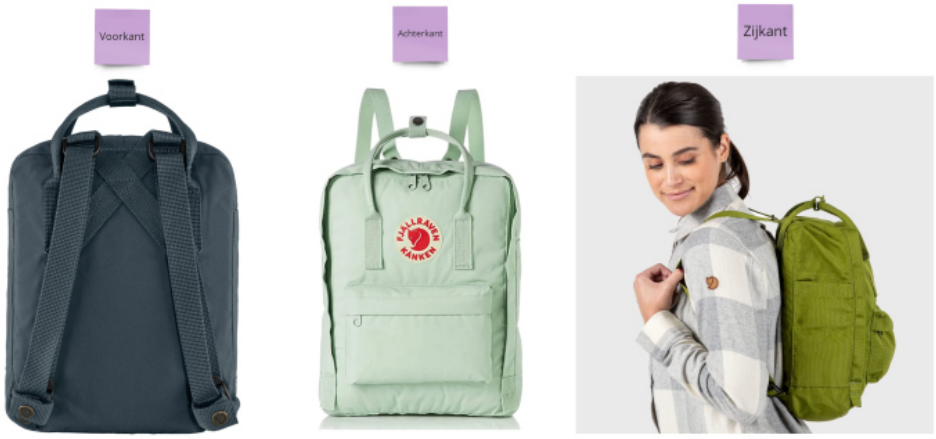
Blazer



Broek: ga er van uit dat dit een jeansbroek is

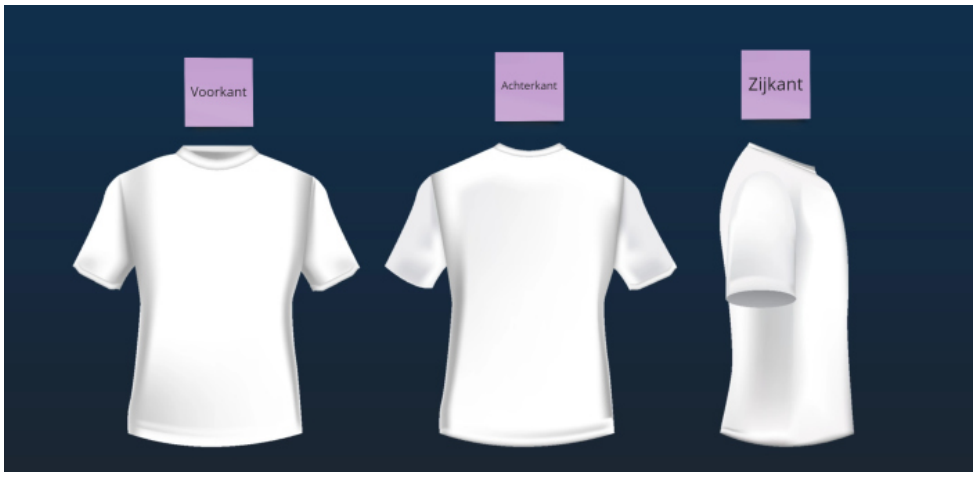
Hemd

Rugzak

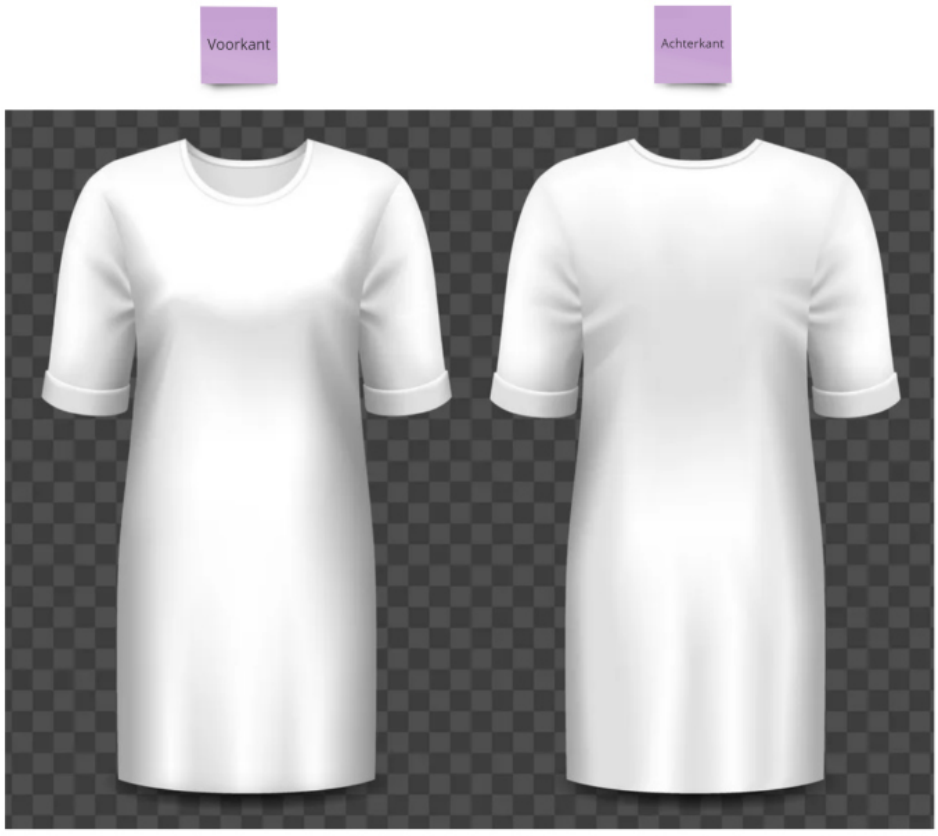


Sweater

T-shirt



Jurk

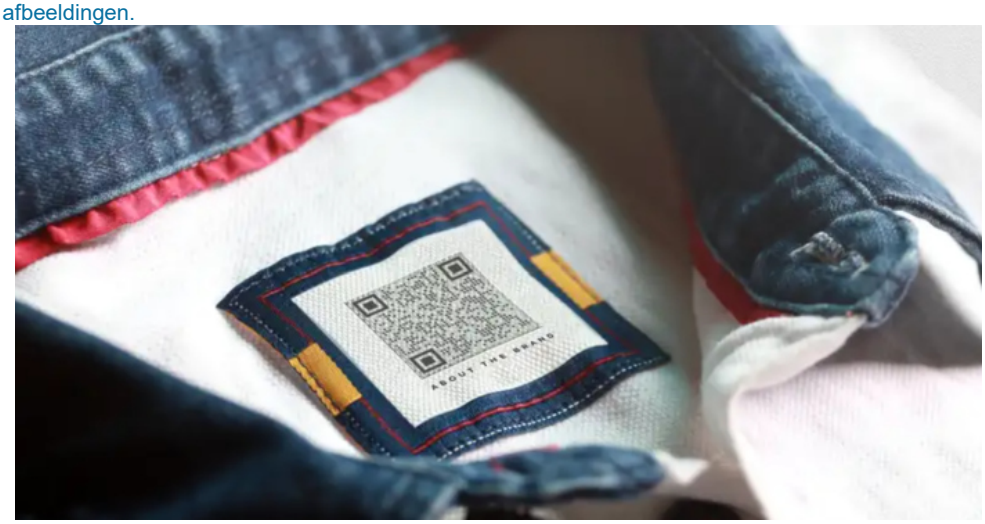


Heb je opmerkingen over deze uitwerking?

Concept 2

(Deel 4/5) Dit is de tweede oplossing. Het Digitaal Product Passport wordt gescand door middel van een QR code. Je opent je camera op je

(Deel 4/5) Dit is de tweede oplossing. Het Digitaal Product Passport wordt gescand door middel van een QR-code. Je opent je camera op je smartphone, scant de code en je wordt gestuurd naar het DPP. De QR-code is geprint op een stukje katoen en langs de 4 zijden genaaid aan de binnenkant van je kledingstuk. De tag is niet op andere locaties te plaatsen, enkel op de locaties zoals je kan zien op onderstaande afbeeldingen.



Deze tag zou geschikt zijn voor volgende kledingstukken:

	1: Totaal niet	2: Waarschijnlijk niet	3: Noch ja, noch neen	4: Waarschijnlijk wel	5: Helemaal wel
T-shirt	○	○	○	○	○
Hemden	○	○	○	○	○
Jeansbroeken	○	○	○	○	○
Blazers	○	○	○	○	○
Jurken	○	○	○	○	○
Winterjas	○	○	○	○	○
Mantel	○	○	○	○	○
Vestje	○	○	○	○	○
