

Digital Product Passports: Increasing Transparency in the Fashion Industry

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Abstract- Increasing sustainability in the fashion industry by adopting a circular economy is an important topic in today's society due to the negative impact the fashion industry has on the environment. This research examines how digital product passports can aid in making a circular economy by increasing transparency in the fashion industry. Through literature review and an interview with an expert in the field of circular economy, this paper discusses what data should be present in a digital product passport in order to fuel circularity. Additionally, it evaluates the willingness of companies to implement digital product passports. Lastly, this paper assesses issues relating to cybersecurity when using blockchain to implement digital product passports. Findings suggest that two separate digital product passports should be created for supply chain actors and consumers. Additionally, findings show that making digital product passports a legal requirement is likely the most effective way to ensure companies implement circular strategies. Lastly, multiple obstacles when using blockchain for digital product passport implementation are identified.

Additional Key Words and Phrases: Digital product passports, supply chain, circular economy, transparency, sustainability, data, cybersecurity, blockchain

1 INTRODUCTION

The past decades have brought forth the normality of constant consumption. Now more than ever, companies are aiming to produce as much as possible to meet consumer demands. The current linear supply chain often does not take sustainability into account. Many supply chains result in large amounts of waste generated during production in order to produce as cheaply as possible [23]. To counteract this, the idea of a circular economy has evolved which ensures that supply chains function in a loop. This entails that there are also backward flows in the supply chain. In an ideal supply chain, all products are resold or recovered. Recovering involves repairing, refurbishing, or remanufacturing in order to return a product to its original state, as well as cannibalizing or recycling if a product is no longer able to be repaired, refurbished, or remanufactured [56]. In comparison to a conventional linear supply chain, more communication between actors in the supply chain [26, 34], and also more effort from the end user is required to allow a circular supply chain to function as intended.

To fully design a circular economy, fundamental processes within the supply chain must change. This includes altering production processes and entire business models [4]. Additionally, industrial ecosystems must be entirely revamped to support a circular economy. With the growth of technology and an all-around digital world, the process of creating a smart circular economy can be made efficient as sharing data becomes simpler [5]. One of the latest ideas

regarding the use of technology in creating such a circular economy is through digital product passports. A digital product passport (DPP) is an intangible document about a physical product's life cycle. DPPs contain useful information about any given product's origin, as well as information about the impact the product has on the environment. Other things are recorded within these passports such as how a product is manufactured and produced, as well as how it is used [25]. This information is meant to inform actors throughout the supply chain about the product. Actors need to be able to update and add information through a system of some kind, and this information can then be used to fuel the reuse and recycling of products. Though this idea seems straightforward, there are many complications when it comes to implementing such a system. This paper addresses how the data in a passport can, in reality, fuel transparency within the supply chain and create a circular economy as a result.

2 PROBLEM STATEMENT

Current requirements for a system allowing DPPs are being discussed by experts, however, no solution for a system has been invented [25]. Furthermore, it is unknown exactly what data is needed for a DPP to aid in creating a circular economy. Though shared information about a product is useful, some companies might be reluctant to share certain data due to privacy reasons. As a new concept, it is unknown where to start implementing DPPs, and how the data contained within can be used.

Research Question

As a result of the aforementioned problem statement the following research question has been formulated:

How can the data collected in a digital product passport help to make processes within the fashion industry more sustainable?

This main research question is answered through the following sub-questions:

RQ1: What data should be present in a digital product passport to fuel transparency within the fashion industry?

RQ2: To what extent are companies willing to change their current business processes and share data in order to implement digital product passports?

RQ3: What are potential cybersecurity threats when it comes to adding data about these specific processes to a digital product passport system?

3 RELATED WORK

Being a relatively new topic, there is still much to be discovered about DPPs. Related work often states the use it can bring in enabling a smart circular economy, but also states that the concept

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still involves a great deal of uncertainty about DPP implementation [23, 26, 59].

A case study performed by Jensen et al. [26] looks at the data that needs to be collected for DPPs. The study identified seven different categories which should be present in a DPP. The categories of "product and materials", "supply chain and reverse logistics", and "environmental impact" are useful as a starting point for this research.

Furthermore, a case study by Ducuing & Reich [14] talks about the political aspect of DPPs. It talks about data governance gaps and data governance of DPPs. They conclude that data governance is necessary to enable trust when it comes to DPPs, however, that there is currently no form of data governance by the law pertaining to DPPs. This is relevant when evaluating whether companies are willing to implement DPPs and willing to share data about their business processes. This is further discussed in Section 6.2.

Moreover, Walden et al. [59] discuss DPPs and how they can enable a circular economy. More specifically, they look into potential opportunities and obstacles which could arise when establishing DPPs. In their research, they mention that blockchain technology is a potential solution to secure data contained in a DPP. This concept is further evaluated in Section 7.

