Aalto University
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and Architecture

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TRANSPARENCY AND TRACEABILITY
in the textile value chain

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Executive Summary

Current value chains are networks that work in a global environment. They generally consist of manufacturers, suppliers, logistics companies, and retailers working together to deliver products or services to consumers. With the expansion of modern supply chains, they become more complex. Textile and apparel value chains are no exception. In their supply chain operations, raw materials are transformed into finished textile products or garments at several manufacturing sites and processes before reaching the retailers. The complexity of this value chain makes it hard to track and trace the product from its origin till the end, while the rapid nature of the chain makes its production and consumption practices unsustainable, negatively impacting climate change, pollution, and biodiversity (triple planetary crisis). In addition, the opaqueness of the value chains leads to operational difficulties for the businesses as more demanding rules are being devised for the sustainable operability of the value chains.

Textile supply chains traditionally use paper-based and fragmented data systems that work in silos. In this type of system, tracking products is not efficient. The data is typically available, with difficulty, from Tier 1 actors only. In addition, lack of traceability and transparency is a common challenge across the whole industry that is causing delays, errors and increased costs. Today, there is a need for linear textile value chains to become circular and sustainable. Data availability, transparency, and traceability are crucial for this transformation of these value chains. While tracking follows the products across the supply chain from the start to the end and hence can be identified, tracing means that the product's origin and its ingredients can be identified. The actors in the value chain need a common understanding of the needed data and its format, without jeopardizing independent and privately verified transactions such as production and transport updates.

To function sustainably and to be transparent, the actors also require relevant and accurate information (which is derived from data) about the supply chains made available for all value chain elements in a harmonised manner,

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allowing for common understanding, accessibility, clarity and comparison. Hence, data can act as a catalyst for sustainability in the value chain, and by integrating data into their planning, merchandising, and other value chain activities textile and apparel companies and brands can see tangible results and improve supply chain visibility. However, most of the data in the textile value chain is still being managed using outdated, inefficient analogue systems, distributed across emails, spreadsheets, and paper records. This is one of the major reasons why textile and apparel value chains are facing a hard time tracking and tracing their raw material and products, in addition to several processes in the value chain. There have been several traceability pilots using different technologies at tracing and transparency technology providers together with frontrunner brands, but it is challenging to get these systems economically profitable.

There are numerous challenges when it comes to employing data. It is often challenging for the value chain to decide the key focus areas, to find where the data is available, which data is needed, which data needs to be shared with whom, and how can it be integrated into the business activities to get sustainable and financial benefits. In addition, there are size, process and management challenges. Even if a business can recognise its data needs and can locate the best technology, the large volume and variety of data are difficult to handle. Furthermore, there are next to no data standards being followed across the industry while capturing, storing, and managing this data. Data standards are critical for managing the vast amount of data generated and used across the industry. The use of data standards in the textile and apparel value chain will bring standardisation to data collection and use and improve the reliability of the data, which is a key aspect in bringing transparency and traceability into the value chain.

Recently, the European Union has also highlighted the importance of increasing user data security and privacy. The data protection laws together with the lack of appropriate data collection and storage methods have increased the need for industry-wide data standards, which could help businesses keep track of the data they use and generate.

> **“It is not possible to be sustainable without transparency.”**
>
> Amit Guatam,
> CEO of TextileGenesis

In addition to various new data and other policies, there are several tools and technologies available and in development that could prove to be fruitful in supporting businesses with not only efficient data management across the supply chain but also improving traceability and transparency. This report introduces data carriers, data storage and data sharing and communication technologies and technology providers. However, even with the most sophisticated data collecting and storing technologies, data is only as accurate as the data that is fed into the system. Hence, it is equally important to train and skill human resources along the journey. There is a need for skilled human resources to undergo the various stages of data processing and management. The skilled human resource must be an expert in the field of data science, but also have enough sector specific knowledge to be able to drive insights from the data. In practice, there is often a need for an analytics translator, who can translate the managerial requirements into technical ones and vice-a-versa.

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This report was produced using information from company websites and social media, blog posts, reports by European Commission and United Nation, expert interviews and scientific articles and books. In this regard, the authors of this report try to give a concise description of the data that is generated across the value chain, and the tools and technologies that can help the value chain to promote traceability, transparency and sustainability in textile and apparel value chains. This report aims to give the reader an understanding of the overall topic with a lot of links for additional reading. It also contains discussions about the challenges that the textile and value chains face with data and the importance and urgency of bringing traceability and transparency to the textile and apparel value chain.

1.

Introduction to textile and apparel value chains

A textile and apparel value chain is one of the most important customer commodity industries with long linear supply chains. They are considered to be among the most polluting industries globally (Niinimäki et al., 2020; Virta and Räisänen, 2021). The textiles sector contributes to 8–10% of global climate change (Quantis, 2018; UNFCCC, 2018). For example, garment manufacturing requires large amounts of water and energy in fibres and textile production. Pollution and vast land use are additional problems. Without proper treatment before discharge, wet processing wastewater contains harmful chemicals that can contaminate exhaust air, wastewater, and the fabric itself, causing severe ecological damage. Moreover, the overproduction and overconsumption of apparel products have led to a massive load on landfills. All these reasons and more make it critical to understand, evaluate, and reform the functioning of this value chain with the help of new technologies and digitalisation.

1.1. Supply chains and value chains

Whenever a value chain is discussed, it is often confused with a supply chain. In a supply chain, companies and their suppliers are in a relationship in complex way. The supply chain represents the steps taken from raw materials, yarn and fabric production to distribution to get the product or service to market. The primary attention of a supply chain is focused on the costs and efficiencies of supply along with the flow of materials coming from different sources to their final point of use in the supply chain. (Figure 1)

A value chain, as the name states, enables a company to create value beyond the traditional cost of providing its products or services to consumers. As Porter has defined it, in order to achieve a competitive advantage, organisational expertise in the critical values chain activities needs to be developed. (Porter, 1985) For the value chain to be prosperous, connections between consumer demand and what a company produces are desired. The main focus of the value chain is direction testing of products, innovation, research and development and marketing, i.e. it is the activities carried out by the company to maximise the competitive advantage. (Porter, 1985)

The main difference between a supply chain and a value chain is that instead of focusing on supply only in the supply chain, the focus of the value chain is in customers. Supply chains integrate supplier and producer processes to work together, improve efficiency and reduce waste, i.e. the focus is upstream. Conversely, value chains create value for and with the customer, i.e. the focus is downstream. (Porter, 1985; Tseng and Lin, 2005)

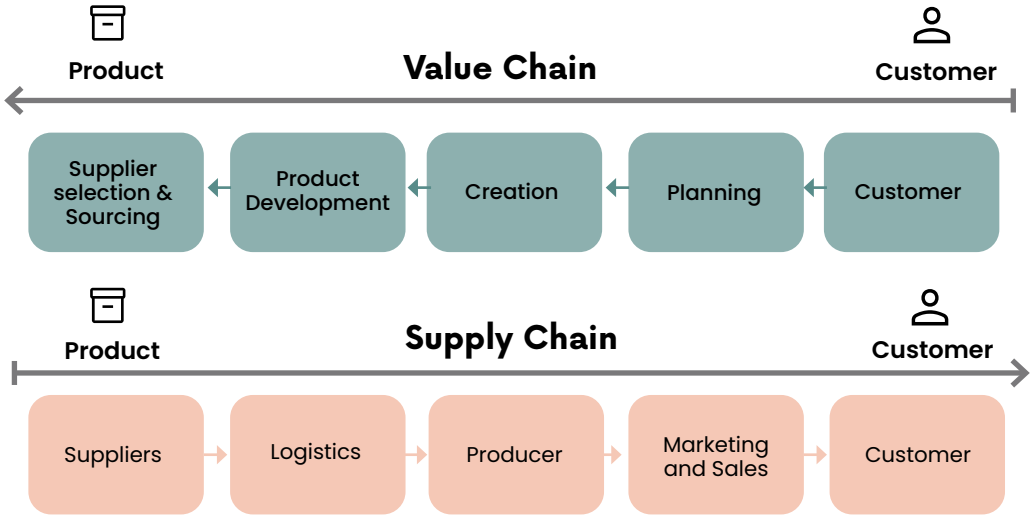


Figure 1. Textile supply chain vs value chain.

1.2. Textile and Apparel Value Chain

A textile and apparel value chain consists of the following main activities: design, production, marketing, distribution, and customer support (described in Figure 2). These supply chain activities operate through the following five factors which are typical for an apparel supply chain (Ariyatum and Holland, 2003):

1. Seasonal and fashion demands define a product development phase.
2. The purpose of the product development phase is to demonstrate a garment collection to potential customers.
3. The product development phase is always iterative.
4. Constant planning and development are very important due to short life cycle of the garments.
5. Retail buyers are the key decision-makers regarding the quality of fabric, style, colours, sizes, and manufacturing quality, as retail is intensively involved when designing new product development cycles (Gereffi and Memedovic, 2003).

Along with an ongoing transformation in the textile and apparel industry, retailers acknowledge and aim at the well organised flow of apparel from suppliers to shops to offer apparel products at the right time. Therefore, apparel retailers form alliances with their suppliers to succeed in competitive conditions. (Reinartz et al., 2019)

There are, however, challenges to overcome such large changes of processes, actions and mindset towards circularity. A considerable change in working habits, potentially sharing your trade secrets, in addition to at least some financial investment is required at the same time. These challenges are described in more detail in Section 2.5.

1.2.1. Important Stakeholders

As stated in the previous section, apparel supply chains consist of design, production, marketing, distribution, and customer support. They can be managed within a single company or together with several companies (Gereffi and Frederick, 2010). The designers, who typically work for retailers, define the product information, containing the type and design of garments, their technical specifications, sizes, the colourways of the garments to be produced, the type of fabric to be used, and the quantities of fabric and garments (Goworek, 2010). Based on the instructions from the designers, the garment manufacturers produce prototypes, at the same time exchanging information with the retailer. The fabric manufacturers follow the instructions from the designers to produce the required fabrics from specified yarns (Bruce and Daly, 2011). The approval for fabric is typically required much earlier in the process as enough time needs to be reserved for the mass production of fabrics. After the approval of the garment prototypes, production houses start production planning by defining instructions for pattern making, cutting, sewing, assembly, finishing, inspection, and packaging (Nayak and Padhye, 2015). One of the most important steps in the whole process is the pattern creation as it determines a template for the fabric cutter (Glock and Kunz, 2005). After cutting, the fabric pieces are sewn together using the specified yarn, trims, and accessories. Once the products are ready, they are delivered by distributors or logistic providers to different warehouses round the world according to the retail plans of companies (Nayak and Padhye, 2015). By then, the brand owner has created marketing plans and the produced garments can be sold through the brand's retail channels to customers (McCormick et al., 2014).

> “ The most important data for circular textiles is not accessible, inaccurate or simply doesn't exist.”
>
> Traci Kinden,
> TEXroad

Supply-end

This part of the supply chain is responsible for sourcing raw material and producing yarn, fabric and finally, the apparel.