Sweaters	○	○	○	○	○
Sjaal	○	○	○	○	○
Muts	○	○	○	○	○
Pet	○	○	○	○	○
Sportkledij	○	○	○	○	○
Zwemkledij	○	○	○	○	○
Rugzakken	○	○	○	○	○

Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet.

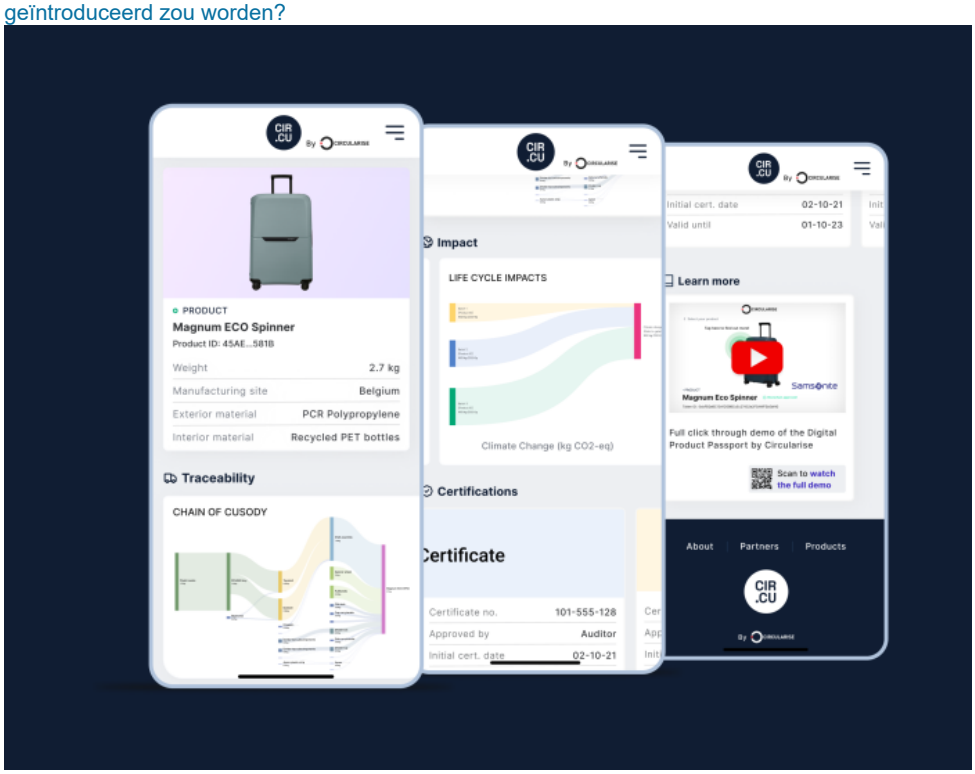
	1: Totaal niet	2: Waarschijnlijk niet	3: Noch ja, noch neen	4: Waarschijnlijk wel	5: Totaal wel
Ik zou deze tag gemakkelijk kunnen verwijderen met items die ik thuis heb liggen (schaar, naadplukker/tornmesje)	○	○	○	○	○
Ik zou gemakkelijk deze tag onleesbaar kunnen maken met items die ik thuis heb liggen	○	○	○	○	○
Ik zou deze tag willen verwijderen, ongeacht de waarde ervan	○	○	○	○	○
Ik vind deze tag lelijk	○	○	○	○	○
Ik vind deze tag te groot	○	○	○	○	○
Ik vind deze tag te dik	○	○	○	○	○
	1: Totaal niet	2: Waarschijnlijk niet	3: Noch ja, noch neen	4: Waarschijnlijk wel	5: Totaal wel

Het zou me storen mocht deze tag mijn huid aanraken	○	○	○	○	○
Het is duidelijk dat ik deze tag kan scannen	○	○	○	○	○
Deze oplossing zou voor een allergische reactie kunnen zorgen stel dat het mijn huid zou aanraken	○	○	○	○	○
Ik zou me ergeren aan deze tag stel dat deze op de foutieve locatie wordt geplaatst	○	○	○	○	○

Heb je opmerkingen over deze uitwerking?