4 METHODS OF RESEARCH

This research consists of a literature review supported by an interview with an expert in the field of building a circular economy within the fashion industry. These methods of research were chosen because it is useful to evaluate whether the information found through literature aligns with the knowledge of an individual working in the actual field of circular economy and sustainability. The sources for the literature review were found using the search engines Google Scholar and Semantic Scholar.

The literature review with the help of the expert answers the first and second sub-questions. The literature review delves into the current processes in the supply chain, and then evaluates areas where the fashion industry is unsustainable. In addition it looks at current circularity practices, and evaluates if companies are willing to implement DPPs. The interview and literature review ultimately help determine what data should be included in a DPP for the fashion industry.

Furthermore, the literature review looks at the potential cybersecurity obstacles when using blockchain to implement DPPs. The literature review and the contribution of the expert interviewed are ultimately tied together to answer the research question mentioned in Section 2.

5 LITERATURE REVIEW

In order to best understand how DPPs can increase sustainability within the fashion industry, the fashion supply chain is first explained in Section 5.1. The overview of the supply chain is followed by current areas within the fashion industry which lack sustainability, in order to give an overview where sustainability should be increased. Additionally, current efforts in creating a circular economy

are discussed in Section 5.3 to understand why DPPs are of value in creating a circular supply chain and increasing transparency.

5.1 The Fashion Supply Chain

The supply chain within the fashion industry has grown to become complex due to its many actors across the globe [35]. Though fashion supply chains can differ based on the company, a broad overview of the general actors within a typical supply chain is given starting in Section 5.1.1.

A review published about the supply chain of the US fashion industry [64] gives a detailed overview of the typical supply chain for the production of fashion items. The supply chain is split up into four major segments namely, fiber and yarn production, fabric production, apparel manufacturing, and retailers [64]. The flow of the supply chain can be seen in Figure 1, followed by an explanation of each segment.

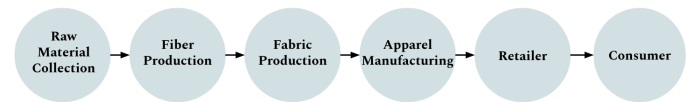


Fig. 1. The Fashion Supply Chain

5.1.1 Fiber and Yarn Production. The production of fiber includes both natural and man-made fibers. Natural fibers are plant fibers such as cotton and linen, or fibers such as wool, made from animals [8]. The most popular synthetic fibers are nylon and polyester, as well as acrylic [8, 64]. These synthetic fibers are often created through a process called melt spinning. These melt-spun fibers are the most crucial fibers for producing clothes [22]. The different types of fibers used for apparel production are important for DPPs because fiber usage has an impact on recycling, which is further discussed in Section 6.1.

5.1.2 Fabric Production. The fibers made are afterwards used to create various fabrics. The manner in which this is done differs widely, sometimes including weaving or knitting [52]. Other forms of transformation include non-woven chemical or thermal compression methods [52, 64]. Ultimately the goal of fabric production is to allow all fibers to be usable in manufacturing.

5.1.3 Apparel Manufacturing. Apparel manufacturing is where the design aspect of the fashion industry comes into play. Designs are first made by various designers, and afterwards fabric pieces are cut from patterns created to match any given design [64]. The fabric is afterwards transformed into a finished product through various methods of assembling [64]. This part of the supply chain is crucial for DPPs because the design phase largely determines the impact a product will have on the environment [11]. This is important to take into account when understanding what data should be present in a DPP to reduce waste.

Traditionally speaking, apparel manufacturers oversee and involve themselves in all of the above mentioned processes. This includes not only the design and manufacturing of the designs, but also material sourcing and eventually marketing finished goods to consumers [64].

Recently, it has become very popular for companies to outsource the job of apparel manufacturing to contractors because it is often cheaper to outsource overseas than to produce locally [46]. Clothing produced when outsourced is often less sustainable because the mass production is often not monitored, and allows for unethical working conditions as well as unsustainable production methods [42].

5.1.4 Retailers. The produced clothes are distributed to many different retailers for sale [64]. Once distributed to the consumer it is up to their discretion what occurs with the clothing. Retailers are important because they interact with the consumers and are knowledgeable about consumer purchasing behaviors [61]. This is important for DPPs, as retailers can play a large role in increasing knowledge about product returns which is further evaluated in Section 6.1.

5.2 Unsustainable Practices within the Fashion Industry

Out of all industries, the fashion industry has one of the largest negative impacts on the environment today [24]. In order to understand how DPPs can have an effect on sustainability, it is first crucial to understand which areas within the industry lack sustainability.

