CLOSING THE INFORMATION LOOP

– PRODUCT LIFECYCLE FEEDBACK IN SWEDEN'S TEXTILE VALUE CHAIN

Thesis for Two-Year Master, 30 ECTS
Textile Management

Majid Ali Alvi

2026.7.06

THE SWEDISH SCHOOL
OF TEXTILES
UNIVERSITY OF BORÅS

Title: Closing the Information Loop: Product Lifecycle Feedback in Sweden's Textile Value Chain.

Publication year: 2026

Author: Majid Ali Alvi

Supervisor: Jonas Larsson

Abstract

The transition from linear textile value chain to circular models is increasingly driven by regulatory pressures within the European Union, most notably the Ecodesign for Sustainable Products Regulation (ESPR) and the Digital Product Passport (DPP). These mandates act as primary catalysts for heightened information transparency and lifecycle-centric responsibility. However, the operationalization of system wide circularity is critically hindered by fragmentation inherent in textile production and consumption. This research highlights that such fragmentation leads to varying levels of Absorptive Capacity (ACAP) across Sweden's textile value chain. This in turn disrupts the critical feedback loops between Beginning-of-Life (BOL), Middle-of-Life (MOL), and End-of-Life (EOL) phases of the product journey.

Employing a qualitative abductive research design, this thesis explores the mechanisms of information exchange through semi-structured interviews with stakeholders in the Swedish textile sector. The study theoretically embeds the four stages of ACAP framework which includes acquisition, assimilation, transformation and exploitation with widely researched paradigm of Product Lifecycle Management to analyse how knowledge is captured, organized and reused across organizational boundaries.

Empirical findings reveal widespread information blackout occurring in post-sale phase. The current inability of BOL actors to acquire EOL data prevents the crucial transformation requirement in business processes, limiting Swedish retailers into a wait-and-see strategic posture, impeding circular transition. Furthermore, the study identifies traceability loss occurring in the recycling stage as garments are aggregated in heterogeneous batches for processing. Crucially, the value chain's reliance on uncodified tacit knowledge creates risk for organizational learning. To address these challenges, this study highlights the transition toward lifecycle-oriented product data models as the primary method to enhance ACAP. By internalizing comprehensive, bi-directional information loops, organizations can increase their internal capacity to process lifecycle data. The study concludes that the transition to circularity is primarily an information challenge, requiring the enhancement of organizational ACAP to close the product information loops

Keywords: Product Lifecycle Feedback, Absorptive Capacity, Product Lifecycle Management, Digital Product Passport, Textile and Clothing Value Chain.

Acknowledgements

This study would not have been possible without the valuable time given by the participants for the interviews. I would also like to express my sincere gratitude to my principal supervisor Jonas Larsson who guided me throughout the process.

Additionally, I want to thank my teachers for their guidance and thorough engagement throughout my master's journey. Finally, I extend my profound gratitude to my family and friends for their support, without whom this journey would not have been possible!

Table of contents

1 INTRODUCTION ..... - 1 -
1.1 PROBLEMATIZATION ..... - 2 -
1.2 RESEARCH GAP ..... - 3 -
1.3 PURPOSE ..... - 3 -
1.3.1 Research Questions ..... - 4 -
1.4 RESEARCH DELIMITATION ..... - 4 -
2 LITERATURE REVIEW ..... - 5 -
2.1 LIFECYCLE-CENTRIC EU REGULATIONS AND INFORMATION FLOWS ..... - 5 -
2.2 DATA, INFORMATION AND KNOWLEDGE ..... - 6 -
2.3 FEEDBACK LOOPS IN PRODUCT LIFECYCLE MANAGEMENT ..... - 6 -
2.3.1 Knowledge Capture ..... - 9 -
2.3.2 Knowledge Organization ..... - 10 -
2.3.3 Knowledge Reuse ..... - 11 -
3 THEORETICAL FRAMEWORK ..... - 13 -
3.1 ABSORPTIVE CAPACITY ..... - 13 -
3.1.1 Acquisition ..... - 14 -
3.1.2 Assimilation ..... - 15 -
3.1.3 Transformation ..... - 16 -
3.1.4 Exploitation ..... - 17 -
4 RESEARCH METHODOLOGY ..... - 18 -
4.1 RESEARCH DESIGN ..... - 18 -
4.2 SAMPLE SELECTION ..... - 19 -
4.3 CONCEPTUAL FRAMING AND CONSTRUCT ALIGNMENT ..... - 21 -
4.3.1 Thematic Consolidation and Guide Formulation ..... - 21 -
4.3.2 Interview Execution and Protocol Adaptation ..... - 22 -
4.4 PRINCIPLES OF QUALITATIVE ABSTRACTION ..... - 22 -
4.5 DATA COLLECTION ..... - 22 -
4.6 DATA ANALYSIS ..... - 23 -
4.7 DECLARATION OF USE OF AI ..... - 23 -
4.8 QUALITY OF RESEARCH ..... - 24 -
4.8.1 Trustworthiness ..... - 24 -
4.8.2 Credibility ..... - 25 -
4.8.3 Transferability ..... - 25 -
4.8.4 Confirmability ..... - 25 -
4.8.5 Dependability ..... - 26 -
5 FINDINGS ..... - 26 -
5.1.1 Strategic Vision and Lifecycle Goals ..... - 26 -
5.1.2 Product Lifecycle Information Flow. ..... - 27 -
5.1.3 Organizational Dynamics & External Knowledge ..... - 30 -
5.1.4 Product Aspect Improvement & Quality Optimization ..... - 32 -
5.1.5 Data Ecosystem, Storage & Integrated Orchestration ..... - 34 -
6 DISCUSSION ..... - 40 -
6.1 ACQUISITION ..... - 40 -
6.2 ASSIMILATION ..... - 43 -
6.3 TRANSFORMATION ..... - 45 -
6.4 EXPLOITATION ..... - 46 -
6.5 INTER-ORGANIZATIONAL FEEDBACK LOOPS ..... - 47 -
6.6 PLF AS A 4-STAGE SEQUENTIAL PROCESS ..... - 48 -
6.7 PLF IN 3-PHASE PLM FOR A TEXTILE VALUE CHAIN ..... - 50 -
7 CONCLUSION ..... - 51 -
7.1 LIMITATIONS ..... - 52 -
8 THEORETICAL CONTRIBUTION ..... - 53 -
9 MANAGERIAL IMPLICATION: ..... - 53 -

10 FUTURE RESEARCH..... - 54 -
REFERENCES: ..... - 55 -

1 Introduction

The study's background is first presented in this section, which is then followed by a problematization outlining the main concerns that need to be addressed. Next, it highlights the research deficit and describes the study's goal, and then the research questions are presented. To make the study's scope clear, the chapter concludes by defining the research delimitations.

The production and consumption of textiles have a negative impact on the environment and climate, resulting in enormous pressures from greenhouse gas emissions and resource use such as land and water. The average annual consumption of clothing, footwear, and household textiles in the European Union (EU) stands at 19 kilograms per person (EEA 2025a). As a result, EU textile consumption represents the third highest source of pressure on water and land use, and the fifth highest source of raw materials consumption and greenhouse gas emissions. While textile waste redirected to landfills in the EU decreased from 21% in 2010 to 12% in 2022, incineration rates concurrently increased from 10% to 15% during the same period (ibid.).

To tackle this problem, research highlights a systems perspective in operationalizing a lifecycle-based policy strategy intended to create the synergistic effects required for a transition to a Circular Economy (CE) (Milios 2018). The focus of EU policy instruments through a lifecycle approach in the production, consumption and waste management phases bridges the disconnect between resource efficiency and material circulation. Consequently, such a pathway for transition includes strengthening information flows for communication between actors in a value chain and reinforcing feedback loops. This is particularly achieved with the introduction of Digital Product Passport (DPP) in the Ecodesign for Sustainable Products Regulation (ESPR) (ESPR 2024).