Verandering

(Deel 4/4) Ongeacht hoe een Digitaal Product Passport (DPP) in kledij verwerkt zou worden, zou je volgende zaken doen stel dat een DPP geïntroduceerd zou worden?



	1: Helemaal van niet	2: Waarschijnlijk niet	3: Noch ja, noch neen	4: Waarschijnlijk wel	5: Helemaal van wel
Transparante informatie waarden, zoals CO2 waarden, waar het geproduceerd is, door wie, in welke omstandigheden,... zal mijn aankoopproces kunnen beïnvloeden	○	○	○	○	○
Een DPP in tweedehandskledij zou me ertoe kunnen aanzetten om meer tweedehands te kopen (duidelijke wasinstructies, wanneer gekocht, hoe lang gedragen, waar gekocht, objectievere prijs)	○	○	○	○	○
Een DPP zou me ertoe kunnen aanzetten om kledij door te verkopen omdat een objectievere doorverkoopwaarde gegeven wordt of ik weet aan wie ik het kan doorverkopen	○	○	○	○	○
Een DPP in kledingverhuur zou me ertoe kunnen aanzetten om meer kledij te huren (hoe vaak al gedragen, hoe lang gedragen, hoe vaak gewassen)	○	○	○	○	○
Een DPP zou me ertoe kunnen aanzetten om kledij zelf te repareren (gemakkelijk reparatieonderdelen zoals knopen en juiste garen bestellen)	○	○	○	○	○
Een DPP zou me ertoe kunnen aanzetten om kledij te laten repareren door iemand anders (gemakkelijk in contact komen met de juiste kledingmakers)	○	○	○	○	○
Een DPP in kledij zou handig zijn om kledingstukken met elkaar te vergelijken	○	○	○	○	○
Een DPP in kledij is nuttig	○	○	○	○	○

General questions

Wat is uw leeftijd? Gelieve enkel een cijfer als antwoord te geven (bv: "55")

Wat is uw gender?

- ◯ Man
- ◯ Vrouw
- ◯ Non-binair
- ◯ Prefer not to say
- ◯ Andere

Heb je nog iets toe te voegen?

Results

H0a

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	(Deel 1/4) Beantwoord volgende vragen. Deze gaan over je huidige modeconsumptie. - Mijn aankoopproces van nieuwe kledij wordt beïnvloed door bijvoorbeeld waar het geproduceerd is, door wie, in welke omstandigheden,...	2,77	47	1,146	,167
	(Deel 4/4) Ongeacht hoe een Digitaal Product Passport (DPP) in kledij verwerkt zou worden, zou je volgende zaken doen stel dat een DPP geïntroduceerd zou worden? - Transparante informatie waarden, zoals CO2 waarden, waar het geproduceerd is, door wie, in welke omstandigheden,... zal mijn aankoopproces kunnen beïnvloeden	3,57	47	,827	,121
Pair 2	(Deel 1/4) Beantwoord volgende vragen. Deze gaan over je huidige modeconsumptie. - Ik koop tweedehands kledij	2,67	49	1,477	,211
	(Deel 4/4) Ongeacht hoe een Digitaal Product Passport (DPP) in kledij verwerkt zou worden, zou je volgende zaken doen stel dat een DPP geïntroduceerd zou worden? - Een DPP in tweedehandskledij zou me ertoe kunnen aanzetten om meer tweedehands te kopen (duidelijke wasinstructies, wanneer gekocht, hoe lang gedragen, waar gekocht, objectievere prijs)	3,39	49	1,115	,159
Pair 3	(Deel 1/4) Beantwoord volgende vragen. Deze gaan over je huidige modeconsumptie. - Ik verkoop kledij	1,80	49	1,099	,157
	(Deel 4/4) Ongeacht hoe een Digitaal Product Passport (DPP) in kledij verwerkt zou worden, zou je volgende zaken doen stel dat een DPP geïntroduceerd zou worden? - Een DPP zou me ertoe kunnen aanzetten om kledij door te verkopen omdat een objectievere doorverkoopwaarde gegeven wordt of ik weet aan wie ik het kan doorverkopen	3,16	49	1,007	,144
Pair 4	(Deel 1/4) Beantwoord volgende vragen. Deze gaan over je huidige modeconsumptie. - Ik huur kledij	1,00	48	,000	,000
	(Deel 4/4) Ongeacht hoe een Digitaal Product Passport (DPP) in kledij verwerkt zou worden, zou je volgende zaken doen stel dat een DPP geïntroduceerd zou worden? - Een DPP in kledingverhuur zou me ertoe kunnen aanzetten om meer kledij te huren (hoe vaak al gedragen, hoe lang gedragen, hoe vaak gewassen)	2,40	48	1,162	,168
Pair 5	(Deel 1/4) Beantwoord volgende vragen. Deze gaan over je huidige modeconsumptie. - Ik repareer kledij zelf	3,06	49	1,329	,190
	(Deel 4/4) Ongeacht hoe een Digitaal Product Passport (DPP) in kledij verwerkt zou worden, zou je volgende zaken doen stel dat een DPP geïntroduceerd zou worden? - Een DPP zou me ertoe kunnen aanzetten om kledij zelf te repareren (gemakkelijk reparatieonderdelen zoals knopen en juiste garen bestellen)	3,45	49	1,119	,160
Pair 6	(Deel 1/4) Beantwoord volgende vragen. Deze gaan over je huidige modeconsumptie. - Ik laat kledij repareren door iemand anders	2,88	48	1,362	,197
	(Deel 4/4) Ongeacht hoe een Digitaal Product Passport (DPP) in kledij verwerkt zou worden, zou je volgende zaken doen stel dat een DPP geïntroduceerd zou worden? - Een DPP zou me ertoe kunnen aanzetten om kledij te laten repareren door iemand anders (gemakkelijk in contact komen met de juiste kledingmakers)	3,31	48	1,291	,186
Pair 7	(Deel 1/4) Beantwoord volgende vragen. Deze gaan over je huidige modeconsumptie. - Ik vergelijk kledij tijdens het kledingshoppen op basis van duurzaamheid	2,80	49	1,040	,149
	(Deel 4/4) Ongeacht hoe een Digitaal Product Passport (DPP) in kledij verwerkt zou worden, zou je volgende zaken doen stel dat een DPP geïntroduceerd zou worden? - Een DPP in kledij zou handig zijn om kledingstukken met elkaar te vergelijken	3,98	49	1,010	,144