The supply chain described in Section 5.1 is successful in generating a substantial amount of clothes everyday [49]. This mass production has resulted in the worth of the fashion industry rising to a staggering almost 3 trillion USD in total [30].

The industry has severe negative impacts on the environment, and many of the actors within the supply chain are not working in a sustainable manner. There is also a lack of accountability when it comes to being sustainable. Sustainable production is more expensive and, as a result, companies opt to produce unsustainably because it cuts costs [29].

The most obvious negative impact companies within the fashion industry have on the environment is the tons of waste discarded yearly. This waste is generated throughout the entire supply chain. It is estimated that 100 billion pieces of clothing are produced each year [49]. The production of this apparel results in 92 million tonnes of waste annually getting thrown into landfills [43]. There are recycling efforts in place, however, a very small percentage of clothes which are collected for recycling actually get recycled. The technology currently is not present, and therefore recycled clothes also end up in landfills [16, 24].

Clothing which is discarded by consumers is considered post-consumer waste [18]. Though this contributes largely to the waste building up, pre-consumer waste also has a negative effect on the environment. Pre-consumer waste refers to any waste which is generated before reaching the hands of the consumer [18]. This ranges from scraps, to sample material, to rejected clothing, to unsold apparel, and much more [57].

Tangible materials are not the only downside of current fashion production. Many chemicals and pollutants are released into the environment throughout the current supply chain [18, 24]. This occurs during production and transportation of the produced goods, but also when apparel enters landfills [50, 62]. There is a significant amount of water consumed during production, and additionally, energy consumption is high [24]. Since the manufacturing of clothes is

often outsourced to other companies, there are additional environmental costs in order to transport the finished clothes to the retailers. This results in a high consumption of fuel during transportation. The transport evidently results in carbon dioxide (CO₂) emissions and the emission of other greenhouse gases [24].

Due to the waste, pollutants, and chemicals suffocating the environment as a result of fashion, many experts are aiming towards creating a circular economy in order to reduce the impact the fashion industry has on the environment [8].

5.3 Current Circularity Efforts

Because the fashion industry is one of the leading industries in disrupting the environment, there is a big focus on changing the current linear supply chain. The essence of the circular economy is that waste and current discarded materials, as well as disposed consumer clothing, are reused or recycled back into the supply chain. This essentially makes the supply chain one large circle [32, 50]. The complexity of the fashion industry's supply chain ensures that creating a circular economy is not easy. Current efforts in creating a circular economy are arising more and more despite the challenges [31, 32, 37].

Some companies are creating efforts to reuse post-consumer waste. H&M, for example, offers customers a discount when they bring any old clothes and textile to their stores [6]. Nationwide recycling efforts are also in place in many countries, however, many of the items sorted for recycling still get dumped into landfills [44]. A large issue with recycling is that the technologies to adequately break down the fibers in various fabrics are not available [16]. Because of this reason, other ways to decrease waste have been evaluated by experts in the field of sustainability. Since recycling is very difficult and requires other aspects such as sanitizing to come into play, experts are looking more at reusing pre-consumer waste [33].

Next, Fashion Revolution is a non-profit organization which ranks companies based on their transparency. Each year, Fashion Revolution releases a new "Fashion Transparency Index" (FTI) showing the rankings. The goal of the FTI is to show which companies are transparent in their business practices so consumers can make purchasing decisions based on the index [3]. Brazil was the first country to also have a country specific FTI, which are becoming more popular [40].

Similar efforts are taking place on a larger scale. A few years ago, the European Union introduced the EU Ecolabel. This is a third-party certified label [12] which can be placed on products that have a low impact on the environment. The label shows the life cycle of the product in order to give an idea of how eco-friendly the product has been made. When assessing whether a product can be given the Ecolabel, mainly pollutants, consumption of water, and air emissions during transport are taken into consideration. Placing the label is entirely voluntary, but gives consumers an overview of the impact the product they purchase has on the environment [24]. The goal of this Ecolabel is to encourage companies to be sustainable throughout the entirety of their supply chain in order to increase sustainability.

Similarly, in an effort to increase transparency for its customers, Zalando has implemented an ID pilot where customers can scan

a QR code on the label of a given product and the code takes the customer to a site [2]. On the site information is displayed on how said product was manufactured [21]. Likewise, in a study done by Heim and Hopper [21], various companies were interviewed to gauge how they view technology which is used to fuel a circular economy. One of the participating companies revealed that they have a QR code which is put on every piece of clothing in order to show how the piece of clothing was made. This goes as far back as where the fibers used to produce a given piece of clothing were grown. This effort is currently done manually, and the interviewee mentions that there is certainly room for error.