To support implementation of ESPR in textiles, the European Parliamentary Research Service (EPRS) (2024) proposed a generic DPP model for textiles based on lifecycle approach to a product in the value chain from raw material, manufacturing to recycling. The study offers a phased-deployment scenario for EU-level DPP where the flow of information progressively becomes more complex and integrated. Within this context DPP is conceptualized to track and trace data through all stages of a product's lifecycle enabling value chain actors to rely on this lifecycle information to scale their industrial processes towards an efficient product lifecycle management (PLM) (Psarommatis & May 2024). This mechanism transforms a product, enriching it with information related to both its technical and operational traceability or provenance, resulting in improved product-related insights that can enhance decision-making in various processes (Harkonen, Guerrero Rodriguez & Mustonen 2024). This is particularly important when considering proposed sector-specific delegated acts of ESPR for textiles which call for standardized tests to determine product-aspects i.e. durability, repairability and recyclability of textile products (Joint Research Centre [JRC] 2025).

However, a lack of information flow between product lifecycle phases prevents effective lifecycle management due to loss of information and control of the product after point-of-sale terminal in an organization (Horn et al. 2023). Without such feedback loops the reliability and efficacy of standardized test results such as those used in proposed delegated acts in JRC (2025) become questionable at best. One important factor for enabling a product's lifecycle management in this context is the exchange of information about a product between all the actors in a product's lifecycle. Jäger-Roschko & Petersen (2022) argue that previous research on information sharing for CE can be used as the foundation for inter-organizational

information sharing between all actors. Information flows on Product Lifecycle Feedback (PLF) can allow actors to improve their design and manufacturing processes towards more durable, repairable and recyclable textile products (Jäger-Roschko & Petersen 2022). Additionally, Tai (2017) suggests that PLM systems enhance a firm's absorptive capacity (ACAP) by acting as a foundational capability for identifying, integrating, and exploiting external knowledge (Tai 2017). This approach may allow organizations to leverage external knowledge to refine not only their product lifecycle, but also the PLM systems and the operational routines that govern them.

Chapter one problematizes the research topic followed up identification of research gap, purpose and delimitation. Chapter 2 explores feedback loops in PLM systems. Followed by chapter three where theoretical framework is systematically explored followed by research methodology and findings. Discussion section synthesizes the findings considering the framework and proposes models for T&C value chain and maps feedback loops. Lastly conclusion is drawn to address the research question before highlighting theoretical contribution and managerial implication. Lastly, future research recommendation is illustrated based proposed models to further expand the scope of information flow.

1.1 Problematization

Researchers have aimed to bridge the gap between CE and sustainability for conceptual clarity by employing frameworks at organisation's strategic level which influence tactical and operational levels (Geissdoerfer, Savaget, Bocken & Hultink 2017; Puglieri et al. 2022). In a phased plan, a fully circular DPP by 2033 will require brands to record information beyond distribution to include usage, aftersales services, sorting and recycling while automating impact calculation for regulatory labelling (EPRS 2024). Additionally, the life cycle approach of EU policy instruments such as ESPR further reinforces the importance of information flows in a product's lifecycle (European Commission [EC] 2024a; 2024b). This approach is further supported by the proposed sector-specific data requirements for DPP in textiles (Joint Research Centre [JRC] 2025). This highlights the importance of information flow between various stakeholders such as design, manufacturing, use, end-of-life and circular activities such as repair, remanufacture and reuse

Feeding back a product's lifecycle information and decision from each phase (production, consumption, recycle) of a product's lifecycle referred to as "Voice of the Product" may enable access to valuable information and knowledge for improvement in various areas including quality and the value that is placed on a product based on its performance in each phase (Stark 2015).The information and knowledge gained from a product's lifecycle in all its phases help simulate or inform future decision making for related products (Morshedzadeh, Oscarsson, Ng, Jeusfeld & Sillanpaa 2018). To meet the requirements of these regulations, textile and clothing (T&C) companies will have to expand sources of information flows at inter-organizational levels covering all sources of all product lifecycle from design, manufacturing, use and recycling (Bufardi et al. 2007).

However, the textile and clothing (T&C) industry lacks transition frameworks for information sharing and coordination across a product's entire lifecycle (Thomas et al. 2024; Brydges 2021) which results in loss of control over products during use and end-of-life phases. The lack of product lifecycle feedback data also impedes the reliability of lifecycle assessment and costing studies in textile sector (Horn et al. 2023). Additionally, non-supportive organizational structures, lack of feedback channels and internal awareness have been identified as some of the critical barriers for inter-organizational information feedback

(Lindkvist Haziri, Sundin & Sakao 2019). Addressing structural limitations is important to enable continuous and circular information feedback across an entire value chain (Kurilova-Palisaitiene, Lindkvist & Sundin 2015). Leveraging ACAP can enhance a firm's capacity to acquire and assimilate external knowledge from partners and inter-organizational networks (Zou, Ertug & George 2018). This knowledge transfer further converts into an organization's commercial and financial gains where knowledge infrastructure i.e. technical systems for accessing and moving knowledge further enhances this process (.ibid).

1.2 Research Gap

While studies in operational research, environmental management, computer science and engineering focus on developing solutions to share information among all actors for remanufacturing, recycling and maintenance. Limited attention has been given to inter- and extra-organizational information flows in the context of product lifecycle feedback in T&C value chain in Sweden (Jäger-Roschko & Petersen 2022). Existing research on information flows for CE in textiles are being explored by various pilot projects and collaborations, they are largely focused on access to data generated in either design and production phase or actors for forward information flow (TrusTrace 2025; Wan & Jiang 2025; WRAP 2024). These limitations highlight the need for product lifecycle information feedback from organizational learning standpoint to understand how managers can identify value in feedback information flow. Such reverse information flow may improve product aspects in textile value chain and allow capture of real-world data to manage and optimize product lifecycle in terms, including but not limited to, durability, repairability and recyclability.

Understanding the state of a product over its complete lifecycle can help organizations understand the dynamics around its product aspects i.e. durability, repairability and recyclability. Product lifecycle feedback within Product Lifecycle Management (PLM) may facilitate in understanding product performance. Additionally, acquiring and exploiting feedback knowledge may also enable an organization to re-orient its functions at strategic, operational and tactical levels. Research on product lifecycle feedback (PLF) within PLM in T&C value chain has been underexplored. Additionally, a distinct research gap exists when exploring this feedback through the lens of an organization's absorptive capacity standpoint.

1.3 Purpose

To bridge this empirical gap, the purpose of this study is to explore how T&C organizations in Swedish textile value chain can absorb and operationalise Product Lifecycle Feedback (PLF) by leveraging information flow in PLM. Additionally, the study attempts to identify internal and external capabilities that support inter- and extra-organizational information flows. Furthermore, against the backdrop of shifting sustainability demands and circular economy regulations, this study aims to shed light on the managerial challenges and requirements across the four stages of Absorptive Capacity (ACAP) i.e. acquisition, assimilation, transformation and exploitation, to create pathways needed to exploit PLF information flows to optimize product durability, repairability and recyclability. As a result, the study attempts to investigate circular transition through description of information loops from an organizational management standpoint. Through this theoretical lens, this study addresses an unexamined viewpoint by offering new insights into the organizational management of closed-loop information systems, specifically through absorptive capacity and PLF integration within circular T&C value chain in Sweden.

1.3.1 Research Questions

To meet the objectives of this study, the following questions are answered:

RQ1: How are Product Lifecycle Feedback (PLF) loops currently structured and practiced in Swedish textile value chain?

RQ2: What organizational capabilities are required for textile firms in Sweden to operationalize product lifecycle feedback?

1.4 Research delimitation

The delimitation of this study defines the scope and boundaries for a focused analysis of Product Lifecycle Feedback (PLF) within the Swedish textile value chain. While this research is centered around the context of information flow and retrieval in Product Lifecycle Management (PLM) and Digital Product Passports (DPP), it does not conduct a technical or systems-oriented evaluation. The boundary is confined to the organizational management level, specifically investigating from an Absorptive Capacity (ACAP) standpoint of firm's acquisition, assimilation and transformation by utilizing lifecycle feedback in PLM to identify gaps in information flow and institutionalize learning processes to achieve CE routines.

