Towards a Digital Product Representation in the Textile and Clothing Industry: Exploring Design Requirements and the Role of Industry 4.0 Technologies

CINTO1005E Master's Thesis in MSc. Business Administration & Information Systems

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Abstract

The textile and clothing industry faces significant transparency, traceability, sustainability, and counterfeiting challenges. In response to these challenges, this thesis explores the design requirements for a digital product representation in the industry and how Industry 4.0 technologies can support these requirements.

Using a practical, utility-driven, and problem-oriented design science research approach, we created an IT artifact consisting of a layered supply chain model and a digital product representation requirement visualization through two iterations - organizational-focused and expert-focused. We identified and collected technical, stakeholder, and regulatory requirements that represent the complex demands of the industry.

We then assessed these requirements against the capabilities of Industry 4.0 technologies, in our case, blockchain and IoT, to identify potential areas for technological support. Our findings revealed that, while these technologies could cater to some requirements, stakeholder collaboration, regulatory support, and standardization are equally critical but cannot be addressed through technology alone.

Additionally, we highlighted several challenges that need to be considered to successfully implement a digital product representation in the industry's future, including high investment costs, non-holistic adoption, and interoperability complexities.

In conclusion, our research emphasizes the importance of designing a universally accommodating digital product representation that considers the diverse actors, technological proficiency, and regulatory framework within the textile and clothing supply chain. The insights provided in this thesis can guide organizations and policymakers seeking to implement a digital product representation in the industry to enhance transparency, traceability, sustainability, authentication, and efficiency.

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List of Abbreviations

Abbreviation	Full Text
BC	Blockchain
C2S	Create2Stay
CBS	Copenhagen Business School
DAO	Decentralized Autonomous Organization
DPP	Digital Product Passport
DPR	Digital Product Representation
DSR	Design Science Research
DSRMPM	Design Science Research Process Model
EAN	European Article Number
EU	European Union
GC	GreenCotton
GOTS	The Global Organic Textile Standard
GS1	Global Standards
IoT	Internet of Things
IPR	Intellectual Property Right
IS	Information System
POD	Print-on-Demand
QR	Quick Response
RFID	Radio-Frequency Identification
T&C	Textile & Clothing

1. Introduction

The textile and clothing (T&C) industry is a fundamental pillar of the global economy, with a rich history and a significant impact on society. However, despite its long-standing presence, the industry has become increasingly scrutinized due to its outdated and environmentally harmful practices. As a result, society and legislation demand a change - a transformation that could be facilitated by the revolutionary potential of Industry 4.0 technologies. These technologies have the potential to pave the way for a more sustainable future, offering a new kind of fashion statement - one that prioritizes ethics, transparency, and environmental responsibility. The T&C industry is a paradox - a creative and expressive symbol of human ingenuity that exploitative and polluting practices have marred. The urgency of sustainability demands a new approach, one that is informed by the promise of Industry 4.0 technologies. Therefore, this thesis aims to explore:

What are the design requirements for a digital product representation in the textile and clothing industry, and how can Industry 4.0 technologies support these requirements?

The scrutiny that the T&C industry pivoted in 2013 due to the Rana Plaza incident in 2013, where over 1,000 garment workers died in a factory collapse which shed light on the poor working conditions and violation of human rights in the industry (Henninger et al., 2017; Manshoven et al., 2019). The fashion industry is one of the most polluting industries globally, contributing to greenhouse gas emissions, waste, and water pollution (Ellen MacArthur Foundation, 2017; Henninger et al., 2017). Furthermore, textile waste has become a significant issue, with only a tiny fraction of used clothing being recycled or repurposed (Manshoven et al., 2019). These challenges highlight the need for sustainable practices and innovation in the fashion industry.

To address these challenges, the European Union (EU) has launched initiatives like the Circular Economy Action Plan (European Union, n.d.), the RESET-Trend program (European Union, n.d.-a), and the Green Deal (European Union, n.d.-b), which all aim to transform the industry's traditional linear model into a more circular and sustainable one. Upcoming legislation that serves as a key motivation and purpose driver for our research is the EU’s development of a Digital Product Passport (DPP), which is intended to provide consumers with more information about the environmental and social impact of the T&C products they purchase. According to the World Business Council for Sustainable Development, a DPP is "a structured collection of product-related data across a product's lifecycle to advance the transition to a circular economy and thereby support economic growth" (Stepke-Müller et al., 2023, p.2) and it is expected that DPPs will be mandatory for most industries by 2030 (ibid.).

The DPP requires a unique identifier for a product and aims to provide environmental, social, and traceability information through a digital platform (ibid.). Although the overall objectives of a DPP are set (ibid.), details of the legislation, such as information sharing and hosting the platform, are unclear as it is finalized. The EU is taking steps towards sustainability in the T&C industry, but the lack of details in upcoming laws leaves companies unprepared. This uncertainty highlights the need for our research, which explores T&C companies' perspectives on the need for a digital product representation (DPR).

Apart from regulatory initiatives to address the T&C industry's challenges, Industry 4.0 technologies such as blockchain (BC) and the Internet of Things (IoT) have been explored to improve supply chain transparency, traceability, and efficiency (Queiroz et al., 2018). BC technology has the potential to provide a secure and transparent ledger for tracking transactions and product information (Alves et al., 2021), while IoT devices can collect and transmit data throughout the supply chain (Hussain et al., 2021). However, their implementation in the fashion industry is still in its early stages, with most studies focusing on conceptual frameworks and case studies (Queiroz et al., 2018) rather than practical applications. Therefore, it is crucial to investigate the requirements for a DPR in the T&C industry and how Industry 4.0 technologies could support these requirements.

Thus, the research question for this master thesis is centered on exploring the design requirements for a DPR in the T&C industry and how Industry 4.0 technologies such as BC and IoT can support these requirements. The sub-questions are designed to support the research by providing a comprehensive understanding of the challenges faced by the industry, the requirements for a DPR, and the potential future considerations and challenges of implementing Industry 4.0 technologies. In our research context, "design requirements" are the specific needs and specifications that must be addressed to digitize a product or process. In this thesis, for ease of understanding, the term "requirement" is used synonymously with the concept of "design requirement".

As such, we pose the following sub-questions to answer our overall research question:

1. Sub-question: *What challenges of the textile and clothing industry has literature identified, and how have Industry 4.0 technologies such as blockchain and IoT been explored to tackle these challenges?*
2. Sub-question: *Based on understanding the textile and clothing industry's as-is supply chain, what are the requirements for a digital product representation, and how can Blockchain and the Internet of Things support the industry's demands?*
3. Sub-question: *What are the potential future considerations and challenges in implementing Industry 4.0 technologies, such as blockchain and IoT, to support digital product representation in the textile and clothing industry?*

Our initial research motivation was enhanced by an ongoing program called "Trace - a transition towards circular economy", funded by the Innovation Fund Denmark via "Innomissions", precisely, mission 4 "CE-PT - Circular economy with a focus on plastic and textiles" (Innovationsfonden, n.d.), and the EU from within "NextGenerationEU". Trace encompasses a "broad partnership of 90 partners consisting of universities, knowledge institutions, and public and private companies have joined forces" (Trace, n.d.). For our research, we were exposed to their textile project "Blockchain, IoT and Resale 3" (Trace, n.d.-b), which our supervisor, Jan Damsgaard, leads. The exposure to this project allowed us to get in touch with companies that are part of the Trace partnership program, especially at a workshop hosted at the end of March 2023, where around ten company participants attended together with the Lifestyle Design Cluster to learn about BC, IoT, and the DPP plus existing solutions for it. This workshop played a crucial role in our research inspiration and elevated its relevance after we heard the companies' concerns and demands. Consequently, we collaborated with some of the companies present at the workshop who expressed interest in our research topic.

Thesis Structure & Outline

To provide an outline of our thesis, including the chapters and main themes covered in each chapter, we divided it into ten chapters, with this introduction representing the first chapter. The literature review represents the second chapter of our thesis, highlighting the challenges faced by the T&C industry and to what extent research has been conducted on the potential of Industry 4.0 technologies to address these challenges, answering our **first sub-question**. Following the literature review, the third chapter explains our methodological choices based on Saunders et al.'s (2019) research onion (Figure A1), thus covering our research philosophy; approach to theory development; research design and strategy; time horizon; techniques and procedures; and lastly, research ethics, credibility, and quality. We highlight what factors influenced our methodological choices, such as following a pragmatism philosophy and conducting design science research (DSR). In the fourth chapter, we define the theoretical concepts that our research builds upon. These concepts are related to the T&C industry and supply chain and, naturally, the Industry 4.0 technologies we explore, namely, BC and IoT.

Chapter five presents a prelude to the DSR activities to explain how we planned to execute each activity and design iteration. The sixth chapter of our thesis revolves around the results of each DSR activity, starting with the problem identification and resulting definitions of our IT artifact objectives. Then follows our analysis of findings from the first and second iterations of designing, demonstrating, and evaluating our IT artifact in chapter seven. This analysis answers the former part of our **second sub-question**, namely creating an understanding of the T&C industry's as-is supply chain and identifying the requirements for a DPR. The latter part of our second sub-question is answered in chapter eight, in the assessment of matching the collected requirements with the technological capabilities of BC and IoT to explore any requirement gaps these technologies cannot support.

Lastly, to answer our **third sub-question**, chapter nine presents our discussion of the impact a DPR based on BC and IoT may have on the T&C supply chain activities based on a theoretical reference model. Given future legislation, we discuss the considerations for a future implementation of a DPR, given the insights gathered from primary data. We reflect on our methodological choices and which future research directions result from our research. Finally, we conclude our thesis in the tenth chapter and summarize our key findings.

2. Literature Review

To review the academic literature on our topic, we followed Saunders et al.'s (2019) literature review process (Figure A2). From the 23rd of January to the 5th of February 2023, we conducted multiple search and evaluation cycles based on defined and redefined parameters and keywords. For our first sub-question, we searched for literature on the challenges of the T&C industry, the exploration of Industry 4.0 technologies like BC and IoT to address these challenges, and how this evidence supports researching the requirements for a DPR.

After defining our research questions, we continued "Phase I" of the upward spiral (Figure A2) by setting search parameters. Webster & Watson (2002) emphasize the importance of a comprehensive review not limited by methodology, journals, or geography. Thus, our search parameters included English language results and were executed on Google Scholar and CBS Library Search via our student login, including any material, even if CBS does not have complete access.

Our concept-centric review (ibid.) utilized a concept matrix to group and present key concepts. Due to our research motivation and the context of our research within *Trace*, initially, we focused on the following keywords: "Blockchain", "IoT", "Design", "Fashion", "Sustainability", and "Traceability". However, further refinement of keywords and parameters was necessary after conducting initial searches. In the second phase of the literature review cycle, we replaced "Fashion" with "Textile" to better reflect the industry we were researching. Additionally, we limited our search to results from 2017 onwards to ensure a more recent representation of reality as technological advances happen rapidly.

These improvements helped scale down the number of results, yet the Google Scholar database still yielded a too-extensive result list (**62.270** across all search rounds). In the third phase of our review, we modified the search query only to show results with titles containing the specified keywords rather than showing results that mention the keywords only once, resulting in **216** records. To improve the quality of our literature reviewed, we limited results in CBS Library Search to peer-reviewed findings. Despite lacking peer review due to its recent publication in February 2023, the systematic literature review by Forno et al. (2023) was essential to our research and included in our review. As the authors are not generating new claims but reviewing current literature, we found it acceptable to include this non-peer-reviewed source. The focus on peer-reviewed articles allowed us to decrease our results by 1.155 records in CBS Library Search. With these parameters and keywords, we had a list of **968** articles to filter further. Figure A3 shows a visualization of our literature filtering process.

By reading the title and abstract, we excluded articles that were too narrow or irrelevant to our research focus and others that were not comparable to the T&C industry. Highly technical articles focusing on specific parts of the BC, like hash functions, were also removed. We prioritized primary sources, such as reports, theses, and conference proceedings. However, most of the literature explored falls into the secondary source of literature (journals, books) (Saunders et al., 2019). We selected 19 articles for full-text analysis and added 25 articles from cross-references. The number of added articles can be traced back to systemic literature reviews identified during the search rounds, allowing extensive cross-referencing.

During the full-text analysis of each of the **44** articles (Sheet 1, Table B1), we used the five critical questions Wallace & Wray (2006) proposed: "*1. Why am I reading this?; 2. What is the author trying to do in writing this?; 3. What is the writer saying that is relevant to what I want to find out?; 4. How convincing is what the author is saying?; 5. What use can I make of the reading?*" (ibid., p. 63), to filter our selection to **33** papers presented in an overview on Sheet 2 "Literature Overview (33)" in Table B1.

We documented search rounds to comply with the "Record" step (Figure A3), capturing parameters such as the database, date, keywords, and results. Once selected for review, we recorded the article's facts, summary, and contribution to our research (Sheet 2, Table B1). Our literature findings are presented below, grouped into **1) textile and clothing industry challenges highlighting the importance of our research and 2) exploration of Industry 4.0 technologies, such as blockchain and IoT, to address industry issues.**

2.1 Challenges in the Textile & Clothing Industry

Our literature search found 14 relevant textile, fashion, and clothing industry articles from various journals. We filtered out 11 papers and will discuss them under four subheadings in this section.

2.1.1 Environmental Impact

Several papers (Manshoven et al., 2019; Niinimäki et al., 2020; Henninger et al., 2017) identify key sustainability challenges facing the T&C industry, including agricultural and chemical resource usage, greenhouse gas emissions, textile and packaging waste, and poor working conditions that often violate human rights. For example, cotton production requires significant amounts of water and pesticides, while textile transportation generates more greenhouse gas emissions than international flights and shipping combined. Jacometti (2019) cites two causes of these sustainability challenges: 1) production shift to countries with low labor costs and 2) the fast fashion trend, which promotes low-priced and disposable clothing. Fast fashion's success and high sales exacerbate the issues mentioned. Although the industry has faced criticism for the last two decades, fast fashion brands continue to grow. Niinimäki et al. (2020) focused on the environmental impact of fast fashion and suggested a paradigm shift in the global supply chain.

Henninger et al. (2016, 2017) defined sustainable fashion for micro-organizations, experts, and consumers (2016). Since they found that the "interpretation of sustainable fashion is context and person dependent" (ibid., p.400), they proposed a matrix of principles that organizations should follow to set targets for their collections along different priority levels (low, medium, high) to avoid greenwashing. This study focuses on UK companies, but the authors suggest exploring the matrix's applicability to other regions.

A year later, Henninger et al. (2017) published "Sustainability in Fashion", a book that addresses industry challenges and proposes new business models for a circular economy and changing consumer behavior. The authors highlight the potential mistrust in current certifications such as eco-labels and emphasize collaboration between government and business "to broaden the prospect of slowing down consumption, thereby convincing consumers to make more environmentally friendly choices as a way of enacting a changing social value system" (ibid., p. 2).

2.1.2 Reporting on Sustainability & Lack of Traceability

Others emphasize accurate environmental impact reporting for the fashion industry along its complex supply chains by using, for instance, *official metrics*, e.g., European Organization Environmental Footprint (OEF); *assessment methodologies*, e.g., Life Cycle Assessment (LCA) and Product Carbon Footprint (PCF) modeling; and *technical tools*, e.g., SimaPro to analyze all the steps along the lifetime of a textile product (Muñoz-Torres et al., 2020; Muthu, 2014). Muthu's (2014) book proposes methods for calculating textile products' carbon, water, and energy footprints along their life cycle, highlighting the lack of a comprehensive study comparing different fibers' environmental impact along their entire life cycle. Challenges and difficulties, such as data verifiability, selection, and quality, persist despite the availability of metrics and tools. Future research should support improved data quality through sensors attached to the life cycle. Muñoz-Torres et al. (2020) question whether sustainability reports "show a limited and biased picture of the real impacts" (p. 3910); thus, they also call for improved data sources to achieve accurate reporting of sustainability impacts in the T&C industry.

Measuring a textile's life cycle requires **visibility, traceability, and transparency** in its supply chain, as this demonstrates the importance of interacting and exchanging information between actors for efficiency/performance enhancements (Kumar et al., 2017) and to move towards more sustainable practices by understanding these concepts better via definitions (Garcia-Torres et al., 2021). Kumar et al. (2017) differentiate between "internal" and "external" traceability and propose a framework to implement both types, emphasizing the importance of effective information sharing to streamline operations and make informed decisions. To make more informed decisions on finding "quality-conscious and cost-effective producers", organizations need to ensure "effective information sharing" because "inadequate information sharing hampers the flexibility and synchronous functioning of the textile supply chain" (ibid., p.1). Relational database management is critical to the traceability framework's proper implementation. Garcia-Torres et al. (2021) investigate these concepts' definitions in the context of sustainable supply chain management (SSCM) and propose a relational model that is beneficial to consider all the stakeholders required to achieve improved traceability. By testing their model and receiving approval from industry experts, they contributed to a better understanding of sustainable practices in the T&C industry.

2.1.3 Regulatory Pressure & Initiatives from the EU

Establishing regulations and laws can hasten changes to reduce the fashion industry's environmental impact. For instance, enforcing the EU's Green Deal resulted in evaluations of business models in a circular economy for the T&C industry (Manshoven et al., 2019). As the production chain is complex, enforcing new standards can be difficult since European brand owners may have limited influence on production methods abroad (ibid.). The briefing by Manshoven et al. (2019) maps out textile value chains, analyzes textiles' environmental and social impacts, and proposes a "vision for a more circular and sustainable production and consumption system" (p.4).

The briefing emphasizes a socially just and distributive circular system and past experiments have had limited success in achieving scale and market penetration.

In 2019, Jacometti assessed the impact of existing EU measures on sustainable practices and the transition to a circular economy in the fashion industry, specifically focusing on the 2015 Circular Economy Action Plan. The EU is committed to the UN's SDGs and advancing a sustainable development agenda, which includes advocating for sustainable clothing supply chains on bilateral, regional, and worldwide scales. The paper provides further details from the EU Commission, including "The Extended Producer Responsibility Clause". However, it emphasizes the importance of implementing a circular economy model that ensures sustainability across the textile's life cycle from design to end of use. Already in 2017, the EU highlighted that it requires "sustainability of textiles across their life cycle from design to end of use" (ibid., p.2) to implement a circular economy model, which further stresses the importance of finding a solution that could support this life cycle tracing. Regulatory pressures have driven companies to improve textile sustainability throughout the lifecycle. Zalando released its first collection in 2020, featuring a DPP via a QR code on the label (Zalando, 2021). It plans to expand and test an end-to-end solution "to offer a wider range of products designed with circularity principles in mind" (ibid.).

2.1.4 Change Initiatives

Many papers propose ways to reduce the T&C industry's environmental impact by reducing water, energy, and chemical usage, improving working conditions, and enhancing supply chain traceability (Manshoven et al., 2019). However, a more robust collaboration among stakeholders is required, primarily if the industry aims to transition to a circular economy, assuming that successful initiatives possess sufficient transformative capacity to scale. Niinimäki et al. (2020) suggest fundamental changes to slow down manufacturing, encourage sustainable practices, and transform consumer behavior, as the long-term stability of fast fashion depends on abandoning this model and decreasing material throughput to achieve eco-efficiency.

To improve traceability and transparency in the T&C industry, Agrawal et al. (2018) propose a secured tag as a unique identifier. Key takeaways relevant to our research are alternative data collection methods and events along the supply chain that the authors capture. However, the tag's limitation is that it may not remain visible after washing. Sandvik & Stubbs (2019) studied the Scandinavian fashion industry and technology's importance in changing textile-to-textile recycling. They identified “the drivers, inhibitors, and enablers of creating a textile-to-textile recycling system” (ibid., p.366). The authors highlight the need for systemic changes, such as enhancing recycling technology through digitalization, collaboration, and different strategies for slow and fast fashion systems. Achieving these changes requires companies to understand the technology-driven solution requirements.

2.1.5 Sub-summary of Sustainability in the T&C Industry

Academics studying the T&C industry's sustainability issues have raised awareness about the challenges, emphasized the need for measurement and reporting on environmental impact, assessed regulatory efforts, and proposed ideas for changing the status quo. However, some studies are limited in scope and may not reflect updated legislation, suggesting future research needs to test applicability in other regions. Additionally, as an entry point for our research, Henninger et al. (2017) emphasized the need for trustworthy certification, which our research could expand upon by examining how BC and IoT sensors could provide tamper-proof certification.

Jacometti (2019) provides insight into mapping out stakeholders involved in an industry-wide BC and IoT solution for the garment-manufacturing supply chain, which could support tracking the environmental impact of textile products. BC and IoT could complement existing methodologies and tools presented by Muthu (2014) presented for reporting on the industry's environmental impact. Another gap identified in the literature is the need to improve the data sources to come closer to the actual impact when, for instance, reporting on sustainability (Muñoz-Torres et al., 2020). This highlights the need for our research to investigate how improved data sources could be created using Industry 4.0 technologies. Thus, our research addresses the need for improved data sources by identifying the necessary information and material flow along the supply chain events. Furthermore, our research aims to experiment with potential options and design requirements for achieving a socially just and distributive circular system at a sufficient scale, including exploring the need for a more permanent tag for tracing textile products throughout their lifecycle. Therefore, we see a need to explore the requirements for a DPR in the T&C industry and find out how Industry 4.0 technologies could support them.

2.2 Internet of Things & Blockchain Technology

Based on our literature search, we identified 22 articles relevant to our research question regarding BC and IoT applications in the T&C industry and its supply chain in general, which will serve to uncover and investigate the current body of knowledge.

2.2.1 BC in T&C Industry: Visibility, Transparency & Traceability in Supply Chain (Management)

This literature review section examines the use of BC in the T&C industry, specifically in supply chain management, intellectual property rights, and sustainability. T&C supply chains are often fragmented and complex, making resource tracking challenging despite using ERP systems. Tripathi et al. (2021) suggest that BC can enhance transparency and traceability at every stage of the supply chain, from raw material procurement to end-users. Data sharing and advanced analytics would enable "better and informed decisions can be taken to maintain the balance between the supply and demands" (ibid. p. 211). According to Tripathi et al. (2021), the challenges of implementing BC in the T&C industry include technology immaturity, high cost, loss of actors in the supply chain, complex blocks, lack of standardization, need for two-level security, transparency of information, intellectual property protection, and BC incorporation. To overcome these challenges, they stress the importance of "strong enthusiasm and anticipation among the concerned players" (p.218).

Albeit these challenges, several solutions have been implemented and studied, including the fiber producer Lenzing's BC platform "TextileGenesis", as studied by Ahmed & MacCarthy (2021). The authors conducted a case study to analyze the platform's degree of traceability achieved downstream. The study concluded that despite the promising applications, pilot projects worldwide, and case studies, achieving traceability of textiles on a granular level upstream requires the implementation of yet-to-be-proven technologies.

A big part of the literature on BC implemented in T&C supply chain management involves conceptualizing frameworks to map potential BC solutions involving different actors across supply chains for objectives like traceability (Agrawal et al., 2021; Elmessiry & Elmessiry, 2018; Hader et al., 2022). Agrawal et al. (2021) suggest a BC framework for T&C industry supply chains that consists of a private network with various levels of access for different actors to maintain trust and transparency without compromising their competitive advantage. This framework encompasses organizational and operational aspects, including network configuration, customized accessibility, smart contracts, transaction validation, and information storage capabilities. However, the proposed framework is entirely simulated and not based on empirical data. It serves as an “interesting starting point for gauging the feasibility” (ibid. p. 11). They faced challenges in block formation delay when running their simulation when “nonce complexity increases” (ibid.) (nonce is the number those miners try to arrive at when mining a new block for a BC) and “a number of transactions increases per block” (ibid.).

Elmessiry & Elmessiry (2018) proposed a BC framework for supply chains to enhance transparency, traceability, and quality. The framework features a connected machinery system with shared information through wallet transfers, enabling block tracing to the genesis wallet. Consensus mechanisms verify batch transactions and automated protection alerts for inconsistencies with block information (ibid.). The framework is relatively novel and conceptual and lacks granular details for implementation, suggesting significant work is needed before the framework can be practically applied.

Hader et al. (2021) introduced a BC-integrated big data framework for traceability and information sharing in the textile sector. The model, addressing scalability issues, integrates big data technologies, and offers real-time product status information. Despite its comprehensiveness, the authors suggest future research on implementation in the actual textile supply chains and the variety of exchanged information.

A consensus on the lack of empirical data-based frameworks for BC in T&C supply chains is evident (Queiroz et al., 2019). Queiroz et al. conducted a systematic literature review in 2019, finding 27 articles on BC and supply chain management. They observed a scarcity of empirical studies reporting on implementation lessons and challenges. Sunny et al. (2020) supported this finding, concluding that actual implementations of BC traceability solutions are rare. Research on the benefits of such solutions is in high demand, further emphasizing the need for our research.

2.2.2 BC in T&C Industry: Fighting Counterfeits & Enforcing Intellectual Property Rights

The shared goal of enhancing traceability and transparency in T&C supply chains has prompted a literature subset on BC's role in addressing intellectual property rights (IPRs) issues in the T&C industry. Thanasi-Boçe et al. (2022) propose BC as a crucial technology for luxury brands to safeguard their IPRs. Luxury brands' supply chains, which often "rely on centralized database systems" (ibid. p. 6), are vulnerable to "attacks that may result in data record violations" (ibid. p. 6). Authentication services primarily cater to producers rather than consumers, with some exceptions like holograms and QR codes (ibid). The authors suggest that BC offers a cost-effective anti-counterfeiting solution for luxury goods, enhancing supply chain transparency and efficiency, bolstering management capacity, and allowing consumers to verify product authenticity. Thus, implementing BC can deter counterfeiting and boost trust in the industry (ibid.). One existing example is the AURA consortium, a well-known BC solution for luxury fashion authentication developed by LVMH, Prada Group, and Cartier as a non-profit organization (ibid.).

2.2.3 BC in T&C Industry: Revealing Environmental Impact to Improve Sustainability

BC's unique features have prompted research on improving sustainability practices in the T&C industry. Cruz & Cruz (2020) suggest that BC traceability systems enhance supply chain transparency, sustainability, and accountability. Although they recognize BC's transaction processing limitations, they anticipate technological advancements to improve speed and capacity.

Academics have developed frameworks for implementing BC traceability systems focused on sustainability. Rusinek et al. (2018) propose a framework to trace the life cycle of individual garment components, enabling enhanced sustainability identification at various stages. Metrics in economic, environmental, social, and functional categories would be recorded on blocks, allowing sustainable decision-making. The authors discuss system requirements like human capital, labeling, and consumer behavior but not technical aspects, suggesting future research on quantitative and local implementations.

Limata (2019) explores how BC technology can enable a circular economy by tracking sustainability throughout a product's lifecycle. BC can improve visibility and intelligence within the circular economy, offering benefits such as reduced costs and smart contract implementation. Limata (ibid.) acknowledges challenges like governance, economic, and organizational issues and believes BC can address them. However, the article also notes BC's limitations, including centralization risks but argues that transforming to a circular economy with BC implementation may yield societal benefits. Further research is needed, as Limata's work (2019) is based on academic contributions and theoretical assumptions. The author suggests that future research should focus on case studies, literature reviews, and in-depth interviews with leading scholars and sector actors.

2.2.4 IoT in T&C Industry

Regarding the T&C industry, IoT has mainly been researched with other Industry 4.0 technologies such as big data analytics, artificial intelligence, machine learning, and BC. Before diving into the literature on IoT and BC combined in the T&C industry, we review research on IoT in isolation. IoT has intrigued researchers as a technology to optimize the early stages of the T&C industry. Hardin et al. (2022) explore current IoT applications in cotton harvesting and processing, envisioning future use cases and identifying research needs. They discuss John Deere's Harvest Identification system for round module identification, including parameters like serial number, date, location, and moisture content (see Figure 1 below for an example of a cotton module and its unique RFID tag by John Deer). RFID tags enable automated tracking of module movement throughout the supply chain. However, challenges like rural connectivity, data standardization, ownership, and security impede IoT adoption in agriculture. Advances in understanding factors affecting fiber and yarn quality and optimizing cotton fiber logistics are needed.

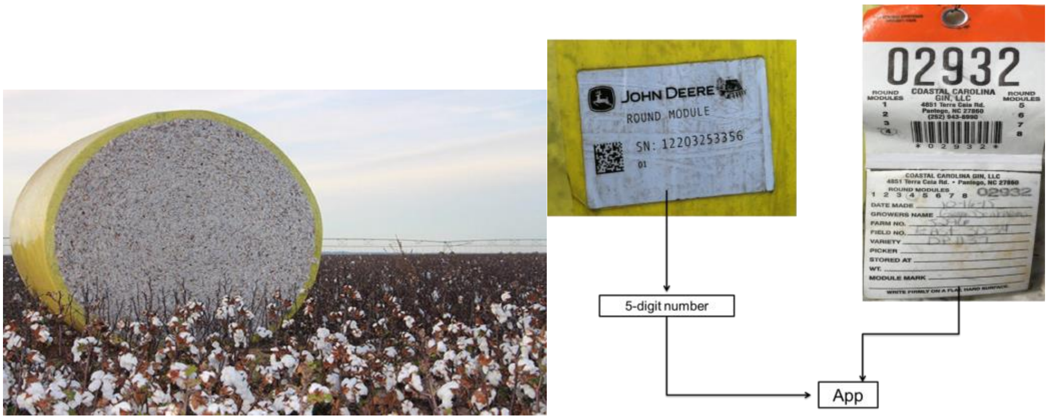

Figure 1: Example of Cotton Module (left, Gorman, 2022) and RFID tag by John Deere (right, WEF Nexus Research Group, 2022)

In other areas of academia, researchers have studied how IoT can enable smart clothing to communicate biometric information to the garment user (Fernández-Caramés & Fraga-Lamas, 2018). The authors examine IoT wearables and garments requirements along with recent smart clothing applications. Dal Forno et al. (2023) contribute to IoT knowledge in the T&C industry with a literature review, exploring three Industry 4.0 applications, including IoT. They summarized significant opportunities for IoT application in the T&C field as:

- "Planning, control, and management of the production chain:" The following steps from the stage in which an IoT sensor is employed can utilize real-time data in decision-making.
- "Areas of creation and development:" IoT sensors allow for data collection throughout a product's life, which can be used to increase the processes of its creation and the product itself.
- "Monitoring and maintenance:" Connecting textile machinery to the internet would allow for remote monitoring and maintenance.
- "Wearables" (ibid. p. 102)

2.2.5 IoT & BC

The integration between BC and IoT gained considerable traction within the academic community. Many researchers propose the possibilities the pair can generate in the T&C industry and supply chains across industries. The complementary relationship between IoT and BC in supply chain management was studied by Aich et al. (2019). They suggest that IoT's privacy and security challenges can be overcome by integrating BC technology due to its decentralized nature, anonymity, and ability to provide a secure network for IoT devices (ibid). The authors also suggest that the combination will allow for "information continuity and traceability, information accessibility, the link between information flow and material flow, and a decrease in code of conduct violations and fraud" (ibid. p. 139). Further, the article implies that this combination will successfully solve the problems of conventional supply chains, such as "lack of visibility, flexibility, trust, risk management, and lack of advanced technologies" (ibid.).

Pal & Yasar (2020) explore the challenges of integrating IoT and BC in the T&C industry, specifically supply chain management complexities and the need for flexibility. They emphasize the importance of secure information systems architecture for sharing, storing, and processing data, proposing a hybrid architecture combining IoT and BC technology. Their system captures real-time data for improved decision-making but faces challenges like limited transaction throughput capacity. The authors propose that BC technology addresses security issues in IoT systems. At the same time, IoT data management concerns emerge, such as interpreting data concerning reference data and managing information from external sources.

A focal point of the literature regarding BC and IoT in supply chains has been the creation of frameworks. (Raza & Singh, 2022; Chen et al., 2017). Raza & Singh (2022) propose a BC-IoT supply chain system framework based on Ethereum and Hyperledger to combat the shared supply chain issues of trust, security, transparency, and traceability. The framework includes four main modules, "the Input data module [...] IoT module [...] Blockchain module, and [...] Supply chain module" (ibid. p. 9). The authors propose that their framework could "serve as a candidate to realize a secure and reliable [Supply Chain Management Systems (SCMS)] addressing the limitations in the traditional SCMS like securities, transparency, and reliability in a decentralized fashion." (ibid. p. 26). However, they propose that several areas should be improved further, such as the use of real-time data as they used synthetic data for their testing and "event monitoring verification framework" (ibid. p. 26) as, in their framework, shipment data is collected by third parties which cause data delay. Chen et al. (2017) propose a BC-based supply chain framework for laptop quality management, using IoT sensors for real-time data and smart contracts to address quality errors and reverse transactions. However, the article is short on technical requirements and real-life data testing. The authors suggest the framework could serve as a "theoretical basis for future intelligent quality management based on blockchain technology" (ibid. p. 175).

Other noticeable conceptual literature on BC and IoT are those of Bhat et al. (2021) and Faridi et al. (2021). Bhat et al. (2021) advise an agricultural supply chain management architecture based on IoT and BC that could be employed for a variety of different applications such as food composition, quality, and safety monitoring, food safety across the supply chain, product traceability, food waste, and inventory management. The agricultural BC-IoT-based supply chain management architecture is a proposed solution to address scalability optimization, interoperability, security, and privacy issues in existing single-chain agriculture supply chain systems. Faridi et al. (2021) propose a traceability system built upon previous research for textile supply chains based on RFID sensors and smart contracts. Every business process throughout a textile supply chain is given a BC address account as its unique ID. Every physical object is assigned an EPC (electronic product code) to work as the product ID, which will be stored on an RFID tag to enable the tracing of products throughout each step of the supply chain. It will allow consumers to trace their clothing back to the raw material origin.

RFID tags are one of the most popular IoT technologies in the literature on BC and IoT in supply chains, as stated by Hussain et al. (2021), who conducted a literature review into BC-based IoT applications for supply chain management. They found that integrating BC in RFID-based supply chain management provided “data protection, glassiness, trustworthiness, and management costs compared with the conventional decentralized database system.” (ibid. p. 12). Surprisingly, their literature review did not mention BC-based IoT devices in the T&C industry. However, IoT applications in the T&C industry have been studied extensively, as Forno et al. (2023) reported.

Alves et al. (2022) discuss integrating IoT and BC technology in the T&C industry to improve traceability and promote a circular economy business model. They outline the value chain benefits of IoT traceability, such as transparency, delivery optimization, operational efficiency, and improved tracking. The authors acknowledge the difficulties in implementing IoT and BC technology, which can be classified as non-technical or technical, such as a lack of industry-wide standards, interoperability, and scalability issues. They emphasize overcoming these challenges to enable sustainable development and reduce the T&C sector's environmental impact. They also propose using digital twins and gamification techniques to facilitate adopting circular economy business processes and engage final consumers in recycling efforts.

2.2.6 Sub-summary of IoT & BC in the T&C Industry

The literature on the challenges faced by the T&C industry delves into issues such as transparency, traceability, and sustainability. To tackle these challenges, scholars have investigated the potential of Industry 4.0 technologies, specifically BC and IoT, to revolutionize the T&C landscape. The exploration of BC's role in the T&C industry has been primarily confined to conceptual analyses, with scholars unveiling potential benefits in enhancing transparency, traceability, authentication, and sustainability. The advent of IoT has spurred further research, often in conjunction with other Industry

4.0 technologies such as big data analytics, artificial intelligence, and machine learning. IoT's applications span from optimizing the earlier stages of the T&C industry, and developing smart clothing, to transforming supply chain management. The literature underscores the necessity of delving deeper into empirical research and case studies to gain a more profound understanding of the challenges and opportunities associated with implementing BC and IoT within the T&C industry.

The integration of BC and IoT has captured the attention of academia, as researchers endeavor to devise frameworks and systems that address the multifaceted challenges faced by the T&C industry. The combination of these technologies has been studied for their potential in supply chain management, yielding benefits such as bolstered security, information continuity, and traceability. However, combining IoT and BC presents challenges, including scalability concerns, data management intricacies, and interpretation dilemmas. This body of evidence speaks to exploring the requirements for a DPR in the T&C industry due to the similarities in potential benefits. By leveraging the combined strengths of BC and IoT technologies, a DPR could potentially support greater transparency, traceability, and sustainability in the T&C industry. Thus, future research must focus on investigating the technical requirements, potential challenges, and practical implications of implementing a DPR, grounded in the combined benefits of BC and IoT technologies in the T&C industry.

3. Methodology

This chapter describes our methodology for addressing our research question, including our philosophical stance, methodological choice, and how DSR influenced our qualitative and exploratory research. We discuss data collection techniques, analysis procedures, ethical considerations, and research quality.

3.1 Research Philosophy

To understand our choice of data collection and analysis methods, it is crucial to consider our research philosophy. We align with pragmatism as we are “focused on improving practice” rather than “question[ing] the accepted ways of thinking”, as postmodernism would, “undertak[ing] historical analyses of changing or enduring societal and organizational structures”, as per critical realism; or create “law-like generalizations” (Saunders et al., 2019, pp. 159-160), as suggested by positivism.

We aim to generate new knowledge with practical applications, considering theories, concepts, and ideas regarding their practical consequences in specific contexts (ibid., p. 151). This approach emphasizes the importance of research in solving real-world problems and informing practical decision-making. We aim to advance literature and inform practitioners on solving transparency, traceability, authentication, and sustainability issues in T&C supply chains to contribute to "problem-solving and future practice" (ibid., p. 145).

Therefore, pragmatism applies to our study as we address these specific practical issues identified in the T&C industry. As explained later, pragmatism involves directly collecting data from affected stakeholders to address this challenge. We also recognize the importance of shaping knowledge and understanding, which we accomplish by capturing the requirements of a DPR and assessing whether Industry 4.0 technologies could support them. This contribution is of the highest priority for us, highlighting that we "are more interested in practical outcomes rather than abstract dimensions" (ibid., p.151), further emphasizing our alignment with the pragmatist paradigm.

We acknowledge that multiple perspectives exist, and to highlight this, we involve diverse stakeholders in our research to enrich the requirements for a DPR. While we include various viewpoints in our list of requirements, we recognize that it may not be mutually exclusive nor an exhaustive list; thus, further research is necessary. Regarding the use of our research method, we agree with Saunders et al. (2019) that we pursue those "that enable credible, well-founded, reliable and relevant data to be collected" (p.151).

Pragmatism was the most suitable research philosophy for our study compared to other worldviews. Positivism's universalism clashes with our perspective, making it unsuitable for collecting diverse requirements from multiple stakeholders along the supply chain. Similarly, critical realism is unsuitable for our research as it depends on "historically situated" knowledge (ibid., p.144), which is not feasible due to the limited use cases of Industry 4.0 technologies in textiles. Interpretivism and postmodernism align more closely with our research philosophy as they recognize that stakeholders have different priorities and socially constructed realities. However, we do not fully embrace the postmodernist view that reality is shaped solely by power relations. While we acknowledge that implementing a DPR requires decision-making from those in positions of power, our research aims to gather requirements from a diverse range of stakeholders. The interpretive point of view aligns more closely with our methods of "using small samples, in-depth investigations, [and] qualitative analysis" (ibid., p.145). We acknowledge and embrace the opportunity to be **symbolic interactionists** who derive meaning from social interactions between people (ibid.). However, we maintain some distance from the practitioner's perspective, which aligns better with the pragmatist paradigm we support.

3.2 Approach to Theory Development

Our research philosophy directs our approach to theory development, significantly impacting our research design. We reason for our choice via the logic, generalizability, use of data, and theory approach to either deduction, induction, or abduction (Saunders et al., 2019). As our literature review revealed, there is a limited number of theories or frameworks related to our phenomenon, and the maturity of Industry 4.0 technologies is too low to fully approach theory development in a deductive manner. We cannot generalize from the generic to the specific or evaluate propositions related to an existing theory except by using widely accepted reference models such as the Supply Chain Operations Reference (SCOR) model (Pal, 2019). On the other hand, an inductive approach would have required pervasive and rich data collection to "generali[ze] from the specific to the general" and "create a conceptual framework" (Saunders et al., 2019, p.153). Our research cannot follow the inductive approach solely as our chosen concepts have already been tested or generalized to some extent. The literature review highlights research testing some Industry 4.0 technologies in isolation across several industries.

Our research followed abductive reasoning, combining inductive and deductive approaches as we referred to individual, somewhat siloed findings that we inferred from to "generate testable conclusions" (ibid.). We applied the SCOR model to understand our findings better and infer what impact a DPR would have on the T&C industry, representing the deductive aspect. Meanwhile, using inductive reasoning, we explored the phenomenon of a DPR via a combination of Industry 4.0 technologies. We believe combining the two approaches can complement each other and uncover findings that each reasoning applied individually would not.