Demand-end

This part of the supply chain is responsible for developing new products as per market demand, placing orders with suppliers and sourcing the end-product. It is also responsible for marketing and selling of the products through retail orders.

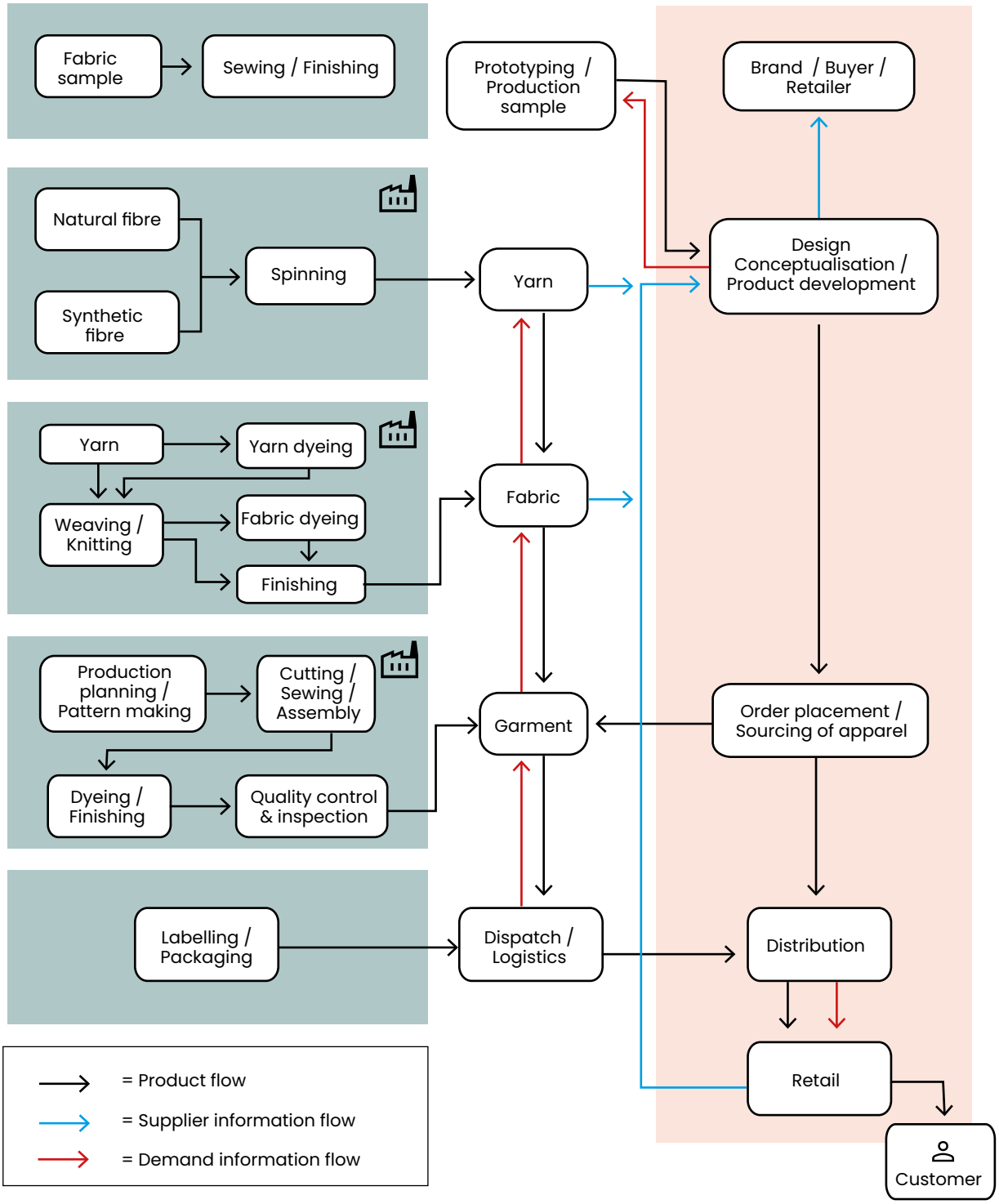


Figure 2. Apparel Value Chain (Jain, 2020, adapted from Mahmood and Kess, 2014).

1.2.2 Data-driven supply chains

Textile and apparel supply chains have no doubt created great social and economic value, but at the same time they have had negative effects on the environment (Akter et al., 2020). One of the main reasons is the culture of "fast fashion", as consumers can afford to buy great amounts of inexpensive garments leading to the ever growing amounts of textile waste (McNeill and Moore, 2015). Apparel brands and companies have reached the point where they have to think again how current value chains are organised and managed. A transformation towards a demand-driven value chains requires digital solutions to supply customer-centric products, but at the same time decrease the amount of textile waste being generated. If apparel companies want to fully understand and implement a demand-driven strategy, they need to rethink their ecosystems and realise the power of data in meeting customer demands and running efficient and effective operations. However, just like IT applications (Weill, Subramani and Broadbent, 2002; Sambamurthy, Bharadwaj and Grover, 2003), new digital technologies are not a guarantee for agility. Understanding of various technologies and their limitations, such as poor data quality, limited analytical expertise, infrastructure that will be needed to store and manage the data, and data security to improve the current business operations (Labrinidis and Jagadish, 2012; Sivarajah et al., 2017), are just some of many challenges also textile and apparel industry are facing in their digital transformation.

A well-managed data-driven supply chain can be a key enabler for apparel companies to become sustainable while maintaining their competitive advantage. A data-driven supply chain is not just about whether products and services are digital or physical. It is really about the way how value chain activities are organised and managed with a vast variety of innovative technologies such as big data analytics, artificial intelligence (AI), cloud computing, and internet of things (IoT). These techniques along with the help of data can help businesses function more sustainably (Ghoreishi, Bhandari and Franconi, 2022). In fact, it is stated that to enlighten practical sustainable circularity assessments, more data is needed (Palm, Cornell and Häyhä, 2021). There are ways in which data has helped companies in various important decisions related to the circular economy, like helping H&M with their packaging strategy to improve circular economy outcomes (Dragomir, 2022), and supporting IKEA to make broader environmental and social impacts by reducing their carbon footprint (De los Rios, 2017).

A circular textile and apparel value chain can create better products for customers, contributing to a resilient value chain, and regenerating the environment. It respects the rights and justice of all the stakeholders involved in the value chain. It can create many opportunities for distributed, diverse, and inclusive growth. It can help to build an industry where as a result of circular design, products can and will be used more time and longer, they are made to be remade, and they are produced from safe and recycled or renewable inputs.

2

Sustainability and circularity

- transparency and traceability

Sustainability is the balance between the environment, economy and equity. There are no exact rules or regulations about what industry should do in order to make its value chains and products sustainable. In addition, there is no clear definition of a sustainable product either. It often requires different concepts and metrics to measure a value chain sustainability. For instance, concepts and scientific targets like zero waste or net emissions have clearer stipulations. Circularity is another such concept that focuses on creating a product keeping in mind its end-of-life. Ideally, in a circular economy when a product is no longer in use, it must go back into the supply chain instead of ending up in the landfill. This, however, is difficult to achieve. There are numerous challenges that many industries face, for example, not being able to track the products throughout the supply chain as well as post-consumption, recognition of the materials used, and materials used in making products are often blends that are difficult re-circulate.

Transparency, in this regard, is deemed as a positive aspect of society as it enhances environmental and social policies and actions and sets a basis for good governance (Ebinger and Omondi, 2020). The traceability of a value chain is more than just simple mapping the supply chain. For instance, value stream maps are visual images of materials and information flows in a process. They are commonly used in the production process to eliminate non-value adding activities. Traceability tracks the origin and journey of products and their inputs, from the very start of the supply chain, through the whole supply chain, to end-use. With traceability tools and technologies, supply chain information of different process steps will be collected, stored and shared across the supply chain. Sharing the information in an appropriate format and content for different actors improves the transparency of a company's supply chain.

Both raw materials and ready-made products or components can be tracked and traced. Digital solutions can provide relevant supply chain actors, such as consumers and recyclers, the exact information that actors need to attain, use, maintain, repair, reuse or recycle a said product after its first lifetime. More complex and valuable products are considered to be worth tracking along their life cycles (Kauppila et al., 2022).

2.1. Introduction to terminology

The United Nations Economic Commission for Europe (UNECE), with its United Nations Centre for Trade Facilitation and e-Business (UN/CEFACT), have defined the key terms that are used in the context of traceability, transparency and sustainability. Some terminology, such as traceability, is standardized according to ISO 9000:2015[1]. The key terms are explained as follows:

Sustainability refers to an ability to support "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*", as stated in the United Nations Sustainable Development Goals. (United Nations, 2014) Sustainability in textile value chains means that "*all activities throughout a product's life cycle take their environmental, health, human rights and socioeconomic impacts into account, along with their continuous improvement*" (UNECE, 2020).

The circularity of a production process refers to "*this process's ability to retain the value of products, materials and resources in the economy for as long as possible and to minimize, to the extent possible, the generation of waste along all the steps of the value chain*" (European Commission, 2015). Circularity is often used as a synonym for a circular economy, but their meanings are not the same. **Circular economy**, by one definition, is "*a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops (…), achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling*" (Geissdoerfer et al., 2017). Circularity and actions related to circularity can be exercised at different phases in the lifecycle of a textile product, and the purpose could be for example resource flow minimisation or closing the loop of resources to enhance circular economy (Manickan et al., 2019). Ideally, circularity metrics should indicate how well the circular economy principles are applied to a product or a service. Circularity in textile value chains is currently a very active topic, and the recent EU Strategy of Sustainable and Circular Textiles by the European Union (European Commission, 2022) will further encourage and even demand to use of various circularity actions. According to the strategy, by 2030 all textiles in the EU market, i.e. the textile products sold in the EU, are long-lasting and recyclable, made as much as possible from recycled fibres, free of toxic chemicals, and produced in accordance with social and environmental standards. Upcoming EU legislation will bring much awaited measures and targets which will help companies to make their sustainability efforts more concrete. It is worth mentioning that circularity and circular economy actions are not necessarily sustainable by default. This has been brought up when criticising circularity metrics for not taking the systemic and multidisciplinary nature of the circular economy into consideration (Reike et al., 2018; Corona et al., 2019).

Traceability, by standard ISO 9000:2015, is "*the ability to trace the history, distribution, location, and application of products, parts, materials, and services*". In the context of textiles, it is defined as the ability to "*identify and trace the history, application, location and distribution of products, parts and materials to ensure the reliability of sustainability claims in the areas of human rights, labour (including health and safety), the environment and anti-corruption*" by United Nations (UN, 2014), and "*the process by which enterprises track materials and products and the conditions in which they were produced through the supply chain*" by OECD (OECD, 2018). Traceability is essential for creating transparency, but it is not a guarantee. Digital traceability refers to a system in which traceability data of a product is stored in a digital form. Physical traceability refers to different types of markers that can be embedded into fibres and fabrics and connect the physical and digital traceable assets (more about these in Section 3.1.1).