While certain companies are making an effort to increase transparency and to work towards circularity, others are not so keen to improve transparency. Some brands prefer to keep a lack of transparency due to claims that it gives a competitive advantage [40]. Being able to keep information such as suppliers private is argued to give a company an advantage over its fellow competitors [40].

Though there are efforts in place, no effort is able to create a circular supply chain on its own. Many of the efforts mentioned in Section 5.3 are optional or are not regulated, making it difficult to hold companies with unsustainable processes accountable.

6 FINDINGS ON RESEARCH QUESTIONS 1 AND 2

DPPs are also being discussed by circular economists in order to create a circular economy by increasing transparency [59]. Similar to some circularity efforts mentioned in Section 5.3, DPPs can aid in giving a standardized view of a product's life cycle. Some of the efforts mentioned in Section 5.3 have a similar goal of informing consumers about a product's life cycle, but the idea of a DPP is that it is used throughout all aspects of the supply chain. It is currently known that the data will be displayed in a digital document, however, what data is necessary to fuel a circular economy within the fashion industry is unknown. The remainder of Section 6 dives into how the data within a passport can increase circularity, and what data needs to be present to do so.

First, it is important to determine what the requirements of a DPP are within the fashion industry. A literature review done by Jansen et al. [25] describes the basic requirements for a DPP. The first requirement mentioned has to do with legal obligations, and mainly discusses complying with the General Data Protection Regulation, among other laws. Functional suitability is also mentioned as an important requirement. Some important examples include allowing individuals to only add data for which they are responsible for to the passport, and enabling the collection of data for the passport. Security, interoperability, and modifiability are also important considerations. Lastly, availability and portability are crucial in allowing a DPP to function as intended. Availability means ensuring the data is available at the right time, and portability has to do with assuring product identifiers can be used between varying systems [25].

Though these requirements are useful, they remain quite broad and do not give insight into any particular industry. Certain aspects of these requirements, such as ensuring functional suitability, will not be looked at within the remainder of this paper. This paper

determines what data is necessary to create circularity through a DPP, but not specifically how this data will be collected.

6.1 DPP for Supply Chain

In order to determine the data necessary to fuel circularity within the supply chain, each step in the supply chain is dissected in this section, starting with the collection of raw materials at the beginning of the supply chain. Additionally, the responses given by a circular economy expert working at a large fashion company are included to support the literature review. Said expert will further be referred to as Participant 1.

The location where raw materials are collected for fibers, as well as where synthetic and natural fibers are produced is important for the supply chain. Because the fibers created at the beginning of the supply chain make up the fabric produced for clothes [64], the materials used for the fibers have an impact on the quality of the products made. Ensuring quality is difficult for companies who outsource due to the production process being far away [53]. As the quality of mass produced clothing is often low [54], and lower quality clothing is more difficult to reuse or recycle [15], it is crucial for companies to understand which fibers are of higher quality. Documenting this within a DPP can give companies an idea about which fibers and producers should be used in order to produce higher quality clothing with a longer life cycle.

During the fabric production part of the supply chain, the fibers used in creating the fabric need to be documented as well because this can help with recycling efforts. Currently, the lack of recycling is mainly as a result of the fact that the costs to adequately recycle outweigh the benefit of having the recycled materials. Additionally, there is no technology to separate the different fibers of the fabric [41]. Though this technology is not present, being able to track exactly which fibers are in which garments makes it easier to recycle once the adequate technology is developed. Fiber usage is crucial for companies to create circularity. Participant 1 explained that "we have low traceability into the supply chain. I believe we currently are even unsure about the robustness of data collection relating to overall fiber usage." Including fiber and fabric usage in DPPs will allow companies to understand their products better, and how to ultimately reuse or recycle them.

Next, the manufacturing step in the supply chain is relevant as it is one of the steps which produces the most waste. When designs are created for various articles of clothing, the scraps and leftover fabric is currently not reused but rather discarded [18]. For the sake of the supply chain, it would be useful to add which leftover scraps are produced by a certain product. This is helpful because it can demonstrate which scraps produced by a certain piece of clothing can be reused if it is documented which scraps are present. Therefore it is also crucial to have documented the fibers used for fabric production, as scraps can again be reused based on the fibers they contain.

Furthermore, Participant 1 went on to explain that some information is collected about individual products at their company, but that the extent to which this information is accurate is unknown. Participant 1 explains that collecting information about individual products

would be very beneficial. They state that storing information about individual products “would allow us to understand how much of each fiber type we’re using, what packaging is on each product, and how many garments we have in a store at a certain time. I’ve heard anecdotally that we only know about 40% of what is in our stores at any time.” Tracking individual products is a way for companies to understand what happens to their products. Being unaware of what is in a company’s stores at any given time makes it difficult to ensure products can be reused and recycled to the fullest extent.