3.3 Methodological Choice & Research Design

This thesis explores the requirements for a DPR and how Industry 4.0 technologies could support these requirements, positioning this study as an **exploratory** research design (Saunders et al., 2019). Following this research design comes with uncertainty in exploring a new research subject. We, as researchers, may be forced to change our direction if newly discovered data would provide new insights regarding our phenomenon of interest (ibid.). Uncertainty was evident in our initial research stages, prompting a comprehensive literature review to gain insight into T&C industry challenges and the use of BC and IoT to address them. We employed a **qualitative multi-method** approach, combining a literature review, semi-structured interviews with T&C companies, and expert evaluations to ensure data validity through triangulation. The literature review served as a theoretical foundation, while case company interviews supported our goal of producing practical knowledge, and finally, expert evaluations served the purpose of validating our findings. Considering the specific nature of our research question and resource constraints, we concluded that a qualitative multi-method approach would yield the most credible, reliable, and relevant data for our study, despite the historical preference of researchers with a pragmatic worldview for mixed-method approaches (ibid.).

3.4 Research Strategy

A research strategy is the methodological research plan of action to achieve the answer to a research question. Aligning with our pragmatic worldview, we decided to follow the DSR methodology as our research strategy, which will guide us in establishing requirements for a DPR and assessing BC and IoT's capabilities in supporting these requirements. We want to acknowledge that DSR is solution-oriented and aims to provide knowledge through utility. Business management researchers have criticized DSR for not considering the "wide variety of organizational phenomena that are often ambiguous" (ibid., p. 9). Due to DSR's problem-solution focus, this research strategy may struggle to capture the multiple dimensions of business management research. However, we argue that in the case of this thesis, DSR is a useful research strategy to employ, given the focus on the combination of technology and business in our master's education. Additionally, Information System (IS) research has long embraced DSR as an appropriate research strategy for researchers (Peffers et al., 2007; Hevner et al., 2004, referenced in Hevner & Chatterjee, 2010; Nunamaker et al., 1990; March & Smith, 1995). Furthermore, we argue that following the DSR methodology and creating an IT artifact generates practical and useful knowledge.

In the context of this thesis, for product-based T&C companies interested in understanding the necessities of a DPR. Furthermore, our research can extend to developers of a DPR as they can benefit from the requirements we capture to validate if their solution has sufficient elements, features, or functionalities to cater to the T&C industry needs. Finally, by creating our IT artifact based on the combination of current literature and collaborating with case companies to collect their requirements and get it evaluated by experts, the DSR approach enables us to bridge the gap between academia and industry better. Finally, it allows us to compose more relevant and applicable knowledge for our case companies to evaluate their contributions to a DPR system and how it could be implemented to impact their supply chain positively.

3.5 Time Horizon

Although the requirements for a DPR may change over time with further technological advances, for our research question, we captured them at a specific point in time which influenced our research design and called for a cross-sectional study (Saunders et al., 2019). By conducting a study with this time horizon, we collected data from participants representing a specific population in approximately one month. Thereby, we exploited some of the benefits of cross-sectional studies, such as efficient data collection, meaning we conducted our research in a relatively short period with fewer resources compared to longitudinal studies that would have required following the research objects over time. Nonetheless, we acknowledge that this only represents a population snapshot which can be considered an advantage and a limitation. An explicit limitation of cross-sectional research is our ability to establish causal relationships or capture changes over time. Nonetheless, given this thesis's resource and time constraints, we considered studying our research phenomenon cross-sectionally as the more appropriate, viable, and feasible choice.

3.6 Techniques & Procedures

We collected primary data through interviews due to our research philosophy, methodological choice, and strategy. It is essential to consider how our data collection and analysis approach relates to our research strategy, including the level of standardization or structure, number of participants, and interview modes (Saunders et al., 2019). Therefore, in this section, we will specify the type of interview we conducted, explain our rationale for this choice, and describe how we analyzed our primary data.

3.6.1 Data Collection

We achieved standardization in our interviews by preparing an interview guide (Appendix C) and allowing for flexibility in responses by including follow-up questions. Our “predetermined list of themes” and “key questions related to these themes” (Saunders et al., 2019, p.437) aimed to guide each interview, but we explored new avenues of discussion based on the interviewee's responses. This approach allowed for a more in-depth understanding of the participant's issues and needs regarding the DPR requirements. By collecting enriched and detailed information with nuances, we uncovered perspectives that may not have been identified through other methods, such as quantitative surveys. This aligns with our pragmatism worldview, and we chose **semi-structured interviews** as an appropriate method for data collection. We also utilized **internet-mediated clarification questionnaires** to gain deeper insights into the data collected during the interviews. These email questionnaires (Appendix D) allowed participants to provide additional context and ensure a more comprehensive understanding.

To ensure diverse perspectives and experiences, we selected case companies representing different T&C product life cycle stages. However, due to practical limitations, we employed a **non-probability sampling** technique, specifically **heterogeneous purposive sampling** (Saunders et al., 2019), guided by our knowledge of the companies' operations and their representativeness of specific phases. Saunders et al. (ibid.) state that determining the appropriate sample size for research is ambiguous and complex, depending on the research objectives and questions. Given the time and resource constraints, our sample size of two case companies and two experts was carefully considered for data saturation and representation of the supply chain stages. We decided on a heterogeneous purposive sampling technique, as we anticipated a smaller sample size. Although a smaller sample size carries the risk of missing valuable data, it also allows us to identify key themes, as any patterns that might come from the data collection are “likely to be of particular interest and value” (ibid. p. 321), as noted by Patton (2015) in Saunders et al. (2019).

Due to the Trace research context, we collaborated with other researchers in some of our interviews to cover common themes and questions, conducting two-to-many interviews. We spoke with more than one representative in each interview with case companies to obtain enriched data, eliminating the option of group interviews. Despite the risk of off-topic discussions in two-to-many interviews, we maintained discipline and preparation to ensure valuable information was collected for all parties. In other interviews, we questioned the case companies in one-to-many interviews focused and tailored to our objectives. All the expert interviews were conducted in a one-to-one setting as we wanted to collect their opinion and feedback individually rather than in a collaborative setting to remain more neutral. We conducted interviews face-to-face or virtually based on the company's availability, with consent to record the discussion obtained in all cases. An overview of our data collection, including our notation system for in-text citations for the primary data analysis, can be found in Table B2 and an explanation of every interview description and its purpose is in Table B3.

3.6.2 Data Analysis

Our research followed an abductive reasoning approach to theory development, which influenced the structure of our interview guide (Appendix C). While our initial questions were informed by existing literature, we allowed for inductive elements through follow-up questions and comments that could lead to a discussion. This approach also impacted our data analysis procedures. As Saunders et al. (2019) note, selecting an appropriate data analysis technique depends on the previous layers of the research onion (Figure A1), including research philosophy and approach to theory development.

We used **thematic analysis** to identify the data's requirement types, overlaps, and relationships. This flexible method helped us identify common patterns and “integrate related data drawn from different transcripts and notes” (Saunders et al., 2019, p.651), which is useful when using triangulation. Thematic analysis can be used regardless of the approach to theory development or worldview (ibid.).

To prepare the data for analysis, we transcribed and cleaned up the recorded semi-structured interviews to a written format for the thematic analysis. Although time-consuming, we used automatic voice-recognition software to facilitate the process. We also considered data sampling by transcribing only relevant parts (ibid., p.645) of the two-to-many interviews, which contained questions from other researchers.

Preparing our data for analysis also helped us become more familiar with it through a “process of immersion” (ibid., p.652). We then coded the data, grouping similar data units to identify better patterns and requirements envisioned by each case company for a DPR. The codes we used as labels came from “actual terms used by participants”, “labels [we] develop[ed], and “existing theory and literature” (ibid., p. 655). Translating coded data into meaningful insights was challenging and required redefining themes and developing visual guidance, such as thematic maps.

3.7 Research Ethics

Regarding the conduction of data collection and data analysis, we find it relevant to ensure the reader that ethical principles were considered and followed. Research ethics refers to “the standards of behavior that guide your conduct concerning the rights of those who become the subject of your work or are affected by it” (ibid. p. 252). Besides abiding by CBS rules and regulations regarding conduct and academic integrity, we also considered several ethical principles proposed by Saunders et al. (ibid.). Regarding the “Integrity, fairness and open-mindedness of the researcher” (ibid. p. 257), we, as researchers, committed ourselves to be transparent and truthful in our writing, data collection, and analysis to ensure the quality of our research further. Furthermore, we informed all interviewees about the interview context and how we would use their statements, thus, ensuring that their consent to take part was made based on an informed decision (ibid.).

3.8 Research Credibility & Quality

Our research design choices, described through the research onion layers (Figure A1) and ethical considerations, directly affect the quality of our research. The quality issues we faced can be traced to pragmatism's high flexibility and lack of standardization. We aimed to increase the **credibility** of our findings by collaborating with an industry expert and conducting a feedback interview to “check[] [our] data, analysis, and interpretation with the participants” (ibid., p. 217).

DSR inherently lacks repeatability, also known as **transferability**, which refers to whether other researchers can produce comparable results. However, we agree with Saunders et al. (2019) that ensuring the replicability of non-standardized qualitative research is not feasible without undermining its strength. Nonetheless, our rigorous design and explanations of choices in each research onion layer allow us to demonstrate some level of generalizability. Qualitative research findings can lead to generalizations across different settings (ibid.), and our study's design can be replicated regardless of geographic location, industry, or company size and maturity. Our overview of the T&C supply chain and list of requirements can be extended, validated, or falsified through a replicated study.

3.9 Sub-Summary of Methodology

This section outlined our methodology, which follows the layers of Saunders et al.'s (2019) research onion (Figure A1). We explain how our choices in each layer were driven by our research question, which seeks to identify the requirements for a DPR in the T&C industry and how Industry 4.0 technologies could support them. The requirements we want to find require a worldview that allows for creating new knowledge; thus, we follow pragmatism in our research. To generate an understanding of the current T&C supply chain, challenges, and technologies employed, we needed to conduct both a literature review to find applicable theory, thus following a deductive approach to reasoning, and collect data to explore the phenomenon in practice, indicating an inductive approach. Thus, we used an abductive approach and employed a qualitative multi-method exploratory study. DSR was our research strategy, which allowed us to create an IT artifact through iterations of semi-structured interviews. Capturing the results at one point in time via a cross-sectional study permitted a resource-friendly approach which, on the other hand, came with implications for the research quality. Our analysis will follow the activities of DSR to answer the second sub-question, where, based on understanding the T&C industry's as-is supply chain, we explore the requirements for a DPR and how BC and IoT could support the industry's demands.

4. Theoretical Concepts

This thesis aims to identify the requirements for a DPR in the T&C industry and how Industry 4.0 technologies can support these requirements. This section will outline key theoretical frameworks and concepts related to the T&C industry, sustainability, circular economy, supply chain management, traceability, transparency, and visibility, as well as the potential of BC, IoT, and DPR to provide a comprehensive understanding of the theoretical concepts that underpin this research.

The T&C industry is crucial to the global economy, supplying products to billions of people worldwide. At the same time, as highlighted in our literature review, the industry faces significant environmental and social challenges. With the growing awareness of the need for sustainability, attention has shifted toward circular product life cycles and more sustainable consumption practices. Yet, implementing sustainable principles would require changing how industry players engage and manage their supply chains. We use the SCOR model's defined processes to assess the case companies' current supply chains.

The potential of Industry 4.0 technologies, such as BC and IoT, to enhance supply chain efficiencies and enable transparency and sustainability in various industries, including T&C, is examined. This research aims to contribute to understanding how BC and IoT can be utilized to drive sustainability in the T&C supply chains. Finally, we want to emphasize the technological capabilities of emerging Industry 4.0 technologies like BC and IoT. These technologies have shown significant potential to enhance supply chain efficiencies, support sustainability commitments, and enable transparency in various industries, including the T&C supply chains. By examining these theoretical concepts, we seek to contribute to the growing knowledge of how BC and IoT can be leveraged to drive sustainability in the T&C supply chain via a DPR.

4.1 Textile & Clothing Industry

From the literature review, we observed that academia defines the industry around garment and textile production, manufacturing, storage, transportation, and distribution differently due to its vast size, complexity, and global reach. Due to globalization, the industry value chain now includes various stakeholders such as fiber and filament, clothing, home linen, technical textiles, and other suppliers, each of which can operate internationally (Alves et al., 2021). Within the value chain, several sub-processes are involved, including spinning fibers into yarn, weaving, or knitting fabric, dyeing or further processing the fabric, and designing and sewing the final product (Wadje, 2009).

The T&C industry has a significant environmental impact during production and transportation and throughout the life cycle of T&C products, as highlighted in various reviewed papers (Henninger et al., 2017; Manshoven et al., 2019; Ellen MacArthur Foundation, 2017). The rise of "fast fashion," a successful business model that has exceeded traditional fashion retail, has resulted in almost double the clothing production since 2000 (Niinimäki et al., 2020). According to Statista (2022a), the fast fashion market is valued at 106.86 billion US dollars as of 2023 and is forecasted to increase by around 30 billion US dollars in the next three years. Niinimäki et al. (2020) have created Figure A4, which provides an overview of the fashion supply chain's key stages, including their geographic location and broad-scale environmental impacts.

Given that the case companies we will work with are based in Denmark, it is relevant to present some specific information about this geographic area. According to Statista (2022c), there were around 340 enterprises in Denmark's manufacturing of wearing apparel industry in 2020 (Eurostat, 2022). Bestseller A/S ranked highest in revenue with 14,189 million DKK as of July 2020 (Statista, 2022b). Regarding sustainable cotton usage, Bestseller A/S ranks fourth among other Europe-based apparel retailers with a score of 51 out of 100, while H&M leads with a score of 77.4 out of 100 on the sustainable cotton ranking score (Statista, 2022a).

In terms of the consumption and impact of T&C, in 2021, Danish households spent around 36 million euros on clothing (OECD, 2023). To provide context on the impact of textile consumption, the greenhouse gas (GHG) emissions resulting from the annual textile consumption of an average Danish person is equivalent to driving a car for 2,143 km (Nielsen et al., 2014). Textile consumption also accounts for 55% of the average household's CO_2 emissions from electricity use, and the water needed for textile production "is 1.8 times higher than the annual consumption of the average household" (ibid., p. 21). These comparisons underscore the pressing need to address textiles' environmental impact. The report from the Danish Environment- and Food Ministry (Miljø- og Fødevareministeriet), published by the Danish Environmental Protection Agency (Watson et al., 2018), maps out the textile flows in Denmark, which emphasizes the situation's urgency. The report illustrates the different routes textile products take (Figure A5) from household, government, and business consumption to recycling, incineration, reuse, or losses. The report reveals that most textiles end up being incinerated rather than recycled or reused.

For this research, the T&C industry will be defined according to Muñoz-Torres et al. (2020), considering the **supply chain actors** as "B2B actors (producers of fibers, spinners, weavers, chemical processors, knitters, apparel manufacturers), B2C actors (brand owners, retailers, retail shops) and customers” and the **stages of its supply chain** as “raw materials, yarn production, fabric production, garment manufacturing, transportation and distribution, consumer use, and disposal and recycle” (p.3887).

4.2 Sustainability & Circular Economy

The T&C industry's environmental impact is expected to increase as fast fashion grows and textile waste accumulates in landfill or incineration. To conquer this, the UN has set out sustainable practices goals for the industry and created the "UN Alliance for Sustainable Fashion" to contribute to the Sustainable Development Goals through coordinated action (United Nations, 2019). In 1992, the United Nations Environment Programme (UNEP) set Sustainability as the main political goal for humankind's future development. According to its original definition by the Brundtland World Commission on Environment and Development, it “is the development that meets the needs of the present without compromising those of the future” (Henninger et al., 2017, p.32). It comprises three dimensions: environment, economy, and social. The UNEP aims to promote sustainability and circularity in the textile value chain (Notten, 2020), which is illustrated in the circular model in Figure A6. The EU’s objective is to engage a shift in the T&C industry from a linear to a circular economy, creating a more climate-neutral and sustainable approach, with substantial material savings throughout the value chains and unlocking economic opportunities (Alves et al., 2021).

4.3 Supply Chain Management & Supply Chain Operations Reference Model

A supply chain encompasses “all the operations and activities that contribute to the final word end product beginning from initial raw resources for the roles and services within or outside an organization” (Raza & Singh, 2022, p. 4). Supply chain management involves planning, managing sourcing, procurement, conversion, logistics, and coordination with channel partners, so “in essence, [it] integrates supply and demand management within and across companies” (Queiroz et al., 2019, p. 242). However, other recognized definitions by Mentzer et al. (2001) and Stock & Boyer (2009) exist where all three together “are convergent and complementary” (Queiroz et al., 2019, p. 242).

To understand a company's supply chain complexity, we utilized the widely recognized Supply Chain Operations Reference (SCOR) Model endorsed by the Supply Chain Council (Pal, 2019). The SCOR model provides standardized definitions and critical performance indicators for supply chain management, serving as a reference point for understanding the globally fragmented, complex, and opaque T&C supply chains. By mapping out the case companies' supply chain processes using the SCOR model, we can gain greater visibility into their operations, allowing for a deeper understanding of the implications that a DPR supported by BC and IoT would have on T&C supply chains. The SCOR model consists of five process categories: Plan, Source, Make, Deliver, and Return, as presented in Figure 2 and explained in Table 1 below. These categories represent the different stages of a company's supply chain (ibid.).

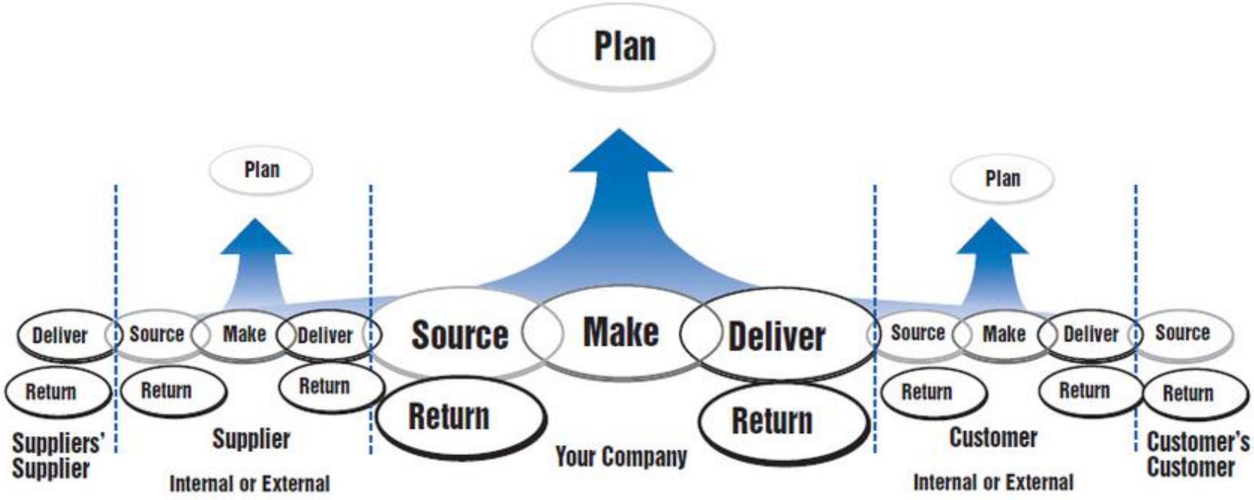

Figure 2: Supply Chain Operations Reference Model: Overall Categories

Table 1: Description of SCOR Processes

SCOR Process	Description
Plan	Coordinate sourcing, making, delivery, and return activities; for example: determine material flow, resource management, and trend forecasting. = Overarching business strategy that guides the following 4 activities
Source	Procure materials or services needed to make finished garments.
Make	Produce finished products such as clothing, fabric, and yarn. It depends on the company's level of vertical integration, i.e., can include multiple stages of a supply chain, which all focus on different aspects of the raw materials journey in transforming into a garment
Deliver	Transport, store, and distribute finished T&C products to retailers, customers, or end-consumers.
Return	Manage the reverse flow of products and materials due to issues such as lack of quality, incorrect sizing, or customer returns.

Using the SCOR model, we can analyze a T&C company's high-level supply chain processes and comprehensively understand its complexity. We will examine our case companies along with their respective SCOR activities to ensure the generalizability of our study and highlight their differences.

4.4 Traceability, Transparency & Visibility

Academic debate surrounding traceability, transparency, and visibility in supply chains continues, with definitions often overlapping and difficult to isolate (Garcia-Torres et al., 2021). Definitions provided are either “too generic [...] or so context-specific that they cannot be interchangeable between works” (ibid., p. 345), and the concepts of sustainability, traceability, transparency, and visibility are often not combined.

According to the International Standards Organization (ISO), **Traceability** is defined as the “ability to identify and trace the history, distribution, location, and application of products, parts, materials, and services” (Agrawal et al., 2018, p. 2564), while also stating that traceability involves recording and following the trail of products as they move through the supply chain. However, the need for traceability, the desired level of granularity, the configuration of the supply chain, the variety of suppliers, the volume of supply, regulatory and customer requirements, the degree of network trust, and the capabilities of current traceability systems and technologies are variables that can affect traceability system requirements in the supply chain (Ahmed & MacCarthy, 2021). Traceability involves capturing detailed data and information to track specific batches of components or purchase orders, including batch related IoT data and purchase order data along the supply chain (Langner, 2020). This information facilitates identifying and targeting product recalls, reducing the scale and cost of such incidents.

Transparency in business processes helps to collect vital information, including supplier names, facility locations, product components, and associated certificates. This level of transparency enables producers to map their entire supply chain, ensuring that all operators meet safety, sustainability, and social responsibility standards. Supply chain transparency promotes accountability by allowing all stakeholders to upload and access relevant data, keeping teams informed of updates, and reducing lead times, delays, and redundancy (ibid.).

Visibility within the supply chain is the result of combining transparency and traceability. It allows teams to track the movement of orders and materials from source to destination, ensuring that quality is a top priority. Access to accurate and real-time information enables businesses to proactively manage their projects, gaining confidence in their schedules, costs, and expected outcomes. The permanent audit trail created by recording each transaction provides trading partners with a means of verifying a product's quality and tracing it through its chain of custody.

4.5 Blockchain

The first occurrence of BC as a distributed ledger was in the role of the backbone technology of Bitcoin, introduced in 2008 by the creator of Bitcoin, Satoshi Nakamoto (2008). BC has since evolved into a separate technology, with researchers foreseeing the potential of this Industry 4.0 technology to revolutionize numerous industries and processes. At its core, BC is a distributed data structure that stores data in a chronological sequence of blocks, enabling transparency of the stored data evolution. This section explains the main features and components of the technologies for later assessment of their abilities to support the requirements of a DPR in the T&C industry's supply chain.

4.5.1 Decentralized Distributed Ledger Technology

BC networks are typically referred to as decentralized peer-to-peer systems, where individual peers act as nodes and work together with other nodes to form the network, thereby eliminating the need for a central authority. Each participant in the network (nodes) is equipped with their own copy of the BC, which updates when new transactions are added to the BC. Transactions refer to tasks that have been committed and stored on a BC, such as an event in a supply chain (e.g., received of raw materials from supplier to manufacturer). Enabling every participant of a BC to store their own copy of the BC creates the decentralization aspect of BCs. Having each participant store their own copy of the ledger means there is no need for a centralized authority or intermediary to validate and authorize transactions. This also helps to ensure the integrity and security of the network, as any attempt to manipulate or alter the ledger would require the consensus of most nodes in the network. Unlike traditional databases, which are commonly stored in a central place, BCs have no central storage, meaning no central point of authority or vulnerability. Each copy of the BC is a record of all the previous transactions that have been added to the BC, stored on digital ledgers. BC's decentralized and distributed aspects resemble the world wide web, as they both lack a central authority or single point of control. While the internet is built on a network of interconnected computers and servers, BC relies on a network of nodes that maintain and validate a distributed ledger. Furthermore, the internet and BC both allow for direct communication between participants, which diminishes the need for intermediaries. In the case of the internet, users can share information and content through peer-to-peer networks. Similarly, BC allows for transactions between participants and transaction validation without the need for a central authority. Due to the decentralized distributed ledger technology of BC, interest has risen regarding the application of BC in other areas that requires trust in transactions and processes, such as supply chains (Tripathi et al., 2021; Sunny et al., 2020; Elmessiry & Elmessiry, 2018).

4.5.2 Types of Blockchain

BC is inherently decentralized and distributed; however, determining the extent of decentralization and selecting participants for a network depends heavily on the specific use case. Although Bitcoin's widely recognized BC network is characterized by a high degree of openness and decentralization, some BC networks have opted to leverage BC capabilities in smaller, closed groups of selected participants, resulting in a lower degree of decentralization. Different use cases for BC technology have led to various configurations of BCs. The most common typologies of BCs are those of **public** and **private** BCs. Public BCs, like Bitcoin's BC, only require internet access and are open to anyone who wants to join the network. Private BCs, like TradeLens' former supply chain BC (Biazetti, 2019), only consist of authorized participants who have been granted access to the BC. In a private BC, each participant has a unique set of public and private keys that grants them access to specific transactions. Access to these transactions depends on the participant's status, such as a clothing manufacturer who may be able to view the journey of fabric in several supply chain stages before their involvement. Furthermore, a private BC allows for specific rules and regulations regarding the transactions, participants, access, and data formats to be put in place. This can create an environment where “it is easy to comply with data protection regulations, maintain data privacy, trace the history of the product, identify the source of the defect and have better control on the data that are appended on the blockchain” (Agrawal et al., 2021, p. 4).

Consortium BC is a type of BC that is owned and operated by a group of organizations and facilitates both public and private capabilities of a BC, combining the two into a network where “selected participants are responsible for the validation process while access to the ledger and transaction posting can be public or private" (Ahmed & MacCarthy, 2021, p. 4). The ability to select participants and configure role-based access control has made private and consortium BCs the prevailing structure for supply chain management BCs (Agrawal et al., 2021; Ahmed & MacCarthy, 2021; Bullón et al., 2020; Alves et al., 2021).

4.5.3 Blockchain Security & Transactions

The security of BC technology is one of its key strengths, providing a solid and impenetrable foundation for digital transactions. BC uses cryptographic methods and consensus mechanisms as a decentralized and distributed ledger system to guarantee the validity and integrity of transactions within its network. The cryptographic method is called "hashing" and is conducted on both the transactions stored in the blocks of a BC and the blocks themselves. This two-layer security, which only can be bypassed by having the keys of the transaction receiver or by being granted access to the transaction, creates impenetrable security from any outside attacks.

The consensus mechanism refers to how transactions are validated throughout the network. Given a set configuration of rules and regulations regarding the format of the transactions, participants validate the transactions to ensure the integrity of the transactions. The decentralized distribution of a digital ledger, combined with the cryptographic methods and consensus mechanism, enables transactions stored in the BC to be immutable, meaning that once a transaction is recorded on the BC, it is inherently resistant to modification. The immutable characteristic of BC transactions is a guiding factor for its increased adoption in multiple industries that demand great trust in/control of data. The issue of trust in data has long plagued the T&C industry, particularly with the global fragmentation and shift in manufacturing to developing countries. Data validity regarding environmental impact and materials used can be significantly improved in a BC network throughout the supply chain. This is due to the virtually non-existent possibility of modifying data or exploiting security weaknesses in this kind of network, which is a risk associated with centralized data storage systems (Lockl et al., 2020; Raza & Singh, 2022; Abed et al., 2021; Agrawal et al., 2021).

4.5.4 Supply Chain Traceability & Transparency via Blockchain

The chronological data structure of BC has received praise from researchers and practitioners for its ability to enable traceability in supply chains with historically low levels of traceability, such as the T&C industry (Ahmed & MacCarthy, 2021). Timestamping of each block and transaction on the BC facilitates chronologically stabilizing asset movements and related information along the supply chain. Additionally, every transaction, for instance, the transportation of T&C materials or manufacturing of specific garments, is assigned a unique ID using hash values or garment/material-specific IDs, creating a reference for subsequent related transactions. Combined with the security aspects of BC and the immutable data, these attributes create interconnected blocks, resulting in an unbreakable chain. This provides a verifiable and traceable record of transactions that becomes even more exhaustive and extensive as more participants and transactions are incorporated and recorded within the BC network, benefitting the complex and fragmented supply chains of the T&C industry - a visualization of traceability in a blockchain can be found in Figure A7. Moreover, the immutable digital ledger of a distributed BC coupled with permissioned access for participants allows for transparency along the supply chain, accessible to all relevant stakeholders, including certification authorities and governmental institutions. Permissioned access ensures the protection of sensitive data while maintaining transparency (Bullón et al., 2020; Hader et al., 2022; Agrawal et al., 2021).

4.5.5 Smart Contracts

Smart contracts enable autonomously appending transactions to a block if a specific set of rules or conditions are fulfilled. They are terms of an agreement written in code that allows for a flexible wide usage in a T&C supply chain to ensure efficiency in the transaction validation of BC-based supply-chain networks (Agrawal et al., 2021). BC-based smart contracts have been praised for their features that enable eliminating intermediaries' transaction processes. Smart contracts' autonomous execution ensures accurate transactions without interference. This is due to the conditions of a transaction being predetermined and thus will not execute before conditions are fulfilled, which also improves trust among parties involved in a transaction (Hewa et al., 2021). Due to smart contracts' autonomy, codifying a transaction's conditions must be done with precaution to avoid unintentional fulfillment of transactions.

4.6 Internet of Things

IoT has been defined in numerous ways since its first mention two decades ago (Sorri et al., 2022). Pal & Yasar (2020) define IoT as a “smart worldwide network of interconnected objects, which through unique address schemes can interact with each other and cooperate with their neighbors to reach common goals.” (ibid. p. 453). Meanwhile, Hussain et al. (2021) define it as “a group of interconnected devices that share data among users” (ibid. p. 2). IoT’s main objective is to collect data through sensors and share this data with users via “gateways connected to private or public networks” (Lockl et al., 2020, p. 1257). In the T&C industry and supply chains in general, IoT’s main application is the sharing of information acquired by objects, which reflects the manufacturing, transportation, consumption, and other details of the T&C industry.

The most popular IoT devices for supply chains include radio-frequency identification tags (RFID), Quick Response (QR) codes, and barcodes. RFID technology uses electromagnetic fields to identify and track tags attached to objects automatically. These tags contain stored information that can be read by an RFID reader, allowing for tracking of objects as they move through, for example, a supply chain or other processes, as well as information regarding products, such as T&C products. Barcode readers scan printed black and white barcodes with information stored in them and, for instance, in a cloud database. Two-dimensional QR codes can also be scanned, like barcodes, but with more extensive data storage (Hussain et al., 2021). These three IoT technologies all fall under IoT, which refers to IoT technologies that supply information upon interaction asynchronously. Active IoT devices are powered by an in-built battery and connected to the internet, supplying a synchronous information flow.

Active IoT devices' biggest strength lies in their ability to communicate real-time data across geographical and organizational boundaries through the internet, enabled by the layered architecture. It allows any relevant stakeholder involved in a supply chain process to access real-time data, enabling data-driven efficient operational decisions. Real-time information from active IoT devices enable better data-driven planning and management of the T&C supply chain, paving the way for optimization throughout its supply chain. Establishing real-time autonomous data collection can result in effective production, stock, demand forecast, purchasing, and logistics control. (Forno et al., 2023).

Collecting data using passive and active IoT devices has gained the attention of researchers and practitioners to establish the connection between physical objects and the digital world and to create digital representations of processes, such as the manufacturing of fabric, creating more “seamless tracking and reveals an asset’s full story” (Alves et al., 2021, p. 5).

4.7 Digital Product Representation

Our definition of a DPR is closely linked to the concept of digital twins and DPPs, which are often supported by IoT technology. To define a DPR, we consider related concepts' definitions and the context in which they will be used in this thesis. Firstly, the concept of digital twins has been the subject of numerous interpretations and definitions. According to Alves et al. (2021), “the idea behind the digital twin is to create a virtual replica, completely faithful to a physical object” (ibid. p. 5). However, Alves et al. (ibid.) further clarify the definition by referencing earlier work stating that “the general idea of a digital twin of an asset [...]is an integrated multi-physics, multi-scale, probabilistic simulation of a complex product or system to mirror the life of its corresponding twin” (ibid., p. 5). These two definitions demonstrate the various definitions and classifications of the concept "digital twin" encompassing varying levels of granularity in terms of attributes and applications.

The other relevant related concept to a DPR is the EU's proposed DPP, which plays a significant role in the EU’s Circular Economy Action Plan. DPPs aim to gather product data relevant to the end consumer, which can be shared throughout a value chain (Stretton, 2022). The objectives of the upcoming DPP legislation are to support sustainable manufacturing practices of products, encourage businesses to implement circular business models through shared data, give consumers a more informed foundation for purchases, and verify a product’s compliance with legal obligations (ibid.).

While we acknowledge that the proposed concept of the DPP is similar to a DPR, the focal point of our study will not be that of the legal obligations enforced by the EU. Instead, we propose a definition of a DPR based on the concept of digital twins, DPP, and the context of this thesis. A DPR is a virtual model that conveys essential information and attributes of a physical product, facilitating comprehension, information sharing, and decision-making across diverse applications and industries.

4.8 Design Science Research

DSR strategy focuses on creating an innovative artifact for a specific problem that is evaluated for its utility in solving this unsolved problem or solving it more effectively, such as supply chain inefficiencies or sustainability challenges. This is done through rigorous methods of creating and evaluating the artifact. One creates the artifact through iterative and incremental activity based on theory and empirical knowledge. The research results should be “communicated effectively, both to a technical audience and to a managerial audience” (Hevner et al., 2004, ibid. p. 82). For DSR in Information System (IS) research specifically, the concept of an IT artifact is a broad term that spans several variations of shape and size, but always with the common objective of “enabling IT researchers and practitioners to understand and address the problems inherent in developing and successfully implementing information systems” (ibid. p. 77). IT artifacts can be categorized into four definitions in Table 2 below.

Table 2: IT Artifact Types & Definitions

IT Artifact Type	Definition
Constructs	The building blocks or conceptual elements in the shape of words or symbols. A construct aims to provide a shared understanding of concepts involved in the phenomenon of interest.
Models	A representation of a real-world phenomenon or system using constructs. The objective of models is to describe, explain or predict the behavior of a system.
Methods	Systematic and repeatable procedures for solving specific problems or performing specific tasks.
Instantiations	The realization of the three types as mentioned above of IT artifacts. These IT artifacts provide an understanding of the feasibility and effectiveness of constructs, models, and methods by applying them in a practical setting (Hevner & Chatterjee, 2010).

Hevner et al. (2004) propose that DSR in IS research is fundamentally based on principles and practices but lacks what Peffers et al. (2007) refer to as the last characteristic of a methodology, namely, a procedure that “provides a generally accepted process for carrying it out” (ibid. p. 50). Peffers et al. (ibid.) argue that the lack of procedure provided by Hevner et al. (2004) and the lack of procedure in IS research that follows DSR generally could explain why there has not been an extensive amount of research employing DSR as a strategy. Consequently, Peffers et al. (2007)

developed the Design Science Research Methodology Process Model (DSRMPM). Its objectives are to provide researchers with a nominal process and mental model for conducting DSR and building "upon prior literature about design science in IS" (ibid. p. 50). The DSRMPM consists of four possible research entry points and six activities, some of which are iterated, constituting a cycle. For an overview of this process model, see Figure 3 below (enlarged: Figure A8).

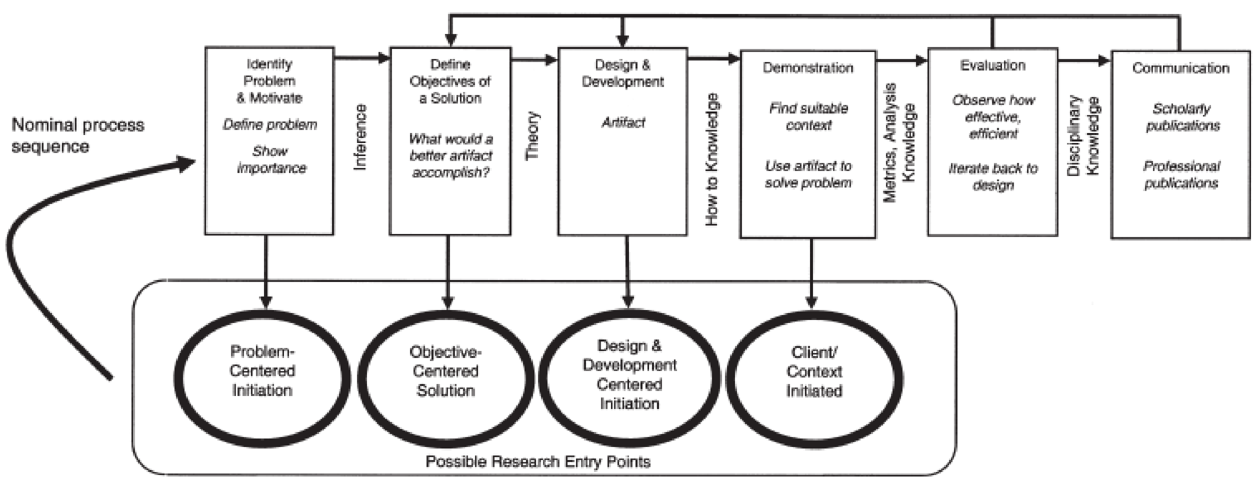

Figure 3: Design Science Research Methodology Process Model by Peffers et al. (2007)

One vital aspect of the DRSMPM is that, despite its sequential order of activities, Peffers et al. (ibid.) state that "there is no expectation that researchers would always proceed in sequential order from activity 1 through activity 6" (ibid. p. 56). Activity one focuses on narrowing down and defining the specific research problem the artifact intends to solve while justifying the value a solution would bring. The authors propose that this will not only create motivation amongst the researchers and the audience "to pursue the solution and to accept the results" (ibid. p. 55) but also create an understanding of the researcher's perception of the problem. In this activity, knowledge regarding "the state of the problem and the importance of its solution" (ibid. p. 55) is the most critical resource for the researchers.

In the second activity, the researchers are to define the objectives for a solution. The objectives can be quantitative or qualitative, but the essential aspect is to derive the objectives from the research problem while considering the current solutions (ibid.). The third activity is designing the artifact, which involves specifying its intended functionality and architecture where one embeds current knowledge of theory in the design (ibid.). The fourth activity is the demonstration of the artifact in various practical settings, depending on the context in which the IT artifact is intended to be applied (ibid.). Activity five evaluates the artifact based on the demonstration in activity 4. How the IT artifact is evaluated highly depends on "the nature of the problem venue and the artifact" (ibid. p. 56). Finally, the last activity is communicating the results of all five former activities through the proper communication channels based on the intended audience (ibid).

4.9 Sub-Summary of Methodological Concepts

By leveraging our understanding of the T&C industry, which encompasses numerous factors such as many different stakeholders, globally fragmented production, and challenges like sustainability, transparency, traceability, and counterfeiting, we are well-equipped to initiate our problem investigation. This insight into the T&C industry empowers us as researchers to investigate the requirements for a DPR within this specific context by employing a knowledgeable foundation for our data collection and assess whether a DPR could address the industry's issues. Utilizing principles of supply chain management and the SCOR model enables a methodical evaluation of the T&C supply chain, both from an industry and organizational perspective, and the potential impact of a DPR. Furthermore, assessing Industry 4.0 technologies, such as BC and IoT, allows us to explore their potential as the underpinning technologies for a DPR.

5. Design Science Research Prelude - Methodological Process Blueprint

Given the above explanation of DSR and concerning our research question, namely: "*What are the design requirements for a digital product representation in the textile and clothing industry, and how can Industry 4.0 technologies support these requirements?*", we structure our data analysis along the DRSMPM. First and foremost, regarding the type of artifact we develop, we design our IT artifact as a **model** based on our research question, as we imagine it should represent a real-world problem and potential solution. This decision resulted from our literature review, which unveiled a gap regarding BC and IoT in the T&C industry and identified the problems of traceability of products and sustainability in the industry. We also saw a limitation in our technical abilities in creating a prototype. We believe it is most appropriate, viable, desirable, and feasible to design our IT artifact in the shape of a model that represents an understanding of the T&C industry's as-is supply chain and the requirements for a DPR.

As highlighted in our theoretical concepts and mentioned by Peffers et al. (2007), the DRSMPM, albeit in its visual presentation of sequential activities, does not need to proceed in a specific order. In light of this flexibility and due to our abductive reasoning, we have experienced that our entry point lies between activities one and two. Our previous experience influenced our knowledge regarding data sharing problems throughout a supply chain, BC's unique features, and IoT technologies' use to counter these problems. As suggested by Peffers et al. (ibid.), this objective stemmed both from “an industry and research need” (ibid. p. 56), which we highlighted in our literature review. It identified a demand for traceability, regulatory pressures, a more efficient supply chain for global activity, and the research gap of empirically based research on BC and IoT in the T&C industry.