To represent stages of a T&C lifecycle and information flow between them, this study draws from the field of engineering and informatics, the lifecycle stages as Beginning-of-Life (BOL), Middle-of-Life (MOL), End-of-Life (EOL) (Kiritsis, Bufardi & Xirouchakis 2003; Jun, Kiritsis & Xirouchakis 2007). The research analyses the role of manufacturer, retailer and recycler. While the primary geographical focus is centered on Swedish textile sector, a manufacturer from Pakistan is incorporated to illustrate the actual fragmented and global configuration of textile value chains (EPRS 2024). This inclusion allows the examination of inter-regional knowledge sharing tensions and causal ambiguities (Szulanski 1996) which often impedes information feedback. While maintaining a clear focus on intra and inter-organizational information flows and organizational learning routines in relation to PLF, consumers and sorters are excluded as direct participants. While identified as critical actors or nodes in the material flow, they are treated as indirect sources of feedback through interviewed management and IT experts.

Sorter is not included as direct participant primarily because sorting organization viewed the research focus on DPP enabled feedback as not directly applicable to their current day-to-today operations. This exclusion, while noted as delimitation, serves as an empirical finding itself, highlights a perception divergence in the implications of DPP for the downstream actors who do not perceive value in garment-level information flow.

Finally, the study is part of the system demonstrator project called "Systemdemonstrator för ett hållbart textilsystem" coordinated by the Science Park Borås at the University of Borås (Science Park Borås 2024; University of Borås 2025). Withing this scope, the study focuses specifically on information flows across textile value chain in the context of key product aspects prioritized by the Ecodesign for Sustainable Products Regulation (ESPR) which includes durability (robustness), repairability and recyclability (ESPR 2024; JRC 2025;). The analysis does not investigate broader operational strategies or consumer interactions unless they directly affect the lifecycle feedback. Theoretically, the study is bound by the constructs of ACAP (Zahra & George 2002) and PLM paradigm (Stark 2015; Kiritsis, Bufardi & Xirouchakis 2003). While alternate theories may highlight different insights, the ACAP lens

is chosen for its ability to reveal dynamics surrounding a firm's ability to acquire and exploit feedback knowledge through knowledge-based systems such as PLM ensuring the study progresses with both research and managerial implications for Sweden's textile value chain.

2 Literature Review

This section reviews literature on EUs lifecycle-centric approach to T&C industry as pathway to achieve circular economy. Subsequently literature on product lifecycle management and feedback loops is explored..

2.1 Lifecycle-centric EU regulations and information flows

To address the negative environmental impacts of the textile value chain, researchers emphasize the necessity of extending garment lifespans (Niinimäki et al. 2020). As a result, CE has become a central mechanism for European policymakers that drives foundational as well as incrementally phased regulations and strategies for a sustainable future (EPRS 2024; ESPR 2024; Maitre-Ekern & Dalhammar 2016). By conceptually integrating environmental and economic sustainability pillars, CE provides the frameworks that can guide organizational strategies systematically and coherently at strategic, tactical and operational levels (Acevedo et al. 2024; Geissdoerfer et al. 2017; Puglieri et al. 2022).

Although guidelines for product development tests, performance standards, and failure thresholds are framed for cross functional routine implementation to help delay or prevent garment failure (Apparel and Footwear PEFCR Technical Secretariat 2025; JRC 2025; WRAP 2021). Efficacy of such a lifecycle approach requires coordination across functional areas within an organization as well as across organizational boundaries (Cooper et al. 2014).

As a result, this coordination requires significant information flows once product passes the point-of-sale terminal into use, and other lifecycle stages. According to Swedish Environmental Protection Agency (SEPA), Sweden reported over 4,000 tons of reused textiles in 2021 using mixed methodologies while noting inability to identify all public reuse initiatives. This inability to track products in the textile value chain may not only hinder an efficient circularization of material but also hinder product lifecycle feedback from real environments.

Findings from pilot projects exploring data and information flows demonstrate that firms adopt heterogenous data strategies driven by their individual sustainability strategies and goals, even when operating under identical regulatory frameworks (TrusTrace 2025). Within these firms, actors primarily focus on impact and compliance metrics. This demands cross-functional business collaboration to map processes, gather data and monitor progress. Whereas Digital Product Passport (DPP) within ESPR (2024) has been positioned as a key mechanism for enabling EU's circular market extending tracking requirements to downstream phases, capturing post-sale data on product durability, repairability, recyclability and end-of-life handling (TrusTrace & Trace4Value 2023). Additionally, the dynamics and value around information are recognized factors in enabling actors and processes in a value chain for operational capabilities (Sandberg 2023; Sandberg, Pal & Hemilä 2018). In this context, it is crucial to clearly distinguish between data, information, and knowledge to understand how organizational learning can facilitate turning product lifecycle feedback metrics into knowledge within PLM.

2.2 Data, Information and Knowledge

To explore how Product Lifecycle Feedback (PLF) can be leveraged for operational capabilities in Swedish T&C value chain, it is vital that data, information and knowledge be distinguished in their evolving nature and its use in organizations.

At base of this structure, data represents the most fundamental layer, characterised as unprocessed numbers, words or letters lacking any spatial and temporal relevance (Uriarte 2008). In the textile industry, the Digital Product Passport (DPP) functions as a database for raw data such as unique material code or batch identified which remains unchanged and lacks useful value until it is specifically analysed within a given framework (EPRS 2024).

Information is created when unprocessed data is structured and contextualized, facilitating the recognition of connections among various data points (Uriarte 2008). Although Information provides the descriptive meaning for the present, its nature is static or linear, allowing limited prediction for future strategic moves (.ibid). Whereas, in the context of PLM, this relates to the static data in BOL phase, such as initial design specifications or the Bill of Materials (BOM) (Xu et al. 2009). While information indicates a recognized connection among data points, it often remains confined in so-called "data-silos" within each department detached from cross-functional units (Stark, 2015).

Knowledge occurs when information is further processed to discover and establish broad patterns of relations, creating a self-contextualizing and dynamic capital (Uriarte 2008). In contrast to information, knowledge offers foresight, acting as a strategic asset that allows an organization to address specific operational circumstances and sustain a competitive edge (Uriarte 2008; Zahra & George 2002). For this study, knowledge is defined as the conversion of dynamic field data i.e. the active information produced during the Middle-of-Life (MOL) and End-of-Life (EOL) stages which can be formalized as organizational practices (Xu et al. 2009; Zahra & George 2002). Managing this knowledge requires continuous interaction between explicit knowledge that is documented in records and systems as well as tacit knowledge that resides within individual cognitive structures (Uriarte 2008). Through a continuous and bi-directional transformation between these two modes of knowledge where personal insights can develop into collective knowledge and visa versa, may serve as a vital shift for institutionalizing circular innovation (Uriarte 2008).

The efficacy of a circular PLM may hinge on an organizational capacity to evolve from simple document management to the ability to reuse knowledge from across the entire lifecycle of a product (Ameri & Dutta 2005). This transition is often impeded by an organization's inability to fully integrate newly acquired technologies in the absence of know-how and know-what (Szulanski 1996; Fichman & Kemerer 1999). As a result, an organization may require a higher degree of ACAP to recognize the significance of incoming lifecycle data or information and integrate it into current knowledge stock or database and utilize it to enhance product-aspects or characteristics such as durability and recyclability (Zahra & George 2002). While the PLM offers the technical framework and data, ACAP provides the organizational capacity to transform the data into specialized knowledge necessary for a genuine circular transformation (Tai 2017).

2.3 Feedback Loops in Product Lifecycle Management

In the context of CE, PLM and organizational frameworks can capture contextually important data during manufacturing that is often lost or hidden within firm boundaries. The T&C

industry has been highlighted in this regard in its ability to repurpose post-industrial fabric scraps into new products without breaking the material down to basic components through collaborative organizational learning within each industry (Halstenberg, Lindow & Stark 2017). This shows that sharing lifecycle data preserves added processing value with minimal reconversion.