Tracking is often used as a synonym for tracing. Olsen and Borit (Olsen and Borit, 2013) have defined the difference between tracking and tracing based on which supply chain direction information flows: tracking is forward traceability, whereas tracing is backward traceability. This means that tracking follows the products across the supply chain from the beginning to the end and the products are identified. Tracing means that the product's *origin and its ingredients* can be identified.

1) ISO 9000:2015(En), Quality Management Systems—Fundamentals and Vocabulary. Available online: www.iso.org/obp/ui/#iso:std:iso:9000:ed-4:v1:en

Transparency is defined to be "relevant information about the supply chain which is made available for all elements of the value chain in a harmonised way, which allows for common understanding, accessibility, clarity and comparison" (Richero and Ferrigno, 2017). When supply chains are transparent, companies know what is happening upstream of the supply chain and this knowledge can be communicated to relevant stakeholders, one of them being consumers. Transparency information tells where, by whom, how with and what inputs and when the product was made. In addition, social and environmental policies are made available. Communication with all stakeholders is very important to make transparency a reality. For example, consumers are requesting more information about the origin of the products. In addition to getting reliable information in the first place, it is challenging to communicate this information to consumers in a user-friendly way and calls for less complex communication. This applies to all stakeholders, i.e. data and information needs to be transformed to an appropriate format for every actor.

Horizontal dimensions of supply chain traceability refer to the start and end points of the traceability in the supply chain. Full horizontal traceability means that it is exercised from the raw material to the end customers, and it can extend to reuse and recyclability of the products as well. Depending on the purpose of the traceability, i.e. if one wants to ensure product authenticity and/or sustainability, different parts of the supply chain are included in the traceability process. (Ahmed and MacCarthy, 2021)

Vertical dimensions of supply chain traceability refer to granularity levels of the traceability level in the supply chain. Granularity is defined by "different levels of traceable units and is determined by the size of the traceable unit and the number of the smallest traceable units necessary to make up the traceable unit at a specific level" (Karlsen et al., 2012). It is important to find the ideal and sufficient level of granularity for a said purpose as higher levels of granulation lead to higher costs and unnecessarily complex traceability solutions. For example, if 1000kg of cotton is used as a traceable token, it does not take a batch level or garment unit level into consideration since the physical product and digital tokens at these levels of granularity is not connected (Ahmed and MacCarthy, 2021). It may be very challenging to take the approach to the garment level in complex and high-volume apparel supply networks, and it calls for a strong commitment from all stakeholders in the value chain.

Chain of custody (CoC) verifies the path from the raw material input to the final product. It is chronological documentation of who handled the product, what did they do with it, and where they stored it. Authenticated purchase orders and delivery receipts are typical documents used. CoC is used for example to prove fibres are organically grown or recycled, or a raw material for man-made cellulosic fibres (MMCF) do not originate from endangered forests. Certifications, such as Content Claim Standard (CCS) by Textile Exchange, FSC by Forest Stewardship Council, or PEFC (Programme for the Endorsement of Forest Certification), assure them that all the steps of the supply chains have taken the necessary measures to track the raw material from the start point of the supply chain to the end product[2].

A unique identifier (ID) is typically used to retrieve information from a backend system/data platform which has been collected from a certain event happening in the value chain. It would be useful for all the stakeholders in the value chain if commonly agreed standards for both IDs and the format of the data to be exchanged were used, so they were inter-operational (the ability to exchange data with a minimum amount of transformation) and machine-readable. Unique identifiers are used to track and trace different traceable assets as they move along the value chain. The traceable asset can be material (for example, a bale of cotton, a batch of man-made cellulosic fibres or a batch of dyed fabric), a single product or a product batch, or a trade or a logistic unit, and their transformation (for example from cotton to yarn to fabric). For the physical identification of traceable objects, generally three main levels of identification can be distinguished[3]:

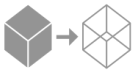
> ***Class-level identification:*** *the object is identifiable by its product/part ID which enables it to be distinguished from different kinds of products or parts*

2) www.textileexchange.org/standards/certification/what-is-chain-of-custody
3) www.gs1.org/docs/traceability/Global_Traceability_Standard.pdf

Batch/lot-level identification: *the product/part ID is extended with a batch/lot number which limits the number of traceable objects with the same ID to a smaller group of instances (for example, items produced at the same time)*

Instance-level identification: *the traceable object is identified with a serialised ID which limits the number of traceable objects with the same ID to one individual instance*

A process and production location also have a unique ID. A traceable asset's ID after the transformation process consists of the IDs of its inputs, which are all unique. It is important to carefully determine what information is collected and linked to unique IDs in order not to collect non-relevant data and avoid collecting already existing sources for the data. Risk-based analyses of the impacts of the value chain are a valuable tool to determine key data and the collection points in the value chain.



A digital twin [4] is a virtual representation and can be created for physical material or a product in traceability software. It stores information about the used materials and processes throughout the supply chain using real-time and historical data. It also provides verified information on where the materials come from, and how and where there were processed. The digital twin can also provide information about sustainability data. Regarding apparels, a digital twin can give each garment a unique digital fingerprint.[5] Use of digital twins gives all supply chain actors the possibility to trace the products during their whole lifetime, including resale and recycling.

Centralised, Decentralised and Distributed systems are different types of data storing systems, and there is a lack of consistency of their definitions and differences among actors[6]. The following definitions are by Berty Technologies[7]:

In a centralised system*, all users are in contact to one central network owner (server). The central owner stores data and user information, and other users can access it but not alter it. This user information can be for example user profiles, user-generated content, etc. A centralised system is easy to set up, can be developed quickly and is affordable to maintain. However, there are limitations associated with this system. If the server crashes, users will not be able to access data. The availability of the network depends on the owner since centralised systems involve a central owner to connect all other users and devices. As there is only one central server, access times are long for those ones that are far from the server. Centralised systems also have higher security and privacy risks for users.*

A decentralised system *does not involve one central owner. It uses multiple central owners, decentralising each central resource centre, i.e. each of these central storages stores a copy of data accessible to its users. These are systems are more resistant to faults, meaning if one central owner fails, others can continue to access the data. A server crash in a decentralised system can have an effect on the system performance by limiting access to certain data, but the system is still more reliable compared to centralised systems. Additionally, compared to centralised systems data access is comparatively faster as the owner can create nodes in different regions depending on activity. Decentralised systems are vulnerable to the same security and privacy risks to users as centralised systems but they are more fault tolerant. Running a decentralised system is generally more expensive, and, if not fully optimised, a system may cause inconsistent performance.*

A distributed system *uses a similar principle as a decentralised system as it does not include a sole central owner. In a distributed system, users have equal access to data but can enable user rights based on needs. These systems facilitate shared ownership of data among its users. Both hardware and software resources are also assigned amongst users, which in turn can improve the performance of the system. Distributed systems avoid independent failures of components, which can greatly improve their uptime. Due to the limitations of other systems, distributed systems have evolved. With ever-increasing security, data storage, and privacy concerns, as well as the constant performance improvement needs, distributed systems are considered to be the best choice to combat these issues. Hence, the technologies that use distributed systems, blockchain being maybe the most known example, are transforming many industries.*

4) www.digitaltwinconsortium.org/initiatives/the-definition-of-a-digital-twin
5) www.innovationintextiles.com/a-digital-twin-for-every-garment-in-the-world
6) www.medium.com/@VitalikButerin/the-meaning-of-decentralization-a0c92b76a274
7) www.berty.tech/blog/decentralized-distributed-centralized

Blockchain technology [8] is a record-keeping distributed technology intended to make it impossible to mishandle the system or fabricate the data stored in it, making it secure and immutable. To be exact, it is a Distributed Ledger Technology (DLT), which is a digital system that records transactions and related data at multiple locations simultaneously. Each processor in a blockchain network maintains a replica of the ledger to prevent a single point of failure, and all replicas are updated and validated simultaneously.

Blockchain is also regarded as a type of database but varies significantly from traditional databases in the way information is stored and managed. In traditional databases data is stored in rows, columns, tables, and files. Blockchains store data, as the name implies, in blocks that are digitally linked together. Blockchain is a decentralised database managed by computers that belong to a peer-to-peer network, which make it different compared to traditional databases. Each participant in the network can have access to a shared ledger that records all the transactions immutably and cryptographically, while there is no single owner of the network. Therefore, a blockchain is a database which is immutable (data cannot be modified and altered without other actors noticing the change) and creates a chain of custody. With regards to a textile supply chain, it can bring trust to all stakeholders, which is key for transparency. It has potential to solve many problems of authentication and the challenge of proving sustainability.

2.2. Transparency and Traceability in Textile Value chain

The global textile and apparel industry is going through a transformation as current production based on the fast fashion business model and consumption is causing severe environmental and social problems. The current textile and apparel supply chains are complex and opaque. More transparency along with traceability information on especially product origin, product content and production practices are required by consumers, industry, regulators, and policymakers. In addition to the high environmental impact, textile and apparel production is known for the concerns of social and sustainability issues. Overconsumption further increases the load of the environmental impact. Another reason for more transparency requirements is related to authentication to tackle counterfeit products, which is important for luxury brands with very high value products. Sustainable practices are expected to improve organisations' competitiveness and reputation.

According to (ISO 9000:2015), "*traceability is the ability to identify and trace the history, distribution, and location of products, materials, and services*". Traceability guidelines, voluntary and governmental, have been used for protection and security of products in different industry sectors, such as food industry and pharmacy (Virta and Räisänen, 2021). However, when it comes to the textile and apparel value chain, the regulations related to traceability are not very well established. There have been some regulations coming into effect in some countries related to the type of raw materials that can be used in manufacturing textile products. For instance, in France manufacturers or importers of textile products must either set up their own officially accredited collection and recycling program, or they are obliged to register with an accredited take-back system.[9]

Even though there has been a lack of momentum in the regulations related to sustainability, some brands have accepted their role in bringing transparency to the value chain. For instance, the Swedish brand ASKET has a full traceability mission, "*From farm to finish line*", in 2018 and they currently claim to be 93% traceable.[10] ASKET has a relatively small collection consisting of less than 40 products, but for this collection they have more than 600 processes and global locations to handle. Keeping this in mind, when we consider a fast fashion brand with thousands of products in every season, the number of processes

8) www.techtarget.com/searchcio/definition/blockchain
9) www.refashion.fr/pro/en/what-epr?
10) www.asket.com/fi/transparency/traceability

and the amount of accompanied production and post-consumption waste becomes a serious reason to worry. Identifying every step in every value chain for a fast fashion brand is regarded challenging, and this adds to the reluctance of the brands to move towards a transparent and circular chain. However, if identification and data collection are carried out during production by each actor themselves, it is possible with good management. If identification and data collection is carried out after the product is finished, it is definitely challenging.