Before analyzing and executing each activity, we will, in the following, explain how we completed the problem identification (activity 1), objectives definition (activity 2), the first iteration of the design, demonstrate & evaluate (activity 3a-5a), the second iteration of the design, demonstrate, evaluate (activity 3b-5b), and lastly how we aim to communicate our results and IT artifact via this thesis (activity 6). For an overview of the steps executed and the data used for analysis and evaluation, see Figure 4 below (enlarged: Figure A9).

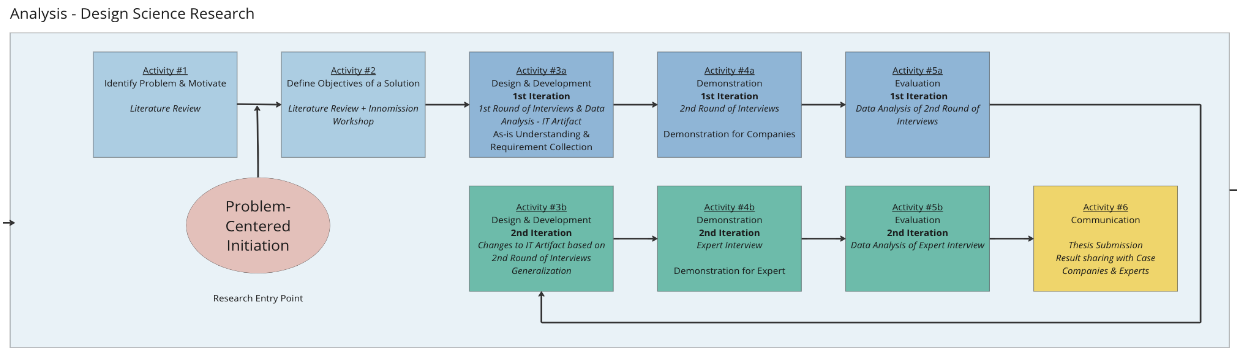

Figure 4: DSR Overview - Our Execution of Activities

Activity 1: Problem Identification

As mentioned earlier, we started our research between activities 1 and 2, based on our prior understanding of Industry 4.0 technologies and supply chain challenges, using an abductive approach. This knowledge guided our actions in the first activity of the DRSMPM. We conducted a comprehensive literature review to identify problems within BC and IoT-based traceability in the T&C industry. The specific problem our IT artifact aims to solve is identified in Chapter 6.

Activity 2: Objectives Definition

Having been familiar with BC, IoT, and supply chain management from previous academic experiences, we had vague objectives for our solution in mind. However, we needed to verify the need for such a solution before defining the objectives. Once we completed the literature review and identified the gap in research, we defined our solution's objectives: A model that represents the requirements of a T&C DPR to achieve supply chain traceability, sustainability transparency, authentication, and efficiency improvements based on an understanding of the industry's as-is supply chain.

Activity 3a-5a: First Iteration of Design, Demonstrate & Evaluate

We conducted two development iterations to **design** and develop our IT artifact. For the first iteration, we created an interview guide (Appendix C) dedicated to the chosen case companies to understand the activities and processes involved in creating, delivering, and supporting a T&C product throughout each case company's supply chain. Our choice of multiple case companies aims at providing valuable data regarding the different stages and stakeholders of a T&C supply chain to provide the most transferable model possible. These interviews and the theory/concepts derived from our literature review lay the foundation for the initial design and development phase. For the **demonstration** of the first iteration, we contacted the case companies for a second interview. We presented the first version of our IT artifact, intending to verify the models' applicability to each of the case companies' value chains. We conducted the demonstration with a prepared presentation of the IT artifact and questions to ensure that the interviewees understood the model, how they could utilize it, and whether it represented their products' life cycle to a satisfying degree. Regarding the **evaluation**, in our case, it was qualitative for both iterations, as our intended IT artifact could not be measured quantitatively. Thus, we aimed to provide "appropriate empirical evidence" (ibid. p. 56) on its utility. Our first iteration aimed to understand and evaluate our model from a practical perspective, thereby, its utility for chosen case companies. During the demonstration, we gathered feedback that we evaluated in this activity to prepare for the re-design in the second iteration.

Activity 3b-5b: Second Iteration of Design, Demonstrate & Evaluate

In the second iteration, after completing the initial design, demonstration, and evaluation cycle, we implemented the necessary adjustments to **re-design** our model. These adjustments were driven by the valuable insights we acquired from the first iteration. To demonstrate this redesign, we interviewed experts, each with expertise on different vital aspects of our model, one with a background in BC consultancy and the other with strong T&C industry knowledge. The decision not to proceed with a subsequent round of evaluation with the companies was based on the substantial validation of utility we received in our initial round. The feedback collected from our first demonstration affirmed that our approach was beneficial and reasonably met the needs of the T&C industry. Thus we found that the most proficient use of resources would be to demonstrate our model to experts to get external feedback on the different aspects of our model. We assessed our model based on the expert feedback for the second evaluation. This choice of evaluation further bridges the gap between industry and research, as our chosen experts, albeit not researchers, were knowledgeable on specific topics, thereby providing more in-depth feedback.

Activity 6: Communication

Our thesis communicates the cumulative results of all activities undertaken during our research. As such, it has specific guidelines dictating how we should write it. Furthermore, we followed up with all our case companies to provide them with compressed insights in addition to this thesis, for them to communicate either internally or externally at their discretion. As we follow the research strategy of DSR with a pragmatic philosophy, we attach great significance to expressing ourselves in a manner that is intelligible to both practitioners and researchers alike.

6. Problem Identification & Objectives

As noted in our literature review, the T&C industry is crucial to the global economy. However, it faces significant challenges in the form of highly geographically fragmented supply chains spread across the globe. Many actors constitute these vast and complex stakeholder networks, each responsible for one or more specific stages in the production and distribution processes, ranging from raw material production to the final point of sale or, in some cases, re-sale. Our IT artifact aims to address the T&C industry's complex supply chains by exploring the DPR requirements and Industry 4.0 technologies' potential. To design the artifact effectively, we followed the approach Peffers et al. (2007) suggested: identifying the problem our IT artifact aims to solve and which objectives we aim achieve through our IT artifact.

Supply Chain Traceability

The T&C industry's supply chain complexity, aggravated by multiple stakeholders and intermediaries, obstructs the traceability of products through their lifecycle, especially when production is relocated to developing countries (Tripathi et al., 2021; Hader et al., 2022). This complexity restricts information sharing, with stakeholders often keeping data in isolated, fragmented databases that lack visibility on product origins (Hader et al., 2022). Fear of disclosing competitive information and issues of trust and data security, especially with traditional information systems that are not tamper-proof, further impede comprehensive data sharing (Tripathi et al., 2021; Ahmed & MacCarthy, 2021). This lack of traceability, which can mask unethical conduct and significant CO2 emissions, is a key motivation for our research on the requirements for a DPR. Therefore, our IT artifact aims to enhance supply chain traceability, improving transparency and visibility within the T&C industry's intricate, multinational supply chains.

Sustainability Transparency

As mentioned earlier, the T&C industry grapples with significant sustainability issues. Environmental and social impacts of production processes, lack of visibility in supply chain activities, unethical practices, and high global CO2 emissions are prevalent (ibid.). The relocation of production to developing countries intensifies these problems, raising concerns over sweatshops and unsustainable production processes. The fast fashion trend, resulting in overproduction and increased textile waste due to short product lifetimes, further exacerbates these sustainability challenges (Niinimäki et al., 2020; Cruz & Cruz, 2020). Consequently, there is a rising demand for transparency in sustainability metrics and impact reporting throughout T&C supply chains. Additional sustainability issues include the lack of recycling (Jacometti, 2019) and a significant global carbon footprint (Alves et al., 2022). Given these problems, our IT artifact aims to enhance the visibility of environmental impact throughout a product's life cycle. This visibility is crucial for identifying waste reduction opportunities and potential sustainability improvements by tracing raw materials' impact on manufacturing, delivery, resale, recycling, or disposal. The lack of sustainability transparency is a key motivator for us as researchers. Thus, our IT artifact aims to address these challenges and foster sustainability transparency, enhancing an organization's competitiveness, reputation, and recruitment (Ahmed & MacCarthy, 2021).

Authentication

Counterfeiting is a critical issue in the T&C industry, as identified by Thanasi-Boçe et al. (2022). Their research showed the negative impact of counterfeiting on brand reputation as “exclusivity of brands is lost” (ibid., p.1). Violating IPRs also diminishes the quality associated with a brand’s craft and origin. What is more, the issue of product authentication extends beyond the luxury sector, as the inability to identify the unique product, its origin, product type, and composition impedes the resale of second-hand items of any product, no matter if fast fashion or luxury. Lower chances of resale and threat of counterfeit products are the issues identified which underscore the need for authentication as a key design objective of our IT artifact. The problem of counterfeiting serves as an additional motivator for us as researchers, to explore the requirements for a DPR that can support verification of T&C product’s authenticity and aid in protecting the brand’s reputation. Thus, it highlights the importance of addressing the issue of counterfeiting and authentication in the T&C industry and demonstrates the need for our IT artifact to seek the objective of enabling authentication.

Supply Chain Enhancements

Our literature review has uncovered diverse challenges beyond the ones described in this section. However, focusing on the problems of traceability, sustainability transparency, and authentication, researchers have, as mentioned earlier, proposed that solving these problems would bring additional benefits within supply chain management. Due to the lack of traceability and sustainability transparency coupled with a significant problem of counterfeiting, the T&C supply chain is not as efficient as it could be, which serves as another critical motivational factor for us as researchers. The T&C industry will face increasing pressures to comply with new regulations, such as enforced product information communication to consumers (Jacometti, 2019), which we see as an opportunity to not only comply with regulations but as an opportunity for stakeholders in the T&C industry to achieve supply chain enhancements. Thus, our IT artifact's final objective is enhancing the T&C supply chain efficiency, such as cost-saving and improved productivity.

To explore the requirements of a DPR, it is crucial to understand the complexity of the T&C supply chain and processes, given the substantial amount of data that would be included from stakeholders across the entire product life-cycle supply chain. The link between the flow of information and materials creates a fundamentally symbiotic relationship, making the exploration of the T&C supply chain imperative. Thus, our IT artifact consists of two components to answer our research question holistically. The first part is a layered model of the as-is T&C supply chain to depict and understand the complexity of the material flow and, thus, information flow. The second part is a visualization of the collected DPR requirements that depicts the interdependencies and (inter/intra) connections between different requirements.

7. IT Artifact Development: Design, Demonstration & Evaluation

After identifying the problem and defining the objectives of our IT artifact, the following activities, according to the DRSMPM, are the design, demonstration, and evaluation of it. As indicated in our specific flow of execution explained in the prelude (Figure A9), we conducted two iterations of these activities. For the first iteration, we interviewed our case companies twice, first individually for initial input on their current supply chain and requirements for a DPR, then combined in a workshop where we demonstrated and evaluated the first version of the IT artifact. In the second interaction of design, demonstration, and evaluation, we spoke to two experts individually to get an external assessment of our IT artifact. As pointed out in the previous section, our IT artifact is composed of a layered model of the T&C industry's as-is supply chain to capture the complexity of it and follow the material flow, the second component is the collection of requirements for a DPR in the industry. Both components are designed, demonstrated, and evaluated throughout the two iterations.

7.1 1st Iteration - Design: As-Is T&C Supply Chain - A Layered Model

Our interview guide (Appendix C) for the first individual interviews with the case companies indicates that our first questions were related to understanding the case company's operations along the SCOR stages. Understanding which stages of the supply chain are controlled by them, where they rely on information being shared from previous tiers and capturing this in a visual model was the activity's objective in the first iteration. Overall, we divided the supply chain model into several layers, from more generalizable to company-specific supply chain (Figure A10), and in the following, we will explain each layer.

7.1.1 T&C Supply Chain Phases

The T&C industry follows a physical product's supply chain, comprising raw material sourcing, production, transportation, distribution, consumer use, and disposal or recycling, as defined by Muñoz-Torres et al. (2020) and illustrated in Figure 5 below (enlarged: Figure A11). The product may enter a circular lifecycle through recycling or reselling, while disposal marks the end-of-life. These high-level **supply chain phases** form the first layer, the basis for further breakdowns. This macro-level depiction applies to cotton or polyester textile products.

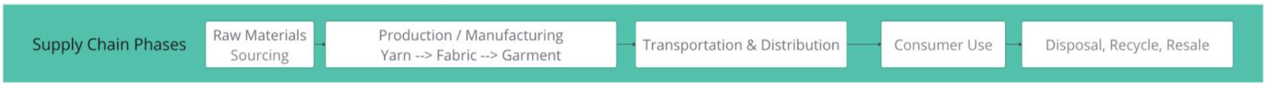

Figure 5: Layer 1 of As-Is Supply Chain Model - Supply Chain Phases

7.1.2 SCOR Processes

The SCOR layer breaks down the previous layer and aims to identify bottlenecks and inefficiencies in the supply chain processes of the case companies. To design the SCOR layer, we asked questions about the plan, source, make, deliver, and return phases and analyzed the stakeholders involved. This step was crucial in understanding how information is exchanged and the extent to which each case company can trace its supply chain tiers. We used the SCOR model as a reference to comprehend the interconnections between the different phases and the organizational processes executed by each company. The following section outlines the supply chain processes of GreenCotton (GC) and Create2Stay (C2S) per the SCOR activities.

GreenCotton's SCOR Processes

Make

GC's make activities involve the conversion of fabric rolls into finished T&C products, such as baby clothes. The company produced more than 1.8 million pieces of clothing in 2022, with around 1.5 million produced for private labeling and roughly 350,000 for its own brands (Appendix D). GC's Managing Director emphasizes efficiency, control, and sustainability in the company's production approach. GC controls most of its supply chain, influencing the production process more than the average T&C brand. According to GC1 (01:56), "we have a company in Turkey that is sourcing and controlling and doing all the quality control and visiting the factories. [We] buy [fabric rolls] from there, drive it to Ukraine, where [we] have [our] own production." This level of ownership and control allows

GC to ensure compliance with sustainability and quality standards. The company maintains thorough documentation due to the certification of Global Organic Textile Standard (GOTS). It conducts “inline quality control, and [..] end quality control” (GC1, 09:11) at their production facilities in Ukraine as well “as a lot of the quality control in Turkey” (GC1, 09:42). GC1 (09:11) explains that the production process involves initial quality control of products, followed by cutting the fabric rolls into bundles, which are distributed to the sewer, embroidery, or print departments. In terms of identification, GC highlighted that “all bundles have an EAN code, so [they] know which sewer actually did this because she has to scan, and then the production line starts.” (GC1, 08:39). Through its approach to production, GC maintains its commitment to sustainability while ensuring control and efficiency.

Source

GC's sourcing activities are mainly carried out by their Turkish subsidiary, GC Turkey, focusing on sourcing eco-labeled fabric materials certified by, e.g., GOTS (GC1). From 15-30 different suppliers (Appendix IV), organic cotton makes up 90% of their sourcing. At the same time, they also procure wool and polyester based on customer demand (GC1, 02:01). GC's MD emphasizes their unique position in the industry, stating that they can go further back in the supply chain also due to long-term relationships. GC's MD states that this is "not normal for the industry. [...] [and] it would be difficult to go further back than tier one for a lot of people" (GC1, 04:22) in the industry, highlighting their superior efficiency and quality. GC's extensive supplier network results from decades-long collaboration, with an average relationship length of more than five years and an emphasis on trust and collaboration.

Deliver

GC is directly involved in delivery activities at multiple stages of its supply chain. Their logistics department is in Ukraine, at their production facilities. From here, they oversee all the logistics from Turkey to Ukraine and, depending on whether they are transporting their own brand, to Denmark, or directly to their B2B customers (GC1).

Return

GC’s reverse logistics processes are designed to minimize costs and environmental impact by catching any complications in product quality as early as possible in their supply chain. Most quality control takes place at the fabric sourcing stage in Turkey. This is overseen by their employees at GC Turkey as “it shouldn't end in Ukraine if it's so bad that [they] can't make anything of it” (GC1 11:15). This approach allows them to prevent any issues from progressing further down the supply chain, ultimately reducing the need for expensive and environmentally harmful reverse logistics. When issues arise later in the supply chain, GC focuses on finding alternative solutions rather than resorting to expensive returns. For example, they have a Zero Waste program (GC1) for their own brands where they can repurpose products that do not meet quality standards. When working with private label customers, the company negotiates a price adjustment rather than returning products. Additionally, when a quality issue arises, GC’s approach to customer returns is to request a photo of the issue and not ask for the item to be sent back, further minimizing the need for reverse logistics. These return process rules suggest a high commitment from GC to both customer satisfaction and environmental responsibility (GC1).

Plan

GC manages its supply chain activities from its head office in Denmark and delegates the planning of more company-specific activities to their respective locations (GC1; Green Cotton Group, 2023). As its business model relies on producing garments for other brands, GC has adopted a Print-on-Demand (POD) system to manage its supply chain processes, which requires close collaboration and an efficient supply chain to ensure timely order delivery.

GC maintains high-quality standards by implementing quality control checkpoints at their sourcing office in Turkey and production facility in Ukraine, both of which aim to adhere to GOTS requirements. To ensure efficient operations and transparency, GC uses an integrated POD system to manage and track critical data related to quality, planning, transactions, and other processes. This system enables GC to maintain transparency and efficiency in line with GOTS certification requirements of tracking and linking all transactions throughout a supply chain (GC1). The POD system handles data received from their suppliers regarding the tests carried out on the fabric and batch information, such as the composition of materials. GC's rigorous data management processes and GOTS certification requirements contribute significantly to their planning capabilities, allowing them to see beyond their own suppliers and providing better visibility than industry standards (GC1). It is therefore relevant to acknowledge that the planning and supply chain management activities of

GC are not the industry norm due to their strong involvement at various stages of their supply chain and enhanced visibility. Yet, the fundamental processes they must fulfill and plan for are coherent with the general stages of a T&C industry established in the theoretical concepts section. As a researcher, this allows us to apply the insights gained from studying GC's supply chain processes to a broader context. According to SCOR, GC's supply chain activities are depicted in Figure 6 below (enlarged: Figure A12).

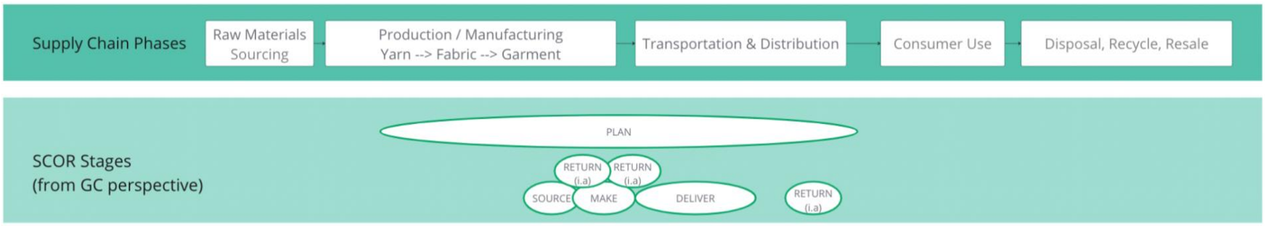

Figure 6: Layer 2 of As-Is Supply Chain Model - Green Cotton's SCOR Stages

Create2Stay's SCOR Processes

C2S, a white-label software solution, represents a different type of stakeholder in the T&C supply chain, specifically the reselling side. They provide software solutions to host second-hand clothing e-commerce in their customers' web shops, such as Soulland and Markberg, and soon GC's resale web shop (Create2Stay, 2023). Their partnerships with clothing brands follow two business models: take-back and peer-to-peer. According to C2S, the peer-to-peer business model allows consumers to "in the same shopping basket, have new and second-hand items" (C2S1, 03:51). The consumer directly resells their clothes to another consumer, which is why the consumer is responsible for taking pictures of the item, providing a description of the quality, and organizing the transportation to the new owner of the item. In this model, the consumer resells their clothes directly to another consumer, with C2S only serving as a passive intermediary without physically interacting with the item resold. However, our analysis focuses on C2S's take-back business model, better representing a reseller's supply chain activities. Therefore, the following section will concentrate on their supply chain processes concerning the take-back business model.

Make

C2S's make processes involve cleaning, repairing, media work, and quality control of used clothing purchased back from consumers through the take-back resale model. Once a product is deemed resalable, C2S stores it in their warehouse, making it available on the brand's website (C2S1, 12:08).

While the process of preparing used clothing for resale is relatively simple compared to manufacturing new clothes, identifying specific items presents a significant challenge for C2S. As they explain, "there can be millions of items here which [they] need to search for" (C2S1, 19:23). This search is necessary to ensure that the correct product is uniquely identified, a time-consuming and resource-intensive activity that negatively impacts their operations. C2S acknowledges the importance of accurate product information in the resale process, stating that "the product information when [they] are going to sell it is very important" (C2S1, 03:51).

Source

C2S's sourcing processes involve working with logistics providers such as GLS, Postnord, and Shipmundo, as indicated by primary data (C2S1). The sourcing process begins with the consumers of C2S's customers who wish to sell their used clothing items, such as a customer of GC. When selling their items back to a customer of C2S, in our example GC, they are provided with a shipping label to send their clothing items to C2S for inspection, cleaning, media, and repair if necessary. The sourcing process for reselling companies depends on consumers deciding to sell their used clothing. Thus, the efficiency improvements for resellers in this process are limited to making "it easy for consumers who trade [their clothes] in" (C2S1, 12:08). C2S addresses this issue by providing the consumer with the shipping label and "drop-off points" (C2S1, 12:08).

Deliver

Much like the sourcing processes, the deliver processes are solely demand-driven as C2S Co-Founder explains: "we are just facilitating for brands. So then it's available on the brand's website. And if it's sold, we are then ensuring fulfillment when it's sold" (C2S1, 12:08). Consequently, their delivery process is initiated once a consumer purchases a second-hand product from one of C2S's customers' resale web shops. C2S ensures that the delivery of the second-hand product is facilitated, i.e., they work with logistic partners to transport the product from their warehouse to the new owner of the item.

Return

C2S places a strong emphasis on sustainability and minimizing waste in its return processes. As part of their commitment to responsible practices, they have a return process that focuses on recycling products for sale. When a product cannot be sold, C2S “[is] ensuring recycling, and then it will be recycled, fiber-to-fiber recycled“ (C2S1, 28:56). Given that C2S cannot send the products unfit for sale back to the end-consumer, as the buy-back encapsulates “the brand have bought it back and owns it” (C2S1, 28:56), C2S is left with the choice between disposal or recycling. Rather than linearly disposing the product and ending its life, C2S ensures that resources are efficiently re-utilized and repurposed. This speaks to the company's dedication to sustainable and eco-friendly practices.

Plan

C2S's planning processes are closely linked to their make, source, deliver, and return processes. To effectively carry out these activities, C2S needs to plan how each process is executed. Resource management is critical for C2S to balance its two different business models. They must maintain their software solution while facilitating staff for cleaning, repairing, and warehouse facilities for storing items and coordinating logistics to consumers and recycling facilities. While not the primary purpose, C2S's software services can be considered an intelligent data source for planning. The software sends notifications when certain actions are triggered in their supply chain, which allows C2S to proactively plan and execute the necessary tasks for smooth operations and more efficient resource utilization. An overview of C2S's SCOR processes is depicted in Figure 7 below (enlarged: Figure A13).

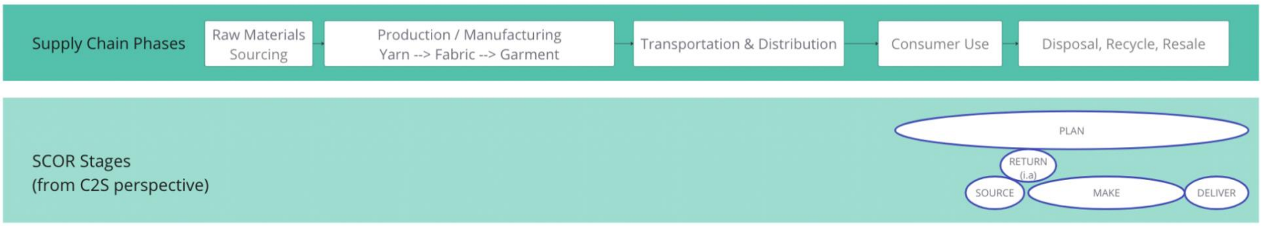

Figure 7: Layer 2 of As-Is Supply Chain Model - Create2Stay’s SCOR Stages

As part of the analysis of the current supply chain processes of GC and C2S, an opportunity arose to conduct a joint design workshop as part of the first iteration of the demonstration. As the two companies were in the process of forming a partnership, this presented a unique chance for the researchers to bring together individuals from both organizations to provide feedback from an organizational and collaborative perspective. To better understand the holistic picture of the T&C supply chain, we decided to combine the SCOR activities from both companies' as-is supply chain models in the overall T&C as-is supply chain model component our IT artifact while keeping the analysis of it at a high level. By doing so, we could identify which supply chain phases of the first layer were covered by the cooperation between GC and C2S, as shown in Figure 8 below (enlarged: Figure A14).

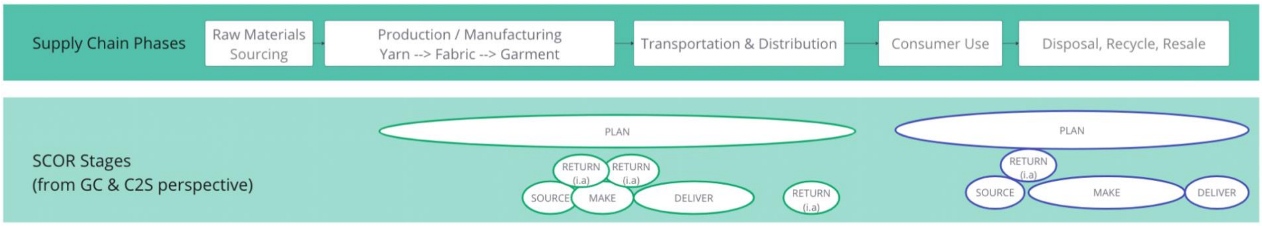

Figure 8: Layer 2 of As-Is Supply Chain Model - Combined SCOR Stages

7.1.3 T&C Supply Chain Activities / Events

In addition to examining the specific SCOR processes for the case company interviewed, representing different stakeholders in the T&C supply chain, we broke down the high-level supply chain phases from the first layer and the material processes behind the SCOR stages in the **activities/events** layer shown in Figure 9 below (enlarged: Figure A15). The first event in the process is labeled as "harvest," but the type of raw material harvested depends on the product composition, such as cotton or chemically generated polyester. After “harvesting”, the raw material is processed and spun into yarn, regardless of its original form. Depending on the desired fabric result, the yarn may be weaved and knitted first or require dyeing first. Fabric printing may not be necessary. Therefore, it is essential to note that the order of activities is not entirely fixed. For example, a roll of yarn may be dyed first and then weaved and knitted into fabric. Similarly, the end of a textile product's life cycle may not involve reselling but rather disposal by the consumer.

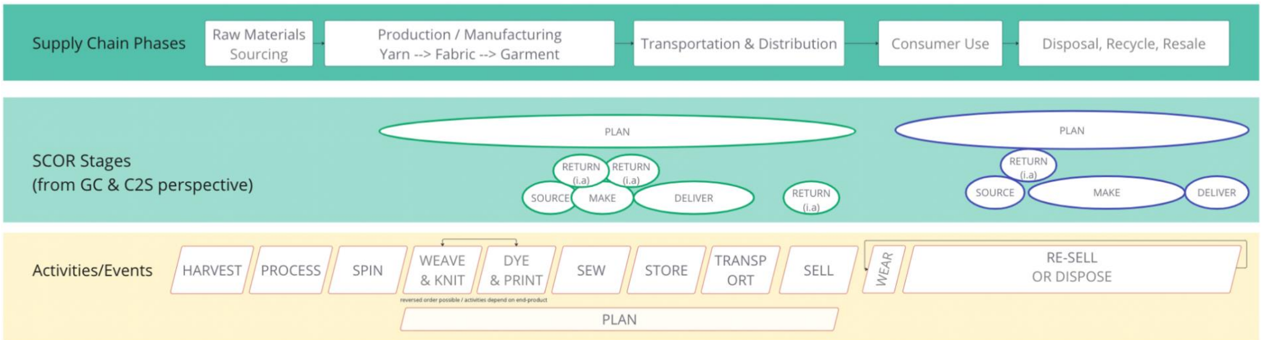

Figure 9: Layer 3 of As-Is Supply Chain Model - Activities/Events

7.1.4 T&C Supply Chain Stakeholder Types

The following layer shows the **stakeholder types** involved in the T&C supply chain activities mentioned in the previous layer. This layer indicates the types of stakeholders that may participate in activities like raw material sourcing, such as farmers, textile mills, or recycling facilities. This may depend on the type of raw material used, such as cotton or recycled polyester. Moreover, the type of raw material used can affect subsequent production and manufacturing phases. Although the ownership and outsourcing strategies may differ across organizations, Figure 10 below (enlarged: Figure A16) aimed to represent stakeholder types that may participate in any T&C supply chain, such as textile mills, spinning facilities, and resellers, although not all textile products require printing or dyeing.

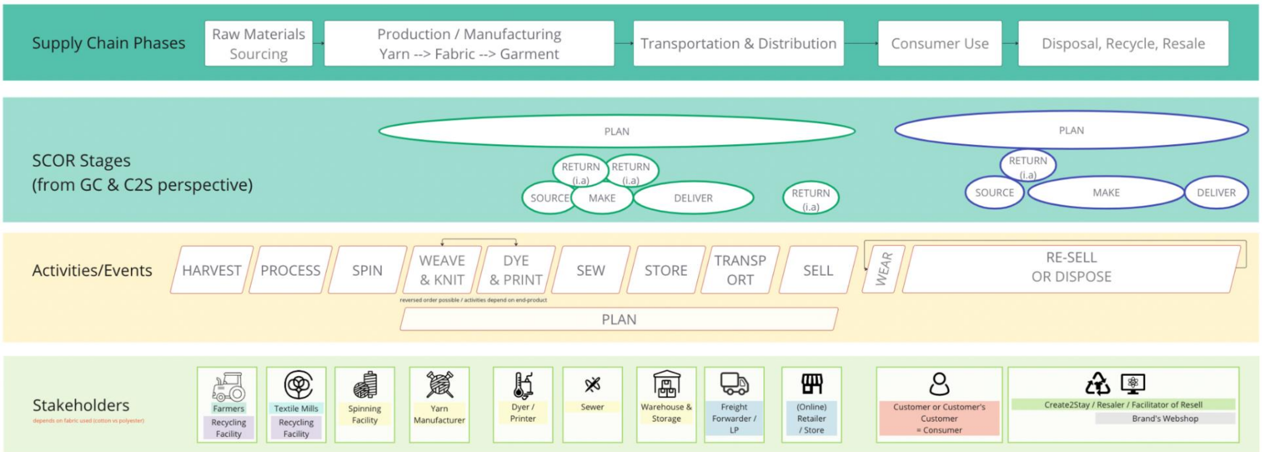

Figure 10: Layer 4 of As-Is Supply Chain Model - Stakeholder Types

7.1.5 Locations & Process Deviations

The next layer of our supply chain model provides a more detailed view, capturing company-specific information essential for understanding the supply chain's complexity. We identified which parts of the supply chain are owned by GC or C2S and where the process steps may vary depending on decisions made outside of their control. This layer highlights the **location and process deviations** in a separate model layer, as depicted in Figure 11 (enlarged: Figure A17). For example, variations may occur depending on whether a consumer resells their items through peer-to-peer channels or use the take-back model.

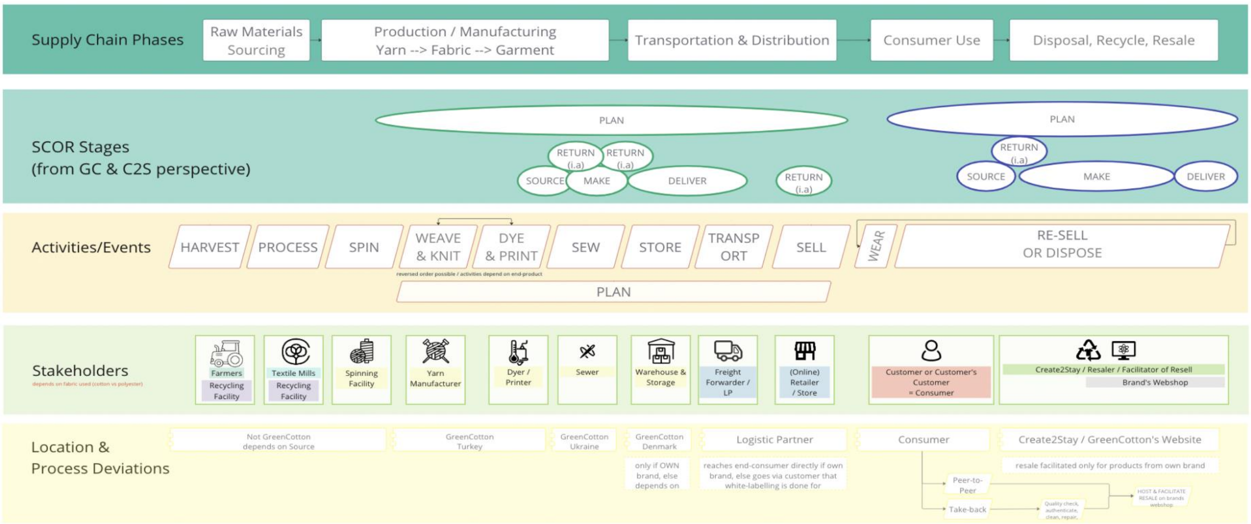

Figure 11: Layer 5 of As-Is Supply Chain Model - Location & Process Deviations

Based on the described layers, we could understand the case companies' as-is supply chains. Additionally, the responses received in the first individual interview rounds with them helped us discover the requirements for a DPR. The main objective of mapping and understanding the T&C industry's as-is was to validate which problems identified from the literature and noted in Chapter 6 are present in the case companies interviewed. That way, it was more apparent that a DPR is needed. Which specific needs exactly would enable such representation along the supply chain and material flow was the next step in our design stage which resulted in a visualization of 37 requirements.

7.2 1st Iteration - Design: Requirement Collection, Categorization & Visualization

With the as-is supply chain captured based on the first round of interviews, additional data collected via emails and literature input, we saw the problems identified, namely the fragmented information sharing and complex web of stakeholders, validated. Apart from asking companies about their as-is supply chain, we also asked questions regarding the requirements of a DPR that would apply to all stages along their supply chain. Based on our thematic analysis, we collected the statements GC and C2S made regarding their needs and conditions to design such representation enhanced by Industry 4.0 technology. As mentioned earlier, given the demonstration of the IT artifact's first version in a collaborative workshop between GC and C2S, we extracted the requirements mentioned from each interview. Then we combined them into one mode that showcases the holistic findings from our first interviews. We ensure that, in doing so, to convey the different viewpoints of each company best to classify each requirement to belong to each company visually. From each quote coded, we inferred requirement statements, and after merging some duplicates, we found 37 requirements from both case companies. Following the thematic analysis, we identified overlaps and relationships between requirements for a DPR across the interviews. The resulting patterns from the thematic analysis identified three patterns to categorize the requirements into **technical, regulatory, and stakeholder**. Table B4 defines each category, examples of sub-categories, and the category's objective for a DPR.

However, some requirements overlapped categories and were assigned to two classes, resulting in 10 requirements being classified as interconnected requirements. Of the requirements, 7 were regulatory, 13 were stakeholder, and 27 were technical (some of which were assigned to multiple categories). Subsequently, we analyzed each category to identify additional grouping patterns, resulting in sub-categories. Upon analyzing the requirements and assigning sub-categories, we discovered that a requirement could be linked to multiple sub-categories within the same category, thus establishing intra-connected requirements. For example, a DPR's technical stability is essential for both scaling the solution and ensuring data portability. A visual representation of the high-level requirement categories and each of their sub-classes can be found in Figure A18. Building on this visualization and specifically showcasing the identified 37 requirements and their complexity, we created Figure A19, which captures the overall classes and sub-categories and the inter- and intra-connections amplifying the interdependencies and relationships among them. For the demonstration in the design workshop with both case companies, we also wanted to ensure we could trace back each requirement captured to its source, i.e., GC or C2S. Thus, we worked with color-coding on the requirement boxes.

This classification analysis aimed to enhance our understanding of each requirement and its underlying topics, such as modularity for technical requirements or consumer awareness as a sub-class of stakeholder requirements. This process was crucial in creating a visualization for our IT artifact/model and facilitating its demonstration in the next activity of our DSR process. To improve readability, we also translated the requirements into a table format, numbered and listed in Table B5 for easier reference.

After analyzing the statements from the first interview round and assigning patterns to specific requirement types, we will explain how each requirement was derived. This will be done by first discussing requirements allocated to a single sub-group in regulatory, stakeholder, and technical requirements. In the last group, we will also analyze requirements that are intra-connected, as only those only exist in this category. Finally, we will assess inter-connected requirements representing the intersection between classes.

7.2.1 Regulatory Requirements

The regulatory requirements category has the least identified requirements. They refer to rules, regulations, standards, and guidelines mandated by governing bodies for developing and using DPRs of T&C products. This category includes three sub-categories: Clear Regulations, Inclusivity, and Government Support.

Inclusivity pertains to regulatory requirements that address accessibility and equal implementation conditions for DPR. Our interviewees noted a resource imbalance which is why they request that "even if bigger players may already have better resources to understand their value chain, they should not be able to sit on the data but it should be trustable" (GC1, 01:01:36). Thus, the resulting requirement for *Inclusivity* we inferred was that regulation needs to ensure an equal contribution and commitment of "big" and "small" players (RID#1, Sheet 3, Table B5).

Government Support refers to the requirements for government bodies to promote DPR adoption and implementation outside of law enforcement. This can be done through marketing, awareness creation, and investment. Our interviewees emphasized the need for the government to "do some marketing for it and what it means for the consumer because they are so confused already [since] there are so many labels [...] that they have to take into consideration" (GC1, 01:02:47). Thus, this requirement can be noted as government support, e.g., marketing, awareness, and investment (RID#2, Sheet 3, Table B5).

Clear Regulations is the final sub-category within regulatory requirements. It focuses on the need for specific and transparent regulations related to DPR in the T&C industry. Proposed regulations on the DPP so far lack specificity and clarity, making it difficult for T&C companies to prepare and take action in time. Thus, legal requirements need to be clear regarding what information is required and which parties should receive it (RID#3, Sheet 3, Table B5), also because "there is some legal requirement from the government where they need to see some information" (C2S1, 41:00).

7.2.2 Stakeholder Requirements

The second class of requirements is stakeholder requirements, which aim to classify the responsibilities and expectations of stakeholders in the T&C industry when developing, implementing, and using a DPR. To reflect the diversity of stakeholders in the T&C supply chain, we identified five sub-categories: Consumer Needs, Consumer Awareness, Collaboration, and Technological Understanding.

Consumer Needs express the need to understand and address consumer preferences in relation to a DPR. It also highlights the need to recognize consumer demands and expectations regarding the use and interaction with DPRs. Our interviews revealed that consumers lack interest in a product's lifecycle stages. Therefore, they must express a need and interest in the link between digital information and the product (RID#4, Sheet 3, Table B5). This was evident in GC's pilot, where they found no consumer interest. Even though they "did a lot of press release and a lot of PR [...] there was absolutely no interest in this subject" (GC1, 14:23). This lack of interest could discourage brands from investing in DPRs.

Consumer Awareness requirements are closely linked to those of *Consumer Needs*, as they focus on educating consumers about the benefits and usage of DPRs once a need has been identified. These requirements entail campaigns, educational materials, and product labeling that provide information and promote consumers' understanding of DPRs. The key requirements inferred from interviews include that the consumer needs to be able to understand the DPR, its objectives, and how to use it (RID#5, Sheet 3, Table B5) so that it can allow consumers to learn and understand more about the product's lifecycle (RID#6, Sheet 3, Table B5). For the former requirement, GC expressed the "hope that there will be a lot of information in a very simple way. Some kind of labeling maybe or something that can help the consumer" (GC1, 01:03:43). For the latter requirement, C2S emphasized that "more and more consumers will understand how it has been manufactured, what materials, is it good conditions on the factories, [...] are they using children or not, or how is it done that they have the certifications, etc. in a simple way" (C2S1, 41:00).