Product Lifecycle Management (PLM) is defined as "an integrated information-driven approach comprised of people, processes/practices, and technology to all aspects of a product's life and its environment, from its design through manufacture, deployment and maintenance, culminating in the product's removal from service and final disposal" (Grieves, 2011). Utilizing resources to leverage PLM can validate strategic and tactical aims at various organizational levels by meeting or exceeding corporate goals (Walton et al. 2013). At its core, PLM functions as a process that supports the capture, organization, and reuse of knowledge throughout the product lifecycle (Ameri & Dutta 2005). For the objectives of this study this framework is seen as a sequential process of knowledge management loop for a product's lifecycle.

To enhance this knowledge-centric framework, information systems and technological infrastructure must facilitate data flows across both internal and external boundaries. Defining knowledge perspectives is crucial for aligning knowledge management strategy with IT infrastructure which traditionally prioritized the codification and management of explicit organizational knowledge (Alavi & Leidner 2001). In the context of PLM, this knowledge usually follows the product throughout its lifecycle from conception to end-of-life. Within PLM, it is crucial to distinguish two types of traceability at an operational level. Technical traceability, which relates to the ability of PDM/PLM systems to capture and reuse technical product design and manufacturing data from across lifecycle changes, and operational traceability, which records supply chain data tracking a specific product and its components through value-adding stages in a network (Harkonen, Guerrero Rodriguez & Mustonen 2024).

The efficacy of these traceability initiatives is often characterized by the architecture of the PLM system, which can be either-document-oriented or product (relational)-data oriented (David & Rowe 2016). While document-oriented systems are generally suited for methodical workflows and produce numerous intermediary documents (ibid.). Conversely, data-oriented systems are more effective in managing range complexity and variation management, which are the primary requirements within the fashion industry as that allows better integration with Enterprise Resource Planning (ERP) systems to enable faster time-to-market and improved procurement tracking (ibid).

Additionally, facilitating inter-organizational data exchange through technologies such as RFID, Blockchain, Digital Twins and specialized databases requires greater integration among functional units, improved collaboration and better data quality (Jäger-Roschko & Petersen 2022). Where sharing technical traceability data generally focuses on handling both static lifecycle data, and detailed runtime, maintenance or recycling data known as dynamic data (.ibid). This data flow is further characterized by vertical and horizontal closed loops where information generated at any point in the lifecycle can be referred to by various actors or updated and returned to the process for reuse (Jun & Kiritsis 2012). Horizontally, information flows forward from the Beginning-of-Life (BOL) to provide advanced knowledge to successive experts in Middle-of-Life (MOL) and End-of-Life (EOL phases. Whereas reverse flows provide field data back to designers to improve BOL decision-making (ibid.)

Such a closed-loop PLM paradigm was notably proposed by Project PROMISE, which utilized smart embedded systems to capture and utilize lifecycle information across the BOL, MOL and EOL phases (Kiritsis, Bufardi & Xirouchakis 2003). By closing these information loops for feedback, organizations can leverage Design for X (DfX) methods, such as design for environment or recycling to create a pathway for more sustainable and competitive products (Kiritsis 2011). Leveraging this technical and operational data flow facilitates incremental improvement in progressive iterations of a product. Incorporating field data or dynamic data to modify product designs represents a carefully thought-out information feedback process driven by developers to enhance lifecycle performance (Wellsandt, Hribernik & Thoben 2015). In PLM, the Middle-of-Life (MOL) information includes any product-related data generated after a product is sold to the end customer and before it ceases to be useful to the user (ibid.).

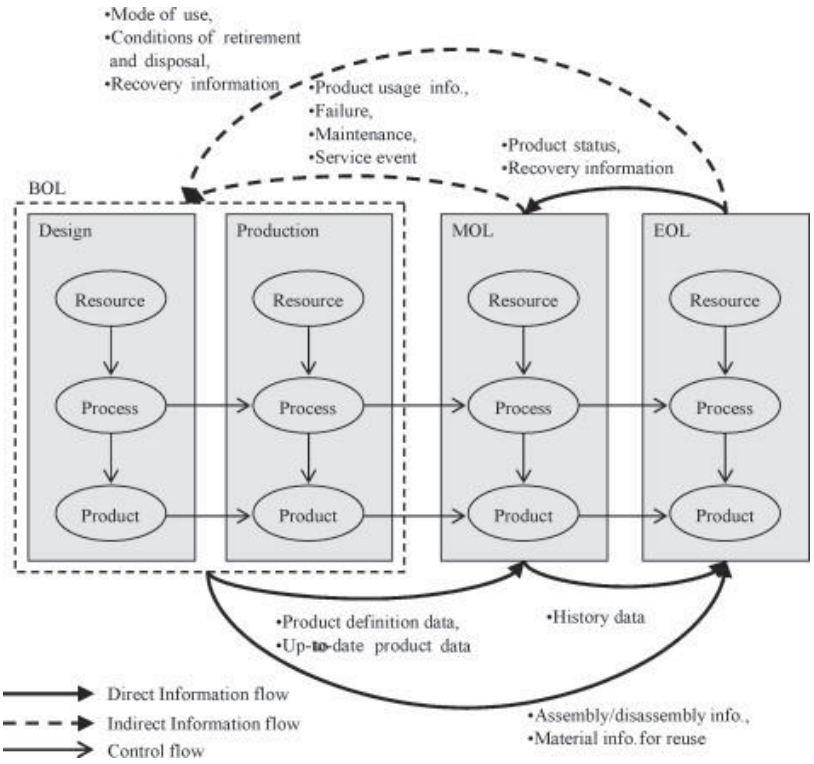

Figure 1 Feedback information flows in PLM (Jun, Kiritsis & Xirouchakis 2007)

To ensure that this heterogenous data can be understood across value chain actors and machines, formal languages such as Unified Modeling Language (UML) are used to create structural and behavioral visualization of the system (Booch et al. 1999). To overcome limitations in UML regarding reasoning and interoperability, research suggests transforming these models into ontologies using Web Ontology Language (OWL-DL) (Matsokis & Kiritsis 2011). Such an ontology-based approach allows for automated reasons and the exchange of data through classes like Field_Data, Event and Activity, which capture MOL performance and maintenance data to provide inputs for Decision Support Systems (DSS) across various organizational functions (ibid.). This shows that the volume of information exchange required depends on a firm's overarching strategy which guides decisions, such as, which connected capabilities to offer or how much functionality needs to be embedded in the product and in the cloud (Porter & Heppelmann 2014). These choices further unlock strategic opportunities for the organization to institutionalize or routinize circular innovation (.ibid).

2.3.1 Knowledge Capture

Within PLM, knowledge capture is the first stage in knowledge management loop, involving systematic identification and collection of insights from both internal and external sources (Ameri and Dutta 2005). A critical distinction is drawn between passive data, which is static information fixed during BOL phase and active data, which represents dynamic field data generated during MOL and EOL phases (Jun, Kiritsis & Xirouchakis 2007) referred to as feedback loops for this study. As capturing active data is critical for circular textiles, Scheidt and Zong (1994) highlight that a major impediment to high-level recycling and reuse is the absence of life history data which leaves operators unable to evaluate a used garment's residual quality or functional value. To overcome this bottleneck a modular product design is required based on standardized data capture formats and a multi-tier architecture comprising of external actor layer, a business logic layer, and a database management system (DBMS) to systematically capture and process continuous Product Lifecycle Feedback (PLF) (.ibid). In the context of textiles, actors in the external layer MOL and EOLs comprise of consumers, collectors, sorters and recyclers. More recently, pilot projects are testing data points and information flow to generate strategies for new value creation and value capture (Pal & Sandberg 2024; Interior Cluster Sweden n.d. University of Borås n.d.).