Paired Samples Test

		Paired Differences					t	df	Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			One-Sided p	Two-Sided p
Pair 1	Current consumption variable 1 DPP consumption variable 1	-,809	1,135	,166	-1,142	-,475	-4,883	46	<,001	<,001
Pair 2	Current consumption variable 2 DPP consumption variable 2	-,714	1,696	,242	-1,201	-,227	-2,949	48	,002	,005
Pair 3	Current consumption variable 3 DPP consumption variable 3	-1,367	1,253	,179	-1,727	-1,007	-7,637	48	<,001	<,001
Pair 4	Current consumption variable 4 DPP consumption variable 4	-1,396	1,162	,168	-1,733	-1,058	-8,321	47	<,001	<,001
Pair 5	Current consumption variable 5 DPP consumption variable 5	-,388	1,681	,240	-,871	,095	-1,615	48	,056	,113
Pair 6	Current consumption variable 6 DPP consumption variable 6	-,437	1,029	,149	-,736	-,139	-2,944	47	,003	,005
Pair 7	Current consumption variable 7 DPP consumption variable 7	-1,184	1,424	,203	-1,593	-,775	-5,818	48	<,001	<,001

H0B

First line = concept 2 (QR code)

Second line = concept 1 (NFC tag)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik zou deze tag gemakkelijk kunnen verwijderen met items die ik thuis heb liggen (schaar, naadplukker/tornmesje)	3,76	49	1,071	,153
	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik zou deze tag gemakkelijk kunnen verwijderen met items die ik thuis heb liggen (schaar, naadplukker/tornmesje)	3,06	49	1,144	,163
Pair 2	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik zou gemakkelijk deze tag onleesbaar kunnen maken met items die ik thuis heb liggen	3,92	48	,986	,142
	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik zou gemakkelijk deze tag onleesbaar kunnen maken met items die ik thuis heb liggen	2,77	48	1,153	,166
Pair 3	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik zou deze tag willen verwijderen, ongeacht de waarde ervan	2,29	49	,979	,140
	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik zou deze tag willen verwijderen, ongeacht de waarde ervan	2,33	49	,966	,138
Pair 4	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik vind deze tag lelijk	2,52	50	1,297	,183
	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik vind deze tag lelijk	2,32	50	,891	,126
Pair 5	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik vind deze tag te groot	2,82	50	1,304	,184
	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik vind deze tag te groot	2,52	50	1,035	,146
Pair 6	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik vind deze tag te dik	1,65	48	,699	,101
	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik vind deze tag te dik	3,06	48	1,227	,177
Pair 7	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Het zou me storen mocht deze tag mijn huid aanraken	2,80	50	1,309	,185
	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Het zou me storen mocht deze tag mijn huid aanraken	3,86	50	1,010	,143
Pair 8	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Het is duidelijk dat ik deze tag kan scannen	4,72	50	,730	,103
	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Het is duidelijk dat ik deze tag kan scannen	3,10	50	1,266	,179
Pair 9	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Deze oplossing zou voor een allergische reactie kunnen zorgen stel dat het mijn huid zou aanraken	2,30	50	1,182	,167
	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Deze oplossing zou voor een allergische reactie kunnen zorgen stel dat het mijn huid zou aanraken	2,36	50	1,120	,158
Pair 10	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik zou me ergeren aan deze tag stel dat deze op de foutieve locatie wordt geplaatst	3,37	49	1,334	,191
	Voor de kledingstukken waarbij je '4:waarschijnlijk wel' en '5: helemaal wel' op geantwoord hebt: Duid voor volgende statements aan of je er akkoord mee gaat of niet. - Ik zou me ergeren aan deze tag stel dat deze op de foutieve locatie wordt geplaatst	4,08	49	,886	,127

Paired Samples Test

		Paired Differences					t	df	Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			One-Sided p	Two-Sided p
Pair 1	Concept 2 vs Concept 1 variable 1	,694	1,402	,200	,291	1,097	3,463	48	<,001	,001
Pair 2	Concept 2 vs Concept 1 variable 2	1,146	1,530	,221	,702	1,590	5,190	47	<,001	<,001
Pair 3	Concept 2 vs Concept 1 variable 3	-,041	,841	,120	-,282	,201	-,340	48	,368	,735
Pair 4	Concept 2 vs Concept 1 variable 4	,200	1,245	,176	-,154	,554	1,136	49	,131	,262
Pair 5	Concept 2 vs Concept 1 variable 5	,300	1,542	,218	-,138	,738	1,376	49	,088	,175
Pair 6	Concept 2 vs Concept 1 variable 6	-1,417	1,235	,178	-1,775	-1,058	-7,948	47	<,001	<,001
Pair 7	Concept 2 vs Concept 1 variable 7	-1,060	1,236	,175	-1,411	-,709	-6,066	49	<,001	<,001
Pair 8	Concept 2 vs Concept 1 variable 8	1,620	1,354	,191	1,235	2,005	8,463	49	<,001	<,001
Pair 9	Concept 2 vs Concept 1 variable 9	-,060	1,058	,150	-,361	,241	-,401	49	,345	,690
Pair 10	Concept 2 vs Concept 1 variable 10	-,714	1,208	,173	-1,061	-,367	-4,140	48	<,001	<,001