The *Technological Understanding* sub-category is a counterpart to the stakeholder requirements' technical requirements, capturing stakeholders' necessary technical skills and knowledge to enable a DPR. This involves providing education and training to improve stakeholders' digital literacy and technical competence, including understanding the required data connections and logic. Our interviewees confirmed the importance of this, as "the problem is that doing blockchain right now in fashion [...] is very, very difficult, and it does not have a good reputation because people have not been good enough at explaining it" (C2S1, 35:06). Therefore, we believe a stakeholder requirement would be to ensure a general understanding of blockchain or any other underlying technology used for the DPR (RID#7, Sheet 3, Table B5). Additionally, motivating the adoption of a DPR based on decentralized technologies would require an improved understanding of the differences between such a system and a centralized database (RID#8, Sheet 3, Table B5). Currently, not all stakeholders are at the same level of understanding, causing collaboration issues. For example, GC is attempting to align with certification authorities but cannot use electronic IoT identifiers/sensors in their products due to certification requirements, making it impossible for them to sell their products with a DPR (GC1).

Collaboration is crucial to enable a DPR, with requirements aimed at fostering cooperation among stakeholders in the T&C industry ecosystem. The requirements of this sub-group often overlap with the technical requirements, involving the creation of opportunities and platforms for communication, information sharing, and collaboration among T&C companies, technology providers, policymakers, consumers, and other stakeholders. *Collaboration* requirements indicate that there is a need for collaboration to share the best practices, build trust with all segments of the T&C sector, and secure loyalty and enthusiasm for a DPR (RID#9, Sheet 3, Table B5) since "[they] need to have some companies cooperating, and no one wants to own it" (C2S1, 37:08). A requirement that is inferred from this sub-group is the need for trust to enable collaboration, which hovers over all three classes.

7.2.3 (Intra-connected) Technical Requirements

The third class of requirements we identified focuses on the technological aspects of a DPR that would enable its success. These requirements are categorized into: Data Portability, Scalability, Security & Access Control, Documentation & Data Capture/Quality, Data Availability & Time Behavior, Interoperability, Interaction, and Modularity. Within these sub-categories, we found overlaps that we consider intra-connected requirements.

Data Portability in the context of technical requirements refers to the seamless transfer of DPR-related data in the T&C industry's supply chain. It involves designing systems and solutions that ensure data can be moved between platforms, applications, or environments without loss or distortion. The requirements captured in this sub-group aim to ensure technical stability so that DPR data can be easily and securely transferred and shared among different stakeholders and systems (RID#10, Sheet 3, Table B5). During our interview with GC, they highlighted the importance of data portability, as they experienced issues transferring data from their BC pilot, resulting in data loss. They expressed that they "would like a solution that is more stable" and where their data "is not just suddenly all just gone" (GC1, 49:10).

The same quote regarding the requirement for technical stability, ensuring data is not lost, is relevant to another sub-group of technical requirements called *Scalability*. *Scalability* involves designing a DPR system that can handle varying data volume levels, complexity, and usage patterns, making it feasible for companies of any size and product volume. The system should efficiently handle increased data loads, user interactions, and system demands as the usage of DPRs expands over time. Therefore, without compromising performance, the system needs to be easier and cheaper to implement as an industry-wide collaboration versus in a siloed setup (RID#11, Sheet 3, Table B5). This requirement was expressed in GC's interview in the context of a regulation coming into place forcing businesses to take action but that "it's easier and it's [] cheaper if we can go together and do it" (GC1, 01:01:12). While some T&C companies have implemented traceability solutions, they often remain within siloed setups due to their resources. Overcoming the challenges associated with decentralized solutions will be discussed further.

The *security and access control* sub-group requires implementing robust security measures, such as encryption, authentication, authorization, and audit trails, to protect data from unauthorized access, tampering, or breaches. These requirements aim to safeguard the confidentiality of DPR's data to ensure that only those authorized have the appropriate access. Our assumption, based on interviews, is that access control and security measures will be both technical and regulatory. Dividing information into levels of sensitivity or purpose (RID#12, Sheet 3, Table B5), for instance, into publicly shareable, secured, or sensitive data, can act as a security layer and help ensure proper access rights. This categorization can counter the vulnerability expressed by case companies, who have stated that "the whole value chain is visible for everybody" (GC1, 53:56). Separating basic data needs from sensitive information is a possible solution, as some information is "the same for most textile companies" (ibid.).

The *Documentation & Data Capture/Quality* group of requirements is related to *Security & Access Control*, as the reading and writing access of DPR data impacts how and what is documented. This sub-category focuses on capturing, documenting, and maintaining data related to DPR in the T&C industry. A DPR system must be designed to effectively manage data along the process stages associated with unique products to ensure accuracy, completeness, and quality. Proper documentation standards are necessary to fully exploit the benefits of a DPR, as reliable and consistent data is crucial for decision-making and analysis

Uniquely identifying a product and connecting a DPR (RID#13, Sheet 3, Table B5) is crucial to enable validation to, for instance, facilitate resale and a digital ID can be used for this purpose. With "millions of items which you need to search for", a "digital ID is interesting because just like Zara has done, then you can just scan the QR code in the items" (C2S, 19:23) and quickly validate which product information is linked to it. However, a DPR should avoid information overload (RID#14, Sheet 3, Table B5) by offering an overwhelming amount of information to the user that is not useful or insightful. Based on GC's BC pilot, they learned that "[consumers] don't want [an] overflow of information and [...] also for clothing because [consumers] still buy a lot of clothes and [] don't want an overload of information of everything" which would be a different situation "if we bought five pieces of clothes per year, then probably we would be more interested" (GC1, 37:31). This highlights the need for a balance to be struck between providing useful and insightful information and avoiding information overload.

Proper documentation needs to enable and/or improve sustainability reporting via DPRs (RID#15, Sheet 3, Table B5), as a tech-supported solution would be beneficial “because you have all the transport [and] geographical locations, so it should be easier to make a CO2 tool from that” (GC1, 01:05:49), thus referring to a reporting tool for sustainability metrics. In the T&C industry, more accurate, product-specific emission insights are needed to diminish greenwashing practices, as rough averages are no longer sufficient due to increasing public and legislative pressure.

To improve sustainability reporting and establish trust in the presented information, a DPR needs to ensure data authentication, reliability, and integrity (RID#16, Sheet 3, Table B5). The interviewees pointed out that a DPR system needs to avoid “just put[ting] data out there, [that] you could just type it yourself into a database and make up stories but a blockchain [involves that] [...] the suppliers themselves that put the data in, more valid data” (GC1, 31:21). Thus, to increase trust and communicate tamperproof information, we inferred this requirement for the *documentation and data capture/quality* sub-group of technical requirements.

To exploit the enhanced documentation and high-quality data on, for instance, sustainability metrics, the DPR needs to ensure *Data Availability & Time Behavior*. This sub-group is two-fold as it indicates that a DPR system and solution should present data in a timely and synchronized manner across different components or modules. This involves making data readily accessible and aligned with expectations regarding its real-time availability for the T&C industry's DPRs.

Active IoT allows for real-time data transmission but implementing it in the T&C industry is not feasible due to the difficulties in maintaining, e.g., certifications with electric chips in products. Furthermore, implementing active IoT does not seem desirable as the need for, e.g., just-in-time deliveries where more enhanced real-time data would be beneficial is not as important for the T&C industry as it is for others. Therefore, the requirements in this sub-group are more centered on the data carrier/identifier and network enabling the streamlining of data (RID#17, Sheet 3, Table B5) as noted by C2S, who mentioned that without this requirement being fulfilled, there would be too many versions and outdated data points that rely on master data on the product being maintained (C2S1).

C2S emphasized the importance that a product's master data needs to be readily available and readable from the network without time-consuming double work (RID#18, Sheet 3, Table B5). For example, when a consumer resells a product, scanning the QR code triggers a demand to obtain related master data, which allows for validation upon receiving the product. The benefit of readily available master data was stressed as "it is all about ensuring to have the master data from all of the items which have been manufactured by the brand and then ensure we can match it when we are receiving it. With digital ID and digital product information somewhere then that can be a huge potential to move forward." (C2S1, 08:07). Additionally, the DPR needs to allow for easy resale/trade-in that transfers all existing information (RID#19, Sheet 3, Table B5), including data added by the consumer during the product's life cycle. This would streamline the processes behind the DPR and ensure that the reseller and consumer have access to all relevant master data related to the product. C2S stated that having all master data available is crucial since the reseller "know[s] exactly what data [is related to the product] [and] the consumer knows exactly what item it is, and [they] have all the master data and that will follow the supply chain into that" (C2S1, 07:30). Overall, the importance of *Data Availability & Time Behavior* can be captured with a quote from C2S: "**Everything is all about ensuring that the right product information is available for each item when it goes through the supply chain in resale**" (C2S1, 07:55).

The *Interoperability* sub-group of requirements is strongly connected to the *Interaction* sub-group and is essential for ensuring that the stakeholders' systems can interact with the DPR. *Interoperability* entails that a DPR solution must seamlessly exchange and share data with other systems or platforms, both within and outside the T&Cs ecosystem. This requires interacting with other systems, without the need to limit custom integrations or modifications. Without interoperability, a DPR system cannot work harmoniously with other software- or hardware-related systems. Standards, protocols, and formats for data exchange, data compatibility, mapping, and data integration are examples of measures that can enable DPRs to interact with other systems, tools or processes seamlessly. First and foremost, this entails that DPR's data connections allow for enriched presentations/use cases (RID#20, Sheet 3, Table B5) during, for instance, resale. To enhance the presentation of a product during resale, a web shop should not only collect the master data but also include enriched data, such as images comparing the new product and the second-hand product to show the condition of the latter. With this enhanced presentation, "they can see what the condition is [and] also see all descriptions of the product" (C2S1, 03:30). This also requires communication between systems and *Modularity*, which will be explained later.

Another specific example from our interviews is the possibility of a DPR enabling a virtual wardrobe for consumers, including store-bought products (RID#21, Sheet 3, Table B5). Master data is gathered from historical online orders, allowing for resale. At the same time, a data carrier scanned by the consumer post-purchase enables the transfer of ownership. It generates a digital wardrobe (C2S1), but "if you go into a department store or another multi-branded retailer and you want to buy something, then you do not know what the item is" (C2S1, 5:30). This requirement is linked to the *Interaction* sub-group mentioned earlier.

Interaction refers to the technical requirements that facilitate user interactions with DPRs of T&C products. This may include user-friendly interfaces, functionalities, and workflows. One example is the creation of a digital wardrobe that allows consumers to view their items and potential resale prices and enables clothing brands to tailor recommendations based on the consumer's preferences. Our interviews revealed that the consumer experience of a DPR must enable an interaction with the product (RID#22, Sheet 3, Table B5) since "for the consumer, it needs to be an experience where they can see everything about the product" (C2S1, 41:02).

Interviews revealed that that the DPR should allow consumers to add transactions that enhance product information (RID#23, Sheet 3, Table B5), such as information on how many times clothes have been worn or that C2S can learn from the usage of the product when assessing its quality for resale. This requires the technical functionality of *interaction*. As C2S noted: "so they know the basic knowledge of a product and attributes of a product [and] they also know a consumer can add different areas on it" (C2S1, 31:22).

We identified many intra-class connected requirements between *Interaction* and *Modularity*. Modular functionalities provide flexibility, adaptability, and scalability for future changes, updates, or customization without disrupting system functionality or major system redesigns. The reason for this strong connection between the two sub-groups lies in the fact that modular functionalities are often those that enable interaction. We found that these two categories incorporate the requirement of the DPR providing an option to add additional services on top of the product information (RID#24, Sheet 3, Table B5). This was stressed in interviews indicating that consumers need interaction with the item and more services on top, including resale, repair guides, and upselling (C2S1). This requirement leads to the need for dynamic and enriched DPRs, incentivizing multiple scans (RID#25, Sheet 3, Table B5). Without this, the interaction would be disconnected, and instead, case companies suggest styling tips based on trends and purchases to enhance interaction (C2S1). The intra-class connection between *Interaction* and *Modularity* of technical requirements becomes evident with these two requirements.

GC learned from their BC pilot that the *Modularity* and *Interaction* requirement of capturing consumer feedback of what is demanded so that having a DPR information can be a selling point and competitive advantage (RID#26, Sheet 3, Table B5) is crucial. Since our case companies are highly engaged in sustainable practices and certifications, they were interested in using the DPR as a marketing tool so that "all [the] information that supports that [they] have a high quality could be used as a selling point" (GC1, 32:31). Therefore, the DPR needs to be modular, allowing stakeholders to adapt the layout, user experience, and information according to their needs and regulatory demands. This requires flexibility so that stakeholders can use the information from the network based on their own needs (RID#27, Sheet 3, Table B5). GC supported this since, in their opinion, "**each company should be able to take out the information and then use it or make it, change it, or not change it, but put extra information on top of it for use**" (GC1, 57:17).

7.2.4 Inter-connected Requirements

Earlier, we classified 10 of the 37 requirements from the first round of interviews as interconnected, belonging to more than one requirement class. How we inferred them is explained in the following.

Regulatory & Stakeholder Requirements

In the first iteration of our IT artifact design, we captured one requirement at the intersection between *Government Support* and *Collaboration* because it requires a joint effort from both stakeholders and regulatory bodies, namely that certification authorities allow and support a digital link via a data carrier (RID#28, Sheet 3, Table B5). Sustainably conscious brands work with certification authorities that have rules not updated to encourage a DPR. Interviews suggest that certification authorities could benefit significantly from a tamperproof chain of custody when auditing companies for sustainable practices. Due to GOTS certification rules, GC cannot add electronic devices to their clothes. According to GC1, "We can't sell it with a GOTS label on if it has an NFC" (28:48). Thus, *government support* is needed to encourage certification authorities to update their rules to incorporate digital links via data carriers to enable a DPR. On the other hand, *Collaboration* is required between certification authorities, producers, brands, and other stakeholders to ensure that the necessary means are incorporated to allow for a tamper-proof chain of custody when auditing companies for organic fibers, used chemicals, fair working conditions, and the environmental footprint of the product. In summary, this requirement is a key step towards enabling a DPR and requires both *Government Support* and *Collaboration*.

Technical & Regulatory Requirements

To meet regulatory and technical requirements, the data carrier must be agnostic, allowing any textile product to have a DPR (RID#29, Sheet 3, Table B5). *Interoperability* is essential, and the *government must support* the flexibility of several accepted identifier types to enable companies like GC to incorporate a DPR into their baby clothes. GC is already very limited in the possible data carriers for DPRs as they need to withstand high washing temperatures, more-than-average amount of washing cycles, not touch the baby's skin, and not be of chemical nature, which could, by any means, be swallowed by the baby (GC1). Thus, the data carrier must be interoperable with the physical product and durable to apply to any T&C product.

We found that data security and access concerns need to be clear to all stakeholders and addressed orderly (RID#30, Sheet 3, Table B5). This requirement falls under both *Clear Regulations* and *Documentation & Data Capture/Quality* and *Security & Access Control* from the regulatory and technical requirements classes. According to our interviews, stakeholders' main concern about collaborating on a decentralized platform is data security and access control (GC1). Proper data-sharing specifications are required to control this from a technology standpoint, and we suggest that government bodies provide clear regulations to address this concern.

The third requirement is that the “ownership” of the consumer (data) needs to be clarified and set (RID#31, Sheet 3, Table B5). This involves establishing *clear regulations* for *Security & Access Control*. In the downstream supply chain, multi-brand retailers, like Zalando, often sell textile products instead of the producing brand (C2S). This raises the question of which stakeholders can use the DPR data collected post-purchase. Our interviews with industry stakeholders emphasized the importance of clarifying ownership rules, also in case of multiple scans, as C2S expressed: “I think what is important here is [...] who owns the data, who have control?” (C2S1, 35:06) and “who owns the consumer? Who owns the scan?” (C2S1, 41:00). To answer these questions, ownership rules need to be anchored in the access control settings, and government involvement is necessary to establish fair data sharing rules between brands and retailers, particularly in the wholesale business.

Technical & Stakeholder Requirements

The final set of inter-connected requirements pertains to the roles and responsibilities of stakeholders in the T&C industry and technological capabilities. Two requirement sub-groups have not been defined yet. These sub-groups overlap with other classes of requirements, namely *Consumer Interaction* and *Decentralization*, respectively.

Consumer Interaction requirements aim to enable meaningful interactions between consumers and DPRs, such as virtual try-ons, product visualization, and interactive product customization options that could create a more immersive and personalized experience with the product. Yet, the primary objective for case companies is that the DPR would allow them to learn more about post-purchase usage to improve future sales (RID#32, Sheet 3, Table B5), for example, by understanding how their products are treated and washed, as GC does for their baby clothes (GC1). This requirement overlaps with the technical sub-groups of *Modularity* and *Interaction*, as a DPR would need technical features to enable such interactions and additional services beyond information supply.

The *Decentralization* sub-group involves technical requirements that support decentralized architectures and distributed systems for a DPR in the T&C industry. This requires designing systems that do not rely on a central authority or single point of control but instead distribute across multiple nodes or entities. The goal is to enable greater autonomy, resilience, and flexibility in DPR systems, avoiding single points of failure and allowing for distributed decision-making and data management.

The need that a DPR requires a decentralized system setup (RID#33, Sheet 3, Table B5) emerged from interviews where stakeholders expressed concern about the question of ownership and distribution of rights in the T&C industry. One interviewee stated that "no one wants to own" a DPR, and it is unclear how to make money from it in a highly commercial industry (C2S1, 37:08). *Collaboration* among stakeholders is necessary to find a solution to this issue. A possible approach is to enable voting on changes, such as adding features, while maintaining the system's core and preventing disruptions (*Modularity*). The importance of distributed ownership was further emphasized as a DPR should avoid one big (tech) player owning all value chain data on their own server (RID#34, Sheet 3, Table B5). GC expressed this as they “do not want some big player to own all [their] value chain data and put it all on a server in India or something like that” (GC1, 49:30).

In relation to decentralization, a key requirement is that a blockchain network should not be owned or controlled by anyone but generates value for each, is easy for brands to adapt into and has underlying support available (RID#35, Sheet 3, Table B5). Primary data from C2S shows that this requirement demands *collaboration* from stakeholders and *interoperability* to allow for simplified linkage and implementation efforts. Additionally, it was highlighted that the underlying network of a DPR should be open and seen as a connectivity platform for easy connection. However, at the same time, there need to be people maintaining it thus, this requirement calls for elements of decentralization, collaboration, and interoperability. As C2S noted, existing providers like EON manage digital product IDs in a centralized manner, so it is essential to create a BC network that meets these requirements.

Our case companies have expressed their vision of a DPR that could be powered by BC and IoT, but they have also highlighted the importance of technological maturity and clear communication of data ownership, access levels, and the benefits of such a solution for each company (RID#36, Sheet 3, Table B5). This requirement is linked to the need for stakeholders to have a *technological understanding* and the *scalability* and *security of the system and access control*. C2S emphasized that previous experiences with BC have not been successful because of poor communication and buzzword usage, which is why they advocated that “it needs to be mature” (C2S1, 35:06). Without clear guidelines on data ownership and access levels, the DPR would not be able to scale across the industry especially if companies feel threatened that data is exposed to the wrong channels.

Lastly, the case companies identified an additional benefit of a DPR: its potential to positively influence buying behavior (RID#37, Sheet 3, Table B5), for instance, by showing the resale price value that consumers are guaranteed to receive through a smart contract. To incentivize consumers to resell T&C products, brands are looking for ways to motivate them, and this feature could be a strong motivator. C2S specifically expressed interest in this opportunity as it could benefit both their business and the brand by potentially increasing sales. They suggested using a digital contract that could be linked to the BC and allows for a connection between the consumer, the product, and what has been agreed upon between the consumer and the brand (C2S1). Therefore, the DPR needs to be designed in a way that can impact how consumers make purchasing decisions, which requires both *consumer awareness* and *modularity*.

To summarize the collected requirements, our initial conversations with two case companies revealed numerous needs for a DPR in the T&C industry. Especially the relationships and connections between the identified groupings indicate that each requirement cannot be looked at in isolation but need to be considered in conjunction with those it relates to, both within the same requirement class (intra-connected) and across classes (inter-connected). The complexity of these requirements can be seen in Figure A19 and Table B5. With 37 requirements in total for the first iteration, we returned to our research question and IT artifact objectives to ensure alignment. Our next step was to prepare this requirement overview and our IT artifact for the first iteration's demonstration activity.

7.3 1st Iteration - Demonstration: Design Workshop

We prepared the demonstration of our IT artifact’s first iteration on a virtual whiteboard, and Figure A20 shows the overview, including the agenda. Our agenda was split into five parts: 1. recap of our project and progress to emphasize why we are here, set the scene, and clear out assumptions about our research; 2. demo of the combined as-is supply chain to validate that we correctly understood and captured their individual parts of the supply chain; 3. objectives of our IT artifact/model (Chapter

6) that we developed based on the problems identified from the literature and the case companies' input on challenges in their current setup which could be tackled with a DPR; 4. DPR requirements collected so far presented to verify or discredit their applicability; 5. considerations for future implementation to hear the companies' thoughts on concerns, potential benefits they see, and hopes for the future. A note on the third agenda point: presenting the goals of our IT artifact was not necessarily to get feedback on their feasibility, viability, or desirability, as we considered having this evaluation with the experts, but it was to put the requirement collection into a context of: *what should a successful fulfillment of these requirements for a DPR be able to achieve?*

After the first three agenda points were covered, the focus of our demonstration in the first iteration was to gather feedback on the requirements we collected during the design stages of this research. We presented how we classified the requirements into three overall groups and how those each have sub-groups. We then went into each individual sub-group and showed the inter-connected requirements to validate our findings and gather feedback. During this walkthrough, we gathered some validation, emphasis, and points for improvement that we would touch upon in the evaluation stage. Due to the color coding in the visualization, we could refer to GC and C2S's requirements individually to validate them and to hear if the other party agreed with the requirement, given that they represent two different types of stakeholders, brand and reseller, respectively. Evaluating the requirements this way motivated us to conduct the workshop jointly, with both case companies present. We believe a future DPR implementation would also need this alignment on requirements.

7.4 1st Iteration - Evaluation: Feedback from Case Companies

Firstly, one can say that the general feedback for the first iteration of our IT artifact was positive, as emphasized by C2S's Co-Founder who, at the end of the workshop, said he was "impressed [by] how much [we] have gone into details and how much [we] understand, so the vision is correct" (C2S1, 01:15:18). GC agreed with this and, in connection to the first interview where they expressed that T&C supply chains "can get really complex" (GC1, 18:01) and that "it's not a very simple value chain" that is easily depicted" (GC1, 18:34), they were happy to see how much of the elements we identified correctly (GC2).

Specifically for the evaluation of the as-is supply chain, we asked if "it depicts the elements that [they] can resonate with for [their] own supply chain" (AK2, 13:50) and the response was "yeah [they/GC] think[s] [we] got it right" (GC2, 14:10). The case companies had some input on the activities/events layer of the as-is supply chain model as they clarified that not only could the weaving/knitting and dyeing/printing happen in a reversed order, but that "you can also sew before you dye" (GC2, 11:44). Another point of confusion in this layer linked to the location layer was the question of transportation between the GC facilities in Turkey and Ukraine (C2S2), as the model from the first iteration only included the "transport" as one activity after "store" the activity/event layer. GC's MD clarified that there are, of course, many transportation steps, also "just inside of Turkey, it's also transported a lot" (GC2, 11:55). However, to simplify it into a model, she agreed that it could not all be placed on a visualization (ibid.). On the lowest layer of the as-is supply chain, in the area of GC's delivery SCOR processes, their MD noted for the process deviations that, due to there being seven companies, it was harder to follow. However, she understood that we were considering the process from a location point of view. The detail added to the deviations was related to their private label production that can reap custom benefits by crossing the Danish border.

Analyzing the feedback received for the requirements collected, one can capture that the case companies suggested minor changes. In most cases, they stated further points that validated and emphasized the existing requirements noted. Furthermore, it was positive that both case companies agreed with each other's requirements. This was not a given as we collected the requirements from each company individually during the first interview round.

Going through each of the requirement classes, in the regulatory requirements we clarified that "there may have to be regulation in terms of the digital product, but anything on top, any module that would be added on top, any business that would be built on top of this data, [there would be] no regulations" (CH2, 23:06) and this was confirmed by C2S as "that's how [they] see it" (C2S2, 23:35). Thus, the involvement of regulatory bodies in the specific design and components of a DPR would be very limited according to our case companies. Regarding the data carrier being agnostic (RID#29, Sheet 4, Table B5) as a requirement of both regulatory and technical sub-groups, GC's digital manager noted that "there's a lot of power [...] from the government because if the government says something has to be NFTs or a code or whatever, then the GOTS label that will make the GOTS certification will also have to regulate their restrictions which links to the requirement of certification authorities allowing and supporting a digital link via a data carrier (RID#28, Sheet 4, Table B5).

The ownership of consumer data was a topic that was discussed among the case companies regarding the requirement "ownership" of the consumer (data) needs to be clarified and set (RID#31, Sheet 4, Table B5). Especially because the "majority of business here is not direct to consumer [but] through everyone else" (C2S2, 24:15), thus sales are executed via resellers that might not want to share their sales and consumer data with the brand owner (C2S2, 22:02). The complexity of setting the ownership rights to consumer data emphasizes the need for this requirement. Although the case companies had some ideas on how this could be solved, it remains necessary to clarify who owns the T&C item and linked consumer data at what point. Regardless of the need for this requirement to be clarified, the case companies agreed that they "don't think there will be regulation on that" (C2S2, 21:44) but rather that it would be a business-to-business agreement just like stating on your own website "who has access to the data" (GC2, 21:52). This was an interesting alteration to the positioning of this requirement as it removed the regulatory involved and would more so need the collaboration from stakeholders. Further evidence for this change in requirement class was delivered by C2S, who said that, from their point of view, "the government will only be requiring the needed data for insight, for consumers etc." (C2S2, 22:46) and not set ownership rules, which was met with agreement from GC (23:04).

An inter-connected requirement that remains somewhat uncertain is whether it lies within governmental power to ensure that data security and access concerns need to be clear to all stakeholders and addressed orderly (RID#30, Sheet 4, Table B5) because GC noted: "don't know, but I think that the government mostly are interested in protecting the customers" (GC2, 23:45) rather than focusing on the other stakeholders of the industry. This uncertainty exemplifies that affected stakeholders in the T&C industry remain puzzled regarding the specifics of regulations and the direction the upcoming laws will take due to the lack of clear legislation thus far. For the successful implementation of a DPR, these uncertainties would need to be clarified in time for organizations to take action and find out where their responsibilities lie in comparison to those of the government bodies.

A new requirement that was collected during the design workshop was that **regulation requires data formatting standards for reading data** (RID#38, Sheet 4, Table B5). Even though fashion companies “want to be different” (C2S2, 01:00:50), they are actually all “more or less equal” (ibid.), however, “the big issues you have right now is to operating and integrating data” (ibid.). Without “one standard for data in fashion” (ibid.) resulting in a lot of different representations of data, creating and enabling a DPR is close to impossible/very challenging “because otherwise, it would be impossible for them to read the data” (C2S2, 52:06). Therefore, the case companies suggested that it would require a similar standard as exists for battery (and battery passports) where authorities like GS1 are involved in “some kind of standardization, just like you have XML or some kind of standard” (ibid.). The responsibility of setting and enabling this standard lies within regulatory power as “regulation will require standards for getting data in and out. There will be requirements from the government about a standard for reading data” (C2S2, 51:36) which is why we saw a need in adding this as a requirement of both regulatory and technical nature.

7.5 2nd Iteration - Re-Design: Incorporating Case Company Feedback

Based on the first iteration of activities 3 to 5 of the DRSMPM, we conducted a second iteration of the design, demonstration, and evaluation activities to improve the IT artifact based on the feedback received on its first iteration. The second iteration aimed to alter the as-is supply chain layered model and requirement collection and categorization so that our IT artifact objectives could be achieved.

Firstly, we adjusted the elements in the layered as-is supply chain model as the case companies pointed out changes to the order of activities, representing some activities differently and adding missing parts. To show an independent order of execution in weaving/knitting and dyeing/printing, we added a two-sided arrow in the activities/events layer. The other alteration in this layer is related to the “transport” activity, which triggered splitting the layer into those activities that, for simplification purposes, can be assumed to be executed once per T&C item and those that reoccur along the supply chain, such as “transport”. We aimed to clarify to the viewer that planning and logistic activities can be executed once harvested until re-sold. A detail we added to the lowest layer on the process deviations was the note from GC that for private label production, there is a border crossing involved where GC Denmark is involved, at least on paper. These changes are captured in Figure 12 below, which shows the before and after / which shows changes made in red (enlarged: Figure A21).

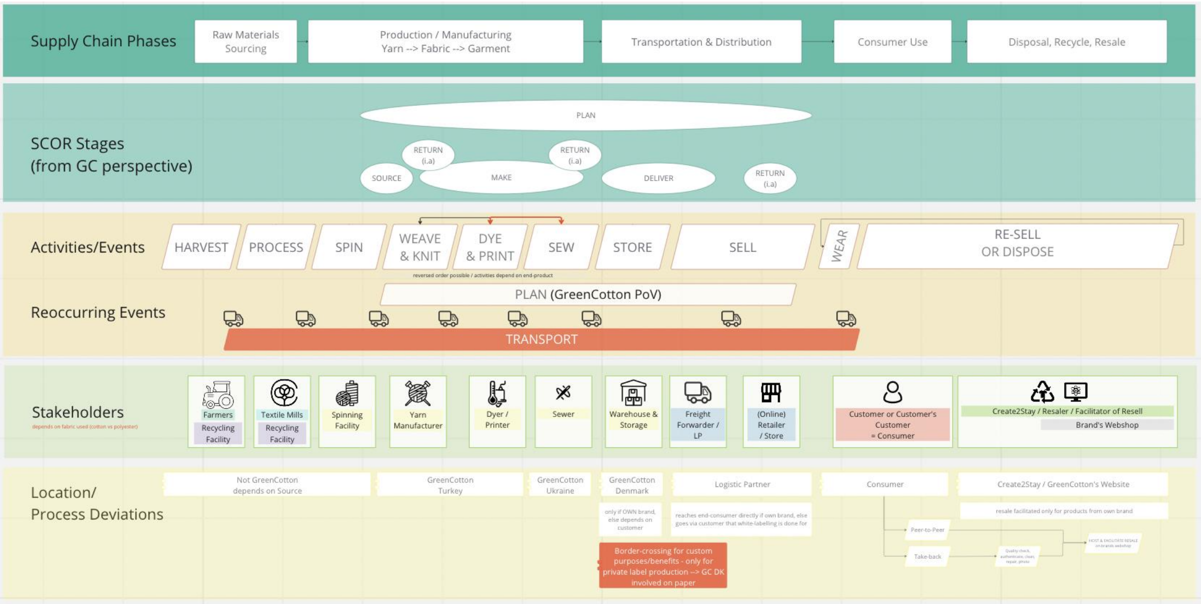

Figure 12: 2nd Iteration of As-Is Supply Chain Model - Changes highlighted in red

For redesigning the requirement overview, we focused on the minor changes that the case companies suggested during the design workshop, which were around re-allocating a requirement to belong to a different class and adding a requirement. The previous requirement of *Clear Regulation* on the regulatory, and *Security & Access Control* on the technical side, namely "ownership of the consumer (data) needs to be clarified and set" was moved to be an additional inter-connected requirement between the previous technical sub-group and *Collaboration* as a stakeholder requirement. This transition was needed as the case companies expressed that they did not see government involvement in regulating access rights of consumer data between two or more businesses but that this would have to be negotiated on a B2B basis instead. The additional need for a data formatting standard for reading data, as suggested by C2S, resulted in adding an inter-connected requirement between *Clear Regulation*, *Data Portability, Interoperability,* and *Documentation & Data Capture/Quality*. It was clear from the data collection and analysis that regulation would enforce this but would be grounded in technical capabilities that allow data to move, interoperate, and be adequately documented to be accessible and readable. The changes are captured in red highlights in Figure 13 (enlarged: Figure A22). Additionally, the requirements that received additional validation are marked with bold frames.

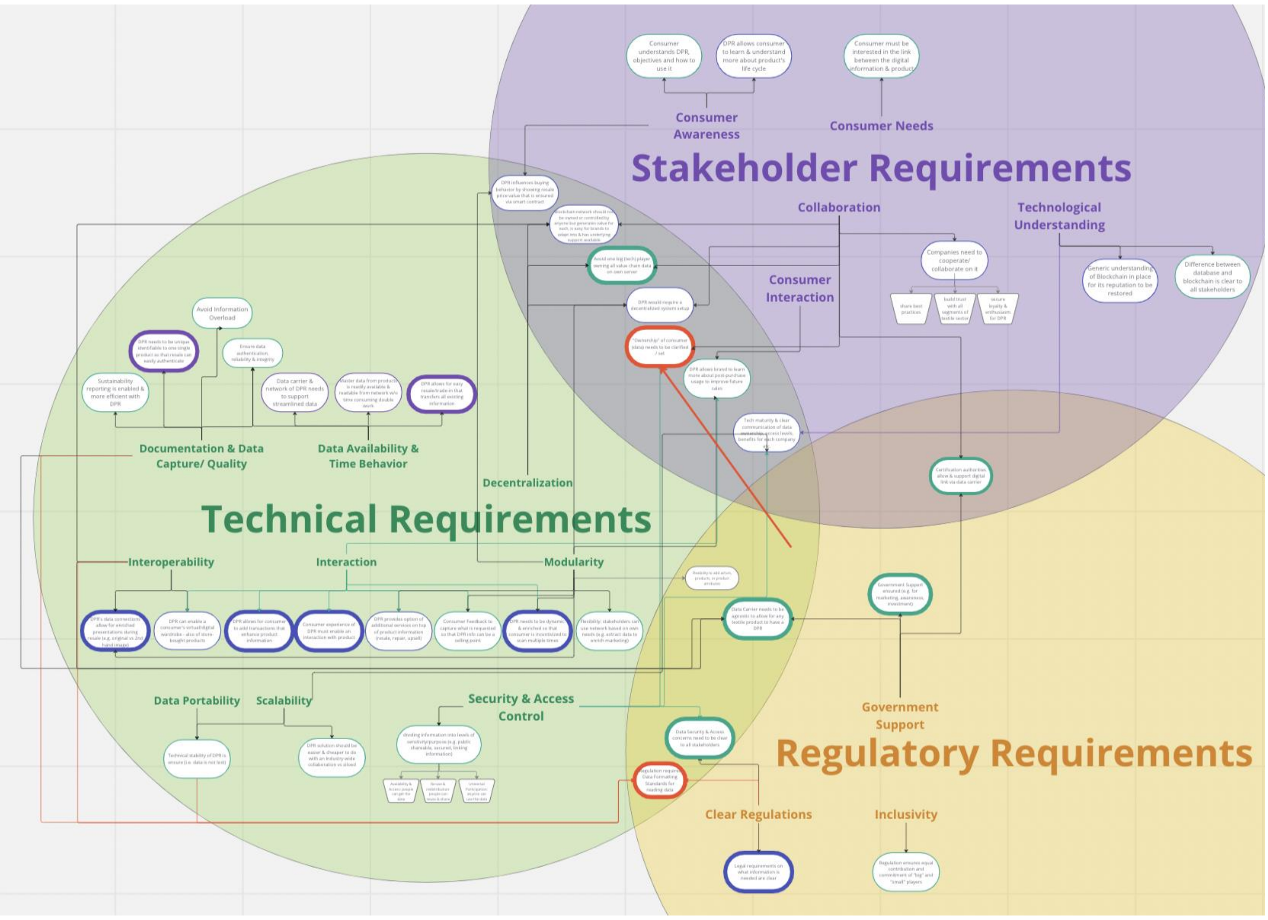

Figure 13: 2nd Iteration of Requirement Collection - Changes highlighted in red; validations in bold

7.6 2nd Iteration - Demonstration: Expert Interviews

For more accessible demonstration purposes and to provide a pre-read in advance of the expert interviews, we shared the tabular format that captures the drill-down of the level 1 requirement classes definitions, level 2 sub-groups definitions, and level 3 requirement list with their respective allocation to class(es) and sub-group(s) (Table B5). Before the meeting, this was shared with experts to ensure they could get an overview of the requirements collected. Based on the material shared during the demonstration, the goal was to get their reflections on how comprehensively we defined our requirements, whether the list of requirements is complete and could be generalizable for other T&C companies, if the relationships and interactions among the requirements are coherent and logically consistent, and lastly, if the IT artifact can plausibly address the identified challenges and achieve the IT artifact objectives.

Similarly to the demonstration for the case companies in the first iteration, we prepared an agenda consisting of 1. an introduction to the expert interview, our overall research question, the presentation of the updated/redesigned layered as-is supply chain model to set the scene for the T&C industry setting that we collected the requirements of a DPR in, and the goals that such a DPR would have, i.e., our IT artifact objectives; 2. the requirements discussion that served as the main component of the interview to get feedback on the above evaluation criteria and additional qualitative input on the suggestions and recommendations from the experts; 3. considerations for a future implementation of a DPR to hear the experts' concerns and thoughts on the upcoming legislation and execution of it. The material used and presented can be found in Figure A23. Since the expert interviews were conducted individually, we will evaluate them individually. Nonetheless, the demonstration followed the same structure, and the only difference was that the senior manager at Deloitte's 60mins interview was split into two separate sessions.

7.7 2nd Iteration - Evaluation: Expert Feedback

As explained in the DSR prelude of our analysis, a crucial part of our research is the external evaluation of our IT artifact, for which we consulted two experts in semi-structured interviews. Based on the demonstration explained above, this section will summarize their general feedback and points for improvement for both components of our IT artifact, namely the as-is supply chain model for the T&C industry and the requirement collection we shared as pre-read. An in-depth explanation of the expert feedback evaluated can be found in Appendix E. Overall, Deloitte's SM shared his view that our IT artifact may be too detailed and tailored to the specific case companies interviewed and that we would need to elevate it more to enhance its applicability to the whole industry. This was somewhat countered by our other expert, Textile Pioneer's Co-Founder, who complimented our approach of understanding the industry first and then finding the requirements for a DPR, which, in his opinion, matched what we would have found by interviewing more companies in the T&C industry. Regarding the structure of this section, we will first present the findings from evaluating the as-is supply chain model and comparing the experts' input and then move to the input received for the requirement collection for a DPR.

For the **as-is supply chain model** we created, their general feedback and points for improvement are captured in Table 3 below and highlight their differences in opinion on and perception of our IT artifact, which we assume can be linked back to their backgrounds.

Table 3: As-Is Supply Chain Expert Evaluation

	Deloitte's Senior Manager	Textile Pioneer's Co-Founder
General Feedback	- "reality is always more messy but that's why we make models in order to extract and understand the world, so that's fine" (JS1, 04:58) - "modeling the world is hard" (JS1, 07:44)	- "it shows the supply chain very well" (KR1, 12:48) - order in which the activities are executed can vary (KR1, 14:52)
Points for Improvement	- in supply chain and ensure we are comparing consistent terms (JS1, 05:18) - Create visualization of overall themes rather than too granular view of supply chain (JS1, 06:35) - More consistent wording of events layer (JS1, 07:09) - Rather than capturing every detail, make assumptions (JS1, 07:50) - Use Business Process Modeling Notion (BPMN) to map out supply chain processes (JS1, 08:41)	- Instead of saying "harvest" in events layer, find word that will make model applicable to stakeholders/T&C products where raw material is not harvested but sourced in other ways (KR1, 12:48) - Mistake to correct in stakeholders and their respective events: weaving & knitting is done by fabric manufacturer and spinning facility is same as yarn manufacturer (KR1, 15:44)

Regarding the as-is, the experts' evaluation of the as-is supply chain model differed significantly. While the senior manager at Deloitte, coming from a more academic background, gave very detail-oriented feedback on the wording of specific elements in the as-is, the co-founder of Textile Pioneers was more focused on the content that should reflect the T&C's industry and its supply chain. This difference in evaluation is fair as the co-founder of Textile Pioneers has a strong industry background, which the senior manager at Deloitte lacks, and vice versa, the co-founder of Textile Pioneers would not per se see the taxonomy levels of the models being faulty as this may also not be a priority for him to clarify.