The textile and apparel industry needs supply chain transparency, traceability, and sustainability to continue successful business in the increasingly challenging environment and requirements. Fibre producers face pressure as their actions and choices determine a great deal of the overall sustainability upstream of the supply chain. They need to have reliable processes and tools to ensure the origin and compositions of the fibres that are fed to the supply chain. In addition to fibre producers, spinners, fabric producers and garment designers and producers are all crucial actors to make sure product information is correct and reliably stored at each stage of the supply chain. Various tracking and tracing technologies are commercially available to make textile and apparel supply chains more transparent. Depending on whether the aim is to ensure authenticity, transparency, sustainability, recyclability, etc., tracking and tracing can start at different stages of the supply chain. Advanced technologies and digital solutions, such as blockchain technology, product passports and DNA markers, have been identified to support traceability systems when exchanging data between stakeholders (UNECE, 2020a). These actions and increased use of technologies and solutions is expected to considerably increase transparency for consumers, businesses, regulators, and investors. However, it is good to keep in mind that the highest technology solutions are not always needed, and a technology solution to be used should be chosen according to the purpose. Complex supply chains produce vast amounts of data and the danger of information overload is present if the data is not analysed. Lack of technology knowledge and availability can be a bottleneck. Technical solutions of traceability and transparency and their providers are presented in more detail in Section 3.

Photo by Derick McKinney on Unsplash

2.3. Data in the value chain

The transparency of textile supply chains is seen as a must for sustainability. Quality data is regarded as one of the fundamental factors to attain transparency, but transparency alone does not guarantee sustainability. It is estimated that 95% of supply chain information is typically recorded on outdated, inefficient analogue systems, distributed via e-mails, Excel spreadsheets and paper records (TrusTrace, 2022). The technology level and cost of the traceability tools and technologies vary, and some of them are specific to certain textiles and fibres. Technologies currently in use, such as barcodes, QR (quick response) codes, NFC (near field communication) chips, and RFID (radio frequency identification) tags are data carriers that can be used to collect and share various data on the products and services throughout the supply chain. A drawback of these physical tags is that they are often deactivated at the point of sale or removed by customers, and consumers cannot add data in a use phase. In addition, recyclers do not want physical data carriers in their recycling processes as they can cause damage to their equipment or interfere with their chemical processes. Companies use various ERP (enterprise resource planning) and PLM (product lifecycle management) systems for managing their production. However, these conventional information systems are not necessarily compatible for reliable traceability data collection, and they are typically originally targeted for internal use. Blockchain-based technologies have been suggested to be the silver bullet for trustworthy supply chain traceability. Many blockchain pilots have been carried out in the textile and apparel industry, and they are mainly concentrated on the authenticity and sustainability of apparel products. (Examples of these blockchain pilots can be found in Table 1 in the article by Ahmed and MacCarthy, 2021). There are some concerns of using blockchain, such as the high energy consumption of the blockchain transaction systems and accessibility in developing countries where the upstreams of textile supply chains are typically located (UNECE, 2020a; Ahmed and MacCarthy, 2021).

There is a strong interrelation between circular economy and how to apply cutting-edge technologies to business operations. The different business operations create all kinds of data. This data has become a new commodity for businesses and individuals. Similarly, the various activities performed in the textile and apparel value chain described in Section 1.2 generate data and require data for efficient business processes.

Most of this data in the textile value chain is still being managed using outdated, inefficient analogue systems, distributed across emails, spreadsheets, and paper records, or sometimes the data does not even exist. This is one of the major reasons why this value chain is facing a hard time in tracking and tracing its raw material and products, in addition to the number of processes in the value chain. Moreover, there are next to no data standards being followed across the industry while capturing, storing, and managing this data. There are PLM and ERP systems, but those are internal to an organisation and are mostly used by merchandisers to track sales and orders. This adds to the fuel when many retailers and other stakeholders in the value chain are being held accountable for creating an adverse environmental impact, and they have no records to help them identify, measure, evaluate and improve their unsustainable practices.

Table 1. Data generated across the textile and apparel value chain.

Value Chain Processes	Data Generated	Data used by
Product development and design	Market research, trends, trade shows, fashion shows, sketches, photographs, fashion magazines, fabric swatches, garment samples	Textile designers, fashion designers, trend forecasters, product development unit
Sourcing	Fibre inventory, fabric inventory, trims and accessories, chemicals, dyestuff	Vendor managers, merchandisers, warehouses, production planners, inventory managers
Fibre and yarn manufacturing	Fibre type data, spinning data, dyeing, yarn production volumes, inspection data, price trends, energy and water consumption	Production planners, costing department, textile designers, auditors
Fabric manufacturing	Spinning, weaving, knitting, fabric technical properties, energy and water consumption	Production planners, textile designers, product developers
Apparel manufacturing	Patterns, production planning data, cutting data, sewing data, finishing data, inspection data, packaging data	Production planners, inventory managers, auditors, logistics unit
Distribution	Warehouse inventory data, logistics data	Logistics unit, inventory managers, retailers
Retail	Transaction data, sales data, point of sales data, social media data, price trends	Retailers, data analysts, business analysts, marketing unit
Customer	Style preferences, shopping behaviour, garment requirements, size data	Trend forecasters, data analysts, retailers, product developers

2.4. Data standards

The EU has given utmost importance to increasing user data security and privacy. With the launch of the General Data Protection Regulation (GDPR)[11] in 2018, they provided the user power to protect their personal data. In order to comply with GDPR, businesses must commit to several rules, such as robust consent requirements, privacy by design, and mandatory breach notifications. The law gives more rights to users to access and control their own data in various systems, including data portability and the "*right to be forgotten*". This also affected the textile and apparel value chain, as it is the most trend-driven industry that requires user data at various stages of its chain. It also increased the need for industry wide data standards, that could help businesses keep track of the data they use and generate. A data standard is "*a technical specification that describes how data should be stored or exchanged for the consistent collection and interoperability of that data across different systems, sources, and users*". Data standards are typically a collection of different data standard components. More comprehensive data standards package can contain multiple components and they can be used for numerous different purposes. The instances of these data standards are further discussed in Section 3.1.3.

These data standards are critical for managing the vast amount of data generated and used across the industry. The use of data standards in the textile and apparel value chain will not only bring standardisation to data collection and use but also improve the reliability of the data.

2.5. Challenges of transparency and traceability

The transformation from linear to circular comes with both benefits and challenges. In the last few sections, the importance, and benefits of adopting and implementing traceability systems towards sustainable and circular business have been discussed. However, as the traditional textile and apparel value chains are not designed to be transparent, they can face several challenges while transforming the way they operate. There are many key factors that challenge the development of transparency in the textile and apparel value chain:

- As the textile and apparel value chain is globally dispersed and opaque, the supply chain actors and stakeholders become increasingly physically remote. This leads to reducing access and visibility along with operations in many time zones.

- Materials and components are of low value and they are transported as bulk products; they undergo a number of processes in which they are transformed from components to apparel products.

- Reluctance, originated from arguments as simple as there is no culture of doing so in the textile industry or aggressive profit targets regardless of the means, of the implementation of a full traceability system; it requires substantial investments in building infrastructure for data feeding and management, product labelling, and verification of processes, products, parts, and components across the value chain. There is the additional cost incurred related to resources needed to construct and maintain

11) www.gdpr-info.eu

transparency systems which requires new skills. There is no clear picture whose responsibility all of this will be in future textile supply chains.

- Different data sharing and management technologies, bar codes, QR and RFID tags do exist, but the use of these technologies could be difficult due to geographical and language barriers. Costs and available infrastructure are not clear, and environmental impacts are also to be addressed.

- Cost is a real concern for especially non-vertically integrated companies, brands and SMEs. The burden for the businesses is in terms of human resources, field presence, and data analytics, and the burden on vendors is in terms of investment and time.

- There are local differences in legal, environmental, and social regulations that can make the implementation of a traceability system challenging.

- The differences in technological capacity and capabilities of retailers, suppliers, and sub-suppliers to support and sustain any transparency system must be reduced. Improving vertical transparency of the textile value chain is very challenging due to the fact that brands simply do not know who their sub-suppliers are.

- Lack of infrastructure and technology for collection and processing of post-consumer textiles, missing or inaccurate information on textile product type and compositions, limited lifecycle information, and technical barriers to trace enough products in large enough volumes to make traceability worthwhile, mainly economical point of view.

- Businesses must consider the challenges related to data from the viewpoint of:
    - Credibility of accuracy, reliability and authenticity of the data being collected, shared, and reported, and whether critical new issues are identified promptly and addressed appropriately.
    - Obtaining data from consumers which can be particularly challenging.

- Businesses need to acknowledge and take into account the need for developing trust and dialogue especially with suppliers who have little or no physical face-to-face interaction with companies and brands.

- Compliance with data privacy, security principles, proprietary data and IPR, and regulations; brands and traders often consider information to be an important competitiveness factor.

- Leaders for taking traceability recommendations and tools into practice: when this requirement is present, there is a greater incentive for actors to work together leading to a decrease in costs and improved results.

Photo by Wander Fleur on Unsplash

In general, more collaboration is needed across the value chain, but also between the corporate sector and government agencies in addition to more vertical collaboration within the industry.[12] To reduce the sheer number of challenges associated with transparency and traceability systems, there is a need for incentives and regulations from the governance both at the industry and national level. By providing economic and fiscal incentives, both positive and negative, for establishing and implementing transparency and traceability systems in value chains, especially SMEs, small farmers and producers, and other vulnerable groups can be encouraged to participate in said systems. Providing non-financial incentives, like measures to facilitate access to markets, fast-track processes, and public procurement criteria that are sustainable and socially responsible, can also attract stakeholders to readily adapt and implement these systems.

> **“ Traceability technology solutions are only as accurate as the data being input.”**
>
> Paul Foulkes-Arellano,
> Circuthon Consulting,
> in Traceability Playbook by TrusTrace

12) www.innovationforum.s3.amazonaws.com/uploads/spina/attachment/file/1062/Sustainable_Apparel_Barometer.pdf

3

Technology solutions and solution providers for transparency

Various approaches, techniques, technologies, and tools are available to provide appropriate aids for making textile supply chains more transparent and sustainable. The origin of material, environmental impacts, social aspects etc. are different points of view to be considered, tracked and traced to enable sustainable supply chains. Smaller companies with shorter and relatively simple supply chains would not necessarily need high technology and expensive traceability systems. Companies with complex and multi-layered supply chains need more sophisticated and comprehensive traceability and transparency tools. Related to the granularity level that traceability reaches, an identification at a product, batch or instance level, and creating a digital twin of a garment can be seen as quite an advanced traceability approach from a company or a brand. In the textile and apparel industry, enabling the traceability of every single garment would require a lot of work and resources, and it has been argued whether this detailed of an approach is needed. At the same time, if all the actors take care of their own part, the overall outcome should be positive from the transparency point of view. The most important factor for every brand or a company, however, is to understand the whole supply chain and its specific processes, before making any decisions concerning investments in advanced technology for data management.

3.1. Tracing and transparency technologies

There is no standardisation on the classification or categorisation of traceability and transparency solutions. Different categorisations from different sectors can be found in the literature. In their open access article, Ebinger and Omondi describe different types of transparency as follows:

I) History transparency means tracking and tracing;

II) Operational transparency means control of current operations and

III) Strategy transparency means planning of future innovative processes (Ebinder and Omondi, 2020).