To execute such a capturing process in supply chains, standardised identification and tracking infrastructure may be required to collect dynamic field data across diverse actors. A raw dynamic data whether it is captured as point-in-time metrics or as a continuous event log must be formatted through standardized schemas such as XML to structure data hierarchies and prevent processing errors (Scheidt & Zong 1994). To maintain a digital link with the product to collect field data for feedback across organizational boundaries, open standards like EPCglobal network can be leveraged to capturing this information across organizational boundaries (Shih et al. 2005; GS1 n.d.). This capturing architecture utilizes a 96-bit Electronic Product Code (EPC) embedded in RFID tags, link physical garments to online data repositories via Savant middleware, EPC Information Services (EPC-IS), and the Object Naming Service (ONS), allowing real-time lifecycle history to be recorded, queried and retrieved on demand or in an event (ibid.).

Once a dynamic field data is captured, modern big-data architectures can utilize data lakes to store lifecycle data from heterogenous sources in varying structures efficiently without losing crucial details (Sreepathy et al. 2024). Traditional database storage methods relied on a "Schema on Write" approach leveraging the concept of Extract, Transform and Load (ETL), which transforms and filters data upon capture, discarding details that could prove to be valuable at a later point in time. In contrast, data lakes use an Extract, Load and Transform (ELT) workflow under a "Schema on Read" methodology, capturing and retaining data in its raw, unrefined state (ibid.). This approach postpones data transformation until specific operational needs arise, ensuring that the captured raw field data can be re-evaluated for different downstream circular decisions over time, saving unnecessary compute cost and available system redundancy (Zagan & Danubianu 2019; Pal & Sandberg 2024).

However, capturing raw data or information through technical systems does not automatically mean its translation to organizational knowledge. This requires an internal capacity to interpret, and operationalise data-centric workflows, based on what has been captured (Kougka, Gounaris & Simitsis 2018). Product development is an iterative, complex process where early cradle-to-grave choices dictate overall lifecycle performance (Tayaran & Schiffauerova 2012). While firms can acquire external knowledge and data streams through market mechanisms or supply chain linkages, external input alone may not always yield a

sustainable competitive advantage (.ibid). To capture and internalize this external information, a firm must possess sufficient R&D to build its ACAP which is the organizational capability to recognize, assimilate and exploit incoming lifecycle data into data-centric workflows (Tayaran & Schiffauerova 2012; Cohen & Levinthal 1990; Zahra & George 2002). Without a strong ACAP, a firm's ability to turn captured field data into meaningful design adaptations may degrade over time.

Lastly, the systematic capture of lifecycle information across textile value chain depends on standardized data exchange protocols and domain ontologies. Seamless information capture has historically been hindered by lack of awareness about standardized data formats in textile and fashion industry (Bindi et al 2018). Whereas, early initiatives like EBiz-TCF (CWA 1667:2013) and recent frameworks agreements like CWA 18291:2025 which include ongoing initiatives such as CISUTAC and PESCO-UP have established structured data-gathering protocols to help firms especially SMEs prepare for regulatory mandates such as the Digital Product Passport (DPP), CSDDD, and the Green Claims Directive (De Sabbata, Scalia & Baker 2008; European Committee for Standardization 2025; PESCO-UP n.d; CISUTAC n.d.).

Despite such advances, circular economy semantic web techniques in textiles remain in an evolving state, as many frameworks still lack explicit channels from all lifecycle phases for product lifecycle feedback to optimize durability, repairability, recyclability amongst other product and operational aspects (Trick Consortium 2023; Li et al. 2023). Addressing these gaps, recent domain mappings in other industries categorize PLF across BOL, MOL and EOL as primary ontologies, illustrating explicit pathways to enable feedback and multidirectional communication with individual consumers, business clients and external value chain stakeholders directly into structured and unified PLM systems (May et al 2022). In the context of T&C value chain, external stakeholders such as collectors, resellers, sorters and recyclers have been well recorded for their potential to generate value (Pal & Sandberg 2024).

2.3.2 Knowledge Organization

Following the systematic capture of internal and external data, the management of content through knowledge organization becomes a critical pillar for ensuring stored information is retrievable and actionable (Uriarte 2008). This organization can be described as a two-stage process, first dividing captured information into management units where the degree of granularity may be carefully determined to balance cataloguing effort with retrieval precision. Secondly, to categorize these units through systematic taxonomies or knowledge maps (Uriarte 2008; Alavi & Leidner 2001).

Technical interoperability during organizational phase is often supported by standard markup languages such as XML, which facilitate the interchange of structured documents across the internet (Uriarte 2008). This structured approach is important for transforming PLM into computational knowledge management system (KMS) which enables the effective representation and reuse of product-related knowledge across an organization (d'Avolio, Bandinelli & Rinaldi 2015). Furthermore, a modern PLM knowledge base is characterized not as a single centralized repository, but as an interconnected network of dispersed repositories virtually unified through IT solutions, aimed at closing knowledge loops between all stakeholders (.ibid).

Beyond PLM, firm's master data management and data governance can support its knowledge organization by transforming fragmented data into structured information through cross-functional data models, metadata management and data lineage (Kalluri et al., 2025).

Complementing these data frameworks, the historical evolution of database management systems from early relational models to modern NoSQL and NewSQL models supports this infrastructure to incorporate complex data models in a firm's operational architecture (Patel, Choudhary & Patil 2023). As a result, moderns database systems keep live transactions accurate through strict ACID rules, while using adaptive schemas to easily handle changing company data requirements. Recent innovations like data fabric, data mesh and Artificial Intelligence-driven metadata engines further enhance this by ensuring that knowledge assets remain contextually coherent and traceable across the data ecosystem (Kalluri et al., 2025).

Moving beyond static data, organization must utilize data aggregation and harmonization layers that collect heterogenous information such as sensor data, operation parameters, and service reports and reconcile inconsistent attribute names into unified format to avoid data redundancy (Abramovici & Lindner 2011; Sreepathy). Models, based on STEP standards, may allow designers to aggregate use-phase incidents and failures into comprehensive product-type data models, providing a high-level or aggregated view of product behavior in its lifecycle (Abramovici & Lindner 2011). Advanced frameworks in other fields have further expanded traditional PDM models by adding dimensions for usage and service delivery phases, incorporating roles for customers and suppliers, and integrating management processes such as PLF and operational decision-making (Abromivici et al. 2009).

The strategic value of organized knowledge is further enhanced through the integration of semantic technologies and graph databases, which allow for more complex relationships between documents and products than traditional hierarchical systems (Abramovici et al. 2016). Additionally, by utilizing Natural Language Processing (NLP) and semantic parsing, search time is reduced significantly by allowing specific use- and post-use-phase information to be accessed by non-technical personnel such as designers with ease using natural language during operations (Abramovici et al. 2016). Lastly, knowledge organization is a social process dependent on employee attitudes, its success depends on socio-technical infrastructure to increase the rate of knowledge accumulation and institutionalizing learning at the chain level within the textile industry (d'Avolio, Bandinelli and Rinaldi, 2015; Uriarte, 2008).

2.3.3 Knowledge Reuse

Following the systematic organization of content, the final stage of the lifecycle knowledge loop is knowledge reuse, where captured and stored insights are applied to improve decision-making and enhance product performance across successive iterations (Ameri & Dutta 2005). The reuse of information within PLM paradigm is derived from field trials and previous generations which provides the basic intelligence necessary for designers and manufacturers to address environmental concerns and develop effective eco-design strategies (Abramovici & Lindner 2011). More specifically, utilizing dynamic field data enables managers and designers to explore innovative parameters for the next generation of consumer products, ensuring that design iterations are grounded in real-world performance metrics rather than theoretical assumptions (Welllsandt, Hribernik & Thoben 2018).

However, the mere availability of knowledge within repository does not guarantee its effective usage or reuse. Knowledge reuse is considerably impeded by organizational silos or a lack of individual engagement. Therefore, firms must actively encourage the reuse of shared insights through motivational instruments and integrated technological infrastructures (Uriarte 2008). Beyond software applications, management techniques such as incorporating knowledge sharing contributions into personnel annual performance evaluations or providing financial incentives are essential to institutionalize or routinize a culture where shared

expertise is viewed as a strategic asset (Uriarte 2008; d'Avolio, Bandinelli and Rinaldi 2015). The success of such initiatives heavily relies upon employee attitudes and social interaction between subunits in an organization (d'Avolio, Bandinelli and Rinaldi 2015).