H0C

T-Test

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
C1 Removability 1	51	3,04	1,131	,158
C1 Durability	50	2,76	1,135	,161
C1 Removability 2	50	2,36	,985	,139
C1 Styling	51	2,33	,887	,124
C1 Ergonomics 1	51	2,53	1,027	,144
C1 Ergonomics 2	51	3,12	1,227	,172
C1 Ergonomics 3	51	3,88	1,013	,142
C1 Signifiers	51	3,08	1,262	,177
C1 Ergonomics 4	51	2,35	1,110	,155
C1 Ergonomics 5	51	4,12	,887	,124

One-Sample Test

Test Value = 3.5

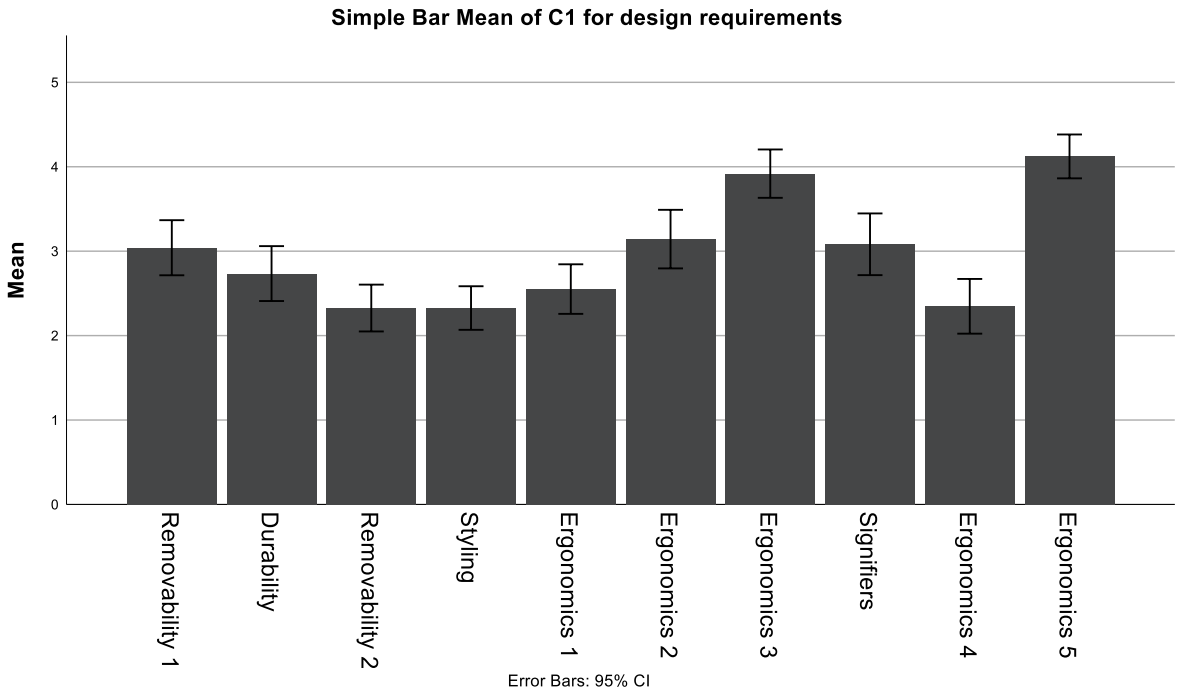
	t	df	Significance One-Sided p	Significance Two-Sided p	Mean Difference	95% Confidence Interval of the Difference Lower
C1 Removability 1	-2,910	50	,003	,005	-,461	-,78
C1 Durability	-4,610	49	<,001	<,001	-,740	-1,06
C1 Removability 2	-8,186	49	<,001	<,001	-1,140	-1,42
C1 Styling	-9,394	50	<,001	<,001	-1,167	-1,42
C1 Ergonomics 1	-6,751	50	<,001	<,001	-,971	-1,26
C1 Ergonomics 2	-2,225	50	,015	,031	-,382	-,73
C1 Ergonomics 3	2,696	50	,005	,010	,382	,10
C1 Signifiers	-2,385	50	,010	,021	-,422	-,78
C1 Ergonomics 4	-7,377	50	<,001	<,001	-1,147	-1,46
C1 Ergonomics 5	4,976	50	<,001	<,001	,618	,37

One-Sample Test

	Test Value = 3.5	
		95% Confidence

	Interval of the Difference
	Upper
C1 Removability 1	-,14
C1 Durability	-,42
C1 Removability 2	-,86
C1 Styling	-,92
C1 Ergonomics 1	-,68
C1 Ergonomics 2	-,04
C1 Ergonomics 3	,67
C1 Signifiers	-,07
C1 Ergonomics 4	-,83
C1 Ergonomics 5	,87

GGraph



T-Test

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
C2 Removability 1	50	3,76	1,061	,150
C2 Durability	49	3,90	,984	,141
C2 Removability 2	51	2,24	,992	,139
C2 Styling	51	2,49	1,302	,182
C2 Ergonomics 1	51	2,78	1,316	,184
C2 Ergonomics 2	49	1,63	,698	,100
C2 Ergonomics 3	51	2,76	1,320	,185
C2 Signifiers	51	4,73	,723	,101
C2 Ergonomics 4	51	2,29	1,171	,164
C2 Ergonomics 5	50	3,38	1,323	,187