This clustering originates from food supply chains, which have a long history of traceability and transparency development. Regarding the textile and apparel industry, TrustTrace recently published The Traceability Playbook (TrusTrace, 2022), which they

claim to be a complete guide to achieving supply chain traceability in the fashion industry. In The Traceability Playbook, two main categories of traceability solutions are described: Traceability Platforms and Tracer Technologies. Traceability Platform consists of Supply Chain (blockchain or cloud-based solutions) and Circularity (digitalisation of operations of a product). They divide Tracer Technologies into three sub-categories: additive tracers, forensic tracers and tags which are described in detail in The Textile Tracer Assessment (Crowley, Rademan and Tan, 2022).

In their attempt to give a simple description of the topic, the authors of this report have divided the elements of transparency and traceability in three categories: Data collection, Data Storage and Data sharing/Communication (Figure 3). These three categories are further discussed in Sections 3.1.1, 3.1.2 and 3.1.3.

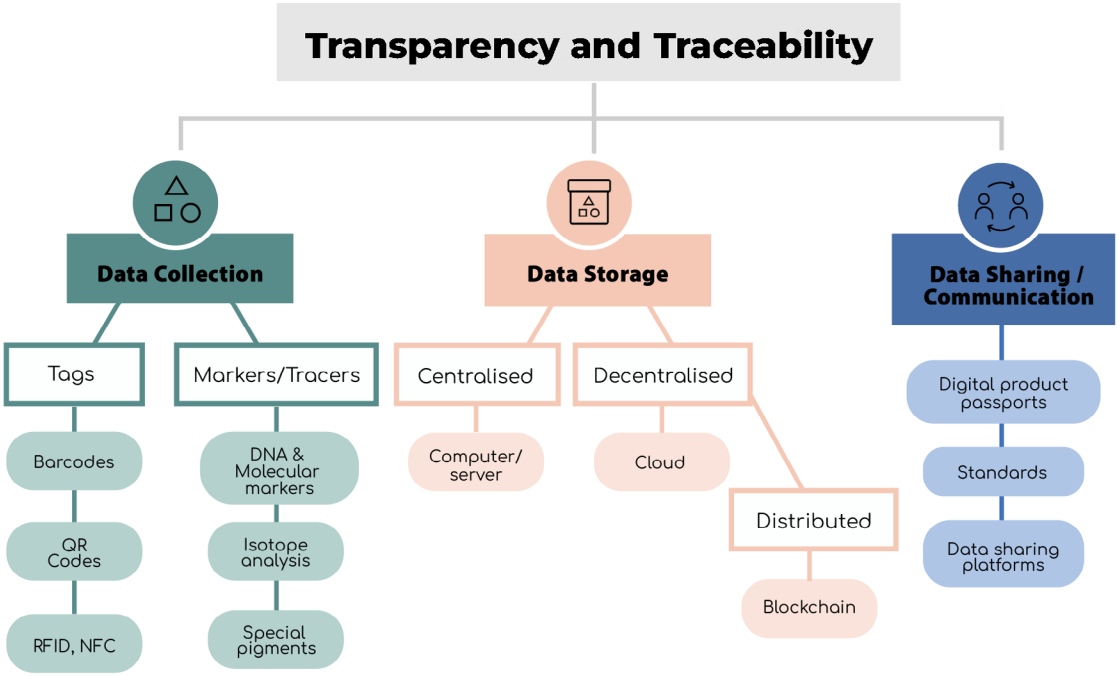


Figure 3. Elements of Transparency and Traceability.

3.1.1. Data collection

Barcodes, labels, and various embedded tracers (aka markers) are used as data carriers. Barcodes and QR labels are physical tags that are attached to a product or packaging. They can also be printed, embroidered, or weaved onto/into a garment. These tags are typically used to provide information about a product's origin, raw material and composition, production process and location, chemicals used, sustainability certification etc. to consumers.

NFC chips and RFID tags are typically used for commercial shipping and logistics and are attached to larger packaging units, such as pallets. An RFID tag can also be embedded into a thread which in turn is embedded in a garment in manufacturing. Embedded markers, by definition, are physical additives that can be placed into yarn in the spinning process. DNA markers are physical markers

"You may think that if a product is traceable, then it must also be transparent, but that's not always the case.

In theory, a brand could have full supply chain traceability (because they have visibility on every stage where their product is made) yet have no transparency of this information if they withhold it from the public."

Ciara Barry,
Policy and Research Coordinator
at Fashion Revolution

that are applied on or in raw material, yarn or fabric. Isotope markers are natural markers in the material. The isotope analysis from cotton fibre, yarn or textile reveals the location of cotton. This is because ratios of stable isotopes of cotton are indicative of different regions, and they can be used to prove the origin of cotton. Different data carrier types along with some leading technology providers are listed along with examples of which textile material is suitable for a certain Marker/Tracer type are listed in Table 2.

Table 2. List of commonly used data carriers, their operating principles and technology providers. The information is collected from company websites.

Object identification technology	How it works	Further information	Technology providers/Users
Tags			
Optical codes (barcodes, QR codes) and other 1D or 2D data matrices	Code on a garment which gives access to the database containing information on the product's origin, raw material, process steps, chemicals used etc. for product, assembly and material. Read by a scanner or a mobile app; the information behind the code is stored in a database (offline or online)	Code can be printed, embroidered or weaved onto/ into a product, or attached on a hangtag or onto a product or packaging	Widely used at apparel brands, for example via circularity.ID by circular.fashion[14], Everledger Platform[15]
RFID tags, NFC chips	Tags containing integrated circuit and an antenna. Data is captured by a reader via radio waves.	RFID tags can be passive or active[16], RFID embedded in the thread is used in garments[17]	Retailers, logistic companies, E-ThreadTM by Primo1D, Digital ID by EON[18]
Markers/Tracers			
DNA and molecular tags/markers	The material is tagged with a unique molecular identifier in any production process (CertainT®) or a DNA marker is sprayed on raw material, fibre, yarn or fabric (Haelixa). Its presence is tested in a forensic laboratory.	Used for cotton, wool, cashmere, viscose, synthetics, leather, recycled polyester	CertainT®[19], Haelixa[20], Birla Cellulose[21]
Isotope analysis	Isotope analysis, which detects naturally occurring elements in the material. The origin of an organic product is identified by comparing the ratios of stable isotopes of elements in product samples against a specification.	Used for cotton	Oritain[22]
Special pigments, (nano)particles and dyes; ceramic nanoparticles, luminescent pigments, fluorescent pigments	Particles are embedded into the material at raw source or in spinning, analysed using a handheld scanner or an inline device.	Cotton, viscose, polyester, polyamide, recycled polyester	Wearaware[23], Tailorlux[24], FibreTrace[25], IN-Code Technologies[26]

16) www.abr.com/passive-rfid-tags-vs-active-rfid-tags
17) www.primo1d.com
18) www.eon.xyz
19) www.adnas.com/certaint-supply-chain-platform
20) www.haelixa.com/proposition/#process
21) www.livaeco.com
22) www.oritain.com
23) www.wearaware.co
24) www.tailorlux.com/en
25) www.fibretrace.io
26) www.unreasonablegroup.com/ventures/in-code-technologies

These tracers are examples of object identification technologies and are typically used to prove the textile material or a product's authenticity, but they are also used for tracking and tracing. Physical materials or products can be connected to digital traceability software by a digital twin.

Fashion for Good released Textile Tracer Assessment in July 2022, and they hope the document will be used as an open-source user guide for physical tracer technology implementation in textile industry. More comprehensive information about which tracer type is suitable for which textile material can be found in Figure 4 and Figure 5 (Crowley, Rademan and Tan, 2022). This information is based on the interviewed technology providers' claims and no proof is given that said tracer technologies will work in real life.

Operational feasibility: Claimed practical evidence (e.g. pilots and/or partnerships) that the tracer has worked effectively on the associated fibre type.

Technical feasibility: Claimed theoretical evidence that the tracer could work effectively on the associated fibre type.

No claimed evidence that the tracer has worked effectively on the associated fibre type.

Not known.

Figure 4. Key for Figure 5.

Photo by JJ Ying on Unsplash

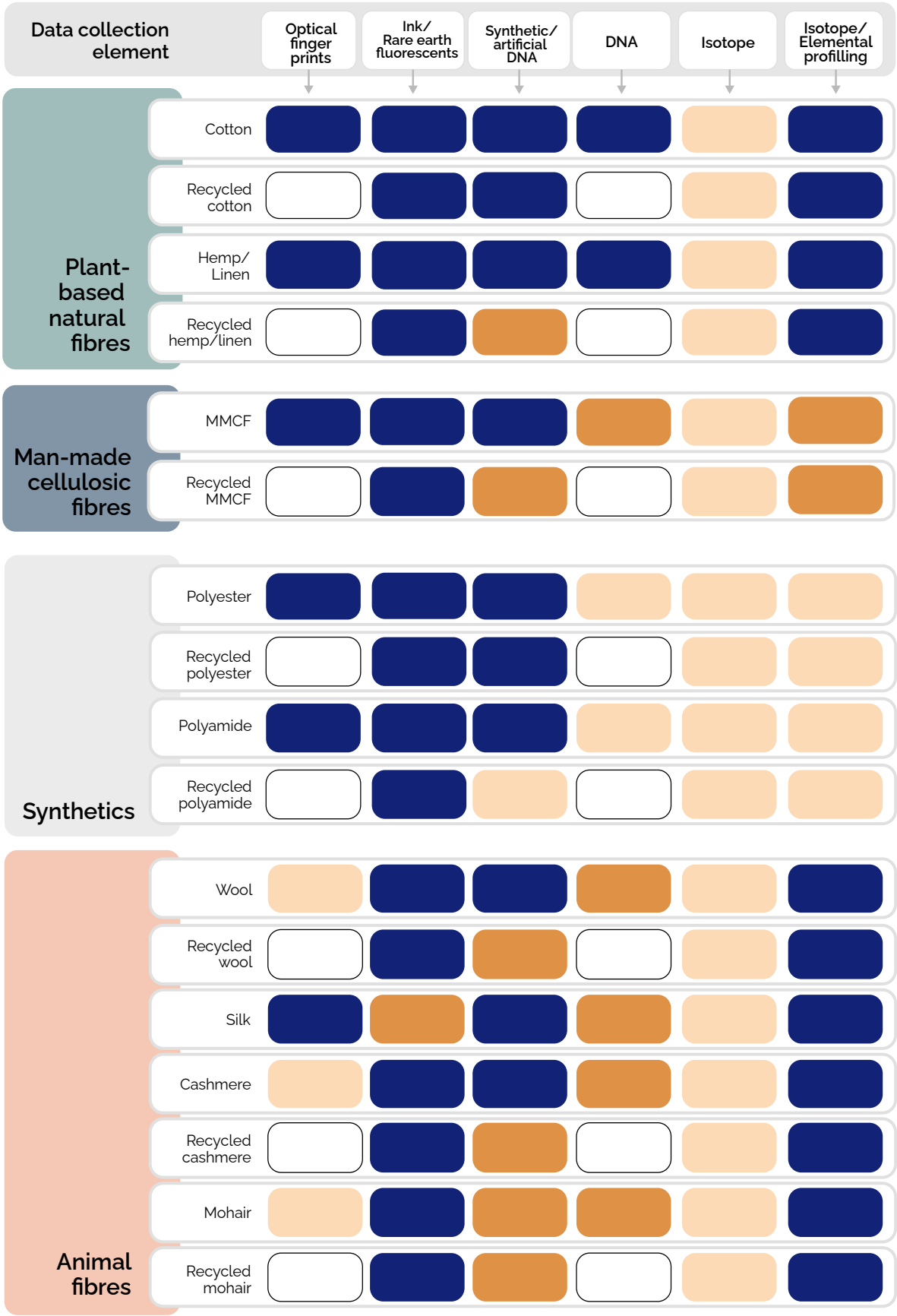


Figure 5. An overview of the claims made by forensic and additive tracer companies on the capabilities of tracing plant-based natural fibres, MMCF, synthetics and animal fibres. (adapted from Crowley, Rademan and Tan, 2022)

3.1.2. Data storage

Data from different actions along the textile value chain can be stored in different types of data storage systems. One option is Centralised data storages and Decentralised/ Distributed data storages (Figure 3). A centralised data storage can be a single computer or a server which has one owner. Decentralised data storage systems can be located in clouds that have several owners (servers), and the same data is stored in all of them. In both centralised and decentralised systems, data can be stored for example in spreadsheets, ERP, PLM and PO systems and software. In today's textile industry, stored data is typically production related and it is not designed to collect and store for example sustainability data. Furthermore, these systems are generally not compatible with sustainability data management technology solutions. Decentralised data storage systems are considered the best option in a first phase development and implementation of a digital product passport, which also includes textiles, suggested by European Commission. (Solita, 2022) Blockchain-based technologies are examples of distributed systems.