To operationalize this reuse at a technical level, research highlights Feedback Assistance Systems that collect objective information such as sensor data and maintenance events directly from products during MOL phase (Dienst, Fathi, Abramovici & Lindner 2011). While feedback systems enabled by embedded sensor technologies have historically dominated higher value industrial sectors as compared textiles, laundry-rated sensors have become increasingly cost-effective and commercially viable for T&C applications (Avery Dennison n.d.; Primo1D n.d.; RAIN Alliance 2026). This technological evolution allows research from complex engineering domains to be explored from adaption into textile value chains.

Such architecture usually follows a three-layer model: a data creation layer (field feedback), a data layer (where unique serial numbers act as primary keys for interchange), and a data access layer where designers and manufacturers retrieve diagnostic tools through the PLM interface (ibid.). By transforming raw use-data and combining it with existing master data, organizations can identify not only that a product has failed, but also the specific causal relationships behind the failure, allowing for targeted improvements in future product generations (Dienst et al. 2011; Wellsandt, Hribernik & Thoben 2015).

Effetive reuse also entails a shift from a fragmented view of the forward supply chain to a comprehensive complete lifecycle view (Xu et al. 2009). In the context of broader supply chain configurations, research highlights closed-loop frameworks that harmonize information flows across three lifecycle stages i.e. BOL, MOL and EOL. This model identifies three primary process-level feedback loops i.e. maintenance feedback within MOL, recovery decision feedback from MOL to EOL, and design improvement feedback flowing from all downstream stages to BOL. Research must transition from partial, forward-only supply chain perspectives to comprehensive, whole-lifecycle architectures using RFID and related tracking technologies (Jun & Kiritsis 2012; Xu et al 2009).

Within T&C value chain, these feedback loops convey critical product lifecycle information such as concurrent engineering criteria and sorting parameters directly to BOL designers and manufacturers (Pal 2017). As a result, such information flow allows insight into product performance, facilitating knowledge reuse in continuous product lifecycle optimization and guiding maximum value capture across the lifecycle (ibid). As integration options become more prevalent in all lifecycle phases, knowledge from multiple actors in a chain can be unified to operationalize collaborative DSS to enhance network capabilities (Pal 2017; Matsokis & Kiritsis 2011; Specim 2026). However, managing post-sale feedback introduces significant complexity. Dynamic operational data generated during MOL and EOL rapidly inflates data volumes and compounds existing fragmentation across CAD drawings, 3D modelling, technical files and unstructured records (Xu et al. 2009; Casciani, Chkanikova and Pal, 2022).

Additionally, lifecycle tracking continues to suffer from semantic inconsistency (different meanings assigned to identical data elements) and structural heterogeneity across systems (.ibid). To solve these barriers Xu et al (2009) emphasize on using Product Data and Knowledge Management (PDKM) system which utilizes data/information transformers. This

system processes static BOL specifications alongside MOL/EOL field data across structured, semi-structured, and unstructured data from all phases of the lifecycle (ibid.). By leveraging closed-loop supply chain information which may range from maintenance in the MOL phase to recovery decisions in the EOL phase, firms can reuse knowledge BOL Design for X (DfX) methods to enhance durability, repairability and recyclability (Xu et al. 2009; Kiritsis 2011)

Lastly, the reuse of knowledge in design is particularly crucial within Product-Service Systems (PSS), where in-service feedback can be leveraged to identify latent design errors or flaws that would otherwise remain hidden from designers and manufacturers (Zhang et al. 2012). The need to capture operational feedback to improve integrated services is more pronounced in Product-Service System (PSS) business models. Zhang et al. (2012) presents a four-layer PSS design knowledge management framework comprising an application (retrieval) layer, a process-task (modelling) layer, a meta-knowledge (representation) layer, and a shared ontology layer. Their model highlights that in-service or use-phase feedback is vital for identifying latent design defects and reducing long-term servicing overhead (ibid.). More importantly, to transform informal field feedback into routinized organizational memory, person-to-person knowledge transfers (tacit knowledge) must be systematically codified into formal management software representations (explicit knowledge) (Uriarte 2008; Zhang et al. 2012). Furthermore, collaborative decision making can enhance operations through regular information exchange resulting in improved network performance (Pal 2016). By routinizing these feedback loops in data-centric workflows, organizations can reduce future service costs and bridge the gap between initial design intent and actual lifecycle performance, ensuring re-orientation towards lifecycle approach and reducing friction with EU policy strategy in the long term (Zhang et al. 2012; Zahra & George 2002; Kougka, Gounaris & Simitsis 2018; Milios 2018).

3 Theoretical Framework

To move beyond a purely technical understanding of PLM and DPP, this study employs a theoretical lens that accounts for the organizational capabilities required as a pathway to leverage explicit systems for circular transition. While the previous chapter established the regulatory and technical infrastructure for Product Lifecycle Feedback (PLF), the successful implementation of closed-loop systems in the Swedish textile value chain will depend on how firms internalize, process and act upon new information (Tai 2017). By processing and internalizing this information firms may in turn reduce the causal ambiguities in product failures (Szulanski 1996). This study, therefore, incorporates the concepts of information systems with organizational learning theory to explore synergy between technical data flow and the cognitive structure of the firm (Geissdoerfer et al. 2018). By focusing on the organizational management of knowledge, the framework aims to identify the specific capabilities needed to bridge the gap between initial design and actual product performance in real-world environments.

3.1 Absorptive Capacity

The primary theoretical construct used in this study is Absorptive Capacity (ACAP), which provides a framework for understanding how organizations identify and exploit external knowledge to drive innovation and maintain competitive advantage. The origins of ACAP are traced back research on technology transfer, where it was established that the success of knowledge acquisition is deterministic on underlying societal, organizational and strategic factors which vary for both transmitting and receiving entities (Kedia & Bhagat 1990).

Building upon this, the concept was more pronounced by Cohen and Levinthal (1990), who defined ACP as a firm's ability to recognize the value of new, external information, assimilate it and apply it for commercial purposes. Crucially, they argued that this capacity is largely a function of a firm's prior related knowledge, which creates the foundational memory necessary to process new signals from its environments (Cohen & Levinthal 1990; Volbreda, Foss & Lyles 2010).

In the context of this study, ACAP is viewed through the reconceptualized framework of Zahra and George (2002), which while distinguish between potential capacity (PACAP) (acquisition and assimilation) and realized capacity (RACAP) (transformation and exploitation), keep it linear and sequential. This four-stage sequential process is essential for leveraging PLM systems, as it defines the organizational routines required to turn the dynamic field data which is the active information generation in MOL and EOL phases into actionable insights (Xu et al. 2009; Zahra & George 2002). When feedback in PLM is evaluated from the lens of ACAP, such feedback mechanism automates the acquisition of external use data directly from consumer environment, eliminating the search cost associated with monitoring field performance (Dienst et al. 2011; Zahra & George 2002). The strategic importance of ACAP is in its ability to highlight internal assimilation gaps, causal ambiguities that occurs repeatedly especially when feedback from product's use and post-use phase to BOL actors is being explored (Fichman and Kemerer 1999; Szulanski 1996). Within PLM systems, a firm's capacity to adapt to changing environments via information feedback as pathway to CE transition may depend on its ACAP to learn and innovate its routine information flow in the form of common industry best practices or uniquely tailored organizational processes (Walter et al. 2023).

The efficacy of ACAP in the textile value chain can be further examined by the interaction between tacit knowledge that reside in cognitive structure of individuals, and explicit knowledge, codified in management systems such as PLM in this study (Uriarte 2008). To achieve circularity, organizations must facilitate a spiral process of conversion where person-to-person insights regarding product durability or repairability are converted into formal representations within PLM database (Zhang et al. 2012). Without this foundational internal expertise and the ability to bridge these knowledge types, firms can risk being reactive or conservative exploiters who only address failures when they become detrimental to financial viability, rather than proactive exploiters who in this case may use PLF to innovate for a circular future (Cohen & Levinthal 1990; Zahra & George 2002).