One-Sample Test

Test Value = 3.5

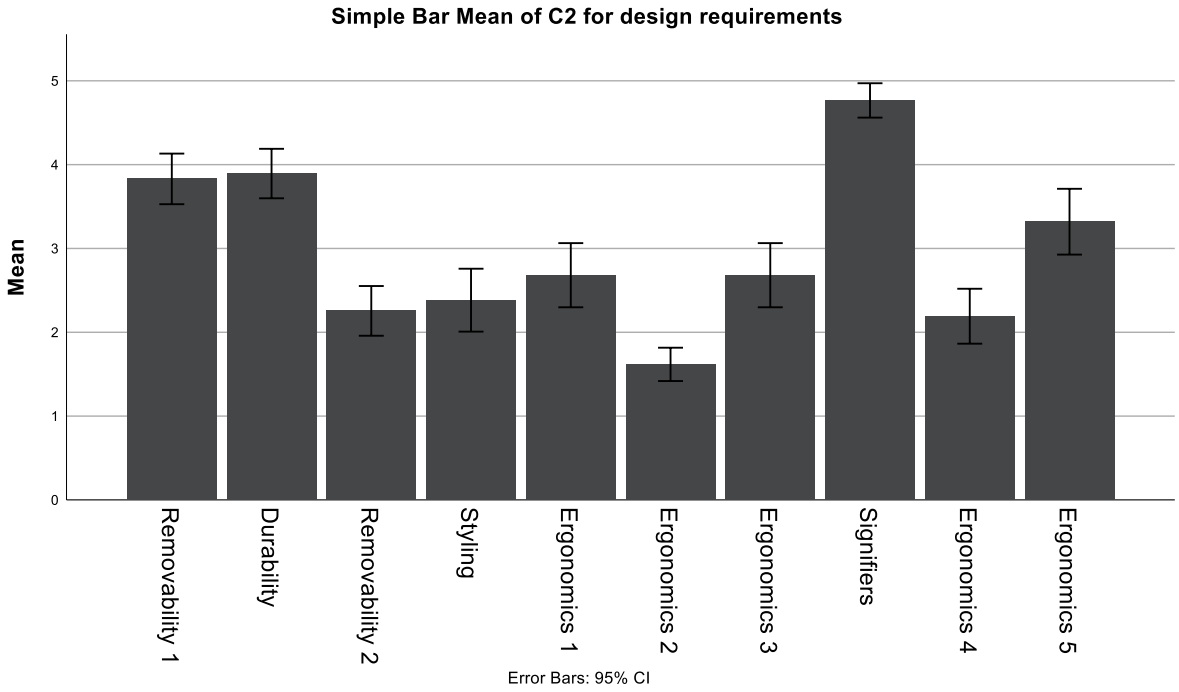
	t	df	Significance One-Sided p	Significance Two-Sided p	Mean Difference	95% Confidence Interval of the Difference Lower
C2 Removability 1	1,733	49	,045	,089	,260	-,04
C2 Durability	2,831	48	,003	,007	,398	,12
C2 Removability 2	-9,107	50	<,001	<,001	-1,265	-1,54
C2 Styling	-5,539	50	<,001	<,001	-1,010	-1,38
C2 Ergonomics 1	-3,883	50	<,001	<,001	-,716	-1,09
C2 Ergonomics 2	-18,726	48	<,001	<,001	-1,867	-2,07
C2 Ergonomics 3	-3,977	50	<,001	<,001	-,735	-1,11
C2 Signifiers	12,100	50	<,001	<,001	1,225	1,02
C2 Ergonomics 4	-7,353	50	<,001	<,001	-1,206	-1,54
C2 Ergonomics 5	-,641	49	,262	,524	-,120	-,50