Not only is tracking useful for a company’s own records, but Participant 1 mentioned that “[They work] on circularity efforts in [the] company and the easier it is to share information with textile recyclers, resalers, and downcyclers, the easier it will be to partner with them and adhere to potential regulator requirements.” DPPs make it easy for companies to share information, and can increase not only sustainability through implementation, but also efficiency.

Many companies focusing on the linear supply chain are losing a substantial amount of money by not focusing on utilizing customer returns [17]. Many companies do not monitor returns and throw out products which were returned with a slight defect or missing part because they do not have the tools to quickly fix such errors. Companies would be able to generate much more revenue if they focused on reutilizing returned products rather than counting them as loss [17]. In order to track returns and to understand why products are returned often, data about returns can be placed in DPPs to give companies insight. If better tracking happens and companies understand why products are being returned, it also becomes easier to implement practices which focus on being able to refurbish or reuse products.

6.2 Company Willingness

Though these circularity practices mentioned in Section 6.1 can be implemented with a shift in business practices, many businesses have the ability to act more sustainably but do not. The biggest reason for this is because companies will make decisions based on what generates the highest revenue. Producing sustainably is more expensive in comparison to producing unsustainably, and changing business processes is costly as well.

Therefore a money-driven incentive could cause companies to enable a circular economy. In a study done by Moretto & Macchion [39], drivers and barriers for implementing blockchain technology to help create transparency are researched. The participating companies discuss incentives to adopt circularity increasing technology. The two most common drivers which motivate companies to increase transparency were found to be consumer desires and increased efficiency within business processes because they can have a large impact on a company’s revenue [39]. Increasing efficiency can cut costs for companies, and similarly, keeping consumers satisfied is key in generating revenue [55].

Since more and more consumers are becoming aware of unsustainable practices, there is a growth in consumers wanting sustainable apparel [47]. Though many are still ill-informed, many customers becoming more and more dedicated to living and purchasing sustainably will in the future not want to purchase from companies

who lack transparency. Therefore, one way to push companies to be sustainable is through informing customers about a lack of sustainability [47]. This is effective because customers informed about sustainability, or a lack thereof, when it comes to apparel manufacturing are more likely to buy the sustainable option [13, 47].

Not all companies will be pushed by consumer desires. When discussing what would be necessary for DPPs to be implemented at their company, Participant 1 suggests that transparency about the costs of implementation is necessary, as well as aid with implementation. More importantly, Participant 1 suggests that DPPs would likely need to become a law or legislation for the lower end brands of their company to implement them. Though there are more and more consumers wanting to support sustainable businesses, larger companies might not be motivated by consumer desires. Participant 1 mentions that from a sustainability perspective, the company would implement DPPs, however, not from a business perspective due to the costs. They enlighten that “[the company] has an enormous amount of units (900M), many of which when they’re designed, [take] every cent into consideration.”

Furthermore, Participant 1 elaborates that though their company references sustainability, the sustainability team’s budget is constantly being cut. The majority of projects being funded are ones that have a big impact on the company’s reputation. Ambitious goals are being set, however, there is little emphasis on meeting the goals. This suggests the company is mentioning sustainability mainly for the approval of the public. When asked how motivated their company is to increase sustainability within its business processes, Participant 1 says the company is “seemingly unmotivated by how small our team is and how little assistance we get financially.” Not only are costs important to big fashion brands, but their reputation also comes into play. Participant 1 discusses that making data about the company’s business and supply chain processes readily available to the public is a risk because “any shared data that can open us up to scrutiny could be seen as a risk by our company.” Companies with practices that are unsustainable might be damaged more by a bad reputation when increasing transparency, than by losing customers because of the lack of data on sustainability provided. Participant 1 mentions that sharing data within DPPs is a significant concern for the company because sustainability claims have a huge influence on a company’s reputation.

Another consideration, however, is competition. Of the companies which are looking at implementing DPPs, many want to be the first in the market so as to beat competitors [7]. Participant 1 also explains that if resellers start to work solely with brands who use DPPs, this could be a huge threat in terms of competition. This is a consideration for companies who are currently not partaking in working towards transparency.

Alternatively, making the implementation of DPPs a legal requirement is another way to ensure companies act more sustainable, as it would mean currently private data will have to be made available to consumers. Should DPPs become a regulation, the data in Section 6.3 should be included in a DPP for consumers, in order to fuel companies to increase circularity.

6.3 DPP for Consumers

Studies show that consumers are more likely to buy products if they have been made sustainably [13, 38]. Many consumers are ill-informed about the environmental consequences of their purchasing decisions, and are often unaware of sustainability when buying apparel. Therefore, it is crucial that customers are informed about the level of sustainability of clothes. Only then are customers prone to choose the more sustainable option [48].