Examples of technology solutions and their providers related to traceability and transparency actions in the textile and apparel sector are introduced as follows:

EON has recently launched EON Product Cloud, which is a decentralised platform to have access of exchange of digital product data between brands and customers, using the Digital ID in the garments.[27] Their Digital ID is connected to a digital standard dataset called Circular Product Data Protocol (CPDP)[28]. These tools are developed to reduce resource consumption, increase transparency, unlock resale, recycling and regeneration and enable measurement and accountability. The Protocol was tested with a large group of stakeholders before launching it through a Creative Commons license in November 2021. It is publicly available to brands, retailers and circular businesses under an open-source license for free. The focus is in assigning and recommending what data should be stored for resellers and recyclers. Washable QR codes, NFC and RFID are used as data carriers, but the Protocol does not define which data carrier technologies should be used. More details, such as the content and governance, standard alignment, and how to implement the Protocol, can be found in the Circular Product Data Protocol™ V1.0 document[29]. Regarding Digital ID, EON just launched an industry-aligned action plan for brands which covers hardware, data, software, implementation, limitations and costs information needed for Digital ID implementation at scale (EON, 2022). The Advisory Council of the Protocol is working closely with European Commission's Digital Product Passport (DPP) development actions[30].

TextileGenesis ™ is a textile supply chain traceability platform that supports two verification types:

1) fibre "forensic" audits to verify fibre origin and
2) the third-party audits to verify the sustainability of the suppliers.

27) www.eon.xyz
28) www.circulardataprotocol.org
29) www.7a5f6f52-74f4-4d72-92f5-680e4691a8ba.usrfiles.com/ugd/7a5f6f_5d1932a7e-97a4d278ff3244dcbbb2a87.pdf
30) www.circulardataprotocol.org/post/dive-into-the-circular-product-data-protocol

Various technologies, such as pigments, DNA markers and isotope mapping, are used for tracing. They have global traceability partnerships with Textile Exchange, US Cotton Trust Protocol and Canopy, and partnerships with the leading sustainable fibre producers such as Lenzing (Austrian viscose producer), Schneider (Australian wool producer) and Arvind (Indian denim manufacturer and fashion house). Viscose fibre from Lenzing[31] was used as an example in TextileGenesis's blockchain traceability platform to study if blockchain technology can be used for traceability product authentication and supply chain sustainability (Ahmed and MacCarthy, 2021). TextileGenesis is working with several leading apparel brands whose plan is to trace all garments made from man-made cellulosics and recycled polyester in 2022[32].

circularity.ID®

Circularity.ID® by circular.fashion is targeted for storing, labelling and identifying digital product data for enabling circular practices for use in the fashion industry. Their ID identifier called circularity.ID® is available as an Open Data Standard to support the applying of circular practices and aligning with upcoming standardisation initiatives. [33] Their digital and physical circular material library, which is connected to circularity.ID®, contains information about sustainable yarns, fabrics, trims, leathers and leather alternatives which helps designers to design products according to their Circular Design Guidelines. When a garment is manufactured, the information of the raw material origin and composition, production methods, chemicals used, etc. is attached to the garment using a woven QR label[34]. In addition, a customer gets information on product care, how to make a garment last longer and what to do when the garment is at the end of its lifetime by scanning the QR code using a mobile phone. A recycler from the dedicated European recycling partner network gets information on how to recycle the product in question through the RFID tag or NFC chip. Currently, there is no information nor calculations of the environmental impacts of the products available through the QR code. The system is being piloted at several global apparel brands such as Zalando.

trustrace

TrusTrace's blockchain-based platform has an automated data collection, validation and sustainability label assignments using their artificial-intelligence-based document classification and extraction engine.[35] Tracing starts at a lot level of raw materials and finishes at a product level. The platform calculates carbon footprint and monitors water use, biodiversity and working conditions, and considers global mass balance. The platform can be integrated into companies' existing product lifecycle management (PLM) and enterprise resource planning (ERP) systems using open APIs (Application Programming Interface which is an integration interface between different systems that provide automatic data transfer). TrusTrace is working with Higg, Open Apparel Registry (OAR), circular.fashion, Renoon and Haelixa via their traceability ecosystem programme[36]. TrusTrace published Traceability Playbook in June 2022 in which they introduced the Three Levels of Traceability that fashion industry actors can assess their level of traceability (TrusTrace, 2022).

31) www.lenzing.com/newsroom/press-releases/press-release/new-level-of-transparency-in-the-textile- industry-lenzing-introduces-blockchain-enabled-traceability-platform#_ftn2
32) www.hmgroup.com/news/hm-group-expands-partnership-with-textilegenesis
33) www.circularity.id
34) www.circular.fashion/en/software/circularity-id.html
35) www.trustrace.com
36) www.trustrace.com/press-release

Made2Flow[37] is a technology company specialised in data collection and analysis of environmental data in fashion industry. Their solutions are based on machine learning that facilitates data collection, validation and analysis of the impact of all products at all times in a transparent, trustworthy and easy way. Made2Flow's system measures the environmental impact of the products across the supply chain which is shown to customers via a mobile application. Their system is compliant with regulations, such as PEFCR (Product Environmental Footprint Category Rules) and Ademe (French Environment and Energy Management Agency). For companies, the system has carbon budget management control in real time, so designers can easily see the impact of their decisions and companies can set and control their science-based targets.

Circularise[38] is a supply chain traceability and transparency platform which uses a combination of a public blockchain, peer-to-peer technology and zero-knowledge proofs (ZKPs) cryptography called Smart Questioning in an advanced decentralised storage and communication platform. This allows trusted information exchange between the different stakeholders of the supply chain. It controls what information is seen by each stakeholder at the same time. The system enables manufacturers, suppliers and recyclers in the value chain to share data securely, know where their materials are, get certifications, and can plan logistics and recycling activities for specific materials. Circularise states that their patent pending Smart Questioning technology does not leave room for compromises of data privacy. Their platform can be integrated into a customer's ERP if their internal system is connected to API. Circularise's aim is that their system would become an industry standard, and their public, permissionless blockchain is the right technology to achieve it. Their most important customers are in plastic industry but AWARE and Tailorux are piloting Circularise's solution for fashion industry.

Retraced[39] has a sustainability and compliance program, based on artificial intelligence, which helps textile and apparel companies to digitise and connect their supply chains, efficiently manage their compliance data, and achieve full transparency starting from raw materials. They have two approaches depending on for which use a customer wants to use their tool: cascade tracing starts at a retailer and collects a chain of custody data top-down across the supply chain, whereas bottom-up tracing is from a fibre to a final garment. Hence, all the process steps of the supply chain are digitised. Cotton farmers and ginners use a mobile application to feed data to a blockchain-based platform.

ChainPoint[40] is an online software platform which manages and shares product, process and supplier information from raw material to finished products. It is a configurable, scalable and secure cloud-based software which helps a customer to see all the stakeholders in the supply chain, how they relate to each other and how they perform. It is not a blockchain-based platform, but a standard software. With their hybrid solution, it is possible to use interfaces such as a web browser, mobile device, XML, and web services of Excel to integrate existing supply chain data into

37) www.made2flow.com
38) www.circularise.com
39) www.retraced.com
40) www.chainpoint.com

ChainPoint. The products can be traced back to the source at any time. ChainPoint supports many standard Chain of Custody models, such as identity preservation, segregation, mass balance and book and claim[41]. They have a designated software for textile and apparel supply chains[42] and Timber Due Diligence Platform for meeting the requirements by EUTR and creating a risk assessment automatically[43].

Everledger Platform[44] by EverLedger is a blockchain-based solution, which creates a unique digital identity for each product. They use a wide range of intelligent labelling solutions such as QR codes, synthetic markers, RFID and NFC tags, and nanosized particles. Products can be authenticated, transferred, and tracked using a mobile phone application. Tracking starts from a product's origin. In addition to fashion, their technology is used in wine and spirits, arts, critical minerals, batteries and diamonds for anti-counterfeiting and provenance assurances.

RADIX Tree[45] by Global Traceability Solutions is a flexible, intuitive and scalable supply chain traceability solution to track products, verify supplier data and manage compliance paperwork. The tool is used to give traceability in timber, seafood and fabric supply chains, and it is claimed to be suitable for all supply chains. Regarding timber, the tool is EUTR (EU Timber Regulation) and Lacey compliant and they offer consultancy services for EUTR issues.

CertainT®[46] by Applied DNA Sciences (Adnas) is a platform that uses a secured cloud database to track synthetic materials using a SigNature® molecular tag. Raw materials or products are tagged with a unique molecular identifier. For example, in polyester recycling process, Adnas's SigNature® molecular tag is applied to masterbatch pellets of polyester and further mixed with shredded polyester flakes in an extruder.[47] The tag undergoes and withstands yarn spinning and weaving or knitting process and the authenticity of the material can be traced back. The tag can be applied from manufacturer level to batch-by-batch level.