For the **requirement collection** discussed, the evaluation again differed greatly between the two experts consulted. Deloitte's SM challenged us strongly on the clarity and coherence of our requirements as he saw stronger overlaps in some areas and proposed another dimension we shuold consider: ecosystem achievability. Meanwhile, Textile Pioneers' Co-Founder commented on the completeness of our IT artifact as it was missing sufficient identification and capturing of the customer. From his point of view, the customer in a B2B setting would have additional requirements that are not captured sufficiently in our IT artifact yet. As with the as-is supply chain model, we have collected the expert's feedback on the requirements in Table 4, which speaks to the different areas the experts commented on. In some cases, we find it necessary to explain further to the reader why certain decisions were made around the IT artifact, which is captured in the "Counter Arguments" points for some of the points for improvement.

Table 4: Requirement Collection Expert Evaluation

	Deloitte's Senior Manager	**Textile Pioneer's Co-Founder**
General Feedback	- "logically, this makes sense, [...] there are some technical requirements, [...] some business requirements, [...] some regulatory requirements" (JS1, 12:21)	- "talking to the three of us [GC, C2S & Textile Pioneers], [he] think[s] [we] have a very good picture" (ibid.) and that he does not think that we "need to talk to a lot of others because they will come up with the same" (KR1, 33:19)
Points for Improvement & Counter Arguments (CA)	1. Grouping of stakeholder and regulatory requirements *unclear/incoherent* as regulatory bodies can be considered another type of stakeholder (JS1, 05:58) and grouping as "stakeholders" is too broad given it includes consumers too (JS1, 19:58) **CA:** Our argument to keep regulatory parties outside of stakeholder requirements was that they are not physically in touch with the T&C product; those involved in material flow have very different requirements than those that do not 2. *Incoherence* in the blockchain-specific requirements is limited to "decentralization" sub-group, which "could be extracted to governance or theory mechanism" (JS1, 25:55)	1. *Completeness* was confirmed since requirements collected would resonate with other T&C companies (KR1, 33:19) **CA:** We assume that this expert meant that other companies like Textile Pioneers, C2S, and GC would agree with the requirements. However, this is not to state that government bodies and tech companies operating in the industry would have nothing else to add. 2. *Incoherent/unclear* who is meant by consumer/ customer

or in a separate governance sub-group; thereby, our IT artifact "can be blockchain-specific" without the model being "technology-focused" (JS1, 27:08) as "in reality, the technical requirements here when implementing them it is fairly small" (JS1, 14:43)

CA: Although infused often, the DPR requirements collected were not aimed to be blockchain-specific and we did not anticipate that the group of technical requirements would be the largest; we aimed to keep it technology-neutral but are aware that the case companies interviewed had background knowledge on the tech that is above average

3. *Completeness:* instead of re-inventing the wheel and building "a very organizational-centric model" (JS1, 21:14), "build on top of models that [...] exist already" (ibid.) and take "problem-oriented approach"

CA: Taking this bottom-up approach where the organizations' needs were in focus was intentional

Alternative Approach suggested:

Model by Deloitte & World Economic Forum published in article on "How to build a successful nationwide blockchain initiative" (Alhaddad et al., 2020)

1. Better classify requirements into four groups: technical feasibility, user desirability, business viability, and ecosystem achievability
2. *Completeness & generalizability* could be improved by adding ecosystem achievability since "hard thing is to understand the ecosystem and understand the value drivers of the entire ecosystem" (JS1, 12:21)

CA: We assume that we did not discover this dimension based on the input from the case companies because they are more focused on their individual operations rather than "a new discipline to have a kind of value ecosystem, value

in stakeholder requirements because in a B2B setting, the brand owners would have different and/or additional requirements (KR1, 31:20), not just the end-consumer wearing clothes; missing "the point of view from a company who is doing B2B, where the brand that is sold to also has requirements" (AK_KR1, 32:47), thus consumer distinction is unclear

3. *Completeness*: expert suggested adding a sub-group for user experience and interface since "the main thing here is how you build up your interface [...] starting up with all the very important information and then [...] the more you scroll, the more nice-to-know data you get" (KR1, 42:05)

CA: Importance of the interface can be linked to the types of information that would exist for a DPR, how they need to be connectable and interoperable in a modular setup but at the same time protected via set access controls which are requirements we have captured. Going into the details of which information exactly is to be shared, the levels of sensitivity for them and how it could best be presented was not within the scope of our paper but would be of interest for future research.

proposition or ecosystem mindset" (JS1, 16:07); educating them in this was not in the scope of our research as we focused on the needs that were generated bottom-up, from case companies directly, rather than top-down as suggested by this expert

When comparing the two expert evaluations for the requirements collected, they had one feedback point that they agreed upon; namely the lack of the B2B cases considered as the brand owner's needs are not reflected in the requirements thus far. Regarding the generalizability of our model, the two experts had very contrasting opinions, as Textile Pioneers' Co-Founder supported that we would get similar input and validation of requirements from other T&C companies in the industry. However, Deloitte's Senior Manager believes that our model is too narrowly fit for the T&C companies interviewed and places emphasis on areas that are secondary when viewing the requirements from an ecosystem point of view that includes perspectives from government bodies and tech companies. One of those areas that we focused too much on, according to Deloitte's Senior Manager, namely the technical requirements, was an area that Textile Pioneers Co-Founder emphasized more by stating that the structure of the interface is pivotal, which indicates another feedback point that the experts disagreed upon.

7.8 Sub-Summary of IT Artifact Development

To conclude, the expert evaluation of the as-is supply chain model and the requirement collection designed for the T&C industry revealed that our IT artifact fulfills, for the most part, the aspects of *clarity, completeness, and coherence,* albeit some suggestions for improvement as highlighted by the experts. The trade-off and balance between a too-narrow versus too-broad model are evident in the evaluation and impacts how applicable the IT artifact is to individual organizations versus the whole industry, respectively. Nonetheless, we received validation that the input received from the case companies would align with what we would encounter with other T&C companies. Regarding redesigning the IT artifact in a third iteration, given the scope of our research, it was agreed that the recommendations for improvement would merely be presented and later discussed along with implications for future research.

We believe that we have gathered sufficient requirements that represent the immediate needs of different types of stakeholders in the T&C industry. Although Deloitte's expert suggested more significant changes to our model, we foresee that adapting the IT artifact accordingly would result in designing a model that would be too broad. It would no longer resonate with the individual case companies interviewed, whose standpoint we took via a bottom-up approach. The discussion will address the trade-off between achieving an IT artifact that represents the needs of case companies from a bottom-up approach versus a meta/high-level/top-down view. After analyzing our findings using DSR, the next chapter will assess the potential matching of DPR requirements with the technical capabilities of BC and IoT, as described in Chapter 8. This aims to answer the second part of our second sub-question regarding the ability of Industry 4.0 technologies potentially support the collected requirements. We will then discuss the possible effects of a DPR on the T&C supply chain, the implications for future implementation, and future research directions.

8. Assessment of Technological Capabilities & Requirements Matching

As mentioned, concerns were raised regarding the applicability of an industry-wide BC as the backbone of a DPR, with GC's Managing Director stating that "it's maybe overkill. Maybe it could be just done with a database, depending on what information they want" (GC2, 01:09:12). The underlying skepticism of whether BC is needed sparked the motivation for assessing the impact of BC and IoT's technical capabilities if these technologies were utilized as the backbone of a DPR, with the objectives of enhancing transparency, traceability, authentication, and supply chain efficiency in the T&C industry. To assess this, we first compare the technical capabilities to the requirements collected and afterward discuss the potential impact of a BC and IoT-based DPR on the T&C supply chain and then address the considerations for its future implementation.

8.1 Matching Blockchain's Capabilities with Requirements

The inherent decentralization capability of BC caters to the requirement subcategory of *decentralization*. The distribution of the record of transactions avoids having a central register of the product identifiers. It avoids one big player owning all participants' value chain data on their own server (RID#34, Sheet 5, Table B5). A decentralized distributed ledger is less vulnerable to attacks than a centralized system, as a failure in the latter would have a greater impact on all involved stakeholders' data and systems. The former can be considered as a more secure approach for ensuring *technical stability* (RID#10, Sheet 5, Table B5). Finally, the potential decentralized ownership and the constellation of BC create an opportunity for collaborative governance of a BC, thereby supporting the potential of generating value for each participant in the T&C industry without it being owned and controlled by one entity (RID#35, Sheet 5, Table B5). This viewpoint of decentralized ownership and operation of the BC was heavily supported by both the co-founder of Textile Pioneers; "I agree that it should not be one company owning all the data. But of course, it's also not a good thing if it's like 100 different systems [...] you should have a combined system" (KR1, 26:10, 48:40); and the senior manager at Deloitte; "How do we ensure that we create incentives that cannot be gamed and where all of a sudden, it's all the big players. Just kind of say, well, we are the biggest, and therefore we will rule." (JS2, 21:45). Experts validated that the fundamental requirement of a DPR network being decentralized (RID#33, Sheet 5, Table B5) can be met through BC's inherent decentralization capability. This suggests that BC can be a valuable tool for DPR.

For the *documentation & data capture/quality* requirement subcategory, BC offers great capabilities in its transparent and secure architecture. Documentation throughout a BC network is conducted through transactions which, as previously mentioned, are recorded in sequential order by timestamping and referencing previous hashes. These transactions can include specific information, such as a unique identifier of one single textile product or material (RID#13, Sheet 5, Table B5). The unbreakable chain ensures transparency and facilitates participants to easily track and verify the origin, ownership history, and authenticity of the product information regarding T&C products(RID#16, Sheet 5, Table B5). Furthermore, the immutability of data that has been recorded ensures trust in the data, thus also enabling trust in the transparent data history. Additionally, the transparency and immutability of BC enable sustainability reporting (RID#15, Sheet 5, Table B5) to be more trustworthy and efficient. The BC can store all pertinent information about a product's lifecycle, including information about materials sourcing, manufacturing procedures, transportation, and end-of-life disposal. This gives stakeholders an impenetrable record of information that can be used for a wide array of use cases, such as calculating the environmental impact of a product.

The main challenge of implementing BC for transparency and accountability for sustainable practices can be attributed to two fundamental issues. The first concerns the consensus on data formatting standards for reading data, thus making this requirement very important. As emphasized by several interviewees (C2S2, KR1, JS2), the standardization of data formatting throughout the T&C industry is largely absent despite similar operations. This is one of the greater hindrances of using BC on a wider scale from a technological point of view due to the lack of interoperability amongst the many systems being utilized in the T&C industry. However, according to the senior manager at Deloitte, this "is interchangeable with any centralized system" (JS2, 10:24). This speaks to the need for a BC network to be interoperable and any network that acts as a shared data storage with established APIs that allows cross-organizational data sharing (RID#10, Sheet 5, Table B5). Secondly, there is a challenge regarding the collection of data and onboarding of users for a shared BC network throughout all stages of a global T&C supply chain due to the significant disparity in IT maturity in developing countries (KR1, JS2). Despite these challenges, the transparent nature of BC and the immutability of data stored on a BC serve as a beneficial supporting factor to a DPR. These capabilities further increase the integrity of any product-specific data recorded and utilized for a DRP.

As mentioned earlier, the requirement subcategory of *data availability & time behavior* refers to the ability of the DRP to provide the correct product information when needed. The distributed ledger and shared network validation ensure that recordings of transactions about specific products are added as an additional link to the chain of information, which is then synchronized throughout the network. This ensures the transmission of information is readily available and streamlined to all participants who have been granted permission to the specific transaction due to the distributed copies of the BC, its integrity, and the stability of the transactions recorded on the BC (RID#19, Sheet 5, Table B5). With the previous transactions being transparent by linkage throughout the BC, this allows for the easy traceability of all existing information on the T&C product.

Additionally, the requirement surrounding the availability and readability of master data from products without time-consuming double work can also be fulfilled due, in part, to the consensus mechanism that ensures the authentication, reliability, and integrity, thus eliminating the time-consuming work of authenticating master data (RID#18, Sheet 5, Table B5). By allowing the T&C supply chain actors to upload data regarding the events that have been undergone at the respective supply chain stage, the authentication of the data is ensured through the immutability and consensus mechanism involved in validating the data. The distributed nature of BC offers significant benefits to a DPR by enhancing stability and data availability, while the immutability and consensus mechanisms of recorded transactions reassure trusted data is accessible at the right time. However, one must acknowledge that data on a BC is not inherently trustworthy, as uploaded data can be untrustworthy but cannot be changed. Thus, the accountable organization responsible for recording incorrect data could be easily identified and held liable due to the unbreakable chain of blocks.

The *security and access control* requirement subcategory entails essential requirements of the DPR, such as dividing stored information into levels of sensitivity or purpose to minimize vulnerability when sharing data within the BC network (RID#12, Sheet 5, Table B5). Additionally, this subcategory entails the need for data security and access concerns need to be clear to all stakeholders and addressed orderly (RID#30, Sheet 5, Table B5), fostering collaboration between T&C supply chain actors. With many stakeholders potentially participating in such a network, individual organizations may have different requirements for dividing information into sensitivity levels, depending on their relationships with their respective supply chain partners and customers. The relationships can also heavily affect the needed data ownership and transfer of such between participants (RID#10, RID#31, Sheet 5, Table B5). As a result, it is crucial to have a flexible data division functionality in place to accommodate these diverse needs. The capability of smart contracts to enact agreements made between partners throughout a supply chain allows for the implementation of encoded terms that governs access control or data ownership (RID#31, Sheet 5, Table B5). This can be accomplished through encoded role-based access authority, which enables data categorization into sensitivity or purpose categories that only specific roles can access. This approach ensures that sensitive information remains protected, thus minimizing the fear of unauthorized “access to data” (GC1, 57:40), considered the main fear of T&C company participants when discussing collaboration on data sharing, according to GC. This approach of role-based access authority enables data sharing and collaboration where needed. Furthermore, smart contracts can be designed to comply with any industry regulations regarding data security and access control, ensuring that transactions recorded and executed on the BC network adhere to embedded rules.

8.2 Matching IoT’s Capabilities with Requirements

IoT being an inherent umbrella term for many different devices thus carries a significant and diverse number of capabilities that cater to the requirements stated earlier. Passive IoT devices are, by definition, highly related to interaction. A connector must interact to transmit information to access the information stored on a passive IoT device, such as an RFID tag or a QR code. According to Thomas from C2S, the *interaction* with the product is a crucial aspect of the DPR in the T&C industry, as it directly impacts the consumer experience. Without the ability to interact with the product, a DPR would be rendered useless as "the consumer doesn't care" (C2S 1. interview, 41:00) about the information stored on a DPR without the interaction being an experience. This requirement links to the *modularity* subcategory, as users would need to be guided to a DPR with enriched presentations of the product and additional services. Embedding passive IoT devices into T&C products enables an experience for the consumer by simply scanning the IoT device with a compatible device, such as a smartphone (RID#22, Sheet 5, Table B5). Additionally, by enabling the consumer to interact with the product, IoT can cater to the requirements regarding capturing feedback (RID#26, Sheet 5, Table B5), allowing brands to learn more about post-purchase usage and allow the consumer to add to the richness of the DPR for a specific product by, for example, specifying that a t-shirt has been repaired due to wear and tear on a specific date.

Passive IoT and active IoT sensors can be embedded at all stages in a T&C supply chain, from raw material to resell platforms, to enhance the data richness of a DPR (RID#20, Sheet 5, Table B5). By employing IoT technology throughout each stage of the T&C supply chain, traceability and transparency would increase, as data carriers would be scanned at each stage, thus providing a streamlined transmission of data from raw material production onwards. This comprehensive approach to IoT implementation can drastically improve the quality and depth of information regarding specific T&C products, providing stakeholders at all stages with valuable data enrichment (RID#17, Sheet 5, Table B5).

Finally, despite the numerous capabilities of IoT, embedding IoT devices in clothing has presented a challenge for GC, as they have experienced resistance from certification authorities regarding applying any electronic device in baby clothing and having the issue of consumers removing tags. Given that GC has experienced issues with finding the correct solution, it can be assumed that other T&C companies are experiencing similar issues. To address the specific situational needs of an identifier component in clothing to allow the consumer to interact with the product, it is essential that a DPR should not be limited to a specific type of data carrier. Instead, an agnostic approach's ability and flexibility to select data carriers should be in place to fully support the T&C industry's potential to utilize IoT devices. As a result of ongoing technological advancements, there has been a significant increase in the number of IoT technologies, encompassing both passive IoT devices such as RFID chips and QR codes to act as data carriers, as well as active IoT sensors with direct internet connectivity. These IoT devices have distinct advantages, making them suitable for a broad spectrum of use cases. The diversity and unique capabilities in IoT devices support the agnostic approach and facilitate *inclusivity* as the disparity in IT maturity and know-how throughout the T&C industry should have minimal effects on the ability to embed information on physical products, whether by RFID tags in clothing or bar codes on fabric roles (RID#29, Sheet 5, Table B5).

8.3 Sub-summary of Technological Capabilities & Requirements Matching

Presuming that a BC and IoT infrastructure were to be widely adopted, the technical capabilities of BC can cater to the requirements of a DPR. BC and IoT can significantly contribute to the IT artifact’s objectives of transparency, traceability, authentication, and efficiency improvement within a DPR, through their comprehensive capabilities of facilitating secure data exchange. However, the extent of this contribution depends on the specific vision for a DPR, which also depends on the brand asked - if fast fashion or luxury. The senior manager at Deloitte asserts: “[H&M] don't want to abstract every t-shirt they use, but that's the law. So that's just their incentive for joining, whether they say it or not. I believe it's a cost exercise [that] they want to optimize for compliance” (JS2, 19:09). On that note, GC added that it will also “depend[] on what information [the EU] want”(GC2, 01:09:12). These viewpoints imply that T&C companies might not be sufficiently incentivized to fully embrace BC and IoT as the supporting technologies of a DPR, given the complexities involved in adopting new collaborative practices and workflows through the implementation of such technologies.

9. Discussion

In this section, we discuss our third sub-question of the potential future considerations and challenges in implementing Industry 4.0 technologies, such as BC and IoT, to support DPRs in the T&C industry. Additionally, we will reflect on our methodological choices, including the use of DSR and a qualitative multi-method approach, and critically evaluate the limitations of our research. Finally, we will identify potential future research directions to build on our study and expand the scope of knowledge on this topic.

9.1 DPR Impact on T&C Supply Chain

Considering the previously mentioned skepticism regarding the use of BC in collaboration with IoT as the supporting technology of a DPR in the T&C industry, we find it crucial to discuss the potential implications and considerations for a potential future implementation of a BC and IoT-based DPR. Firstly, it is relevant to discuss how the case companies' current SCOR processes, i.e., make, source, deliver, return, and plan supply chain processes, could be affected by the introduction of a BC and IoT-based DPR to highlight whether the inclusion of BC and IoT could support our proposed IT artifact objectives.

9.1.1 Potential Impact on "Make"

When manufacturing T&C products, it is worth exploring if BC and IoT will have a notable impact since these technologies cannot directly influence tasks such as sewing a t-shirt. As reported earlier, GC conducts business with 15-30 suppliers and 20 B2B customers and produced more than 1.8 million pieces of clothing in 2022. The sheer volume of materials and clothing passing through their supply chain from many suppliers highlights the incomprehensible quantity of materials and information involved in GC's operations and the T&C industry as a whole. Furthermore, as previously established, the manufacturing processes must adhere to quality and sustainability standards. By implementing BC and IoT technologies, efficiency, control, and sustainability reporting that are already emphasized as necessary by GC can be further improved. For manufacturers and brand owners, using passive IoT devices to record material transactions and store them on a BC streamlines the quality control processes in manufacturing. The material log on the BC reduces the need for extensive due diligence. An example given by the Managing director of GC is that suppliers cannot sell more of a specific material, such as organic yarn, than they have purchased (GC2) due to the transparent transaction history. Thus, by implementing a DPR supported by BC and IoT in the "make" processes, the efficiency of quality controls and sustainability reporting could be further enhanced due to the secure and trustworthy sharing of product and manufacturing information upstream and downstream.

We have discovered that resellers such as C2S face numerous time-consuming tasks when identifying unique T&C products, their master data, and ensuring their authenticity. BC and IoT can address the challenge of product identification by leveraging IoT devices to uniquely identify each item and BC to store and manage this data securely and tamperproof. Using the capabilities of these technologies, companies in the reseller stage of a T&C supply chain can streamline their current processes by more efficiently identifying, authenticating, and acquiring master data of individual products through scanning IoT devices embedded in clothing, as notified in our objectives. This reduces the resource-intensive consumption of their current methods. A DPR could also help resellers manage product information more effectively, ensuring accurate and up-to-date data when listing items for sale. BC's transparent and tamper-proof nature helps resellers verify the authenticity and history of the products they sell. This would allow the resellers to generate significant trust and confidence in information among their customers regarding both their products, but also, as emphasized by the MD of GC and Co-founder of Textile Pioneers, the sustainable efforts that brand owners go through (GC1, KR1).

9.1.2 Potential Impact on “Source”

By creating a DPR on a BC platform, the respective authorized participants can access a more detailed history of T&C products and their materials. In the context of manufacturers and brand owners such as GC, this enhanced transparency enables participants to make more informed decisions about their suppliers and, if needed, verify their commitment to sustainable sourcing. Due to GC's vertical integration and long-term relationships with their suppliers, they already have extensive information about their fabric suppliers as their visibility downstream is 3 tiers (Appendix IV). Thus, the impact of BC would be smaller for GC than for the less vertically integrated brands with little to no visibility into previous tiers. The increase in visibility would impact the T&C supply chain generally by elevating the supplier knowledge for all participants, thus allowing them to have sourcing insights closer to companies with characteristics like GC. Moreover, IoT devices, including sensors and RFID tags, can facilitate the creation of a comprehensive material log through passive monitoring of materials during various supply chain stages, leading to improved quality control processes as the information regarding the materials is enriched and readily available to read.

On the other hand, resellers like C2S BC and IoT can help streamline the sourcing process by providing consumers with a transparent and secure DPR that contains essential information about each clothing item, as well as potential modules built on top for additional services. Alternatively, in cases of take-back, smart contracts can be implemented to facilitate the agreement of a take-back transaction, as suggested by the co-founder of C2S (C2S1). IoT combined with BC-based smart contracts can facilitate a more efficient sourcing process for take-back models by having the option of selling clothes back to brands implemented and encoded on a digital contract as an additional service on the DPR.

9.1.3 Potential Impact on "Deliver"

In delivering T&C products, BC and IoT do not directly impact tasks such as physically delivering a t-shirt, e.g., loading and offloading the truck, or driving the truck. The impact of such technologies as well as a DPR, is thus limited to the processes that are happening in the delivery management. Using the data in a BC network that is shared between parties, along with regular updates on transportation status through IoT devices like scanners, sensors, and data carriers, can enable informed decision-making for GC's logistics department in Ukraine. Moreover, this enhanced data collection can serve as a more robust foundation for calculating and documenting the environmental impact of the transportation per product, thereby strengthening sustainability reporting, and enhancing transparency for T&C products among consumers and other stakeholders across the supply chain stages. This would lead to a significant cost decrease for the process of CO2 calculations, which costs GC's B2B customers "40,000 kroner for a product" (GC1, 01:04:53). As suggested by the managing director of GC, this cost is relatively insignificant for larger B2B customers. However, this is not feasible for smaller brands where orders are sometimes "300 bodies of a design" (GC1, 01:04:53). Thus, due to the transaction record of BC, and the information transmission from IoT technologies, it would "be easier to make a CO2 tool" (GC1, 01:05:49).

9.1.4 Potential Impact on "Return"

Much like the "deliver" processes, the increase in the potential data points that could span several supply chain tiers may enable a better foundation for calculating and documenting the environmental impact of return processes per product. Furthermore, in the case of GC's Zero Waste program and its approach to customer returns, smart contracts could be implemented to automate the negotiation process for price adjustments based on predefined criteria for quality issues, reducing the time spent on negotiations. Furthermore, smart contracts could streamline the process for customer returns from GC's web shop, as return terms could be embedded in the smart contract. Once a customer submits a photo of an issue with a purchased item, the smart contract could automatically assess the severity of the issue and determine the correct action, thus minimizing the need for manual intervention.

9.1.5 Potential Impact on "Plan"

As discussed earlier, GC's supply chain situation is somewhat unusual in the T&C industry (GC1). Due to the degree of visibility, traceability, and transparency of GC's supply chain plan processes, the impact on planning due to a DPR implementation supported by BC and IoT is limited, which is indicated by a statement from the managing director of GC: "we had the control as we wanted now over our supply chain so we didn't look at it from a supply chain view at all" (GC1, 44:09). Knowing that GC's high level of vertical integration is not the industry norm, we argue that the impact on the planning activities due to a DPR based on BC and IoT would be greater for companies that have less visibility, traceability, and transparency into their supply chain. Although this implementation would not result in more control or ownership of their vertical supply chain activities, we believe the insights visible, thanks to BC and IoT, would be beneficial. Implementing BC and IoT technologies can significantly enhance the efficacy of supply chain planning. Enhanced visibility can enable better risk management, thus allowing businesses to detect and address potential fraud or bottlenecks. Access to, and analysis of, a larger amount of data through implementing BC and IoT could allow for more data-driven decision-making in the planning processes due to trustworthy data input. The operational benefits of using BC and IoT as the underlying technologies of a DPR can potentially generate long-term gains and enhance the supply chain processes. Eliminating information silos throughout the T&C supply chain would greatly benefit most actors. However, it needs to be ensured that it would not compromise the competitive advantage of each stakeholder and that others do not exploit the sensitive information of each participant.

Apart from highlighting the potential positive impact of implementing a DPR along the T&C supply chain stages, it would also present potential complications that must be considered before adoption. One of the biggest concerns is achieving a seamlessly integrated and holistic solution for a BC and IoT-based DPR implementation. The reluctance of suppliers and other supply chain participants to adopt these new technologies and share their data (KR1) can hinder the successful implementation of a DPR based on BC and IoT in the T&C supply chain. Implementing these technologies at only a few stages, rather than across the entire supply chain, would significantly reduce benefits and even diminish overall supply chain performance due to increased complexity in data sharing and interoperability complexity. Another concern is related to the significant investments required for hardware, software, and infrastructure, which can serve as a challenge for smaller companies to commit to, thus raising the barrier to implement these technologies. Integration issues may also arise, as these new technologies must seamlessly incorporate existing systems and processes without resulting in duplicated work processes. This would be complex, time-consuming, and disruptive in the short term, as with most transformative changes.

9.1.6 Sub-summary of DPR Impact on T&C Supply Chain

The five SCOR processes in the T&C industry can benefit from implementing a DPR backed by BC and IoT. Improved transparency, efficiency, and reliability - particularly in quality control - are advantages of BC and IoT for the "make" process. IoT devices boost quality control by passively monitoring materials, whereas BC helps the "source" process by providing comprehensive product records. By improving data accessibility and decision-making, BC and IoT can boost the "deliver" process and improve sustainability reporting. Smart contracts with BC and IoT can automate the "return" process, and data-driven decision-making and better risk management enhance the "plan" process. Despite these benefits, the challenges of holistic adoption, initial investments for smaller companies, and potential interoperability issues must be acknowledged. By identifying both the benefits and the potential challenges that need to be overcome in a T&C industry supply chain, this discussion enables us to understand the practical implications of integrating a DPR supported by BC and IoT within the industry. This insight into the potential real-world consequences of adopting these technologies provides valuable information that can inform and educate stakeholders. This comprehensive evaluation of the consequences is instrumental in addressing our third research question by providing a foundation for further exploration of future considerations and challenges related to implementing a DPR supported by BC and IoT in the T&C industry.

9.2 Considerations for Future Implementation

Although BC and IoT may cater to some of the technical requirements of a DPR, as assessed in the technical capability matching, and a DPR with these underlying technologies can have a positive impact on the T&C supply chain, we argue that their implementation alone is not sufficient to fulfill *all* the requirements captured. The success of a DPR also relies heavily on addressing a wide array of stakeholder and regulatory requirements that cannot be solved purely by technological capabilities.

Effective communication, collaboration, and consensus-building among all actors in the T&C product life cycle are crucial for a successful DPR system that caters to the needs of various stakeholders. Technological advancements can improve the efficiency, traceability, and transparency of the T&C industry. However, without effective communication and collaboration among stakeholders throughout the product life cycle, as well as a clear understanding of consumer needs and preferences, the full potential of a BC and IoT based DPR cannot be realized.

Regulatory requirements also play a significant role in the success of a DPR, especially in the EU. Clear regulations, inclusivity, and government support must be discussed and addressed to ensure a well-functioning network. Technology alone cannot cater to these requirements. Although governance mechanisms can be embedded into technologies, human stakeholders must decide and agree upon the rules and guidelines to embed, such as data-sharing specifications. This speaks to stakeholders' need to engage in ongoing dialogue and negotiation with regulatory bodies such as the EU to align their interests and establish a shared network based on trust and coherent standards. Additionally, it lies within the responsibility of the EU to hear out not only the biggest players in the industry but broadening their input so that inclusivity is ensured in forming the legislation.

The standardization of data formats is required to enable seamless communication between organizations. The senior manager of Deloitte emphasized this, as he mentioned the possibility of data communication complications. It needs to be ensured that “the field that is used in the Danish interpretation of the [DPR] called weight is comparable with the interpretation of weight in Spain if I don't use the same standard” (JS2, 10:24). Without agreed-upon data formatting standards, the integration of a BC network and DPR could result in more confusion and negative impacts. The ideal scenario would entail a critical mass of organizations coming together and forming a consensus regarding data formats. However, this scenario is hard to achieve according to GC, as the question of who should govern and decide the standards remains (GC1).

One attempt to work towards a common standard would be to look at current cases of implemented standards, decided and governed by, for instance, NGOs such as GS1's ownership and governance of the EAN (European article number) code. As C2S co-founder states, "[GS1] are actually an open standard where you have a non-profit, where you have a membership. [...] They have managed to get it working with the EAN codes [...] And they are definitely looking into this" (CS2, 34:31). However, the idea of having one central player, albeit an NGO, to govern the standardization of data formats might go against the wishes of a decentralized ownership structure. Another alternative to working towards standardization would be from a governmental side, as done by the Cardossier consortium in which the consortium "was established as a legal entity, which will facilitate combining on-chain and off-chain governance functions and foster market penetration and standardization" (Zavolokina et al., 2020, p. 17).

The idea of establishing a BC network as a legal entity might be sufficient on a nationwide basis. However, due to the globalized fragmentation of the T&C supply chain, there might be complications with agreeing on which governmental institution should govern the standards, as the network would affect markets globally. Furthermore, from a regulatory perspective, it would be unprecedented as "it's a business which has not been regulated in any way" (KR1, 49:50), adding to the complications that might arise. Either way, it would be hard to change their ways of working, going from purely creative to also thinking process-oriented towards information capturing and gathering to comply with regulations (KR1), also because the industry has not been regulated heavily in the past.

Decentralized Autonomous Organizations (DAOs) could offer an alternative approach to governing the standardization of data formats within the context of BC networks and the global T&C supply chain. DAOs operate through decentralized decision-making processes powered by smart contracts and the consensus of stakeholders rather than a central governing authority (Limata, 2019). Involving various stakeholders, a DPR based on BC governed by a DAO could develop more inclusive and democratic data standards by allowing participants to propose and vote on initiatives, with consensus determining implementation.

The data reliability and accuracy in the T&C industry are among the main problems caused by the lack of transparency and trust. While BC and IoT could increase trust due to tamperproof data, complications still arise in gathering the information from, for instance, developing countries and specific stakeholder types that traditionally transmit little to no information along their supply chain. Such as the “little farmer in the middle of Salem in the South region of India. How much IT knowledge does he have and how much connection to the Internet does he have and what is the main purpose of his life? [...] So, [Textile Pioneers co-founder] see[s] the biggest problem in this is to get the far east suppliers to put this into the blockchain technology” (KR1, 26:10). This indicates that the IT maturity and readiness levels of farmers and manufacturers in developing countries may be too low to feed in the data themselves, as their technical capabilities are not up to par with the technological advancement.

Enabling a DPR should be feasible for less IT-mature organizations if the aim for an industry-wide solution includes that all members along the T&C product life cycle can collaborate. At the same time, less IT-mature organizations should also not hinder the industry from technological advancements in efficiency, traceability, and transparency, which proves that this is a difficult balance to strike - ensuring inclusivity of all versus exploiting technological benefits to their maximum. Thus, a significant consideration revolves around ensuring inclusivity so that less IT-mature suppliers can feed data into a DPR based on BC and IoT. The co-founder of Textile Pioneers pointed out one solution, as he suggested that brand owners would “gather all the information from the suppliers and [they would] fill it in [themselves] and [they] would say, OK then [they would] start with the sewing factory and ask them to fill it in and see how it works and then [they] go down, down, down the tiers” (KR1, 49:50). The gradual inclusion of supply chain tiers, starting from the brand owners, could thereby soften the onboarding process of less IT mature suppliers, thus allowing a new status quo of workflow and collaboration to gain a foothold gradually, as suggested by the co-founder of Textile pioneers - "maybe, you know, 10% will start doing it and then fifty other percent sees that nothing happens with these 10% and then they will go well and be open" (KR1, 59:59)”. However, this would not automatically result in reliable data, as incorrect data can still be communicated. Nonetheless, it would hold participants accountable for any information put into the transactions on the BC, thus improving the audibility of data, for example, when reporting on products’ environmental impact.

Low levels of trust among various stakeholders have historically hindered significant collaborations and data sharing in the T&C industry. This absence of trust may stem from concerns on IPR protection, trade secrets, and the highly competitive nature of the market, as emphasized by the co-founder of Textile Pioneers “in the textile industry, there are no patents. There [is] nothing. It's all about what you found all about qualities and stuff” (KR1, 59:59). To foster collaboration and enable the industry to reap the benefits of a DPR supported by BC and IoT, it is essential to create the right incentives for all players to “actually key in the right data and understand the value creation of that” (JS2, 12:21). Thus, there is a necessity to establish incentives for participation that diminishes the trust issues of the industry, which may be achieved through regulatory measures. However, such an approach may result in the perception of coercion rather than genuine incentivization, as it compels adherence rather than fostering voluntary engagement. Furthermore, by having a top-to-bottom approach to incentivization, one could see how the network, governance structure, and purpose might take more of a helicopter perspective, trying to cater to a wide range of different types of participants without specifically understanding the actual problems and needs of each participant. Furthermore, the Senior Manager of Deloitte notes that "if you were to kind of say, well, the EU should actually drive this. I think it's hard to build in incentives on this, aside from the compliance incentives” (JS2, 10:24). This statement suggests a rationale to avoid law enforcement on the specific technologies to be used, such as BC and IoT, since such a detail in the law could potentially introduce complications, such as the exclusion of less IT mature organizations or minimal collaborative efforts by participants due to misguided incentives. Instead, encouraging collaboration among stakeholders throughout the T&C industry is vital for creating an effective DPR, BC, and IoT infrastructure.

Another aspect that could drive incentivization and willingness to collaborate is comprehensive educational resources and improve public awareness about the potential benefits and applications of a DPR supported by BC and IoT in the T&C industry. In addition to understanding the technology, building trust among stakeholders is vital to promoting adoption and collaboration. By educating stakeholders about the inherent security features of BC and IoT and providing education regarding the required IT maturity, trust among manufacturers, suppliers, retailers, and consumers is more likely to increase. Trust-building is crucial for promoting data sharing and collaboration among stakeholders in the T&C industry. Forcing a DPR onto a BC without establishing trust, education, and awareness could hinder the potential benefits of such a system.

9.3 Methodological Reflections

When reflecting on the methodological choices made in our study, it's essential to consider the advantages and disadvantages of each of the elements, namely, the pragmatism philosophy we followed, the abductive approach we took to theory development, our exploratory research design utilizing a qualitative multi-method approach, and lastly the DSR strategy as proposed by Hevner et al. (2004) and Peffers et al. (2007).

Adopting the pragmatic philosophy enabled us to concentrate on practical implications and potential solutions for the challenges faced by the T&C industry, which we discovered through our literature review. However, it is crucial to recognize that this approach does not prioritize pursuing objective truth and can lead to a more subjective interpretation of the data. It is worth noting that our presentation of the current T&C supply chain and the collection of requirements is not a universal truth but instead specific to Danish companies that are not industry leaders but rather niche operators with a focus on sustainability. This acknowledgment is significant because it highlights that our findings may not apply to all companies in the industry. While pragmatism allowed us to use a problem-solving approach that was flexible and adaptable, it also meant that we were more concerned with practical solutions than with theoretical grounding. This was a challenge when designing our model according to the SCOR framework, and it may have limited the generalizability of our findings. Similarly, the inclusion of interpretivism as a worldview recognizes the importance of subjective experiences and the social context of the research topic. However, this can also lead to a lack of generalizability of the findings and may limit the transferability of the results to other contexts, such as other organizations in the T&C industry.

Following abductive reasoning in our thesis was helpful as it allowed us to develop our model iteratively and generate new insights using some existing frameworks like SCOR. Generating new knowledge was crucial due to the need for more research on DPR requirements. It was suitable for exploratory research because the new ideas collected can now be tested further. The insights generated have not been extensively studied before due to the novelty of the upcoming legislation and concept of a DPR, digital twin, or DPP for the T&C industry. Another benefit of using an abductive approach was that we could draw on various sources of information, including literature, case companies, and expert opinions, with which we developed a comprehensive understanding of our research topic. Being able to refer to extensive research on the technologies themselves, the industry, and concepts like sustainability emphasizes that most of our research was deductive. Nonetheless, the requirements identified for a DPR are novel to academia and thus showcased the inductive part of our research. However, it also meant that we had to rely heavily on expert input and may have missed out on the perspectives of end-consumers and other stakeholders of the T&C industry, like fabric manufacturers or even cotton farmers and recycling mills.

Nonetheless, it is important to note that abductive reasoning is not a standardized method and may result in a less structured approach to theory development. Specifically, we encountered a lack of theory that we could have applied to properly assess which requirements exist for a DPR supported by Industry 4.0 technologies. Although theories exist in isolation on each technology, there was a lack of research that showed a combined view of the concepts we wanted to explore in the specific industry that we found relevant. Thus, the back-and-forth between data collection and developing the IT artifact with little theoretical grounding, in our case mostly revolving around the SCOR model, was challenging. What is more, we experienced a risk of overreliance on our intuition and interpretation when using abductive reasoning because, by inferring requirements from the first interview rounds, we may have introduced a bias into our findings that, although validated with the case companies and experts, set a certain tone to our as-is supply chain model and requirement collection.

The choice of an exploratory research design with a qualitative multi-method approach allowed for a more in-depth understanding of our research question and rich data exploration. For instance, we conducted semi-structured interviews with case companies and experts, gaining in-depth insights into their experiences and perspectives on DPRs and the potential of Industry 4.0 technologies supporting a DPR. We also explored the context-specific requirements and considerations for potential implementation. By preparing an interview guide (Appendix C) for the first round of interviews and an agenda for the design workshop (Figure A20 and expert interviews (Figure A23), we tried to maintain some structure but also adjusted our questions to the party interviewed.

Nonetheless, there was some inconsistency in how we conducted the two first interviews with GC and C2S and how the two experts were interviewed. While we only had 20 minutes to ask our specific questions to GC, we had approximately one hour with C2S, which may explain why more requirements were delivered by C2S, not because GC has fewer needs but merely because less time was spent with them. Consequently, we had too many questions prepared for GC and had to follow up via email afterward (Appendix D). Similarly, for the expert interviews, we had an initial introduction call with the senior manager at Deloitte, as per his request, before conducting the actual expert interview which meant he had a better understanding of our research topic than the co-founder of Textile Pioneers. Additionally, the co-founder of Textile Pioneers had less time to review the pre-read material that was shared before the expert interviews. A mistake made and thus difficulty encountered in the data collection was the lack of a "review comparison" of the physical design workshop we conducted. Exchanging notes on how each researcher individually experienced the case companies' reaction to our IT artifact would have allowed us to validate the social cues of the interaction. In the design workshop, we did not, after every one of the 37 requirements, ask for a "yes we agree" or "no we disagree", which would indicate the completeness and validation of our requirements. Additionally, with many participants present, there was often some overlapping in speaking.

This research design also meant that we had to be mindful of potential biases and limitations to our sample. Acknowledging a biased sampling is crucial for our research because we know that the companies we chose to interview (GC, C2S, Textile Pioneers) are all part of the wider *Trace* project. As such, they have a strong motivation for sustainable, innovative practices that include new technologies, which proves we may have encountered some interviewee bias in our research. This motivation may not be the norm of the T&C industry. We tried to counter this bias by staying technology-neutral in collecting our requirements. However, we could not hinder the case companies or experts from reflecting on specific technologies like BC and IoT as they also played a role in our research question. What is more, is that we were reliant on external validation. However, the choice of our experts was somewhat biased as we specifically sought those with a background in BC and IoT technologies, as even the co-founder of Textile Pioneers from a non-technological organization had experience with BC. Although we acknowledge this bias, choosing fewer BC and IoT-knowledgeable experts for our evaluation would not have allowed for a sufficient understanding of the supply chain, requirements, and technologies suggested in combination.