In order to ensure that companies start to create a circular economy, the following information should be included in a DPP and made available to the consumer. Should this information be included in a DPP, studies show consumers will be more willing to purchase sustainable apparel [38]. If consumers are well informed about sustainability, or the lack thereof, their purchasing decisions can be influenced. This is useful because if consumers opt for the more sustainable option, companies with unsustainable practices will likely need to alter their processes to become more circular, unless they can generate enough revenue from consumers who do not choose based on sustainability level.

Some elements of the passport which are useful for actors of the supply chain are also useful for the DPP of the consumer. The location where the materials are produced and the materials out of which a garment is made should be a standard piece of data included in the DPP. Most clothing websites include this information already. The main reason the materials are important are for health reasons, however, also because consumers are more prone to buy something if it has been organically made [20].

Next, the amount of waste produced when manufacturing a product should be included, so consumers understand the waste created when purchasing a single product. This is helpful because when informed about waste, some customers will be motivated to choose the more sustainable option [13, 47]. Likewise, the amounts of pollutants and chemicals released should be displayed. This data should be displayed for the entire life cycle of a product, therefore showing pollutants and chemicals released during manufacturing as well as transportation, in order to give a complete overview.

Stimulating a circular supply chain cannot simply be for the supply chain actors. In order for a full circular supply chain to occur, customers must also ensure their unwanted clothes do not end up in the landfill. Many consumers do not understand the amount of waste and pollutants their clothes cause, and neither do they understand the environmental damage they cause when disposing of clothes [27, 48].

It would be useful to add information about whether or not an article of clothing is second-hand or new. Promoting second-hand clothing encourages consumers to reuse post-consumer apparel. Recycling is an option, however it is much more expensive than reusing clothing, and as stated earlier, not the most effective. Research by Watson et al. [60] has shown that re-use is much more effective than recycling when it comes to circularity. Adding information about the environmental effect of discarding clothes, or reusing them, is therefore important.

A study done by Diddi et al. [13] about sustainable clothing consumption behaviors mentioned that many people justify buying

new clothes by bringing many old clothes to second-hand stores or repurposing organizations. This is not efficient, as many repurposing organizations have become the new landfills [9]. They receive so many clothes that stores are unable to sell many of the clothes due to the constant donations. At Goodwill, a repurposing store in the United States, clothes are only available for purchase for a few weeks before new donated items are hung up. This is due to the sheer amount of items being brought to their collection sites. Many of the clothes do not sell, however, leaving Goodwill responsible to discard them [19]. Customers need to be aware of the repercussions their behaviors have, and therefore the environmental repercussions of discarding clothes should be added to DPPs.

Though transparency is likely to fuel consumers to purchase from sustainable brands, a study by Rausch & Kopplin [48] mentioned that consumers are concerned about greenwashing, and that questions about the legitimacy of the information regarding sustainability can be an issue [48]. In order to provide accurate information, it is also crucial to evaluate potential greenwashing and false information so consumers do not doubt the legitimacy of DPPs.

7 FINDINGS ON RESEARCH QUESTION 3

In order to ensure the information provided in a DPP is truthful, cybersecurity measures must be put in place. There are several large threats regarding DPPs and cybersecurity. Though the manner in which DPPs can be implemented is currently unclear, there are several options being discussed.

Companies must be able to track their products in order to increase transparency. One manner in which this can occur is through DNA tracing or nanotechnology. This means that raw fibers are tagged, and can therefore be tracked throughout the entirety of the supply chain [1]. Though this sounds useful to the company, allowing such tagging can lead to security issues.

As a consumer will become part of the circularity process, it is crucial that the consumer maintains anonymity throughout the process. If a consumer's data becomes traceable through the technology used by DPPs, this can be a threat to their safety [10].

With any digital technology comes the risk of various cyberattacks. One important thing for DPPs is to prevent the possibility of altering, deleting, or collecting of records through cyberattacks [10]. Attacks could be done by an outside individual with malicious intent, or by companies who would like to keep their lack of sustainability hidden. For various actors to use DPPs around the globe, one single database containing all of data mentioned in Section 6 is necessary. The use of blockchain technology to accomplish the storing of data to create a circular economy is being discussed by experts. Blockchain can connect all actors of the supply chain, and any data which needs to be present in a DPP can be stored with the help of blockchain technology [21]. The benefits of using blockchain for DPPs is that once data is uploaded, it cannot be altered or tampered with. This is extremely important, as false information in a DPP defeats the purpose of a DPP. One important thing to note is that any data uploaded into the blockchain network is not necessarily accurate. If inaccurate data is uploaded, the individual responsible for this can be held accountable as blockchain technology ensures whoever

inputs the data signs cryptographically [21]. To understand how blockchain can fuel the implementation of DPPs it is crucial to first understand what the building blocks of blockchain are.