Bext360[48] is a blockchain based Software as a Service (SaaS) for supply chain digitalisation from origin to consumer. Bext360 can be integrated with APIs to websites, supply chain management systems, point-of-sale systems, etc. In addition to data collection, qualifying sustainability measurements are recorded and sustainability metrics are attained. Bext360 focuses on coffee, timber, minerals, cotton and palm oil supply chains to provide a traceable fingerprint from producer to consumer. They were the leading technology partner in The Organic Cotton Traceability Pilot led by Fashion for Good, and Haelixa, Tailorux, IN-Code Technologies and Corebiome provided a range of tracers that were tested. This pilot was the first blockchain and marker pilot in the apparel industry, carried out in 2018–2020. (Bext360, 2020)

41) www.chainpoint.com/solutions/supply-chain-traceability
42) www.chainpoint.com/industries/sustainable-textile-apparel-solutions
43) www.chainpoint.com/industries/timber
44) www.everledger.io/our-platform/identify
45) www.global-traceability.com
46) www.adnas.com/certaint-supply-chain-platform
47) www.adnas.com/r-pet-infographic-2
48) www.bext360.com

Reverse Resources [49] is a SaaS platform intended for global fashion brands, garment suppliers and recyclers. They aim is to enable virtual traceability of fabrics with the help of circular life cycles from production unit onwards. They map volumes of waste by composition, type and location, and link it to the best recycling solution possible in their recyclers network. Their platform builds and manages efficient and transparent supply chains by delivering waste at the best cost and quality. It also gathers and analyses data available throughout the transactions and creates insights which are useful for marketing and traceability of material flows.

Information of the traceability and transparency technologies and technology providers presented in this report is collected from company websites and webinars and is not exhaustive.

49) www.reverseresources.net

3.1.3. Data sharing/Communication

Data sharing is the most important step as communication makes all the traceability and transparency data collecting and storing efforts worthwhile. Communication needs to reach all the steps and levels of the supply chain and extend to reuse, repair, rental, and recycling. Data sharing can be as simple as a shop assistant telling a customer about the product's origin based on the information on the QR code. In this report, different data sharing options are presented as follows (Figure 3):

Product passports

A digital product passport (DPP) is an esteemed tool to communicate textile and apparel supply chain data between stakeholders, such as brands and companies, public authorities, consumers, NGOs and civil society actors. The most recent requirements and upcoming actions originate from a proposal for ecodesign requirements in Ecodesign for Sustainable Products (ESPR) (European Commission, 2022a), and DPP is mentioned in the EU's Strategy for Sustainable and Circular Textiles (European Commission, 2022) from March 2022. DPP is described as follows: "*The product passport means a set of data specific to a product that includes the information (more concrete product group related information will be specified delegated acts) and that is accessible via electronic means through a data carrier.*" Based on company interviews, some of the key points for a successful DPP implementation are: all information requirements should be relevant and fit for purpose, DPP should not cause administrative burden for companies, the decentralised approach is preferred so actors can feed and control data (viable and sovereign data) in their own systems and these systems are connected to a central platform by APIs, data format should be standardised, double work should be avoided i.e. data collection should be automatised, data should be interoperable and machine-readable, not all stakeholders need all the information, and the relevant information for each stakeholder should be available in a user-friendly format (Solita, 2022; CISL and Wuppertal Institute, 2022). More information on concrete actions about the upcoming EU's Strategy for Sustainable and Circular Textiles is expected by the end of 2022.

Several commercial technology providers have been proactive in this field. The aforementioned Digital ID and circularity.ID are leading examples in the textile and apparel sector. Cirmar[50] has developed a product passport tool called C_passport®, which was originally developed for 100% mechanically recycled mixed fibres for automotive interior materials. Their solution also contains a tool for measuring and communicating impact, and locations of products, components, and raw materials. GUT-PRODIS product passport is n use for rugs and carpets[51].

Standards

GS1 Standards [52] help businesses in identifying, capturing and sharing information about their products. It can be regarded as the DNA of products that move through the value chain. It can help in connecting unique products with relevant information with the help of GS1 Identification Numbers which is "used to uniquely distinguish all products (and/or items), logistic units, locations, assets, and relationships across the supply chain from manufacturer to consumer". The product data is shared using the Global Data Synchronisation Network

50) www.cirmar.com
51) www.gut-prodis.eu/en/product-testing-gut/product-passport
52) www.gs1.org/standards

(GDSN). With the help of this GDSN, the product data is automatically uploaded to data pools (master data), stored, maintained, and shared. Businesses individually retrieve data from the master data. There are, however, some basic data pools for exchange of traceability information of textile products, unlike master data as in other sectors like food and grocery industry (Stellmach et al., 2022).

The GDSN does allow traceability at batch level and, hence, Global GS1 Traceability Standard (GTS 2)[53] introduces two important concepts for interoperable traceability: a) Critical Tracking Events (CTEs), which are the real-time events like packing, receiving, shipping, transporting, occurred to the object being traced in its lifetime, and b) Key Data Elements (KDEs), which are the data elements describing the actual instances of the CTEs. With the help of the Global Trade Item Number (GTIN) and Global Location Number (GLN), products can be uniquely identified and tracked. Centred on this, Global Textile Scheme[54] has been developed, which focuses on standardising important data in the textile value chain.

Gaia-X[55] is an initiative originated from European Union. The purpose is to create a software framework of control and governance, by applying a common set of policies and rules that can be used to any existing cloud/edge technology stack. The main attributes that Gaia-X seeks to attain are transparency, controllability, portability and interoperability across data and services. The architecture of Gaia-X is based on the principle of decentralisation. Gaia-X is the result of numerous independent platforms that all adhere to a common standard: the Gaia-X standard. The data infrastructure is based on the values of openness, transparency, and trust. It is envisioned to be a networked system that connects many cloud service providers. Gaia-X has been suggested to help especially SMEs in the textile industry to get access to cloud services that are needed for digital product passports[56].

Circularity.ID® [57] by circular.fashion is an Open Data Standard which has been created for the fashion industry to help them to achieve a circular economy. Fashion industry actors are encouraged to use circularity.ID® Open Data Standard for labelling, identification and storage of digital product data. The purpose of these data standards is to ensure the following: that the data and information about the material and chemical components along with product data is assessed and stored and that the information is easily accessible by all the relevant actors in the value chain; that product data is automatically recognised by software and specific scanners at sorters; that products are linked and visible to appropriate recyclers so they can be recycled according to the best knowledge and methods for recycling available when the item is scanned at end-of-life; and that essential product information is available to consumers in a user-friendly format so longevity and multiple use cycles for a product are possible, e.g. through redesign and resale services.

ODSAS: Open Data Standard for the Apparel Sector [58] uses standardised, downloadable and machine-readable templates that brands and companies can use to disclose their supplier lists. Using this data standard, essential material and products information is accessible for resellers and recyclers to identification and sharing. The datapoints of the templates are aligned with the Transparency Pledge[59] initiative.

EON's (Digital ID) [60] is a digital system that uses a well-defined, circular database to create a digital twin of a physical product which allows the identification of its materials and components. It aims at reducing the extracting and utilisation of natural resources and raw materials to manufacture new products by promoting recycling and reusing materials. It has three strategic elements: Digital birth certificate, Digital passport, and Physical identifier (data carrier).

53) www.gs1.org/standards/traceability
54) www.globaltextilescheme.org/en
55) www.data-infrastructure.eu
56) www.youtube.com/watch?v=zLkg4_emdqE
57) www.circular.fashion/en/software/circularity-id.html
58) www.odsas.org
59) www.transparencypledge.org/the-pledge
60) www.eon.xyz

Platforms

Traceability models are systems that "*should have common, agreed rules that cover implementation costs, capacities of all actors involved, and the importance of building the trust needed for sharing data*" (UNECE, 2021). These systems should be globally practical and easy to use by all actors of varying sizes and technological capabilities, including farmers and small businesses. The purpose of the recommendations is to build a mechanism that enables all the stakeholders to make sustainable decisions. It would consist of a set of internationally agreed practices for the harmonised collection and transmission of data for tracking and tracing materials, products and processes across the whole value chain. All facilities and intermediaries involved would be a part of this model. Relevant information about sustainability performance including claims of human rights, fair labour practices, environment, consumer interest and anti-corruption would be stored in this model. The overall target of these traceability models is to allow simplification, cost-efficiency and improved organisational processes to enable SMEs and industry actors who have limited economic resources available to enhance traceability. More detailed information on different traceability models is available in UNECE's Executive Summary for Policy Makers (UNECE, 2021).

Multiple Stakeholder Initiatives (MSI) are a way of communication and collaboration between corporations, governments and civil society organisations and local communities. They are typically for one specific issue in a sector, for example, sustainability of human rights. MSIs have an active dialogue between different stakeholders and agree on common methods and standards without/before mandatory legislation. Better Cotton Initiative (BCI), Forest Stewardship Council (FSC) and Ethical Trade Initiative are just a few examples from the textile and apparel and forestry sector. MSIs have a long history of being an important part of companies' sustainability and human rights strategy work, and informal discussion is seen as very beneficial. However, there are some concerns about the effectiveness of MSIs, and the Institute of Multi-Stakeholder Initiative Integrity is rethinking the role of MSIs in their report. [61]

Circulytics [62] is one of the most comprehensive tools available for measuring the circular economy performance of a company. It is developed and evaluated by over 30 companies within the network of Ellen MacArthur Foundation. It helps companies assess where they are at in terms of circular economy in their entire operations and not just their products and material flows. It uses a set of indicators available as enablers and outcomes.

Open Apparel Registry (OAR) [63] is an open data tool for the identification of global apparel facilities and their affiliations. It brings together lists of garment manufacturing facilities from industry stakeholders into a single map that is free and interactive and assigns an OAR ID to each unique production facility. The OAR collect and makes accessible data and information which is disclosed from multiple sources, including brands, retailers, multi-stakeholder initiatives, manufacturers and government databases. Data that is collected using the ODSAS standard can be uploaded to Open Apparel Registry. Based on the Open Apparel Registry (OAR), which since 2019 has mapped more than 88,000 garment manufacturing facilities, the new **Open Supply Hub (OSH)** [64] will enable stakeholders to populate the platform with information regarding their supply chain partners.

61) www.msi-integrity.org/not-fit-for-purpose
62) www.ellenmacarthurfoundation.org/resources/circulytics/resources
63) www.openapparel.org
64) www.opensupplyhub.org

4
Discussions

Digital transformation and technological advancement have changed the landscape of several industries in the world including textile and apparel industry (Hagberg, Sundstrom and Engels, 2016; Bertola and Teunissen, 2018; Reinartz, Wiegand and Imschloss, 2019). This transformation has led to the value chains becoming more and more dispersed, increasing the physical distance and differences in geographical regulations between the various actors involved. In addition, the global nature of the value chains has increased the production and consumption of products increasing the post-production and post-consumption waste. Similarly, as discussed in this report, the complex, the opaque and multifaceted nature of the textile value chain is similar in its operations and challenges to other value chains such as the food and electronics supply chain (McGrath et al., 2021). Despite the similarities, the electronics chain was proactive in adopting and integrating technologies. Supply chains in the food, textile, apparel and other consumer goods sectors were much less developed, some reasons being the wide variety of their products and the relatively low digital technology level of many of the suppliers in their supply chains.

The textile and apparel value chain, in particular, is famous for its unsustainable production and consumption practices (Joy et al., 2012; Ütebay, Çelik and Çay, 2020). It not only involves multiple actors and stakeholders, but these are present across the globe. The management of this value chain and its transformation towards circularity, hence, requires dependency on digital mediums which generate a massive amount of data. This data is collected, stored, and shared using various platforms that are unique to organisations, leading to ambiguity, reduced security, and duplicity of data. This data is further needed for developing traceability and transparency systems, critical for bringing circularity into practise.