Another challenge when engaging with our experts was using some evaluation criteria, which, similarly to the inference of requirements, led to our research interpretation of their feedback. The other bias that can be traced back to our initial literature review is the choice made for the potential technologies of a DPR solution. Given prior research, we selected BC and IoT; however, there may be others we did not discover due to an early decision on the two technologies. Due to this selection in advance and the follow-up questions in the semi-structured interviews being influenced by our background knowledge of the technologies, we want to acknowledge the potential interviewer and participant bias we imposed on our study. Measures were taken to minimize these biases, such as providing standardized questionnaires, and we believe that the impact of these biases on our research does not render it invalid or unreliable. On the contrary, due to external experts partially validating that our research applied to others in the industry, we believe in having presented a strong argument. Specifically, the co-founder of Textile Pioneers confirmed that the input we received from GC and C2S would overlap with the input we would receive from other companies in the industry. What is more, we also received validation from the co-founder of Textile Pioneers that our research approach was valid as the first step to work towards future implementation of a BC and IoT DPR would be “for the textile industry to understand: what are the requirements of a [DPR]?” (KR1, 49:50).

When reflecting upon the <u>usage of DSR</u> for IS research, as proposed by Hevner et al. (2004), there are the following areas to discuss: 1.) the *suitability* of DSR for our research strategy; 2.) the *validity, generalizability, and credibility* of our findings due to this chosen research strategy; and lastly, 3.) our research’s *contribution* to a real-world problem or gap in the literature with a focus on utility and applicability, as suggested by DSR.

Starting with the *suitability* of DSR for our research, one can say that it was an appropriate research strategy for our study due to its alignment with our research question and objectives. We aimed to identify the requirements for a DPR and explore the considerations for its implementation. We recognized the importance of generating new knowledge guided by a utility-focused contribution to academia and practice. DSR's user-centered approach and iterative process were particularly relevant to our study as we needed to ensure that the requirements collected were representative not only of the two case companies interviewed but also of the industry as a whole. We incorporated feedback from the case companies throughout our research process, allowing us to develop a model that met their needs. Overall, DSR was a suitable choice for our research as it allowed us to generate practical, valuable outcomes in the shape of requirements for a DPR based on empirical data while contributing to academic knowledge. In the context of a master's thesis, it is vital to acknowledge the inherent uncertainty associated with conducting research using more pragmatic methodologies, such as DSR, as we did not know whether the time and resources invested in the two iterations would be sufficient to design a reasonable IT artifact.

To ensure the *validity* and *reliability* of our findings, we employed multiple evaluation methods, including "user testing" in the design workshop with both companies and "expert reviews" with two external industry professionals to validate our requirements list. This external validation from different types of experts was critical. We found that engaging with companies who would be the actual users of the system was crucial in ensuring that their demands were respected. This approach enabled us to produce an overview of the T&C supply chain and requirement collection for a DPR that would be able to work towards achieving **supply chain traceability, sustainability transparency, authentication, and efficiency improvement** and thus be relevant for industry needs. Furthermore, we used triangulation and participant validation to improve the *credibility* of our findings. We verified our requirements list by checking with participants and external experts.

Regarding our research's (practical) contributions, DSR allowed us to create a novel artifact that addresses a real-world problem and contributes to the field of DPRs and Industry 4.0 technologies' capabilities to industry demands. Our designed IT artifact, which combined the as-is supply chain and requirement collection for a DPR, addresses a critical need in the T&C industry as it tries to tackle some of the industry's issues and would help companies to prepare for the upcoming legislation on a DPP. Companies can use our model to match their requirements for a DPR and find additional ones that might be relevant. The *utility and applicability* of our findings also extend to tech companies that are developing DPR solutions, as they can benefit from the requirements we captured to see if they lack elements, features, or functionalities. Moreover, our research resulted in generating new insights and knowledge about the needs T&C companies have towards a DSR.

Through the critical review of experts and technological capability matching, we were able to contribute findings that specifically assess the usability, applicability, and effectiveness of using BC and IoT as the underlying technology of a DPR.

Thus, our DSR research made valuable contributions to both academia and practice. Although we did not test the implementation of a DPR given the requirements collected, as it was not within the scope of our study, we collected and visualized the complexity of requirements in combination with a tech-capability matching to assess to what extent BC and IoT could support a DSR. We found that these technologies can only cater to some of our identified requirements. This finding is a key contribution to research as our literature review revealed a gap in academia studying the combination of IoT and BC for digital twins within the textile, fashion, or apparel industry.

In conclusion, the methodological choices made in this study were a result of carefully considering the research question and the specific context of the study. The pragmatism philosophy allowed for a focus on practical implications and potential solutions for the problem at hand, while the inclusion of interpretivism recognized the importance of subjective experiences and the social context of the research topic. The exploratory research design with a qualitative multi-method approach provided a rich data exploration. While each of these methodological choices has its strengths and limitations, combining these approaches provided valuable insights into the requirements and considerations for implementing a DPR that BC and IoT could support. The study provided a deeper understanding of the stakeholders' perspectives and identified several essential requirements and implementation considerations that could be used to guide the development of such a DPR. Overall, the methodological choices made in this study were appropriate for the research question, and the findings can be used to inform future research and practice in this area. However, it is vital to acknowledge the study's limitations and the need for further research to validate and build upon these findings.

9.4 Resulting Implications for Future Research

The strengths and weaknesses of our methodological choices, which speak to the quality of our research, are key in determining what improvements we would make if we were to repeat this study and which additional areas and approaches future research could take. A trade-off that became evident throughout our research was the difficulty of balancing our IT artifact/model to be too narrow in scope, as it catered specifically to the case companies interviewed and too broad, as suggested by our experts who tried to elevate our model. We interviewed a niche section of the T&C supply chain and are aware that other actors exist which are not represented in our IT artifact.

The priority for us was to stay close to the actual users of the DPR and those that will be responsible for the implementation, thus brand owners like GC and resellers like C2S. If their demands are not respected in future legislation and technological solutions, there is a high chance for failure, as we have seen with past legislations like GDPR, where companies forced to keep up struggled to cope. This was also part of the reason for not conducting a third iteration that could have resulted in a more high-level, top-down view on a DPR for the T&C industry based on BC and IoT, as suggested by the senior manager at Deloitte. The other part was that we received validation from our other expert that our model of the supply chain and requirements is a sufficient representation of the industry, and we would receive further validation from other T&C companies, according to the co-founder of Textile Pioneers. As we did not engage in a third iteration, we remained in a narrow scope that still somewhat limits the generalizability of our model as we do not know with full certainty that *all* other affected stakeholders involved in the T&C product life cycle would agree with our model. As such, a learning and potential future research that builds upon the current version of our IT artifact could include more stakeholder types, thus perspectives, of the T&C industry to increase the generalizability of our findings and thereby validate the applicability of our as-is supply chain model and requirements collected. For instance, we did not speak to end-consumers, limiting our understanding of their needs for a DPR in the T&C industry. We also could have included more experts to evaluate our findings, another recommendation for future research.

Future research that could build on our findings could interview a larger number and a broader range of companies, stakeholders, and experts within and connected to the T&C industry, including end-consumers, and explore a wider range of technologies for DPR solutions. Given our thesis's scope, time, and resource limitations, this would not have been feasible. Additionally, future research directions for our study could involve expanding our findings beyond the Danish companies we interviewed. It would be interesting to investigate how companies in other countries approach DPR and how it differs from the Danish context.

Additionally, since we focused on the T&C industry, examining how other industries are adopting Industry 4.0-based solutions and their DPR requirements would be worthwhile. In terms of technology, future research could explore the feasibility and benefits of other technologies for a DPR, such as centralized databases, as the solution offered by EON. Researching existing solutions for DPRs and their underlying technology to compare their offerings to the requirements we identified could be valuable research to build upon and assess further whether there is an actual need for advanced technologies like BC and IoT or if simplified alternatives can provide a sufficient minimum viable product for the first legislation enforced. Given that we conducted our research as a cross-sectional study, we propose that it can serve as a preparation for an extended study in a longitudinal manner that would allow for incorporating the impact of technological advances over time. Thus, other researchers could use our IT artifact as a foundation for developing their own DPR models or as a benchmark for evaluating the effectiveness of their own solutions. Overall, based on the limitations we encountered and the improvements we suggested above, future research directions could continue to advance the understanding of a DPR, which suitable technologies exist, and how stakeholders need to collaborate to successfully implement a DPR.

10. Conclusion

In this section, we will bring our thesis to a close by providing definitive insights into our research question and its associated three sub-questions. Firstly, to answer the first sub-question, "*What challenges of the textile and clothing industry has literature identified, how have Industry 4.0 technologies such as blockchain and IoT been explored to tackle these challenges?*", we performed a comprehensive, critical, concept-centric literature review which unveiled several challenges in the T&C that can be classified broadly into issues of transparency, traceability, sustainability, and the enforcement of intellectual property rights.

Industry 4.0 technologies, namely BC and the IoT have been explored extensively as potential solutions to these challenges. BC has been proposed as a potential tool for enhancing traceability and transparency in T&C supply chains, serving as a cheaper anti-counterfeiting solution for luxury goods and boosting consumer trust. It could also improve sustainability in the T&C industry through traceability. Furthermore, IoT applications could optimize various supply chain stages, for example, initial stages like cotton harvesting and processing. The integration of IoT and BC has been proposed to provide real-time data for improved decision-making, address security issues in IoT systems, and allow for information continuity, thus creating a more granular level of traceability. The relevance of our research stems from a gap in the literature, as most contributions have been purely conceptual, with many researchers calling for empirical-based research on the combination of IoT and BC in the T&C industry. The upcoming EU legislation for DPPs further amplifies the need for our research. This supports the need for researching empirical-based DPR requirements as little is known about how DPRs should be constituted, which results in uncertainty about how to comply with upcoming laws from the perspective of the various stakeholders in the T&C industry. By taking the initial steps of assessing these requirements, we contribute crucial fundamental research to the body of knowledge and discuss how future DPRs should be developed.

To answer the second sub-question: "*Based on understanding the textile and clothing industry's as-is supply chain, what are the requirements for a digital product representation, and how can Blockchain and Internet of Things support the industry's demands?*" we followed a DSR approach to developing an IT artifact model consisting of two elements; understanding the as-is T&C supply chain and collecting requirements for a DPR. With the objectives of traceability, sustainability transparency, authentication, and supply chain enhancements, we conducted two iterations of design and development, demonstration, and evaluation of our IT artifact.

We can conclude that requirements linked to regulatory bodies must be met. Additionally, it became evident that DPR's success depends on stakeholders' engagement across the T&C industry. The unveiled requirements for regulatory bodies and stakeholders primarily revolve around enabling a DPR system to succeed. However, the underlying technology is just as crucial if not more. Therefore, most of the requirements found are technological requirements that concentrate on the high-level specifications and features necessary to successfully develop and implement a DPR for T&C products within the industry's supply chain. All these requirements are crucial aspects of a DPR that must be fulfilled. Following the requirements collection, we investigated how BC and IoT could support some of the requirements identified. We can conclude that these technologies alone cannot cater to all identified requirements. This underscores that technology, in isolation, is insufficient to overcome industry challenges and meet our IT artifact objectives.

To answer the third sub-question: "*What are the potential future considerations and challenges in implementing Industry 4.0 technologies, such as blockchain and IoT, to support digital product representation in the textile and clothing industry?*", we discussed the potential impact of a DPR supported by BC and IoT on the T&C supply chain, with specific organizational examples derived from an understanding of our case companies' supply chains. In doing so, we can conclude that there are potential positive impacts on all five SCOR processes, particularly in quality control within the "make" process, reliability of data within all processes, and improved data accessibility leading to improved decision-making. Furthermore, the automation of "return" process through smart contracts and enhanced risk management in the "plan" process are potential positive impacts. However, the potential for negative impacts was also established, with potentially high investment costs, consequences of non-holistic adoption, and potential complexity due to interoperability issues.

Overall, our IT artifact consisting of the as-is supply chain and collected requirements serves as a basis for understanding the considerations for future implementation. If a DPR is to be enabled through BC and IoT technologies, one needs to understand the complexity of the industry's supply chain and the interconnected web of stakeholders involved. To do so, identifying the challenges the industry struggles with was vital in collecting the design requirements for a DPR in the T&C industry, and, together with an understanding of the technical capabilities of BC and IoT, we were able to answer our overall research question: *"What are the design requirements for a digital product representation in the textile and clothing industry, and how can Industry 4.0 technologies support these requirements?".* Given that the T&C supply chain has a multitude of actors with varying levels of technological capabilities, regulatory environments, and operational processes, implementing a DPR that fits all needs, respects all demands, and caters to all levels of technological sophistication is crucial but will be challenging. Our research contributes to approaching this challenge by informing academics and practitioners of needs resulting from a bottom-up, organizational perspective on the DPR. Given the multitude of stakeholder types, we realize this perspective may only represent a fraction. However, it serves as a starting point that we encourage future research to build upon. Since a successful implementation will involve not only T&C companies but also, for instance, end-consumers, we suggest future research to shed light on their needs, concerns, and expectations from a DPR system which would significantly influence its design and implementation.

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Appendices

Appendix A: Figures

Figures used throughout our thesis are either created by us as researchers or adapted from literature. A source in parenthesis will indicate the latter case after the figure's title.

Figure A1: Research Onion (adapted from Saunders et al., 2019, p. 130)

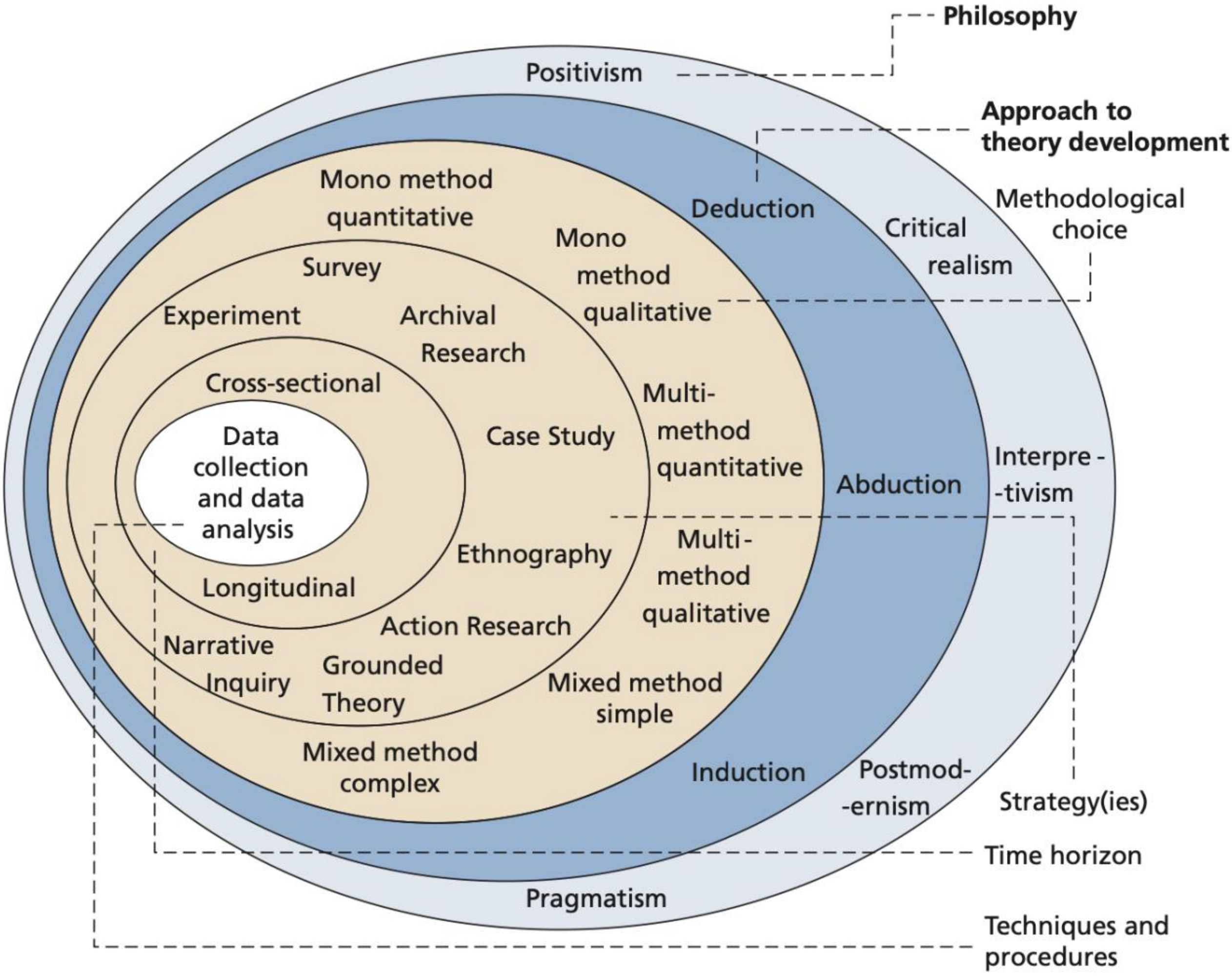

Figure A2: Literature Review Process (adapted from Saunders et al., 2019, p. 75)

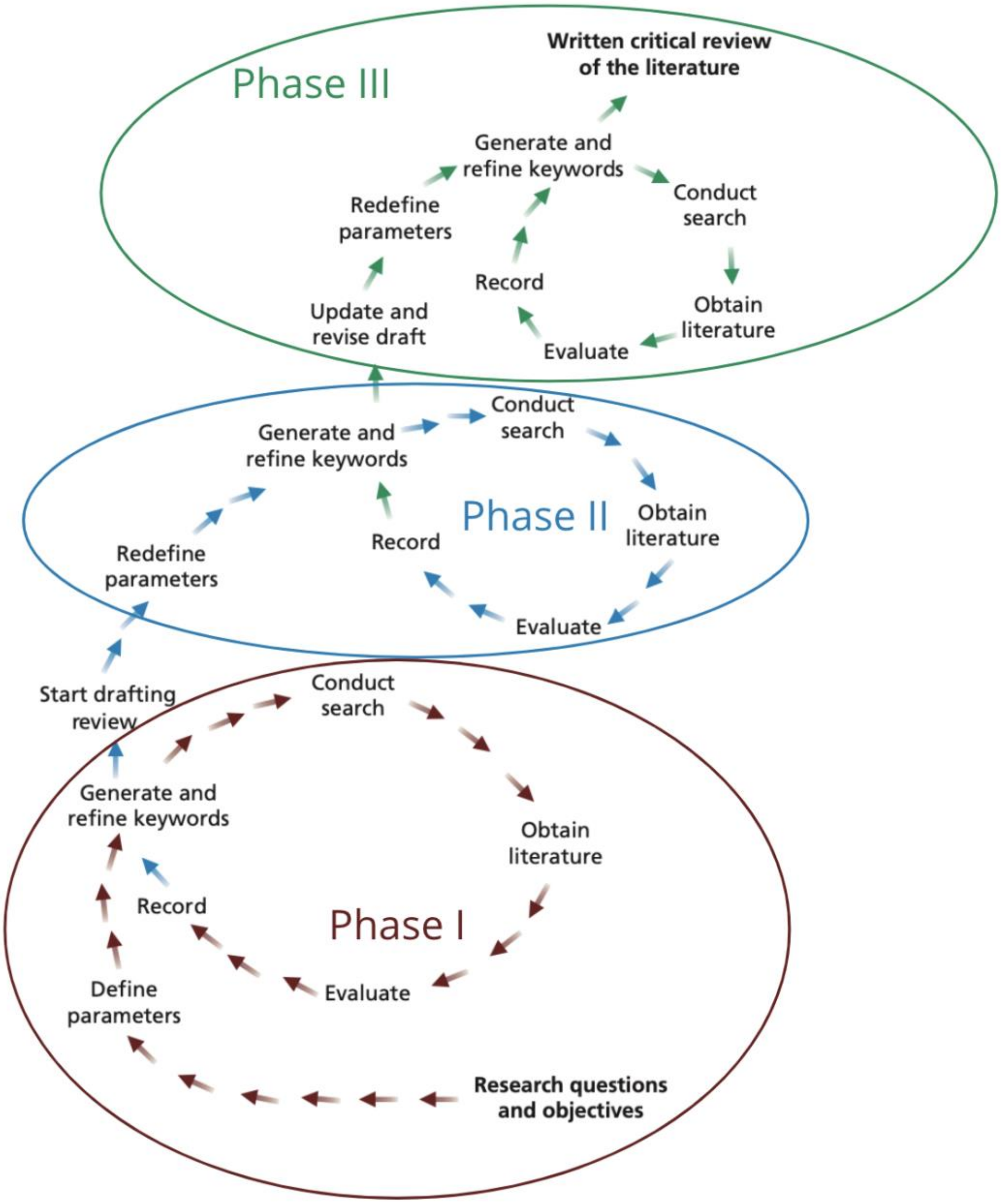

Figure A3: Literature Review: Filtering Process

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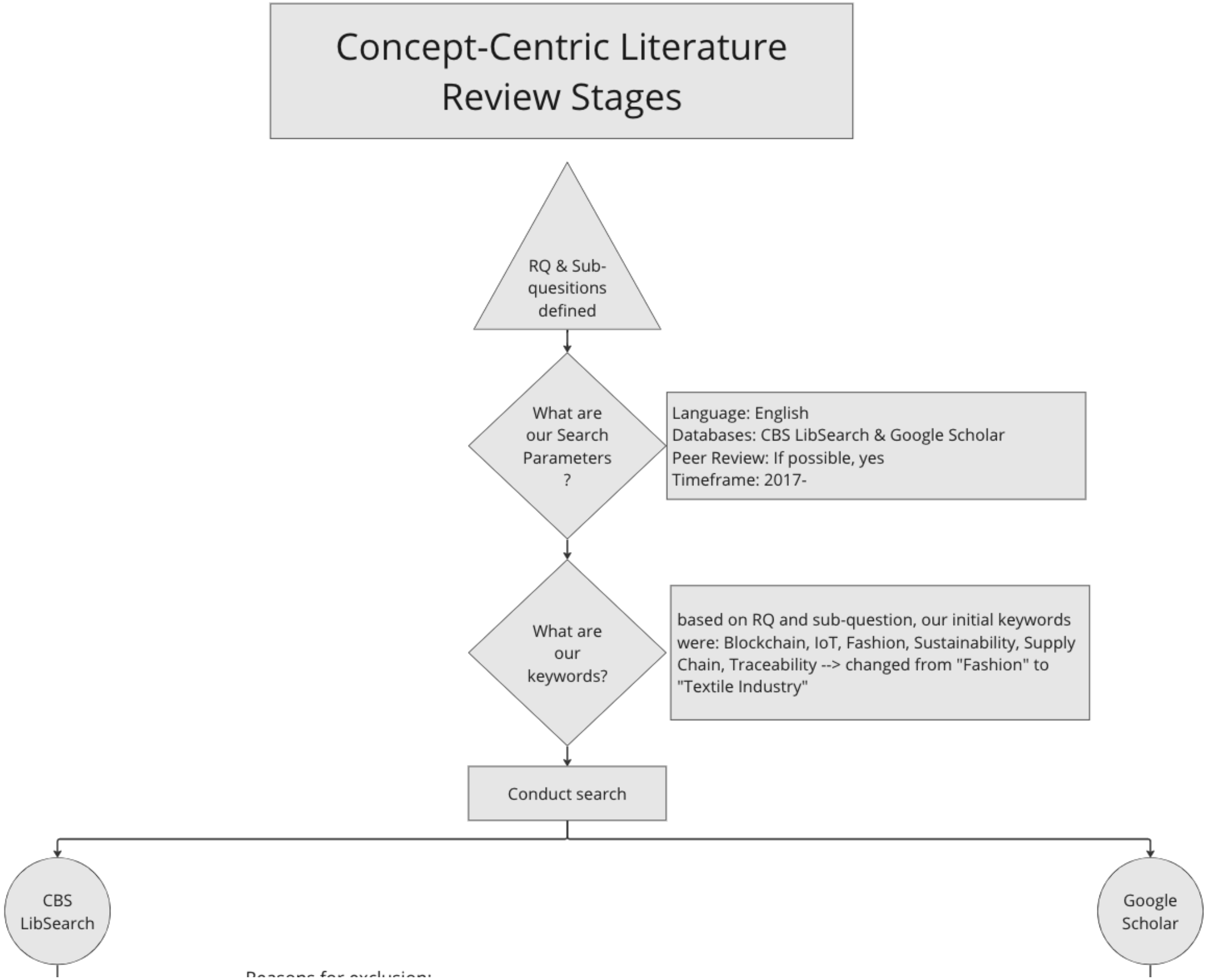

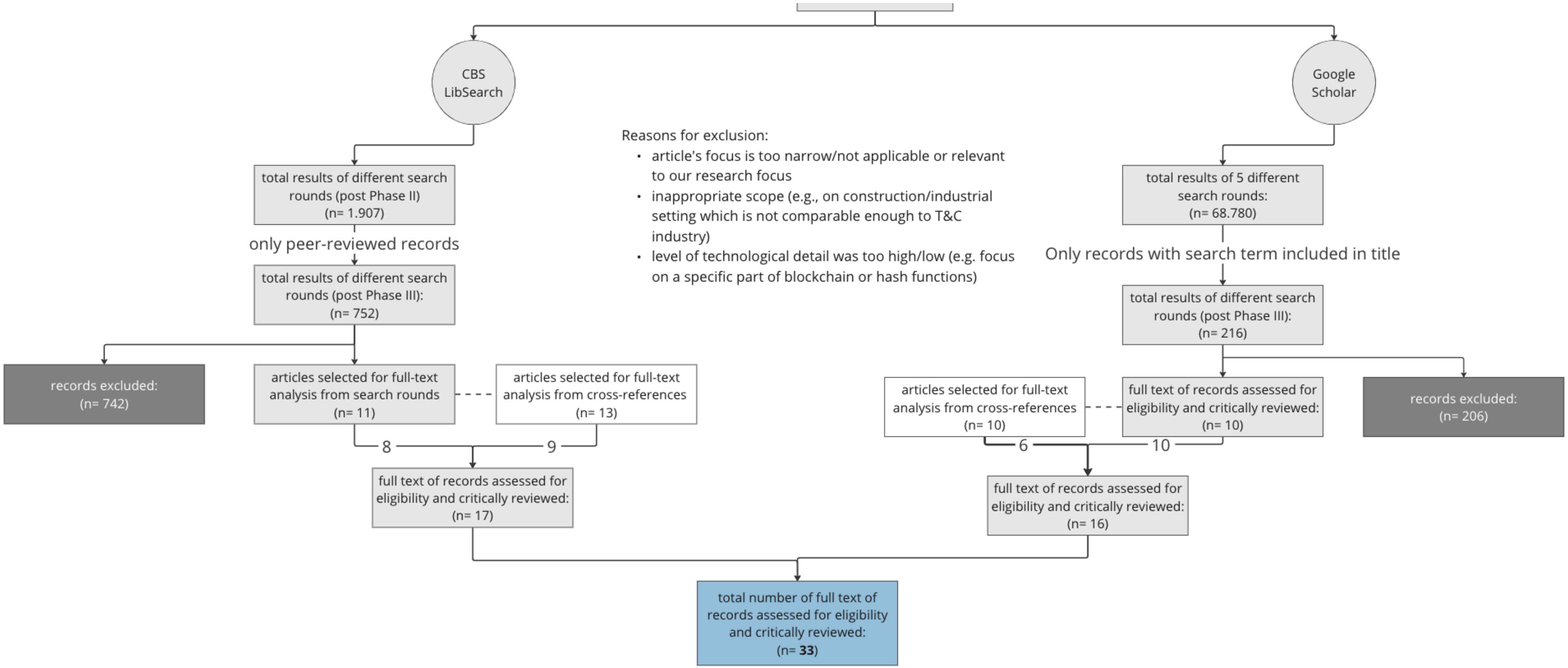
CBS LibSearch
Google Scholar
Reasons for exclusion:
• article's focus is too narrow/not applicable or relevant to our research focus
• inappropriate scope (e.g., on construction/industrial setting which is not comparable enough to T&C industry)
• level of technological detail was too high/low (e.g. focus on a specific part of blockchain or hash functions)
total results of different search rounds (post Phase II) (n= 1.907)
only peer-reviewed records
total results of different search rounds (post Phase III): (n= 752)
records excluded: (n= 742)
articles selected for full-text analysis from search rounds (n= 11)
articles selected for full-text analysis from cross-references (n= 13)
8
9
full text of records assessed for eligibility and critically reviewed: (n= 17)
total results of 5 different search rounds: (n= 68.780)
Only records with search term included in title
total results of different search rounds (post Phase III): (n= 216)
articles selected for full-text analysis from cross-references (n= 10)
full text of records assessed for eligibility and critically reviewed: (n= 10)
records excluded: (n= 206)
6
10
full text of records assessed for eligibility and critically reviewed: (n= 16)
total number of full text of records assessed for eligibility and critically reviewed: (n= **33**)

Figure A4: Overview T&C's supply chain stages including environmental impact & geographic location examples (Niinimäki et al., 2020)

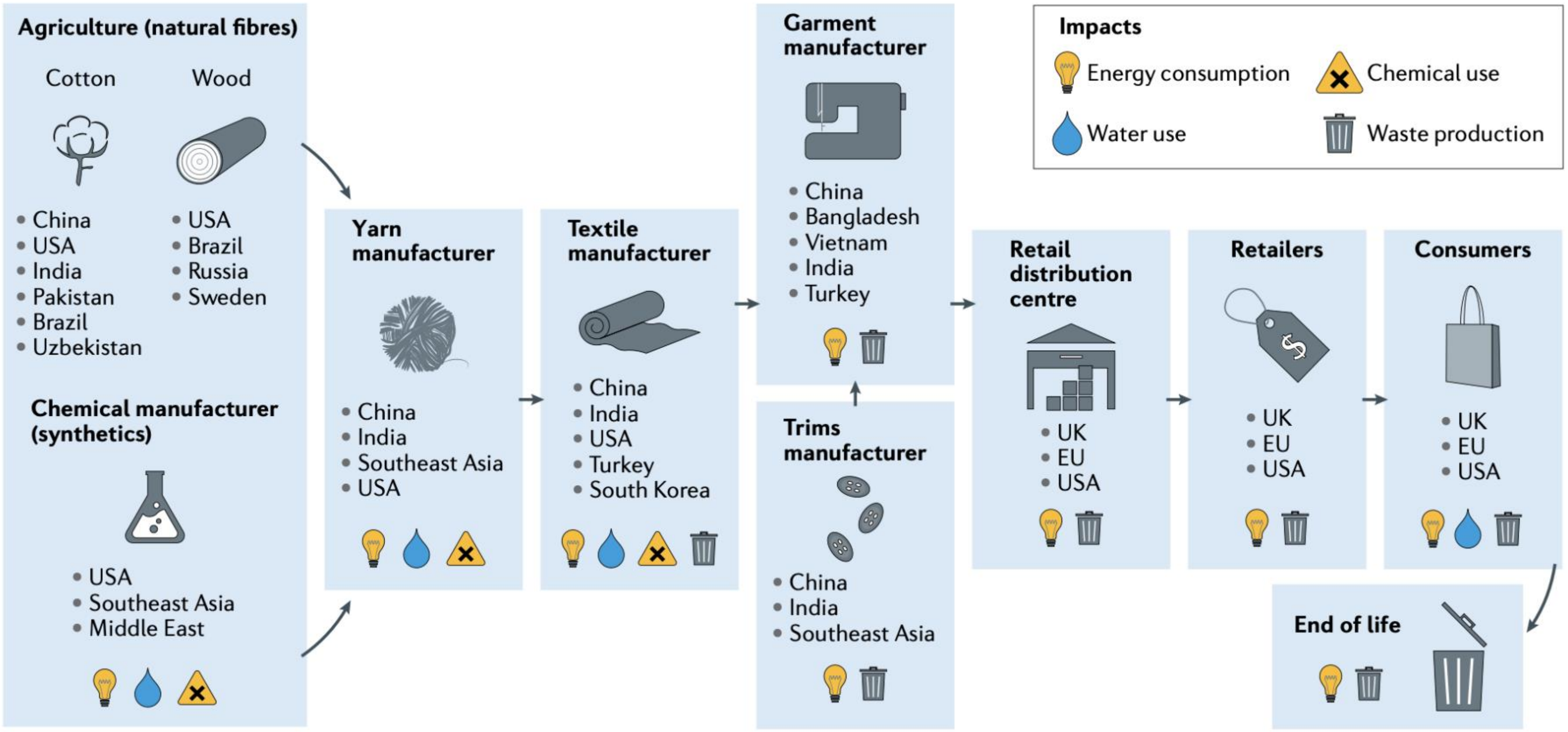

Figure A5: Simplified Overview of Flows of New and Used Textile in Denmark (Watson et al., 2018)

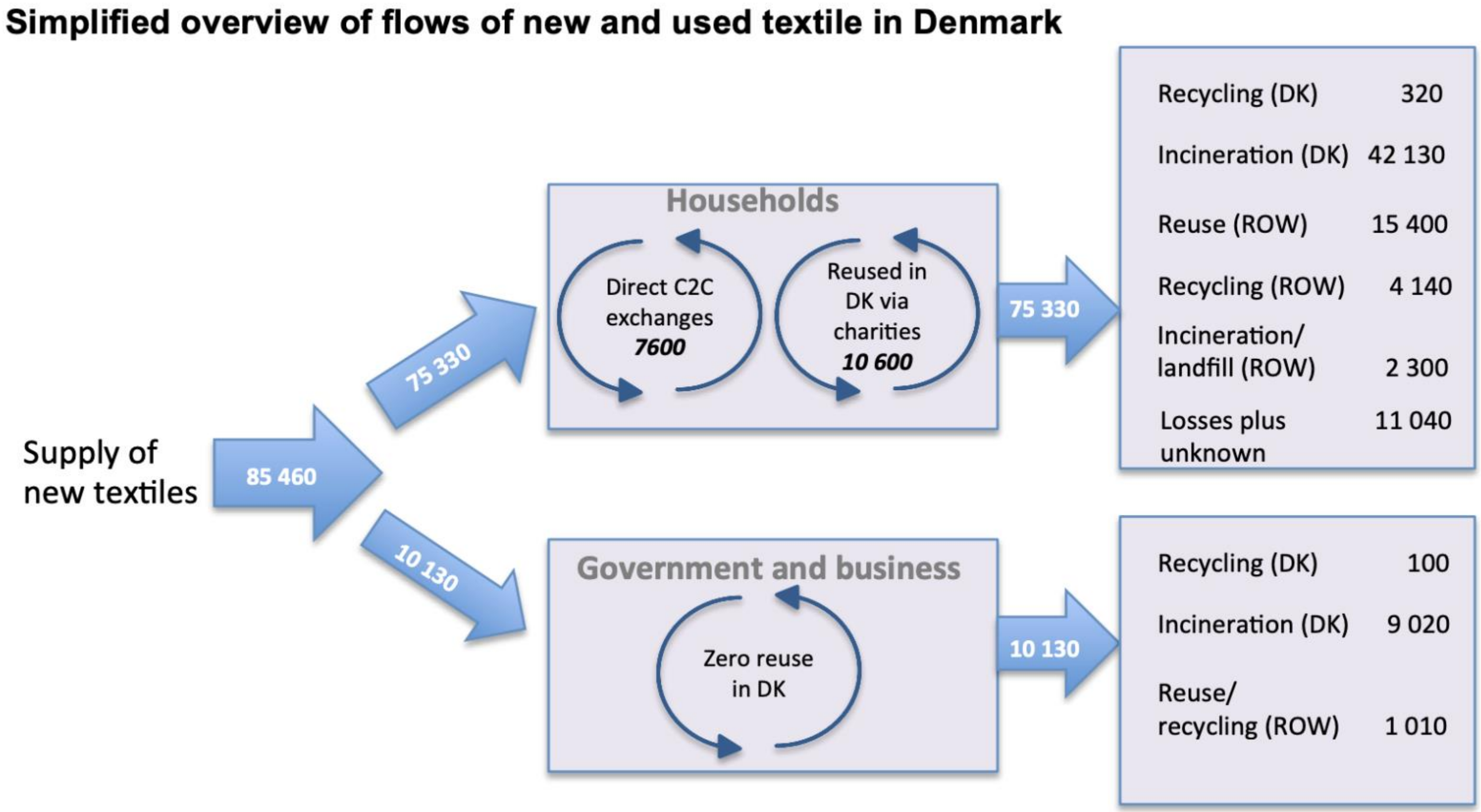

Figure A6: Circular Economy: representation of activities taking place in a circular textile value chain (Notten, 2020)

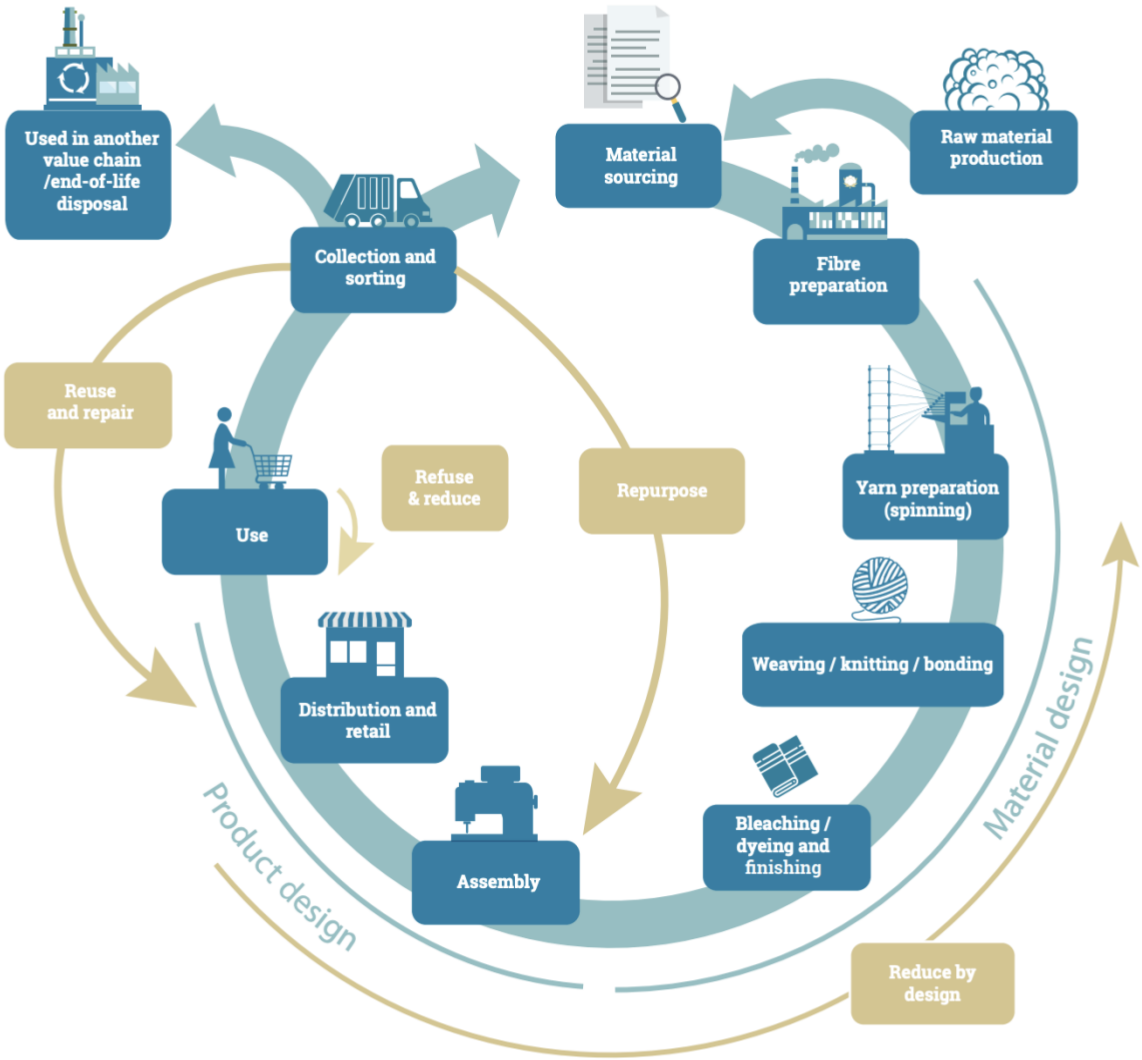

Figure A7: Visualization of Traceability in a Blockchain

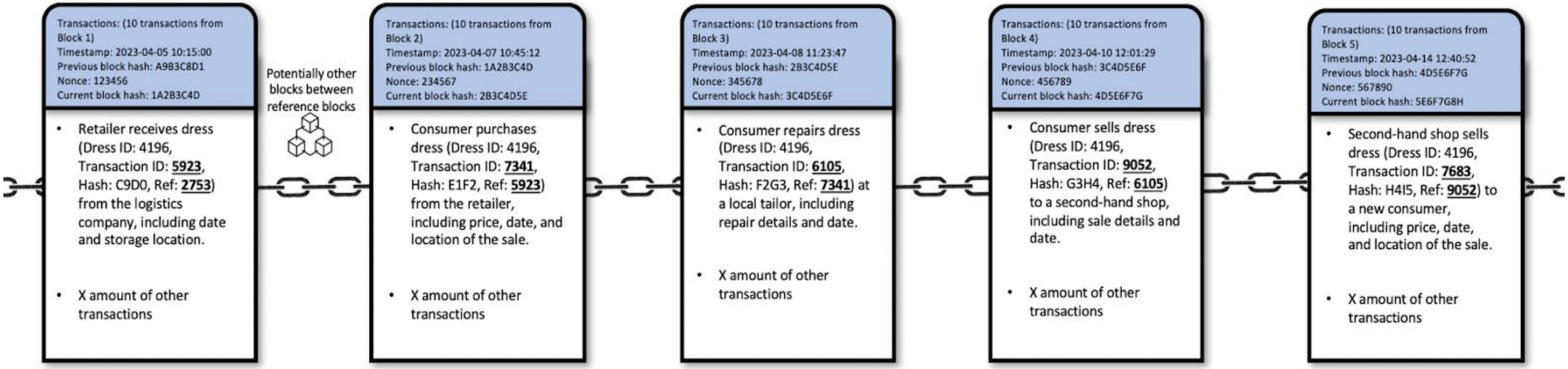

Figure A8: Design Science Research Methodology Process Model (Peffers et al., 2007)