7.1 Building Blocks of Blockchain

Blockchain can be defined as a technology consisting of many blocks containing a time-stamp, a hash, data, and another hash of a previous block [51]. By linking each new block with the hash of the previous block, a chain is created.

One important building block of blockchain is the peer-to-peer (P2P) network. The P2P network ensures that anyone can join the network. There are two different types of nodes, namely miners and regular users. The miners are the nodes which verify and create new blocks based on transactions. The user nodes are the ones performing the transactions [63].

This P2P network leads to another important building block of blockchain called “proof of work”. Proof of work ensures security within blockchain technology by forcing the addition of new blocks to be verified. Firstly, miners must compete with each other to find the correct hash in order to add a block to the blockchain network. Whichever miner finds the correct hash first will create a new block, however, this block must also be declared to all other miners who first verify if the hash is correct. Once verified, the other miners also add this block to their version of the blockchain [45]. This is crucial because it makes it difficult for miners to edit the block once it has been added. Because all of the blocks contain the hash of the previous block, altering a block means all of the blocks linked in the blockchain after must change the hashes of the previous block. Due to the proof of work system, it means other miners must also agree on the change [51]. The chance is small that the majority of the miners on the network will agree to change the data in a block if it is being tampered with, however, not zero.

Being very difficult to alter data once added to the network makes blockchain a great option for DPPs because valid data is crucial in ensuring the usefulness of DPPs. The less useful aspect of a P2P network for DPPs is that anyone is able to join the network. It is necessary that only companies and actors of the supply chain are able to add data about their own processes. Customers should only be able to view this information, while staying anonymous.

This leads to another important building block of blockchain, namely cryptography. According to Saraji [51], Cryptography allows for anonymity within blockchain through public key cryptography. Public key cryptography entails that key pairs are used. Each owner has their own individual private key, which no other users should have access to. Additionally, there is a public key which can be given to any individual as it is impossible to derive the private key from the public key. The opposite, deriving the public key from the private key, is possible. This is essential because if data is encrypted using a public key, only the individual with the private key can access the data. Similarly, if an individual encrypts a message using a private key, anyone with the public key can access the message. This is very useful for DPPs as it can ensure there are different access levels for different users. Since varying information will be

displayed in a DPP for the supply chain actors and the consumers, both can be given different keys, and therefore access varying data.

Allowing an individual to encrypt a message with a private key, and therefore allowing those with the corresponding public key to decrypt the message, ensures the individual with the private key places a so-called digital signature [51]. This signature is crucial for DPPs because it is important to verify whether data is coming from the right source.

7.2 Anonymity

Though public key cryptography provides a digital signature, there remains the problem that blockchain technology keeps the identity of the user anonymous. The digital signature can be traced back to a private key, but not to a specific individual. Each user can be linked to a public address, however, this address is in no way linked to a user’s real identity [45]. For DPPs, it is crucial that the company which adds data about the supply chain can be verified, and that their identity is known so individuals can determine whether the information is coming from the company itself. It would not be beneficial if any individual could add data for or about a given company. This is difficult with traditional blockchain technology due to the P2P network.

Since blockchain is being discussed in many different sectors as a way to simply store information securely, banks and other institutions also realized the problem of anonymity as they need to be able to trace data back to specific customers. This has resulted in the creation of the permissioned ledger [45].

7.3 Permissioned and Consortium Blockchains

A permissioned ledger entails that the identity of miners is established. Additionally, data can be accessed by a chosen group of individuals. This system diminishes the requirement of proof-of-work for blockchains [45]. Permissioned blockchains therefore do require the network to be controlled by one entity [36].

There are several problems with permissioned blockchains that are relevant for DPPs. Firstly, because there is one entity in control of the permissioned blockchain, said entity can change the data in any manner. The permissioned blockchain prevents the concept of fairness [63]. Additionally, it is argued to be worse than having a permissionless blockchain with no proof-of-work. This is because without proof-of-work a user can edit his/her own transactions, but not those of others. A permissioned blockchain allows the entity in charge to alter all data. This could be a potential threat if the authority in charge is corrupt [63].

Next, with one entity in charge it cannot be proved that the data has not been tampered with. The aspect of trust is very important for DPPs because consumers can be skeptical about the origins of the data. Having one entity in charge makes it difficult to prove the data has not been altered.

Permissioned blockchains are suggested to be implemented when there is already a sense of trust between participants [45], however, given the many actors and complexity of the fashion industry, it is difficult to ensure trust between all parties.