3.1.1 Acquisition

As the first sequential phase of a firm's potential ACAP, acquisition refers to an organizations ability to identify and acquire externally generated knowledge that is critical to its operations (Zahra & George 2002). Within the paradigm of PLM, this stage represents the organizational routine that operationalizes the technical knowledge capture phase discussed in previous chapter. To get a good result, acquisition will depend on the point of entry for new information and the underlying managerial knowledge that is required to recognize its value (Boynton, Zmud & Jacobs 1994). In textile value chain that is often fragmented, information flows from diverse geographical locations such as a manufacturer in Pakistan to a retailer in Sweden. This in turn requires knowledge overlap between IT capabilities and business needs to ensure that external trends and dynamic field data are fully internalized by the firm (ibid.; EPRS 2024).

The primary input for this process would be prior related knowledge, which would act as a filter for screening, refining, synthesizing etc., external signal from noise to value (Cohen & Levinthal 1990). As Keller (1996) contends that while an organization may be successful in its acquisition of specific technology, in this case integration of PLF to build data pipelines for PLM, it may fail to acquire the underlying "know-how" required to utilize the data it generates or put it to commercial use. Mowery, Oxley and Silverman (1996) demonstrate that technology or capability transfer in different types of alliances do not occur automatically but are conditional on pre-existing overlapping knowledge, technology and other factors such as geography, firm size and culture. Thus, the development of ACAP within a firm builds over time and is path-dependent (ibid). Therefore, understanding this clear separation is vital for Sweden's textile circular transition meaning, possessing the digital link to a product is insufficient if the firm lacks the intra and inter-organizational knowledge and technological overlap in its value chain to interpret the feedback regarding material degradation, repairability or the information from broader lifecycle strategy (Keller 1996; JRC 2025; Milios 2018).

Furthermore, the acquisition of knowledge does not always follow a linear path of internal R&D; it can be accelerated through proactive crisis construction and migratory knowledge (Kim 1998). Hyundai's model of inverted R&D which is moving from assembly to design and then to research shows how textile firms might first acquire explicit knowledge via licensing or hiring (.ibid). By inducing such intensity of effort, organizations can bridge the gap between simple technology adoption and acquisition of tacit know-how. This would build the foundational knowledge stocks and technical alignment across a value chain necessary to achieve technology-driven Product Lifecycle Management leading to optimizing products circular pathways (.ibid; Zahra & George 2002). Finally, an effective acquisition would ensure that the voice of the product as explained by Stark (2015) is captured through Product Lifecycle Feedback and is recognized as a strategic enabling data pipeline than just a technical noise.

3.1.2 Assimilation

Building upon the successful acquisition of external signals, assimilation represents the organizational routines and processes that allow a firm to analyse, process, interpret and understand the information it has internalized (Zahra & George 2002). Within the PLM paradigm as an explicit system, this stage would correspond to "Knowledge Organization", where raw dynamic field data would be transformed into a structured format that aligns with the organizations existing cognitive systems and knowledgebase (Dodgson 1993). The efficacy of this stage is contingent on a firm's prior related knowledge, which provides the necessary context to categorize incoming product lifecycle feedback loops from a garments MOL Phase and transform it into commercial intelligence for design or other subunits in BOL phase (Cohen & Levinthal 1990; Dodgson 1993).

A critical challenge identifying the Swedish textile value chain's circular transition is the prevalence of the assimilation gap (Fichman & Kemerer 1999). This phenomenon occurs when there is a significant lag between technological acquisition of an organization(s), in this case acquisition of DPP for PLM systems in a Swedish textile value chain, and its actual deployment across all organizational subunits (.ibid). While a firm may acquire the technical infrastructure to capture lifecycle feedback, knowledge barriers and internal stickiness often impede the diffusion of this information to the designers and product developers who may require it (Szulanski 1996; Fichman & Kemerer 1999). To bridge this gap, firms must create routines beyond single-loop learning which focuses on detecting and correcting immediate

errors and towards double-loop learning, where the underlying norms, policies and objectives of the product development process are modified, in this case based on lifecycle insights (Dodgson 1993; Milios 2018).

Furthermore, the assimilation of knowledge in a globalized value chain is influenced by the relative absorptive capacity between partners (Lane & Lubatkin 1998). For a Swedish retailer to effectively assimilate feedback from recycler at the EOL or a manufacturer in Pakistan at the BOL, a degree of similarity in their know-what (knowledge), Know-why (dominant logics), and know-how (knowledge processing systems) (.ibid). The similarity in how these organizations allocate tasks and rewards may facilitate the internalization of know-how (processing) and know-why (logic), enabling a more cohesive interpretation of product durability and recyclability metrics (Lane & Lubatkin 1998; Wellsandt, Hribernik & Thoben 2015). Beyond structural and processing similarities or overlap, Expósito-Langa et al. (2015) demonstrate in a regional context that cognitive social capital in the form of shared vision can act as a vital moderator that enhances a firm's ACAP. Their findings suggest that when actors share explicit goals and collective aspiration, communication barriers dissolve enabling firms to process, interpret and exploit external knowledge effectively (.ibid). Thus, aligning know-how and know-why between actors across the value chain would rely on shared strategic vision to activate relative ACAP across the textile value chain (Lane & Lubatking 1998; Expósito-Langa et al. 2015).Therefore, successful assimilation would ensure that captured product lifecycle feedback is not just stored as siloed data but is cognitively integrated into the firm's routines, preparing it for the subsequent stages of transformation and exploitation in both intra and extra-organizational configuration (Stark 2015; Zahra & George 2002).

3.1.3 Transformation

Following the internal interpretation of feedback, transformation represents an important stage within realized absorptive capacity, where an organization bridges the cognitive gap between knowing and changing (Zahra & George 2002). Within the PLM paradigm, this stage would operationalize knowledge reuse by aligning or reconfiguring existing knowledge stocks to incorporate new, and sometimes incompatible insights derived from the field (Zahra & George 2002l Wellsandt, Hribernik & Thoben 2015). In the context of a Swedish textile value chain, transformation would occur when firms combine dynamic MOL and EOL field data such as repair frequencies, maintenance behaviour, condition in sorting or recycling performance with BOL master data construction specifications to arrive at a new design schema (Xu et al. 2009; Zahra & George 2002).

The importance of this stage is highlighted by the fact that the knowledge required to generalize and scale a circular routine would differ in both kind and magnitude from the knowledge required just to acquire it (Fichman & Kemerer 1999). Consequently, assimilation gap highlights the friction between acquisition and actual deployment, whereas, transformation acts as the mechanism to overcome this internal stickiness by changing underlying internal processes and organizational learning capabilities (Szulanski 1996; Fichman & Kemerer 1999). Transformation in this context would take place when newly acquired field data is mapped against instance master and design specifications in the PLM system, highlighting not only that product has failed but also when and why (Dienst et al. 2011). For actors in T&C value chain, this may involve transitioning from a partial view of the forward supply chain to a comprehensive whole product lifecycle view requiring a radical shift in thinking of how design subunits interact with EOL actors (Xu et al. 2009; Fichman & Kemerer 1999).

Furthermore, transformation can be facilitated through proactive crisis construction where management manipulates performance gaps such as building on top of the proposed requirements of ESPR (2024) to intensify the problem-solving efforts (Kim 1998). This intensity of effort accelerates a knowledge spiral, where individual tacit knowledge regarding product failure can be systematically converted into explicit formal representation within the PLM database (Kim 1998; Zhang et al. 2012). By utilizing migratory knowledge from external experts or partners, textile firms can leapfrog from simple duplicative imitation to innovation capabilities (Kim 1998). Ultimately, while this change is often gradual and evolutionary, successful transformation ensures that the PLF is not just heard but codified into the firm's knowledge base to prepare for the final phase of exploitation (Trinidad 2025; Kim 1998).