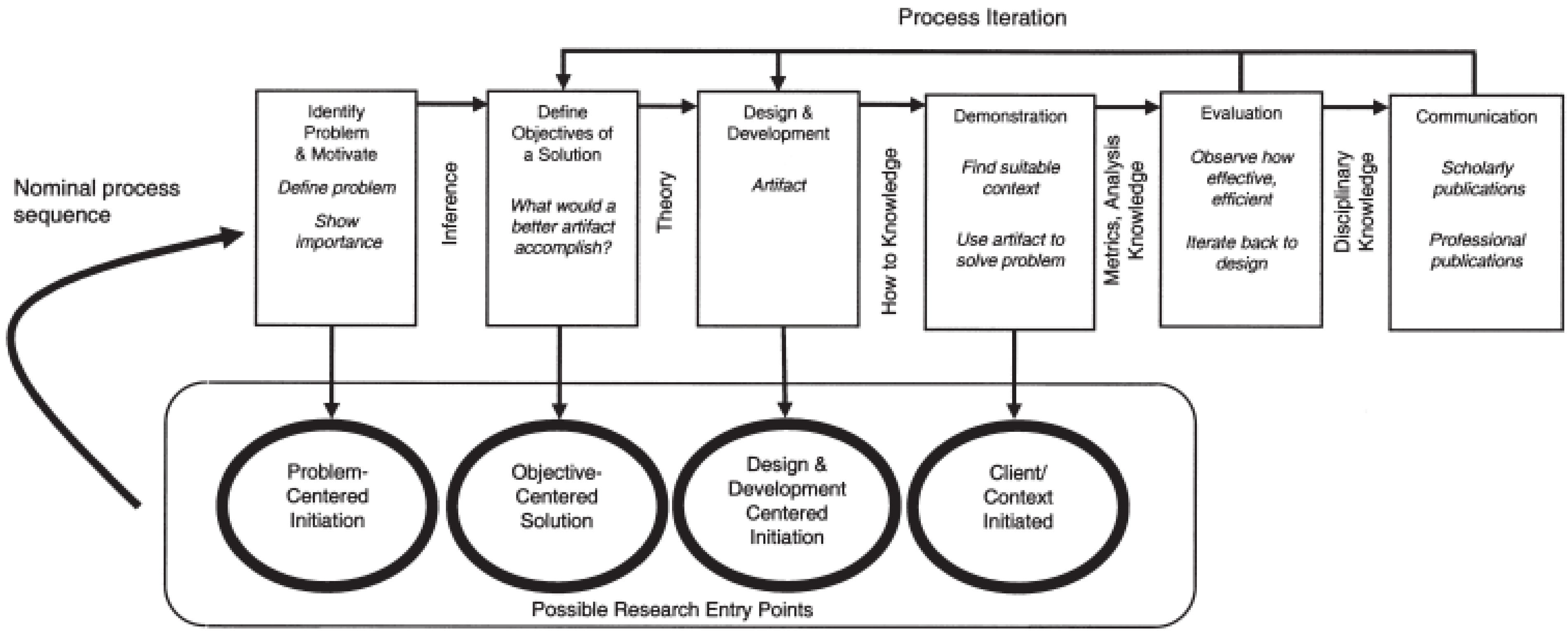

Figure A9: Design Science Research Overview - Our Execution of Activities

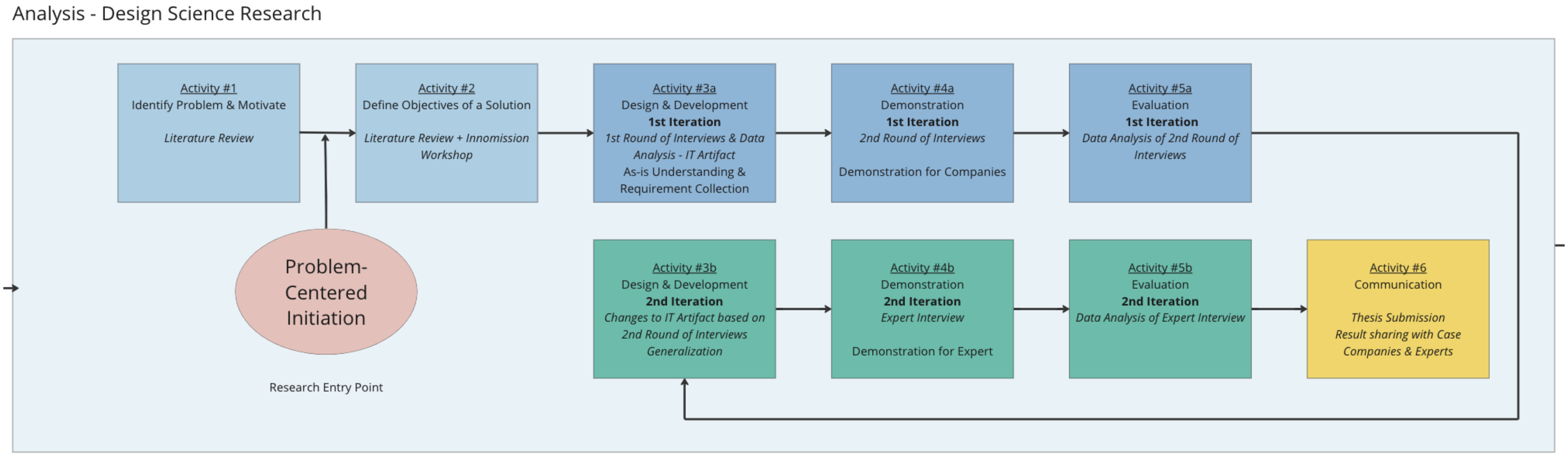

Figure A10: As-is T&C Supply Chain Model from 1st Iteration

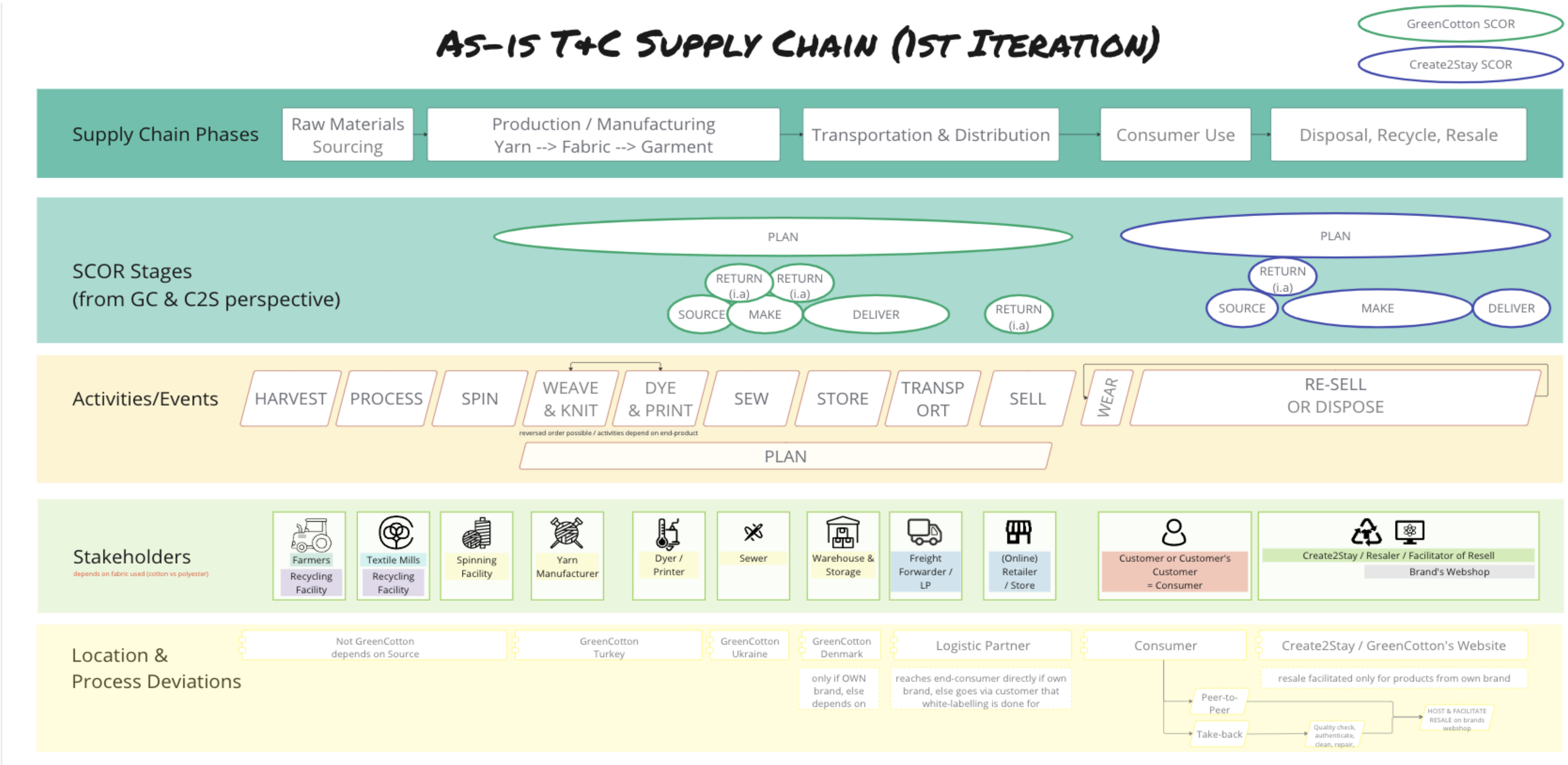

Figure A11: Layer 1 of As-Is Supply Chain Model - Supply Chain Phases

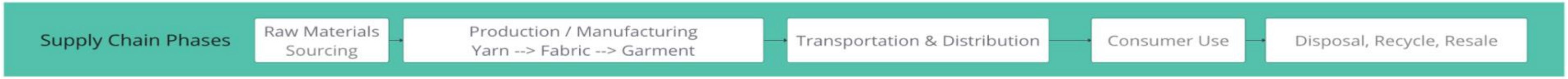

Figure A12: Layer 2 of As-Is Supply Chain Model - Green Cotton's SCOR Stages

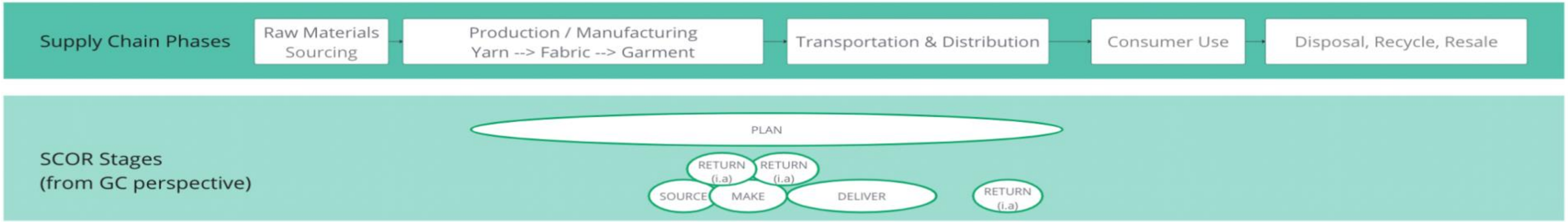

Figure A13: Layer 2 of As-Is Supply Chain Model - Create2Stay's SCOR Stages

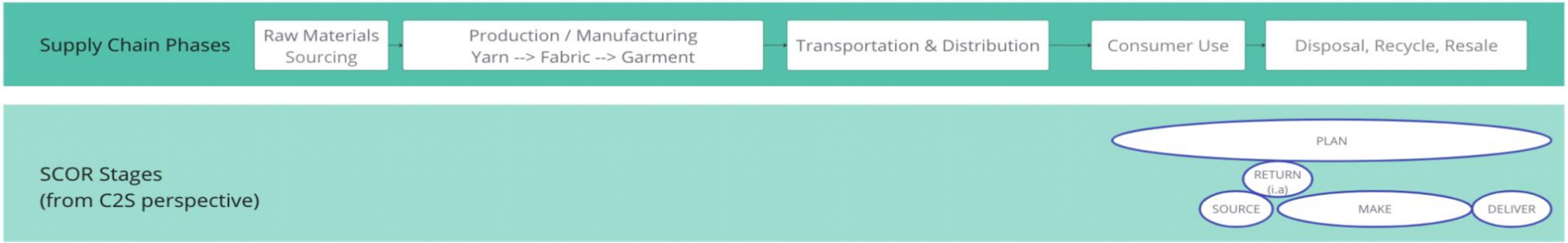

Figure A14: Layer 2 of As-Is Supply Chain Model - Combined SCOR Stages

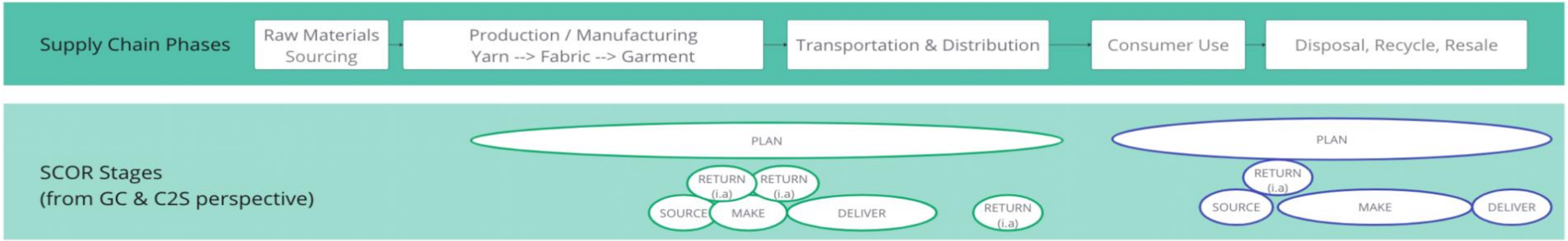

Figure A15: Layer 3 of As-Is Supply Chain Model - Activities/Events

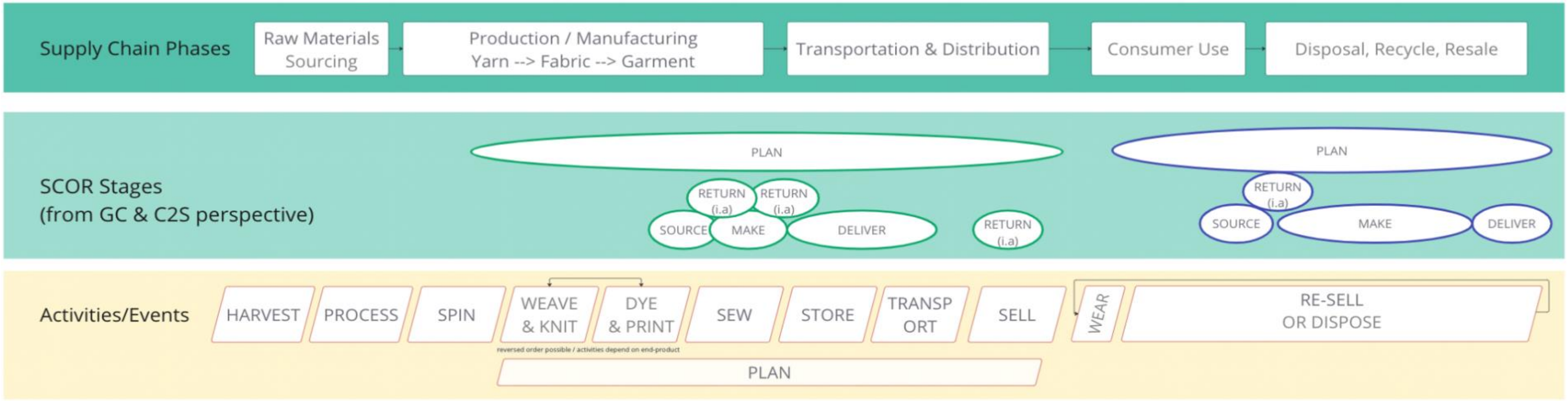

Figure A16: Layer 4 of As-Is Supply Chain Model - Stakeholder Types

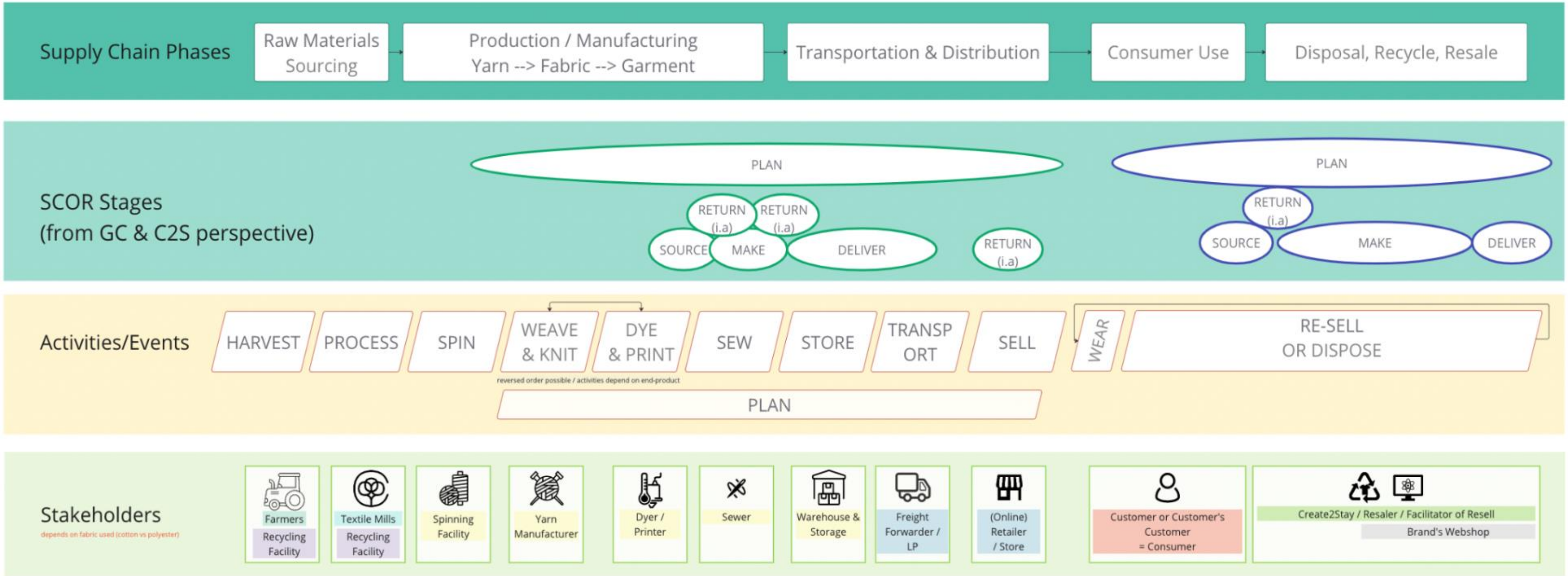

Figure A17: Layer 5 of As-Is Supply Chain Model - Location & Process Deviations

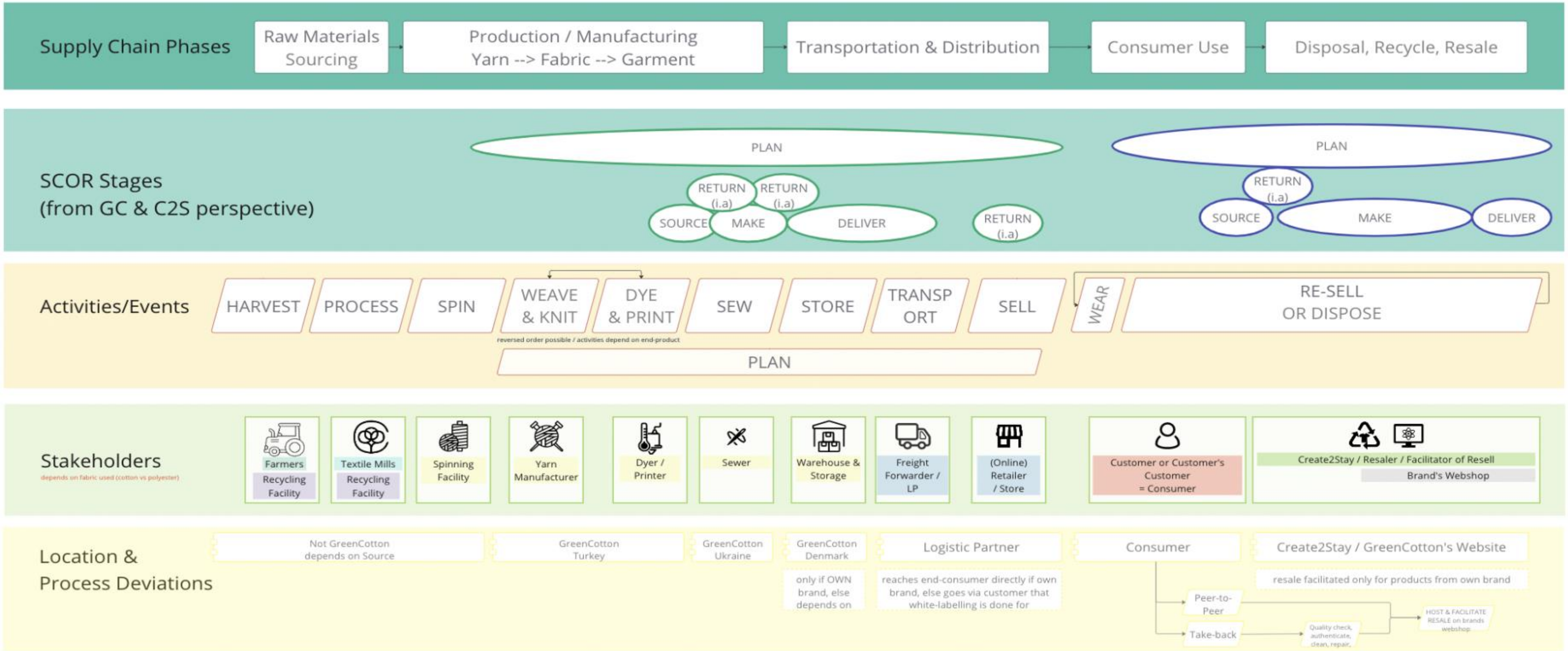

Figure A18: Requirement Visualization: Categories & Sub-categories

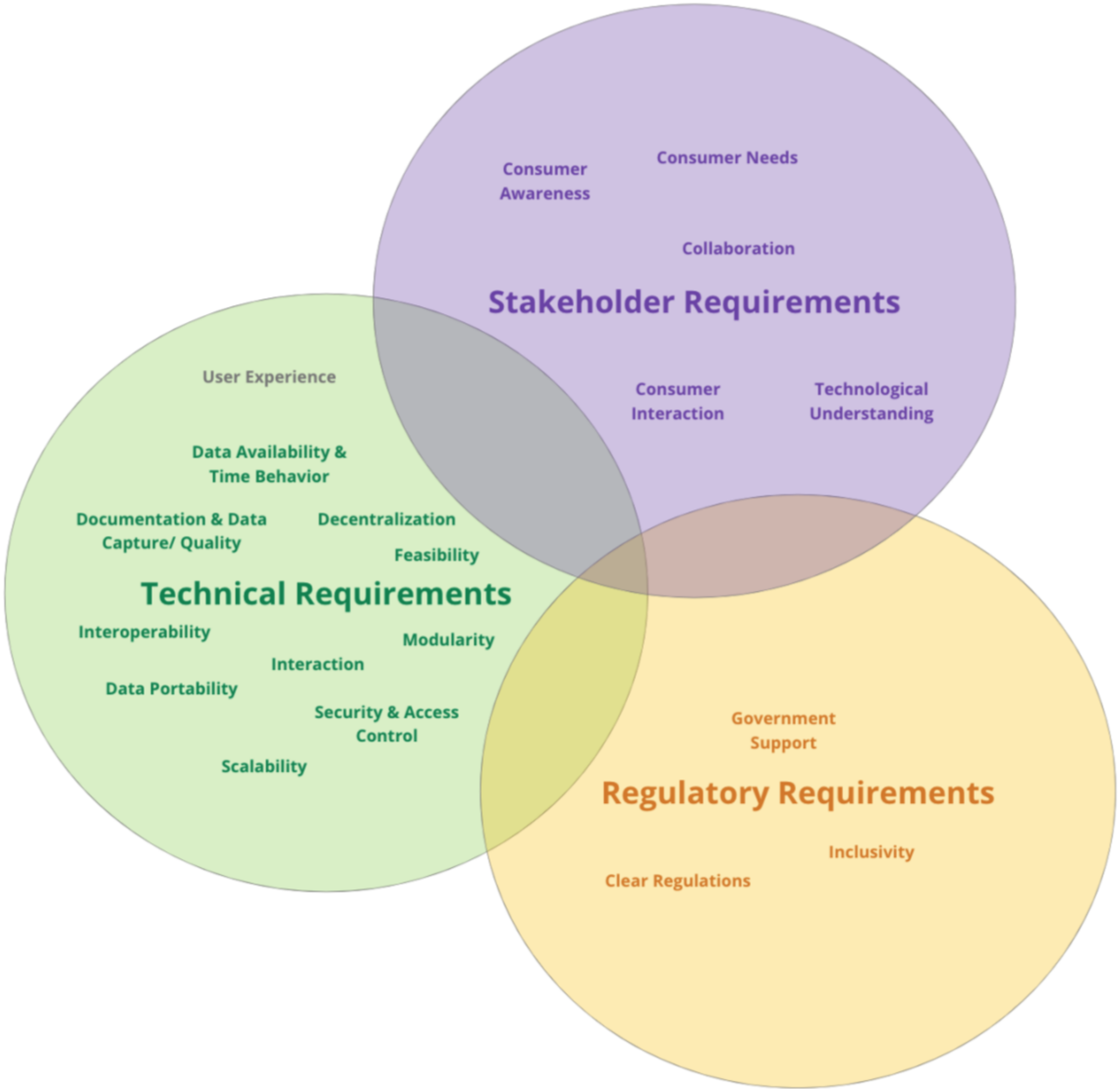

Figure A19: Requirement Visualization: Categories & Sub-categories with Requirements

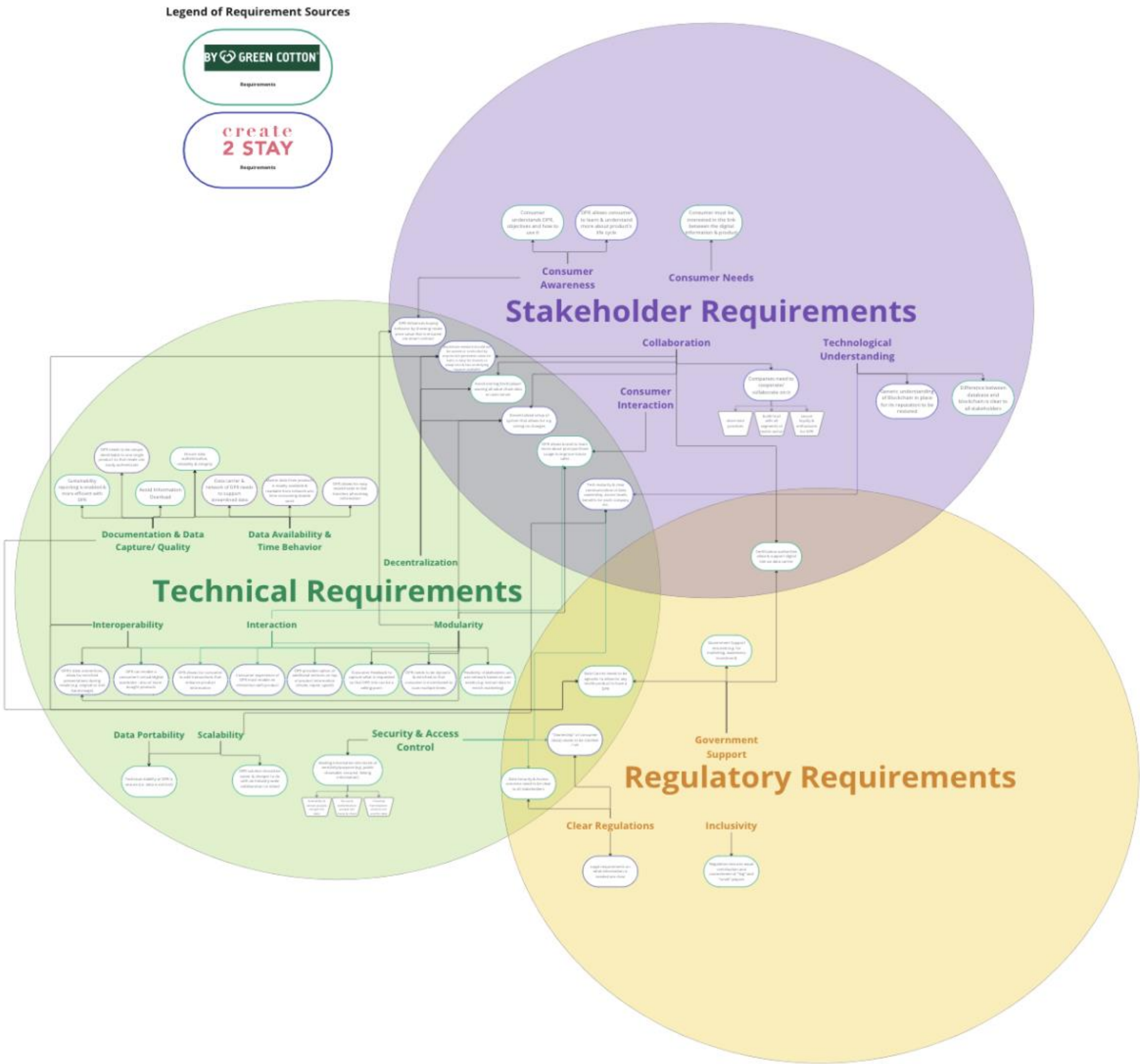

Figure A20: Design Workshop Virtual Whiteboard Material

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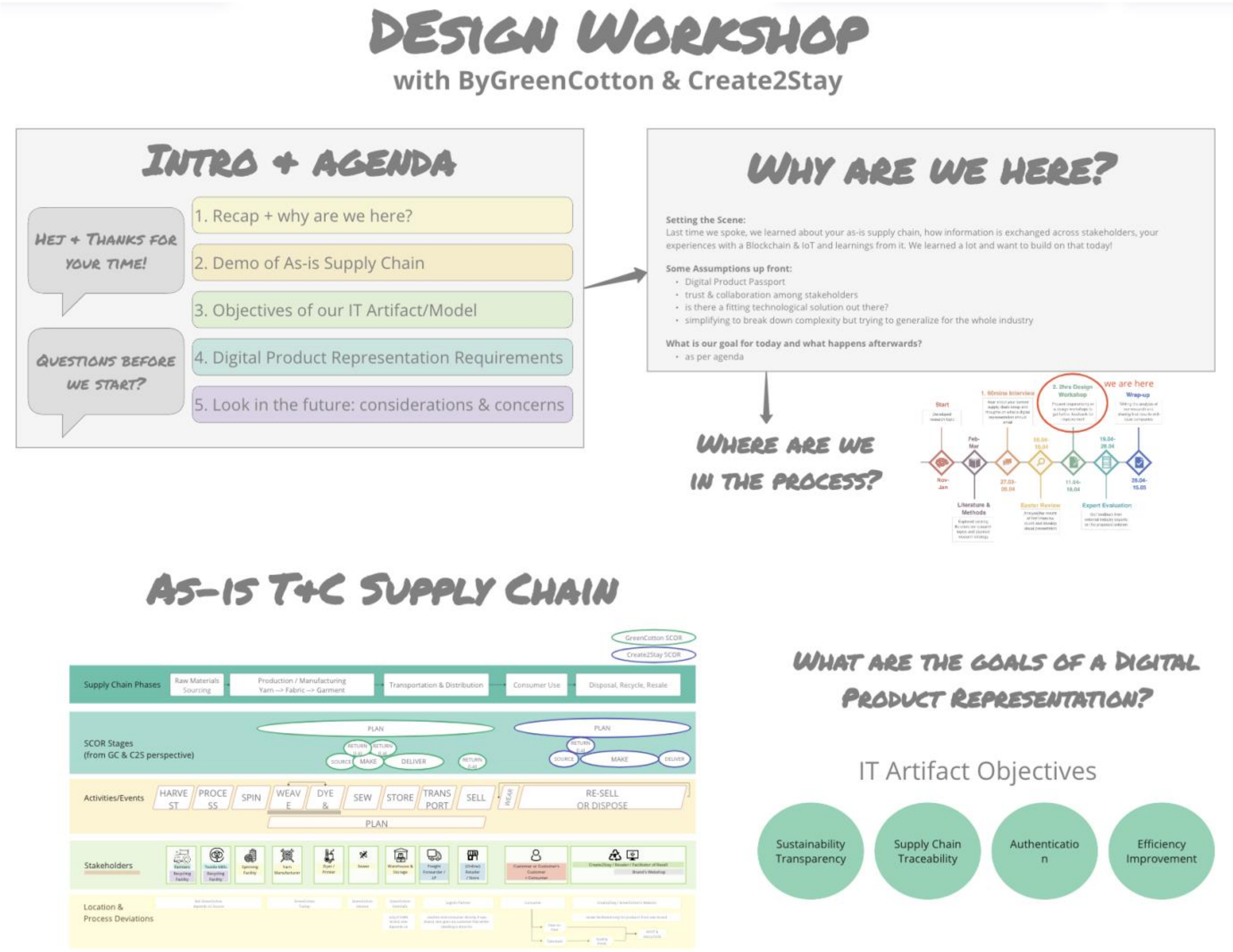
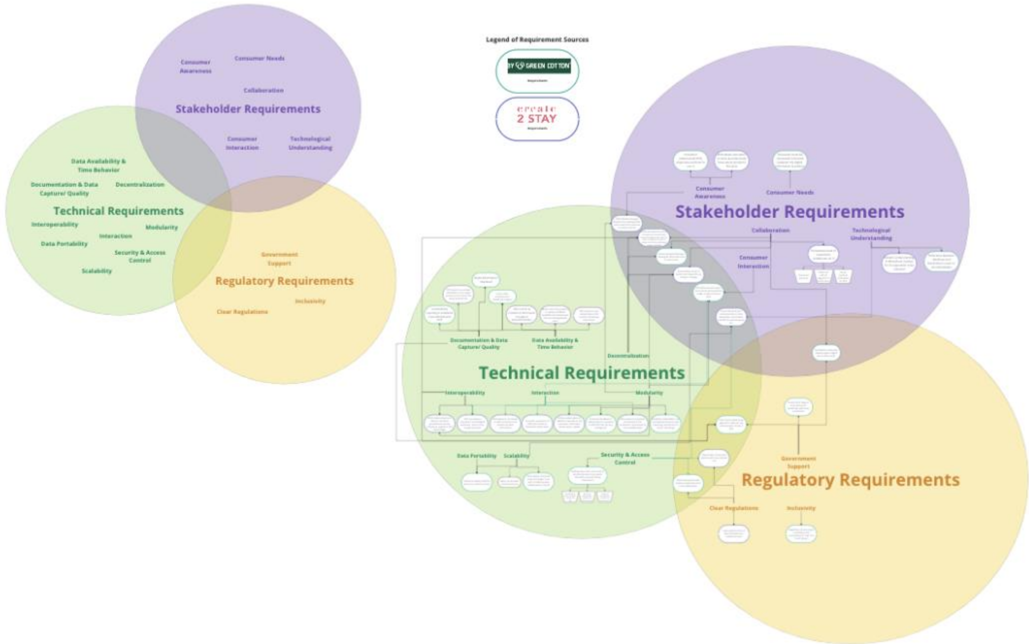
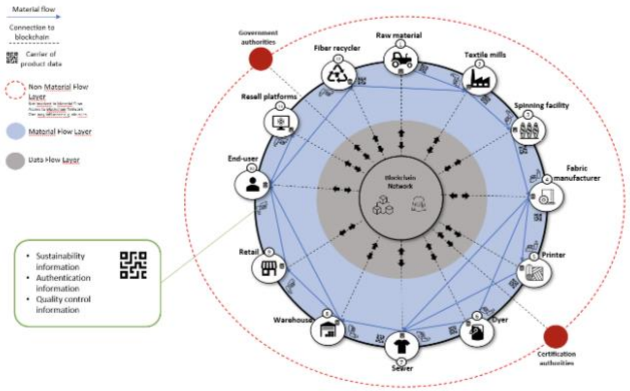


WHAT ARE THE REQUIREMENTS FOR A DPR?



IF THESE WOULD BE PUT IN PLACE, WHAT WOULD THE TO-BE SUPPLY CHAIN LOOK LIKE?