One-Sample Test

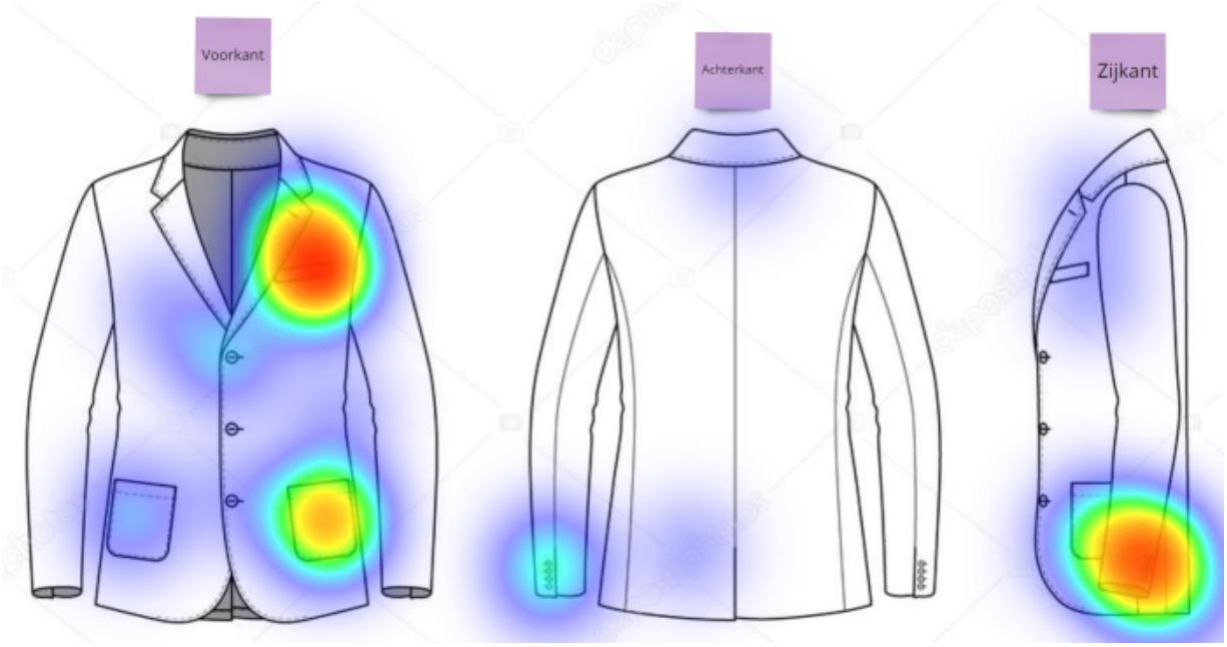
Test Value = 3.5

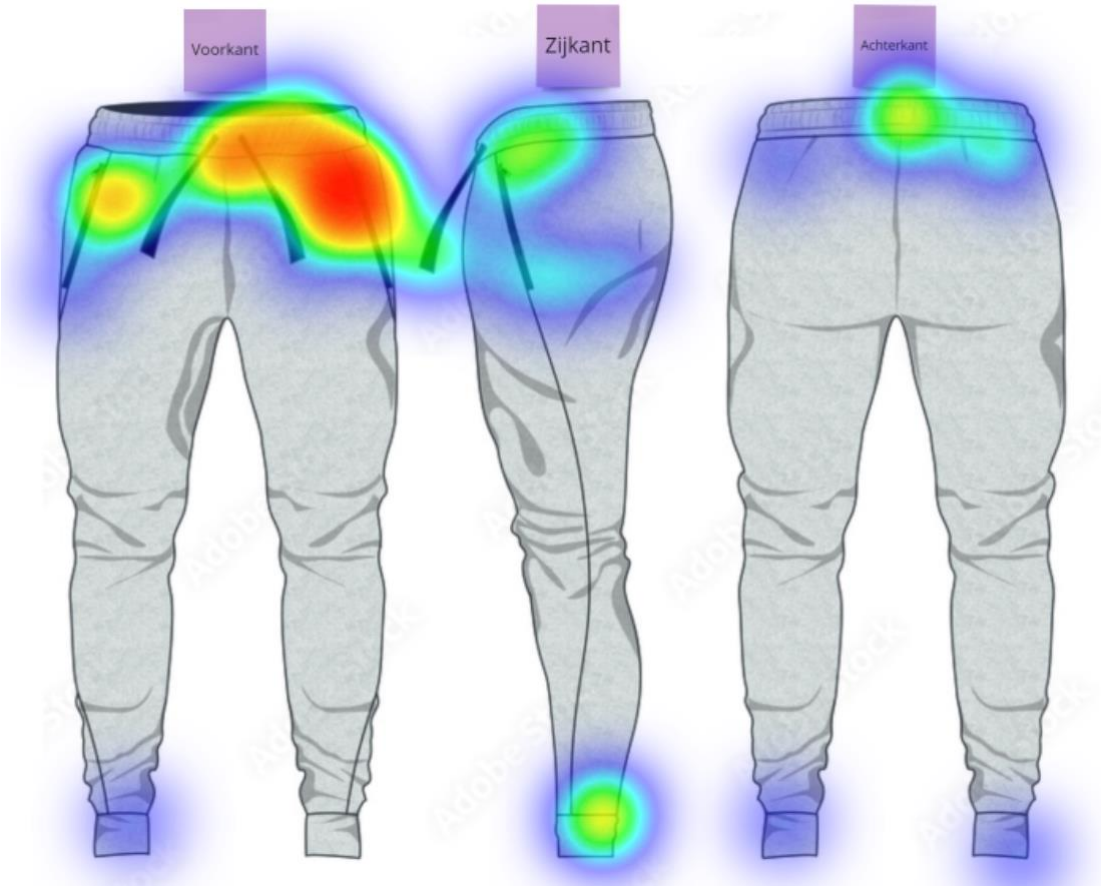
	95% Confidence Interval of the Difference Upper
C2 Removability 1	,56
C2 Durability	,68
C2 Removability 2	-,99
C2 Styling	-,64
C2 Ergonomics 1	-,35
C2 Ergonomics 2	-1,67
C2 Ergonomics 3	-,36
C2 Signifiers	1,43
C2 Ergonomics 4	-,88
C2 Ergonomics 5	,26