4.1. From a Data point of view

Data is the key to unlocking the insights required to adapt to the change demanded in the current production practices and it can act as a catalyst for sustainability in the value chain. The sooner the textile and apparel value chain harness the power of data, the better. By integrating data into their planning, merchandising, and other value-chain activities, the textile and apparel companies can not only see tangible results but also improve supply chain visibility. While improving the value chain, wide visibility can streamline inventory management, enhance returns forecasting, and optimised logistics. There is a long list of uses, and the benefits of data that are well-known. However, there are also various challenges when it comes to employing data. It is often challenging for the value chain to decide the key focus areas, to find where the data is available, which data is needed, which data needs to be shared with whom, and how it can be integrated into business activities. There is the risk of incomplete business information shared by the companies to protect their trade secrets and thereby maintaining competitive advantage.

When collecting and feeding data in transparency and traceability systems, some challenges that accompany data can be the quality and control of data, cultural difference in obtaining data, lack of infrastructure, difficulty in understanding the requirement for achieving transparency, varying social norms, and lack of awareness. It can be difficult to collect data from consumers as they might hesitate to share personal information that can help companies to do behavioural analysis.

Hence, it is critical that the technology managers in the value chain are well-versed with the operations and challenges so that they can choose the appropriate granularity level and the technology to build value adding strategies for their transparency and traceability approach.

4.2. From Technical solutions and solutions provider point of view

As Luoma and her colleagues (Luoma et al., 2022) have stated, digitalisation is a promising enabler of sustainable business of textiles. It is full of opportunities, but there are also challenges that need to be solved to attain a positive impact. In the multifaceted and complex textile and apparel value chains, the focus on the interface of digitalisation and circular economy can include the following:

a) Highly sophisticated data system approach, such as blockchain, can trace product lifecycles but can be energy intensive.

b) Data embedded to garments and textiles can increase understanding but interfere with recycling processes. For instance, metal containing data carriers (such as RFID tags and NFC chips) embedded into fibres and yarn can cause issues in recycling.

c) Open lifecycle data can support companies' sustainability activities but risk losing their competitive edge.

d) Consumers can benefit from sharing data by getting personalised products. However, there is the issue of data privacy and, in addition, personalisation might not necessarily reduce consumption.

e) Consumers value sustainability but are highly price sensitive.

f) Technologies for traceability already exist, with several pilots and some companies already implementing it, but it is a challenge to get profitable business out of this.

There are various technologies and technology providers at different TRL (technology readiness level) available for promoting traceability and transparency. The reality these days is that lack of infrastructure for the collection and processing of post-consumer textiles, missing or inaccurate information on product type and composition, limited lifecycle information, and technical barriers to tracing enough products in large enough volumes are the challenges that need to be overcome to make traceability actions worthwhile. Data quality and compliance together with data privacy, security principles and regulations are serious concerns. Upcoming legislation will shed light on what will be required in practice

from all the textile value chain actors towards traceability, transparency and sustainability. Regarding digital product passport, it has been estimated that it may take 5–10 years before the required actions are in place that start making impact[65].

Transparency and traceability systems require substantial investments, human resources and new skills to build and maintain the systems. It is important to understand the whole value chain and its processes before making any decision concerning supply chain actions (business and production side) or purchasing decisions (consumer side). There could be issues when using advanced technologies due to geographical and language barriers as well as costs, infrastructure and environmental impacts point of view.

The leaders of successful brands are encouraged taking recommendations and tools into practice before legislation and policies are ready. It would be the best that market would agree and solve most of the issues, as they are the experts in the supply chain actions. Communication, collaboration and trust are the key while constructing a data management system.

4.3. From a Policy point of view

When we talk about data and technologies and their implementation in the real world, the question about good governance often arises. Whether this data drives policy-making or vice versa is still not clear, but it is clear that before mandatory regulations are in force, common, jointly agreed rules, transparency and guidelines and self-regulation are needed. There have been various data standard initiatives developed in the textile sector to help with the 'self-regulation' as discussed in Section 3.1.3.

In addition, there have been initiatives by the UNECE specifically in the form of traceability models that provide the value-chain with a blueprint, onto which they can build their traceability approach. The United Nations Economic Commission for Europe (UNECE), supported by the European Commission, have had a wide initiative called "*Enhancing Traceability and Transparency for Sustainable Value Chains in the Garment and Footwear Sector*" during 2019–2022[66]. The purpose of the initiative has been to give governments and companies tools to advance traceability, transparency and sustainability in the garment and footwear sector. The findings are collected in the Toolbox[67]. For example, UNECE has run a pilot project called "*Harnessing the potential of blockchain technology for due diligence and sustainability in cotton value chains*" where they have used an independent blockchain provider and evaluated the merits and demerits of using blockchain technology to ensure full transparency in a textile value chain (UNECE, 2021a). Even if blockchain-based technology is considered to be an appropriate solution for the textile and footwear industry, there is a concern that such solutions can be challenging for SMEs and other small-scale actors because of the digital gap, implementation costs and the required skills.

A global non-profit organisation Textile Exchange, the owner of Content Claim Standard (CCS) and Organic Content Standard (OCS) among other standards and certifications, has a programme called Textile Exchange Trackit[68], which helps the textile and apparel industry to improve integrity, traceability and efficiency of sustainable material provenance. It includes a third-party certification at the site and transactions of the data level. The programme has two traceability paths, Digital Trackit (dTrackit) and Electronic Trackit

65) www.youtu.be/zLkg4_emdqE
66) www. unece.org/trade/traceability-sustainable-garment-and-footwear
67) www.thesustainabilitypledge.org/toolbox.html
68) www.textileexchange.org/tetrackit

(eTrackit), from which companies can choose depending on the level of traceability they want to follow in their supply chain. eTrackit is being piloted on the TextileGenesis platform.

France has been a forerunner on setting up a national regulation for traceability in textile and apparel value chains. A "*French law on fighting waste and on the circular economy*" for clothing, linen and footwear (CLF) was published in March 2020 (Refashion, 2020). It pushes French companies to optimise the lifecycle of their products, reuse, lengthening service life of products, improving textile waste collection, introducing a minimum amount of recycled material into products, donations rather than disposal of textiles etc. This law came into effect on 1 January 2022, when information about a garment's environmental properties and characteristics (recycled materials content, use of renewable resources, service life span, recyclability, presence of hazardous substances) had to be visible or accessible. In addition, it is mandatory to display an environmental and social rating. Furthermore, sorting rules needs to be marked. According to the law, unsold items cannot be destroyed, and it mandates systematic reallocation of garments. As a continuation, Decret nº 2022-748 (formerly known as Loi AGEC) was launched in April 2022. This degree regulates and mandates certain information provided to consumers, such as knitting/weaving, dyeing/printing, cutting and sewing information from textiles. Products that contain over 50% of synthetic materials must mention that it "*emits plastics microfibers in the environment when washed*". The terms "*Biodegradable*", "*Respectful of the environment*" or similar allegations are banned on the product or packaging.[69] Similarly, there are many more initiatives and legislations coming in this direction, the most important ones being a framework for Ecodesign requirements (European Commission, 2022a) and EU's strategy for sustainable and circular textiles (European Commission, 2022) for the whole EU level.

It is important to consider whether there are enough resources and competence within the value chain to successfully follow all upcoming regulation requirement. EU has stated that they will help especially SMEs so nobody is left behind in the digital transition. In particular, the cost of infrastructure to create and maintain transparency systems can be substantial, and especially challenging for non-vertically integrated companies, brands and SMEs. Suppliers are expected and required to improve infrastructure but currently do not receive financial support for it. This is a real issue, especially when it is not clear who would own and maintain the needed new infrastructure as the factories are not owned by brands. Traceability and transparency implementation at large companies may require vast investments in data collection and management systems, data labelling, verification of processes, products, parts, and components throughout the supply chain.

The future plans and footprint regarding improving traceability and transparency give a very good opportunity to develop the governance in this area that not only support the existing businesses in becoming more sustainable but can also support development of new business models that have circularity, data-driven decisions and visibility as their core competencies.

69) www.linkedin.com/posts/policy-hub_4302-climat-dcppastill%C3%A9-pub-activity-6888766927045447680-p0X_?utm_source=share&utm_medium=member_desktop

4.4. Future avenues

A New Circular Economy Action Plan (CEAP) identified value chains that need to go circular. One of those value chains is the textile and apparel value chain. (European Commission, 2020) The area of big and untapped potential in this chain may include the following: design and waste aspects, requirements and incentives, repairability, the requirement for recycled content, and reduced tax and VAT (value added tax) reduction on the repair of textiles.

What sort of business models are emerging and what needs to happen for these circular business models to become a norm?

The circular business model usually makes money by increasing the number of times clothing is being worn, for example, re-commerce, and rental models. They create revenue by creating new revenue streams by rotating the existing products through different users. Data collected during use phase could help to show the long use time and high quality of the garment or materials. Additionally, data could be beneficial in the end of product lifetime when the product is entering the recycling process. In this phase the exact information of the fibre content, chemicals and colours used would make the textile waste recycling easier and commercially profitable. Material, which is most suitable for certain chemical textile recycling, which aim to 100% high quality recycled yarns as end result, would have higher monetary value than textile waste which is suitable only for mechanical recycling (e.g. blended materials) or incineration only (e.g. fabrics containing fibres unsuitable for recycling). Better transparency and data collection throughout the value chain would make it possible to follow textile streams globally and predict the amount of textile waste (and estimate its content) coming back to recycling processes. Fibre factories

Photo by Keagan Henman on Unsplash

with new technologies which are able to use textile waste to produce regenerated fibre would benefit from this kind of data coming from the producers or brand side. This data might enable to match the demand of textile waste recyclers to information from brands how much garments (and in which content) they are taking back. Especially the EPR (Extended Producer Responsibility) might take the development towards this kind of data use. This would enable making business out of data and data management and even managing textile waste streams better than currently happens.

The need for collective actions is clear. The textile and apparel industry, investors, media, etc. – all the actors around the textile value chains need to work collectively. **Collaborative and collective actions** are key to advancing circular economy. Policymakers play a very important role in this and act as a key enabler of innovation and how to make the economics work for businesses. Most people think innovation is technology. There is a technological side to innovation in textiles such as new sustainable materials, and new ways of textile recycling, but there is also social innovation that is equally necessary. Policymakers need to put in place the right rules and regulations to enable the scaling of the circular business models.

While devising policies for this value chain, the following should be considered:

a. Shifting the culture of textile and apparel production and consumption
b. Incentives for textile and apparel businesses to improve their practices
c. Creating policies that hold the industry accountable for the impact created

Another important contribution would be design and consumer engagement in this journey towards circularity. We can talk about designs and business models, but if we do not engage consumers in this journey we will not get there. There is a plethora of roles and areas where we can act, but it is important to choose one and start the journey towards circularity. As stated already several times, transparency is all about communication, collaboration and trust between all the actors and stakeholders.

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