Permissioned blockchains pose the problem of one entity needing to control the network, but there is another form of blockchain called a consortium blockchain. A consortium blockchain is similar to a permissioned blockchain, except there are multiple entities controlling the network [28]. An option for DPPs would be to allow the companies to control the network, however this could lead to a lack of trust from consumers as the companies would be able to alter data as they see fit. Additionally, in order for consortium blockchains to work, there must be a sense of trust between the parties in control. Research by van Deventer et al. [58] shows that governing a blockchain with multiple entities is very difficult, and this could be a potential cause for concern when implementing DPPs. Asking competitors within the fashion industry to work together to implement blockchain for DPPs could cause problems when it comes to determining control within a consortium blockchain.

Though no solution is perfect, blockchain technology is promising for DPPs if solutions to these problems are created.

8 CONCLUSION

Creating a circular supply chain within the fashion industry is crucial due to the negative impact fashion has on the environment. This research evaluated how the data within digital product passports (DPPs) can fuel a circular economy.

Through literature review and an interview with an expert in the field of circular economy, this research determined what data needs to be present in a DPP to fuel circularity. It was concluded that there should be a different DPP for actors of the supply chain, and for consumers.

Data in DPP for Supply Chain	Importance
Location of Collection of Raw Materials	To understand the relation between materials used for fibers and quality of clothes produced
Fiber Usage	The fibers contained in fabric are needed to understand how clothes can later be recycled
Fabric Used for Production	Documenting which fabric is used is also important to be able to recycle or reuse clothes
Scraps Generated	The scraps generated helps designers understand how to reuse scraps for other clothing produced
Return (yes/no)	Helps companies understand the amount of returns being made
Reason for Return (if applicable)	Draws a connection between fibers/fabric used and the impact on returns. Additionally helps companies understand what is necessary to reuse returned products

Fig. 2. DPP for Supply Chain

Figure 2 exhibits the data which should be present in a DPP for supply chain actors, as well the importance of each piece of data. Ultimately, this data will help actors in the supply chain make their processes circular. This data also gives companies insight into their products and helps them understand which processes are currently inefficient and unsustainable.

It was also determined that larger companies will not be willing to implement DPPs due to the costs of implementation. As a result, this research concludes that there needs to be a law which mandates a separate DPP for consumers, in order to fuel circularity.

Data in DPP for Consumer	Importance
Materials	This is important for health reasons, and to inform consumers about which clothing is organically produced
Location and Method of Production	This helps customers know if clothes have been ethically produced
Amount of Waste Produced	Helps consumers gauge the impact their purchase has on the environment, and hopefully fuels them to choose the option with less waste
Amount of Pollutants & Chemicals	Helps consumers gauge the impact their purchase has on the environment, and hopefully fuels them to choose the option with less pollution and harmful chemicals released
Status of Clothing (New, Second-hand, Recycled)	Helps consumers choose the more sustainable option, and fuels customers to refrain from throwing away apparel

Fig. 3. DPP for Consumer

Figure 3 presents the data which should be included in DPPs for consumers. The above data will increase transparency and inform consumers about the effect the product they are considering to purchase has on the environment. Many consumers are more likely to buy the sustainable option, and the transparency DPPs will give can help consumers make informed decisions. This transparency should fuel companies to increase sustainability due to the fact that they will likely lose customers if their practices are unsustainable. Some consumers are concerned about the legitimacy of information regarding sustainability, and therefore the use of blockchain for DPPs was also researched. It is concluded that a permissionless blockchain is potentially not useful for DPPs. This is because the data stored in a DPP should be accessible by consumers, however, consumers should not be able to add data about certain supply chain processes such as production. Since anyone can become a miner in a permissionless blockchain, this is not a favorable option for DPPs as it would allow consumers to also add data about these processes. Additionally, the anonymity in a permissionless blockchain is an issue because it should be verifiable if the data added about specific supply chain processes are added by an individual of the company itself. If a permissioned blockchain is used, it poses the issue that one entity must be in charge, and therefore can alter all data without being held accountable. This could potentially make DPPs ineffective because each company should be held accountable for the data that is presented about their company. Lastly, a consortium blockchain also poses the issue that multiple entities would need to control the network. This could potentially lead to conflict among entities and a lack of trust among consumers about the legitimacy of data.

9 DISCUSSION

The data which should be present in DPPs in the fashion industry has been identified through this research, however, it remains unclear how this data could best be collected. Further research could entail looking at which technologies are necessary to implement DPPs efficiently. Additionally, future work could include research about technology to handle recycling and returns within the fashion industry. Furthermore, a suitable solution to the problems identified about the use of blockchain could be evaluated.

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