GGraph

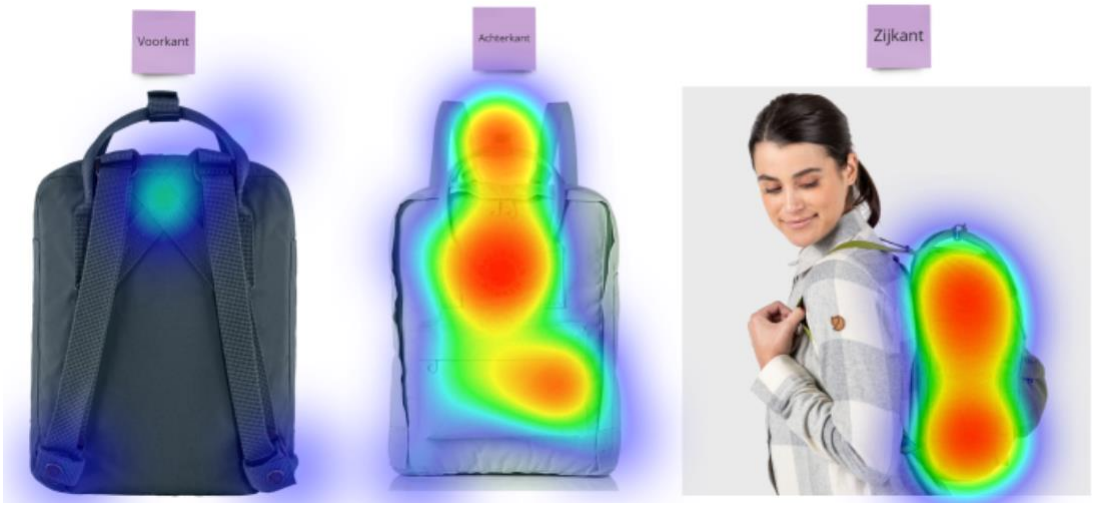


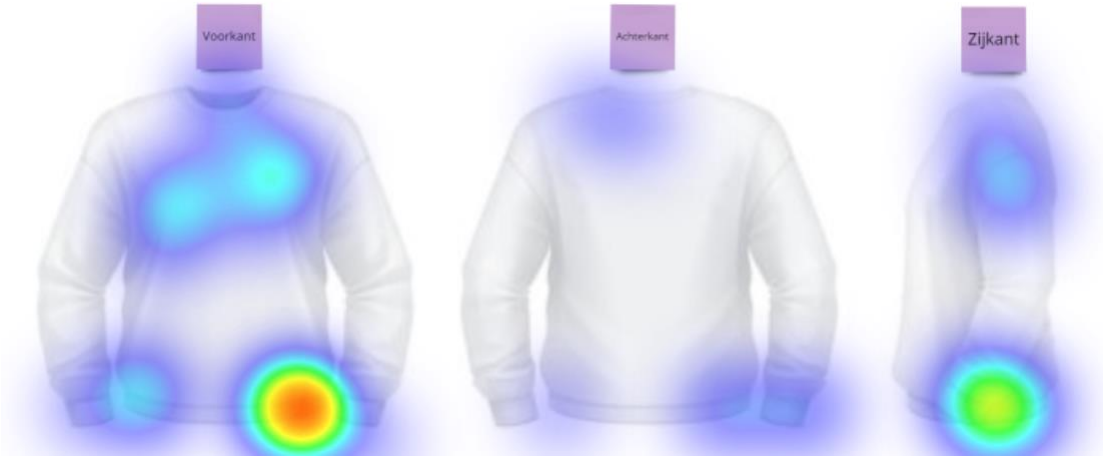
Results location clothing

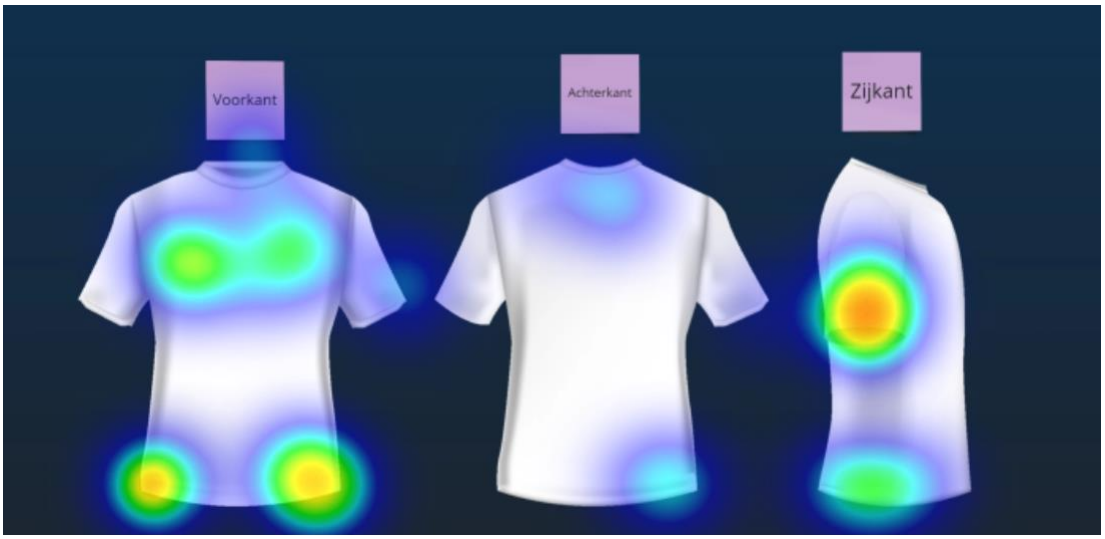


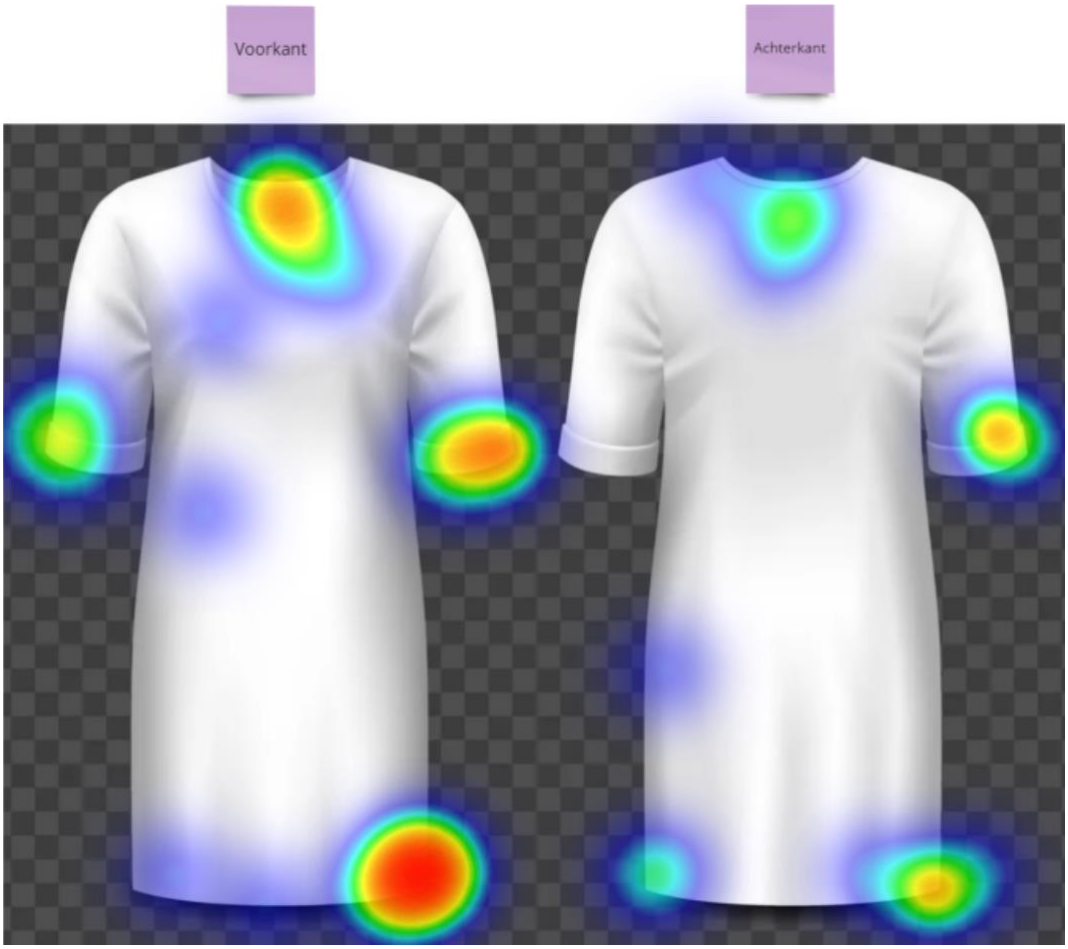

Voorkant
Zijkant
Achterkant


Voorkant
Zijkant
Achterkant


Voorkant
Achterkant
Zijkant


Voorkant
Achterkant
Zijkant


Voorkant
Achterkant
Zijkant


Voorkant
Achterkant