CONVINCED YET? WHY NOT? CONSIDERATIONS ABOUT THE FUTURE: IMPLEMENTING A DPR

Figure A21: 2nd Iteration of As-Is Supply Chain Model - Changes highlighted in red

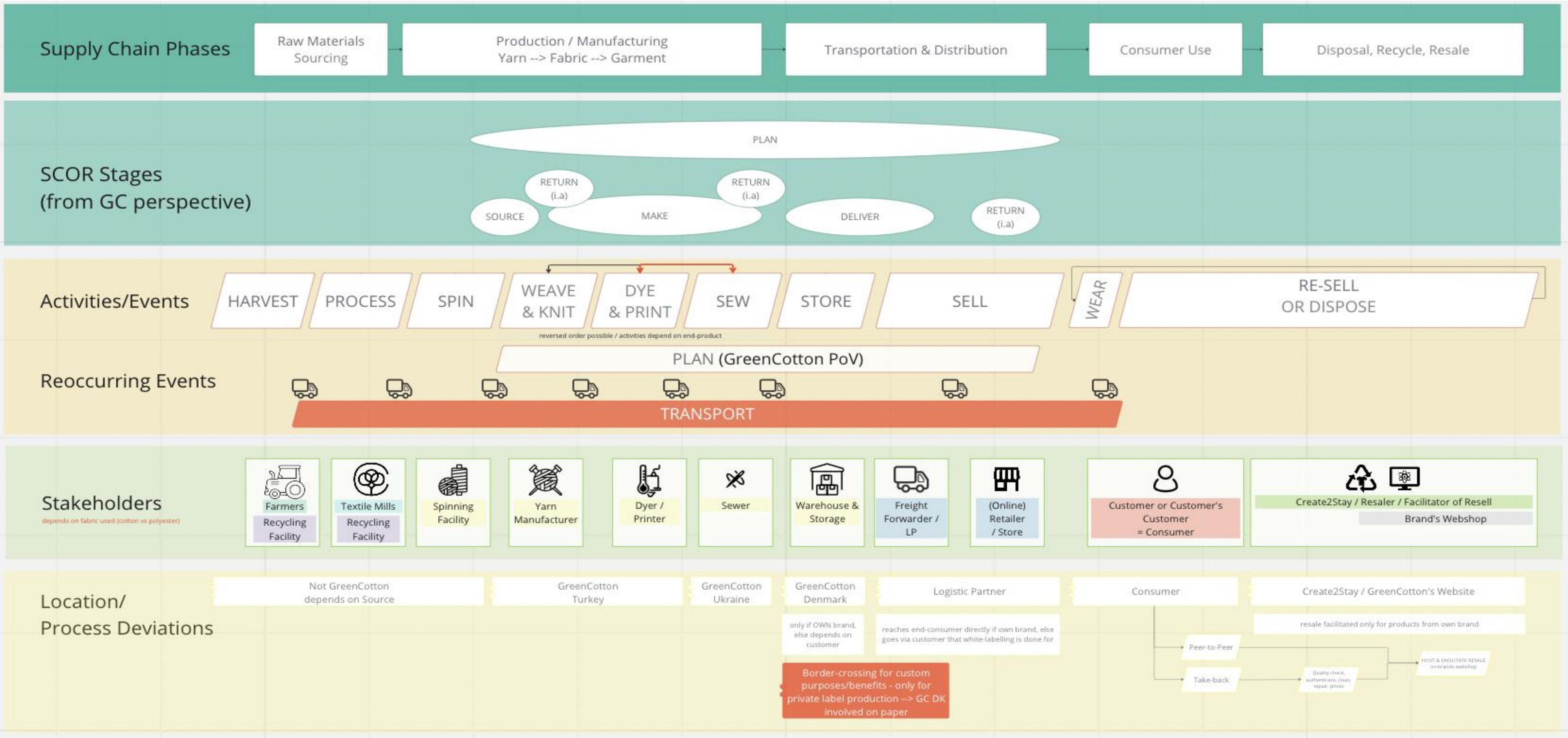


Figure A22: 2nd Iteration of Requirement Collection - Changes highlighted in red; validations in bold

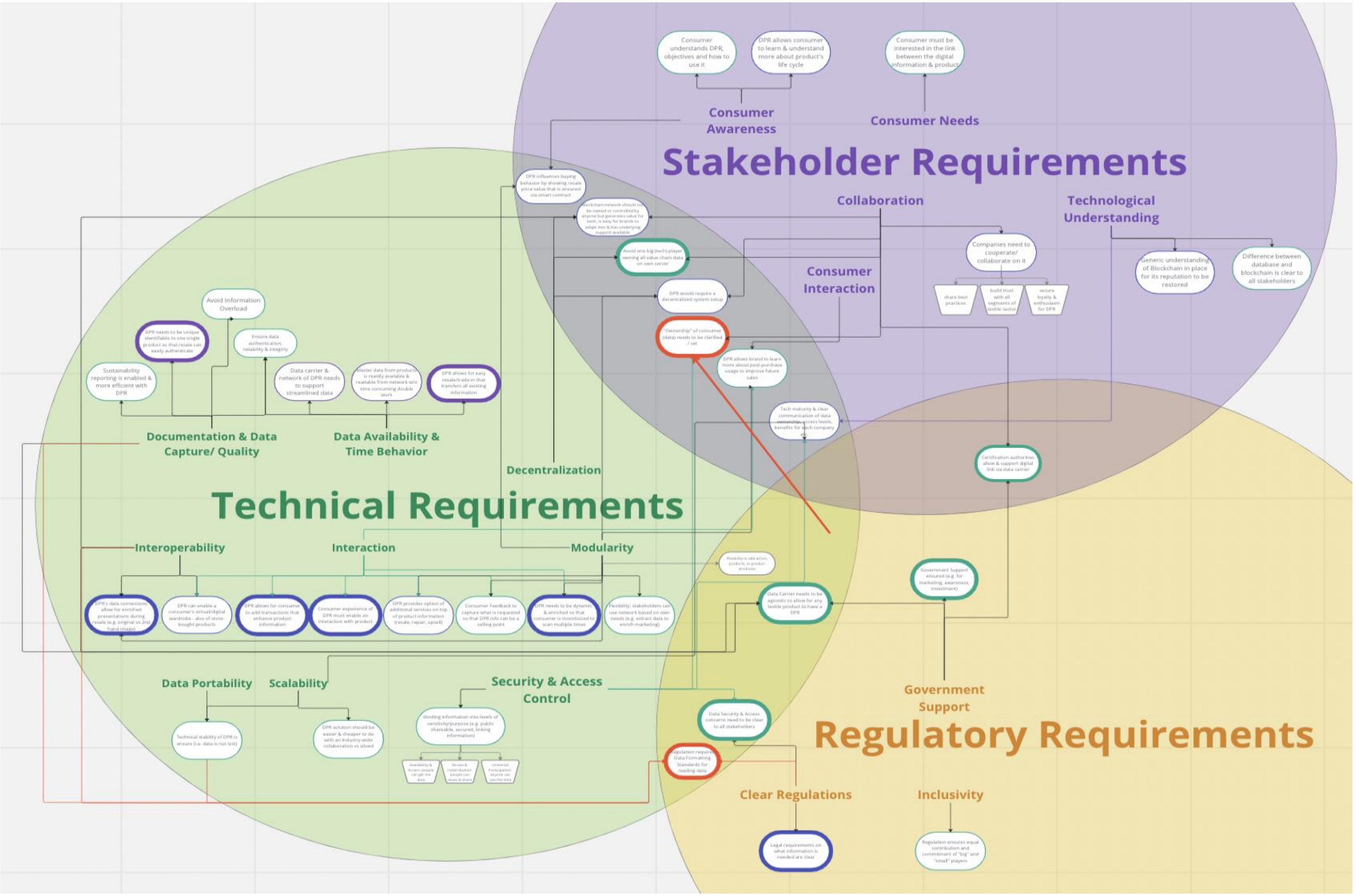


Figure A23: Expert Interview Virtual Whiteboard Material

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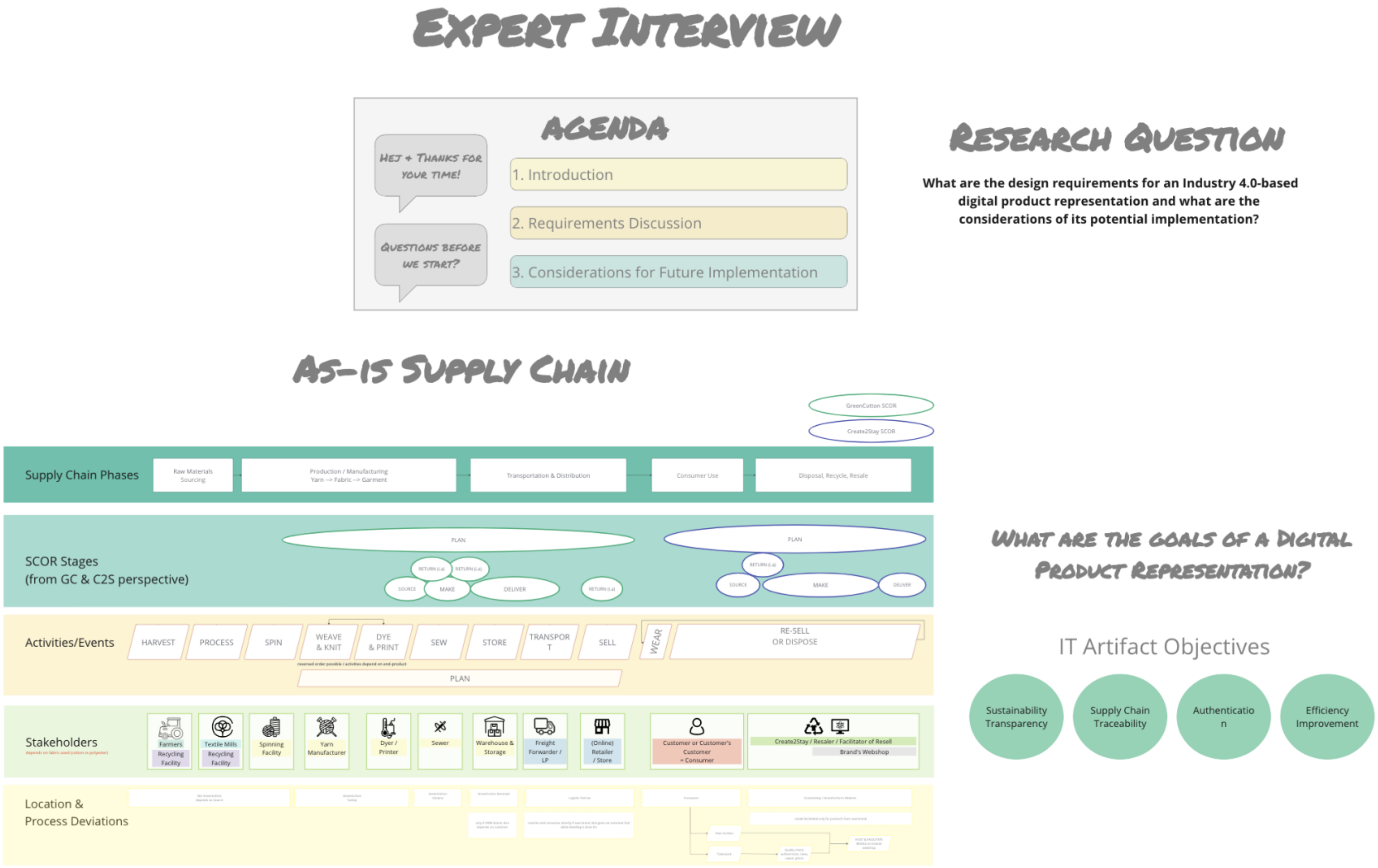
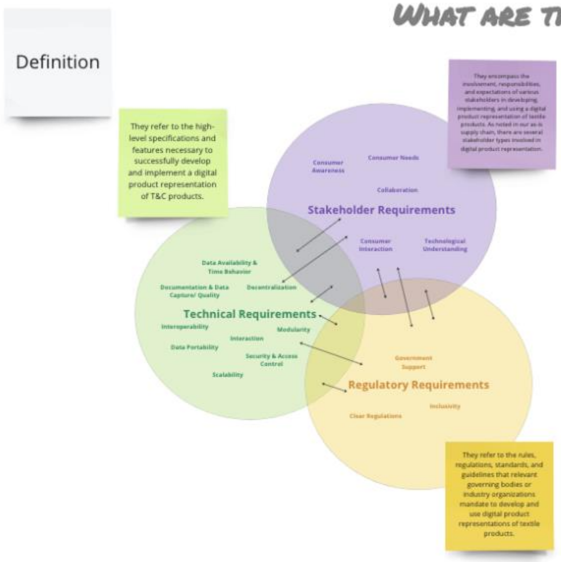


WHAT ARE THE REQUIREMENTS FOR A DPR?

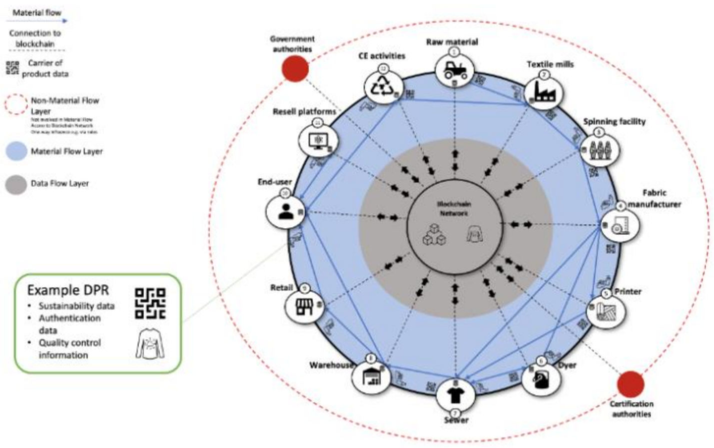


Evaluation Criteria

Criteria	Definition/ Explanation
Clarity	Are the design requirements clearly defined and easy to understand?
Completeness	Do the design requirements cover all relevant aspects of the problem domain?
Coherence	Are the relationships and interactions among the components and processes logically consistent?
Plausibility	Does the model seem plausible and likely to address the identified challenges effectively?

Open GoogleSheets Document to capture feedback

IF THESE WOULD BE PUT IN PLACE, WHAT WOULD THE TO-BE SUPPLY CHAIN LOOK LIKE?



CONSIDERATIONS ABOUT THE FUTURE: IMPLEMENTING A DPR

Appendix B: Tables

Table B1: Literature Overview: Filtering of Articles

Due to the complexity and size of the literature overview, we captured this table in an external file submitted together with this thesis under the title: "*Literature Overview_Filtering of Articles.xlsx*"

Explanation of File: It contains two sheets, the first one, titled "Literature Overview (44)", is the list of 44 articles that we conducted a full-text analysis on and the second one, titled "Literature Overview (33)", contains the articles we ended up presenting in our literature review in Chapter 2.

Table B2: Overview of Primary Data Collection & Notation System

The transcription files were submitted together with this thesis.

Interview	Date & Duration	Participants (Role)	Transcript File	Example for In-Text Citation
1st Case Company Interview: Green Cotton	29/03/2023 01:08:11	2 other student research groups Sanne (Managing Director of GreenCotton) June (Digital Manager)	GC1_29/-03_Transcript	GC1, 00:00
2nd Case Company Interview: Create2Stay	31/03/2023 00:52:23	Thomas (Co-Founder)	C2S1_31-03_Transcript	C2S, 00:00
Joint Design Workshop	11/04/2023 approx. 2 hrs	Sanne (Managing Director of GreenCotton) June (Digital Manager) Thomas (Co-Founder) Annabel (Researcher)	GC2_C2S2_11-4_Transcript	GC2, 00:00 C2S2, 00:00 AK2, 00:00
Deloitte Expert Interview 1	19/04/2023	Jonas Sveistrup Søgaard	JS1_19-04_Transcript	JS1, 00:00

	00:28:45	(Senior Manager, Deloitte)		
Textile Pioneers Expert Interview 1	20/04/2023 01:06:03	Kim Rohde Mogensen (Co-Founder of Textile Pioneers)	KR1_20-04_Transcript	KR1, 00:00
Deloitte Expert Interview 2	26/04/2023 00:33:09	Jonas Sveistrup Søgaard (Senior Manager, Deloitte)	JS2_26-04_Transcript	JS2, 00:00

Table B3: Interviews' Explanation, Purpose & Data Collection Type

Interview	Explanation of Party Interviewed	Reason/Motivation to choose Party Interviewed	Type of Data Collection
1st Interview: GreenCotton	Green Cotton Group is a Danish company with a strong commitment to sustainability and eco-friendly practices in the textile industry.	The choice of GreenCotton was made on the basis of their operations in several parts of the textile supply chain stages and their 40 years experience in sustainable production + made first ever organic cotton shirt (emphasis on sustainability, previous experience with BC pilot)	semi-structured interview; two-to-many
1st Interview: Create2Stay	Create2Stay is a white label reselling software solution, focused on enabling reselling of a brands products to undergo within the brand universe.	Create2Stay bring valuable information regarding the requirements of a digital product representation and activities in the product life-cycle after point of sale from either a retailer or E-commerce store.	virtual semi-structured interview; one-to-many
2nd Interview: Design Workshop with GC & C2S	see above for GC & C2S	We chose to hold the workshop with both companies because their combined expertise and experiences in their respective stages of the T&C supply chain, as well as their upcoming collaboration, could offer a nuanced interaction and discussion regarding the design requirements of a BC IOT-based DPR as well the future considerations of its implementation - what did we do? - etc.	physical, in-person semi-structured interview; one-to-many
1st Expert	Jonas Sveistrup	Jonas is a member of Deloitte's	virtual semi-

Interview: Deloitte NextGen	Søgaard was chosen for the expert evaluation of our research, with the focus being on the blockchain aspect of our research due to his extensive background and experience in the field.	innovation and blockchain team, and his academic background includes a Bachelor's, Master's, and PhD from Copenhagen Business School, with his PhD focusing on blockchain's impact on accounting. Based on his extensive experience, Jonas provided valuable feedback and insights regarding the blockchain aspect, specifically in a supply chain setting.	structured interview; one-to-one
2nd Expert Interview: Textile Pioneers	Kim Rohde, a passionate advocate for sustainable apparel production with over 25 years of T&C industry experience, acts as our 2nd expert interviewee.	Due to his extensive knowledge in ethical apparel production, involvement in Textile Pioneers, familiarity with blockchain technology and practical experience of implementing a DPR in a clothing collection, Kim is an invaluable resource for providing insights and unique perspectives on the subject matter of our thesis from a practical T&C perspective.	virtual semi-structured interview; one-to-one

Table B4: Requirement Categories: Definition, Examples of Sub-classes and Objective

Requirement Category	Definition	Examples of sub-classes	Objective
Technical Requirements	They refer to the high-level specifications and features necessary to successfully develop and implement a digital product representation of T&C products.	These requirements may include modularity, interoperability between systems, flexibility, scalability, and other architectural and design principles that enable seamless integration, interaction, and maintenance of the DPR within the company's existing technology landscape.	These requirements aim to ensure that the DPR is built with a robust and adaptable technical foundation that supports its efficient operation, integration with other systems, and future enhancements or modifications as needed.
Stakeholder Requirements	They encompass the involvement, responsibilities, and expectations of various stakeholders in developing, implementing, and using a digital product representation of textile products. *As noted in our as-is supply chain, there are several stakeholder types involved in digital product representation.*	Stakeholder requirements may include factors such as usability, accessibility, branding, customization, analytics, reporting, integration with existing systems, and other considerations that align with the stakeholders' interests and objectives.	These requirements aim to capture, for instance, the need for consumer awareness, collaboration across parties, data sharing, content creation, product information accuracy, and other responsibilities that stakeholders are expected to fulfill.
Regulatory Requirements	They refer to the rules, regulations, standards, and guidelines that relevant governing bodies or industry organizations mandate to develop and use DPR of textile products.	These requirements may include legal and compliance considerations, data privacy and security regulations, industry-specific standards, intellectual property rights, labeling and tagging requirements, and other regulatory guidelines.	It is necessary to capture these requirements in a separate category to clarify what the digital product representation must adhere to to comply with the relevant laws and regulations.

Table B5: Requirement Collection

Due to the complexity and size of the requirement collection, we captured its tabular format in an external file submitted together with this thesis under the title: *"Requirement Collection.pdf"*

Explanation of File: It contains several sheets that were shared with the experts as pre-read. The most important 2 sheets are the Level 3 Requirement Lists - there is two versions representing the two iterations and the last sheet reflects the technological capability mapping with the requirements collected. See below for a description of each sheet as per its title.

"Sheet 1: Level 1: 3 Requirement Classes"

This is the macro level of the requirement classes we categorized our findings into – split into 3 classes. We provide definitions, objectives, and examples of sub-classes

"Sheet 2: Level 2: 17 Sub-Classes"

Going one level down, in each requirement class, we further grouped the requirements into 17 sub-classes. We provide definitions of each and an example of a requirement we found

"Sheet 3: Level 3: Requirement List (37) 1st Iteration"

List of Requirements based on the first iteration. These requirements were presented during the Design Workshop. A note on the color-coding – those in yellow are purely regulatory, those purple are purely stakeholder, and those in green are purely technical requirements. Those in red are inter-class requirements that span several classes.

"Sheet 4: Level 3: Requirement List (38) 2nd Iteration"

After collecting feedback from the case companies in the design workshop (11/04), we updated the requirements and list the 38 requirements found, which class, and which sub-classes they belong to.

"Sheet 5: Technological Capability Matching with Requirements"

We captured the assessment of which technological capabilities of BC and IoT can cater to the requirements identified in this sheet where columns F and G are critical indicators per requirement.

Appendix C: Interview Guide of First Case Company Interviews

Opening word (3min)
● Firstly we want to thank you for taking the time to participate in this interview ● Our main goal is determining the requirements for a digital product representation of textile products. Given the time restraints of this interview, due to us being three groups, our goal is to understand how your supply chain operates as-is, the exchange of information (i.e. your data flow), and possible painpoints. Thus, we are *are hoping to have a follow-up conversation to continue mapping the requirements given our understanding of your as-is and its challenges.* ● Before we begin, to clarify, would you prefer that we anonymize both your name and which company you are from or would we be allowed to refer our conversation to the company. ● Upfront remark: would you be comfortable with us recording this interview? ● Do you have any questions upfront?
Warm-up (5min)
● To get to know each other briefly, we would like to know more about you and your role in [company name]
SCOR - Understanding your supply chain/product life cycle (17mins)

We have informed ourselves via your homepage from [company name] - *we know that your geographical presence spans into Istanbul and Lviv (Ukraine) and that with your facilities you are in charge of quite a few stages of your supply chain - with that in mind*
- Could you give a high-level description of your products' life cycle?
Specifically/if too broad:
    - For instance, starting with how many different stakeholders are involved in the full life cycle of a product, like a T-shirt?
    - How much of your value chain do you "own" vs what is outsourced to third party?
    - What is the geographical dispersion of your operations?
    - How do you maintain an overview of your supply chain activities?
 	
To understand your as-is supply chain activities better, we would like to know your processes along the Plan, Source, Make, Deliver and Return stages:
- (PLAN): How do you currently plan for the production of textile products?
- (SOURCE): How do you currently source raw materials for textile production?
- (MAKE): How do you currently manufacture textile products? What are your production processes?
- (DELIVER): How do you currently transport and deliver finished textile products to customers? How do you manage shipping and logistics, and how do you ensure timely delivery?
- (RETURN): How do you currently handle product returns and manage reverse logistics?
 	
With the understanding of your as-is, could you talk more about the information receive from upstream, change/generate within your processes/activities and transfer to the downstream actors thereby, exchange.
    - What (type of) information regarding your products do you receive from your

suppliers?
    - What (type of) information regarding your products do you forward downstream? Upstream? With which stakeholders?

Painpoints/Challenges:
- What are the main inefficiencies in your supply chain? What causes them?
  Specifically,
    - Are there any communication or coordination issues among supply chain partners?
    - What are the main challenges your company faces in achieving supply chain transparency and traceability?
    - What steps are you taking to increase transparency and traceability in your supply chain?

Sustainability Concerns (10mins)

- What, if any, major sustainability challenges do you see in your value chain both environmentally and socially? (e.g. child labor, textile waste, etc.)
    - to validate that problems found in lit are happening
- How does [company name] try to deal with these challenges?
    - e.g. do you measure your products' environmental impact?
- How does your company prioritize sustainability within its supply chain strategy?
- Can you provide an overview of your environmental and social sustainability initiatives in the supply chain?
- How do you assess and manage the sustainability performance of your suppliers?
- How do you currently track and monitor the environmental impact of your products throughout their life cycle?
- What is your opinion on this ambition to "close the loop" and what do you think is preventing the industry from transforming?
- Are you familiar with any digital solutions or technologies that could help improve supply chain transparency, traceability, or environmental impact tracking?

  these challenges may align broadly with those we found in literature when discovering the differences between a linear vs circular supply chain and its impact on sustainability

Digital Product Representation - Concept, opportunities & requirements (20mins)

- *You are familiar with the conceptual idea of a digital product representation or Digital Twin that is being pushed by EU legislation in the shape of a Digital Product Passport right?*
- How do you envision the role of digital solutions in improving supply chain transparency, traceability, and environmental impact tracking in the textile and clothing industry?/ How do you envision such a representation for your product?/ Is there a desire to get digital representation?
- What do you think it should be able to do?
- What do you think it should ultimately achieve (for you/your suppliers/customers)?
- What types of information or data do you think would be important to include in a digital representation of your products to enhance transparency and traceability?
- Can you identify any potential barriers or concerns your company may have about adopting new technologies or digital solutions for supply chain management?
- What key features or capabilities would you consider essential in a digital solution to effectively support your company's supply chain management goals?

- How could it address the sustainability challenges and supply chain inefficiencies we discussed before? As in what benefits do you foresee for your company and the textile and clothing industry as a whole by adopting digital solutions to enhance supply chain transparency, traceability, and environmental impact tracking?

If possible, more design requirement-specific questions related to e.g.

- interoperability with current systems - How important is it for your company to have systems that easily integrate and communicate with those of your supply chain partners?
- private data / access rights - How do you currently share information with your supply chain partners? Do you have any preferences or concerns regarding access control and data privacy?
- simple to use for end-users
- ownership of data - How important is maintaining control and ownership of your company's data when sharing information with supply chain partners, and what measures do you currently have in place to ensure this control?

Technology-related questions:

- requirements for information sharing (access, editing, validation, interoperability,
- feasibility of BC & IoT implementation? (BC as data storage and security layer, IoT as collection method)
- How can trustworthy and high-quality data-input be guaranteed? (IoT)
- How are you conducting quality control of the products you receive from suppliers?
- Have you experienced any issues with data security or fraud in your supply chain? How do you address these concerns?
- How do you anticipate your company's transaction volume and supply chain complexity to evolve in the future? What challenges might this present?
- How do you manage decision-making and dispute resolution within your supply chain? Are there any areas where improvements could be made?
- How are you identifying products in your current systems? By batch, piece? And by what identifier?

Considerations for potential implementation (5mins)

- What challenges do you foresee in designing and implementing such DPR?
- Do you think its feasible to implement it? (for all parties in system given the level of technical expertise, cost, time, contrasting interests etc.)
- To what extent do you think that all your supply chain actors will be technically- and financially-capabale of operating their part of a DPR?

Wrap-up (2mins)

- Thanks again for your time and the great insights
- And finally, getting access to people in the industry can be quite hard without the right connections
- So, if you happen to know someone in your network, of whom you think that they might be willing to speak with us as well for a little bit as well, then please let me know

Appendix D: Internet-Mediate Questionnaires: Email Communication

SV: Clarifying questions

Sanne Nørgaard <sn@bygreencotton.dk>
Man 01-05-2023 10:39
Til: Carl Emil Derby Hansen <caha18aj@student.cbs.dk>;June Harrild <jh@bygreencotton.dk>
Cc: Annabel Kathrin Kläre <ankl18ab@student.cbs.dk>

Hi

I have put a red cross at the answer
BR Sanne

Fra: Carl Emil Derby Hansen <caha18aj@student.cbs.dk>
Sendt: 28. april 2023 14:19
Til: Sanne Nørgaard <sn@bygreencotton.dk>; June Harrild <jh@bygreencotton.dk>
Cc: Annabel Kathrin Kläre <ankl18ab@student.cbs.dk>
Emne: Clarifying questions

Hi Sanne & June,

Hope everything is going well!

We have a few clarifying questions that would really help us for our thesis in understanding the complexity of your as-is supply chain.

We have listed some multiple choice questions as well as some questions without multiple choice below which would benefit our concrete understanding of your supply chain. Is it possible to get the answers in written form, or would you prefer a quick call?

1. How many different suppliers are you provding you with fabric in Ukraine?
   - 0-15
   - 15-30 X
   - 30+
2. How long is your average relationship with a supplier?
   - Short term / Changing frequently (0-2 years)
   - Medium term / Changing sometimes (3-5 years)
   - Long term / Changing very rarely (5+ years) X
3. How visible is your supply chain from your perspective? (do we know what these tiers mean?)
   - Tier 2
   - Tier 3 X
   - Tier 4
   - Tier 5+

4. How many B2B customers did you supply with private label production in 2022? 20

5. How many pieces of garments did you produce in 2022 for your own brand? (Rough estimate is more than okay) 350.000

6. How many pieces of garments did you produce in 2022 for private labeling? (Rough estimate is more than okay) 1.500.000

7. Data category

a. How do you receive data regarding the materials for production from previous tiers? Tests, batch information.
b. What data do you pass on to your private label customers? Packing lists, invoices, transaction certificates if necessary.

Thank you in advance for taking the time out of you busy schedule to help us with our thesis!

All the best,

Carl Emil & Annabel

Appendix E: Expert Evaluation (in-depth)

As-is Supply Chain

During the interview with the senior manager at Deloitte, we received general feedback on the as-is supply chain model: "reality is always more messy but that's why we make models in order to extract and understand the world, so that's fine" (JS1, 04:58). When getting into the details, he asked us to reconsider the naming to ensure we do not duplicate the taxonomical level since we had "stakeholders" on one level and "owners" on another and "you would regard owners as a stakeholder" (JS1, 05:18). This change is needed because "otherwise [we] will simply compare apples to pears or something like that" (JS1, 06:34) which would not indicate a coherent and consistent IT artifact/model. Instead, his feedback was to "make the visualization of these as the overall themes, and then when you deep dive, of course, you can become more granular" (JS1, 06:35). This would allow for a better overview and visualization.

Similar to the comment on changing the title of the "owner" layer, the senior manager at Deloitte added that the taxonomy level of the "events" layer is unclear as "you would expect that [...] stakeholders were a part of the events" (JS1, 07:09). This comment indicates more consistent wording is required from his point of view. Nonetheless, he also pointed to the complexity of modeling this out "because modeling the world is hard" (JS1, 07:44) which is why he suggested that "[we] maybe need to make some assumptions instead of trying to encapsulate everything" (JS1, 07:50). His last point on the feedback for as-is was related to another type of taxonomy that he recommended we use to generate a more generalizable model, namely Business Process Modeling Notion (BPMN) which is a standard set of rules and elements that are used in process mapping to indicate what type of activities are executed, by whom, etc. His feedback was that from BPMN "[we] could maybe get some inspiration for the different levels of processes [...] because then [we] can maybe think of how to exemplify [our] process here" since, in the end, the supply chain model is a depiction of a process flow.

In comparison to the senior manager at Deloitte's feedback, the co-founder of Textile Pioneers' overall impression of the as-is supply chain model was that "it shows the supply chain very well" (KR1, 12:48). However, there are, of course, some slight differences to Textile Pioneers' supply chain as they do not harvest. From this evidence, we can infer that using "harvest" as a title for the activity may not be appropriate because the related stakeholders can also be recycling facilities. Furthermore, he confirmed that the order in which the activities are executed can vary (KR1, 14:52). He corrected the connection between stakeholders and which tasks they execute, namely that the spinning facility and yarn manufacturer are the same as they do “spin” but weaving & knitting would be done by fabric manufacturer (KR1, 15:44) which is a stakeholder to be added to the model.

To conclude, the experts’ evaluation of the as-is supply chain model differed greatly. While the senior manager at Deloitte, coming from a more academic background, gave very detail-oriented feedback on the wording of specific elements in the as-is, the co-founder of Textile Pioneers was more focused on the content that should reflect the T&C’s industry and its supply chain. This difference in evaluation is fair as the co-founder of Textile Pioneers has a strong industry background, which the senior manager at Deloitte lacks, and vice versa, the co-founder of Textile Pioneers would not per se see the taxonomy levels of the models being faulty as this may also not be a priority for him to clarify.

Requirement Collection & Visualization

In the first expert interview with the senior manager at Deloitte, the results of evaluating his opinion on the requirement collection was as follows. Generally, on the requirements, he said that “logically, this makes sense, [...] there are some technical requirements, [...] some business requirements, [...] some regulatory requirements” (JS1, 12:21). Nonetheless, there were some points related to our model’s clarity, coherence, completeness, and plausability that he made us aware of.

The first feedback evaluated from the senior manager at Deloitte relates to the high-level classification of requirements where there was some unclarity and incoherence related to the grouping of stakeholder and regulatory requirements as he confirmed that regulatory bodies are just another type of stakeholders so instead we would need to “distinguish between [...] the regulatory side and the [stakeholder side]” (JS1, 05:58). Thereby, for the stakeholder requirements-specifically, he noted that classifying this group of requirements as “stakeholders” may be too broad since “they are kind of encapsulated in one representation” but “there might be a better way to ensure that you’re representing stakeholders’ consumers [since] at the end of the day, they are the ones where you hope that by providing [...] traceability, sustainability data and so on, they will make a better, informed decision” (JS1, 19:58). He recommended us to look at a model that [Deloitte] developed together with the World Economic Forum” (ibid.) which is part of an article on “How to build a successful nationwide blockchain initiative” (Alhaddad et al., 2020). The minimum-viable product model made with the World Economic Forum (ibid.) as the better choice for classifying requirements “because it better encapsulates the viability, the feasibility, and the technical achieveability” (JS1, 19:58). The reason for why we kept the regulatory requirements separate from the stakeholder ones was because we wanted to differentiate between those stakeholders that are not in touch with the T&C

product, such as governmental bodies, and those that are involved in the material flow, which are the stakeholders in our understanding. Making this distinction is valid but needs to be further fleshed out as currently certification authorities like GOTS are noted under the stakeholder requirements, although they are not part of that standard material flow.

Additionally, the senior manager at Deloitte gave feedback on the blockchain elements and their connection to the requirements, which relates to the coherence of our IT artifact. He pointed out that there was "only one [sub-group] that was blockchain-specific and that was the last one around decentralization" (JS1, 25:55), which he thought "could be extracted to governance or theory mechanism" (ibid.). Since we do not have a specific sub-group on governance in any of the requirement classes, this could be a potential group to add to capture these requirements. However, he also noted that the IT artifact "can be blockchain-specific, but [he] think[s] the model itself doesn't necessarily have to be technology-focused" (JS1, 27:08). His last comment here relates to an earlier point, namely that our model may be putting too much emphasis on the technological requirements, which, in the end, according to him, play a smaller role in the implementation. Countering this feedback to provide context, we did not anticipate this amount of technical requirements either since we assumed the case companies interviewed would not be as knowledgeable in this topic but the limited blockchain-specific requirements can be traced back to the point that we, in our first interview round, did not specifically ask for blockchain- or IoT-related needs but tried to keep it technologically neutral. Nonetheless, given the case companies' involvement in the Innomission project, some references to the two technologies were made which led to decentralization as a sub-group emerging.

The article on building a successful blockchain initiative (Alhaddad et al., 2020) points to similar areas of success for blockchain development, as it calls for "Technical feasibility", "User desirability", and "Business viability" and it adds the level of "Ecosystem achievability" (ibid.), which is a dimension that is not considered in our IT artifact/model. Thus, regarding the completeness and **generalizability** of our model, the senior manager at Deloitte suggested that this last dimension is missing "because at the end of the day, you can fulfill all the technical requirements. You can also ensure that the shareholder requirements organization by organization is fulfilled, and you can also comply with the regulatory environment. However, the hard thing is to understand the ecosystem and understand the value drivers of the entire ecosystem. Incentivising stakeholders to actually key in the right data and understand the value creation of that" (JS1, 12:21). Based on this feedback, we countered that we tried to encapsulate this in the *collaboration* sub-group of our stakeholder requirements and that the reason for not discovering the ecosystem dimension is related to the case companies not emphasizing this need or them not considering this higher-level point of view. As a reason for this not being emphasized by our case companies, the senior manager at Deloitte highlighted that “it’s a new discipline to have a kind of value ecosystem, value proposition or ecosystem mindset” (JS1, 16:07), so it is understandable that companies may not consider this dimension for now. Furthermore, although “it’s not a new thing that you outsource [...] and you have partners and all that” (ibid.) what is new to companies is “actually understanding that there are some problems that you cannot solve on your own” (ibid.). Getting the T&C companies to understand this ecosystem need would be something to consider for future research but lies outside the scope of our research as we focused on the needs that were generated bottom-up rather than top-down as suggested by the senior manager at Deloitte. Therefore, we consider the senior manager at Deloitte’s input on this additional dimension in isolation.

Furthermore, in terms of completeness, the senior manager at Deloitte noted that “there are a lot of people who have been thinking a lot about how to balance requirements [for a] solution [that fits] consumer needs” (JS1, 21:14). With this he wanted to encourage us to “build on top of models that [...] exist already” (ibid.) because he analyzed that our collection is representing “a very organizational centric model [that] takes the stands from the organization and out in the market” (ibid.). However, based on our research question and methodology, taking this bottom-up approach where the organizations’ needs were in focus was intentional. Nonetheless, from the senior manager at Deloitte point of view “adding the ecosystem dimension ensures that there’s a more [...] problem-oriented and not organizational-oriented focus” (ibid.), which would have required a different research approach as “it’s also a question of how [we] want to position it - [as] a problem-focused model or [...] an organizational-focused model or [...] a market-focused model” (ibid.). This insight was beneficial for us to reflect on the level of analysis that we took for our research and given the execution of DSR activities and by starting the design with interviews from specific T&C companies, we can confidently state that our IT artifact aims at representing a model that is organizational-focused. If we were to build a more problem-oriented model, we would “have the liberty to be a bit more high level [and] [...] have the liberty to take this kind of ecosystem approach where you actually optimize the value proposition of the ecosystem, rather than just for one company” (JS1, 23:21). However, as the requirements were collected from the companies with whom we validated the problems in their supply chain first, we believe that to some extent our model is problem-centered, as explained in our prelude for the starting point of our DSR process.

This ecosystem dimension would be critical for him to consider, more so than the technical part, which we, in his opinion, are “focusing too much on” (JS1, 14:34). Concerning putting less focus on the technical elements, thus evaluating our model's plausibility, he emphasized that "in reality, the technical requirements here when implementing them it is fairly small, but it's the alignment of stakeholders, it's the acceptance of data sharing, it's the governance model that is really key here, not the technical stuff" (JS1, 14:43). However, as pointed out above, we did not know in advance how many technical requirements we would collect in the first iteration and the fact that both GC and C2S can be traced back to their participation in the Innomission project so it may not be representative of what the "average" T&C company knows about blockchain and IoT.

We also asked the co-founder of Textile Pioneers to reflect upon our model's clarity, completeness, coherence, and plausibility of our requirement collection. When asking the co-founder of Textile Pioneers about the completeness of our requirements for the T&C industry, he confirmed that by talking to GC and C2S we managed to capture the needs that we would most likely also hear from other companies in the industry. This was emphasized by him because "the textile business is done [...] more or less the same way" (KR1, 33:19) so by "talking to the three of us [GC, C2S & Textile Pioneers], [he] think[s] [we] have a very good picture" (ibid.) and that he does not think that we "need to talk to a lot of others because they will come up with the same" (ibid.). Therefore, we can conclude/capture that in regards to the **generalizability of our model**, the co-founder of Textile Pioneers confirmed that the requirements we collected would resonate with other T&C companies of the industry.

For the stakeholder requirements specifically, he referred to those sub-groups that we titled with "Consumer" where it is not clear who that consumer is as it depends on the T&C company you are asking, which revealed some inclarity and incoherence of our model. For GC, we understood the consumer being the end-consumer of their own brand. However, for Textile Pioneers, for instance, the consumer would be Roskilde Festival who ordered T-shirts from Textile Pioneers. Why this matters for the requirements is that when another brand is your consumer, "then there will be some requirements from the brand owner" (KR1, 31:20), not just the end consumer who is the person wearing the clothing item and that would scan the DPR. Thereby, what is not captured in the stakeholder requirements is "the point of view from a company who is doing B2B, where the brand that is sold to also has requirements" (AK_KR1, 32:47). Additionally, this distinction or clarification in the "consumer" subgroups is not clear, thus missing from our visualization. To simplify our requirement collection, we need to acknowledge that we simplified the definition of "consumer" and focused on GC's own brands rather than their private label production. Nonetheless, it is valid input from the co-founder of Textile Pioneers that this spectrum of who the customer can be needs to be considered.

Regarding the technical requirements, the co-founder of Textile Pioneers placed a lot of emphasis on the interface of the DPR because “the main thing here is how you build up your interface [...] starting up with all the very important information and then [...] the more you scroll, the more nice-to-know data you get” (KR1, 42:05). This comment on the importance of the interface can be linked to the types of information that would exist for a DPR, how they need to be connectable and interoperable in a modular setup but at the same time protected via set access controls. Nonetheless, in regards to completeness, the co-founder of Textile Pioneers’ input suggests that there might be an additional sub-group of technical requirements that relates to the user experience and interface. Going into the details of which information exactly is to be shared, the levels of sensitivity for them and how it could best be presented was not within the scope of our paper but would be of interest for future research.

When comparing the two expert evaluations for the requirements collected, they had one feedback point that they agreed upon, namely the lack of the B2B cases considered as the brand owner’s needs are not reflected in the requirements thus far. In regards to the generalizability of our model, the two experts had very contrasting opinions as the co-founder of Textile Pioneers supported that we would get similar input and validation of requirements from other T&C companies in the industry. However, the senior manager at Deloitte believes that our model is too narrowly fit to the T&C companies interviewed and places emphasis on areas that are secondary when viewing the requirements from an ecosystem point of view that includes perspective from government bodies and tech companies. One of those areas that we focused too much on, according to the senior manager at Deloitte, namely the technical requirements, was an area that the co-founder of Textile Pioneers emphasized more by stating that the structure of the interface is pivotal, which indicates another feedback point that the experts disagreed upon.