3.1.4 Exploitation

As the final stage in realized absorptive capacity, exploitation represents an organization's ability to use its knowledge to achieve commercial ends (Zahra & George; Cohen & Levinthal 1990). Within the PLM paradigm, this stage operationalizes the knowledge reuse phase, where transformed institutional memory is applied to optimize product aspects such as durability, repairability and recyclability (Ameri & Dutta 2005; Zahra & George 2002). The efficacy of this stage is the ultimate factor in determining a firm's ACAP, as Cohen & Levinthal (1990) argue that the ability to acquire and assimilate information would be meaningless if the firm lacks the routines required to convert that intelligence into innovative capability or competitive advantage.

The strategic choices of a firm may significantly influence its exploitative routines. Organizations with a higher degree of ACAP act as proactive exploiters, systematically scanning the environment, in this case via product lifecycle feedback, to identify external technical opportunities for circular innovation (Cohen & Levinthal 1990; Wellsandt, Hribernik & Thoben 2015). Conversely, firms with lower ACAP only tend to be reactive exploiters, utilizing technologies or lifecycle data only when triggered by an organizational failure or regulatory pressure, especially in the context of ESPR (2024) (Cohen & Levinthal 1990; Zahra & George 2002). Subsequently, to achieve the state of proactive actor in a textile value chain, an organization requires a diverse background in internal knowledge to generate the capability of creating novel linkages and associations between varying dynamic field data points, such as correlating a specific fabric's composition or construction parameters with its eventual recyclability performance (Cohen & Levinthal 1990; Xu et al. 2009; Kim 1998).

However, the path to exploitation is often constrained by the distribution of consequences across time and space (March 1991). In a fragmented and global textile supply chain, the speed, certainty, and clarity of feedback hinge at the Point-of Sale (POS), meaning significant delays before EOL data can return to BOL designers or manufacturers (March 1991; Wellsandt, Hribernik & Thoben 2015). Such a delay often traps firms in a conservative loop, where they prioritize the exploitation of known, linear alternatives over the exploration of unknown circular ones (March 1991). Additionally, decisions for circular knowledge acquisitions are heavily dictated by a firm's short-term cost orientation, which can further impede its long-term exploitation required to bring circular innovations to market (Stelmaszczyk, Pierscieniak & Abrudan 2023). As competence in a specific activity increase, such as traditional high-volume manufacturing, it further reinforces the likelihood of engaging in the same activity, a phenomenon known as increasing returns (Arthur 1996; March 1991).

To overcome this conservative inertia, firms must leverage inter-organizational collaboration and to introduce novelty and stimulate higher levels of strategic learning (Dodgson 1993). By establishing closed-loop PLM systems that bridge the information flow, textile retailers can transition from a partial view of the supply chain to a comprehensive whole product lifecycle view with remote orchestration capabilities beyond PLF (Xu et al. 2009; Dodgson 1993; Sandberg 2023). From a Pakistani manufacturing standpoint, significant improvement in productivity, performance and competitive advantage is observed leveraging firm-level ACAP and technological capability building (Nazeer, Rasiah & Furuoka 2021). Lastly, effective exploitation of PLF in PLM system ensures that the technical infrastructure enabled by RFID is not just a compliance tool but a valuable data pipeline that can be used operationalize digital circular routines within a firm and optimize a product lifecycle in the entire value chain (Tai 2017; EPRS 2024).

4 Research Methodology

Qualitative research views knowledge and empirical evidence as contextual, situational and, interactional, employing interviews as social settings to examine real-world experiences and underlying processes (Mason 1996). An abductive research approach in qualitative research can be defined as *"a creative inferential process aimed at producing new hypotheses and theories based on surprising research evidence"* (Timmermans & Tavory 2012). By utilizing this abductive logic, researchers can actively leverage existing theoretical frameworks to recognize, defamiliarize, and puzzle out empirical anomalies observed in the field rather than waiting for theories to organically emerge (.ibid). Guided by this approach, this study adopts a qualitative approach to explore the dynamics around PLF information flows in BOL, MOL and EOL phases.

4.1 Research Design

To examine these dynamics, this study puts into practice an abductive research design utilizing semi-structured interviews with key actors across the BOL, MOL and EOL stages. Semi-structured interviewing allows research flexibility, allowing emergent themes from earlier discussions to be integrated into subsequent interviews (Bryman 2016, p.483). Consequently, this study incorporates a secondary focus in mapping phenomena surrounding product lifecycle feedback within a specific geographical setting to identify key factors along the entire value chain that serve as feedback sources across a product's complete lifecycle.

PLM system capabilities have shown to exert considerable effects on ACAP (Tai 2017). Furthermore, ACAP is divided into three distinct subsystems i.e. external sources, knowledge storage, and technology-innovation achievements as exploitation of such knowledge where product lifecycle serves as an external variable influencing a firms ACAP and overall technological innovation (Zou, Guo & Guo 2016).

To operate these concepts prior to data collection, this study developed predefined themes by creating a framework based on PLM and ACAP and aligning them with the primary questions. Within this frame, a comprehensive pool of interview questions were generated which were then categorized and abstracted into thematic questions to form structural interviews for all participants. While this preparation resembles a deductive approach, this study employs these predefined themes abductively (Timmermans & Tavory 2012). Rather than treating these themes as rigid hypothesis to be tested, they function as sensitizing concepts and structural anchors that provide a cultivated theoretical background (ibid.).

By entering the field equipped with these grounded viewpoints, the researcher is equipped to recognize unexpected, surprising, or anomalous empirical evidence that the existing frameworks cannot fully account for (Timmermans & Tavory 2012). This theoretical lens functions as a worldview that shapes data collection and analysis, allows the study to explore how the system may respond to the CE transition through one- or two-way information connections in the value chain in the context of organizational learning. When participants' responses deviate from the predefined PLM and ACAP structures, it results in anomalous findings. These anomalies serve as the starting point for abductive reasoning. This will enable the author of this study to identify what kind of mechanisms take shape and form in both spatial and temporal dimensions of the value chain.

4.2 Sample Selection

The selection of firms for this semi-structured interview study follows a purposive sampling process, where cases are chosen strategically based on their relevance to the research area rather than on a random basis (Bryman 2016, pp 408, 410). Drawing from stage-based findings of Pal & Sanberg (2024), this study comprises actors within a textile value chain as illustrated in Fig. 2

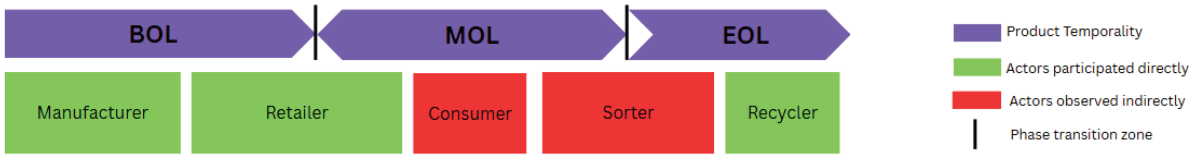

Figure 2 Textile Value Chain Actors in 3-phase PLM

While consumers are not direct participants in the research, they remain highly relevant from the retailer's perspective. Similarly, sorters were excluded from direct sample selection due to their view that the subject area was not directly applicable to their day-to-day operations, through their role remains crucial from this study's standpoint. The possibility of this author's inability to explain the importance of sorter for research cannot be ruled out. Conversely, providing excessive detail about a research topic when inviting participation in an interview can have potential negative impact as contamination in answers, loss of spontaneity and naturalism in answers and prejudicing participant responses as some of the reasons (Bryman 2016 pp. 130, 433, 471). Therefore, while not all actors participated directly, the value chain model incorporates each entity to observe the direct or indirect flow of PLF through the study's active participant.

	Company 1 **Actor 1**	**Company 3** **Actor 2**	**Company 4** **Actor 4**
Type of Company in TVC	Manufacturer	Retailer	Recycler
Origin and spread	Pakistan-MNC	Sweden-MNC	Sweden-MNC
No. Of employees	16000+	1500	3200
Participating departments	Marketing + Compliance	IT + Sustainability & Quality Control	Business Development

Table 1: Actor Profiles

Additionally, while most of the direct and indirect actors belong to the Swedish value chain, the manufacturing actor for the BOL phase is based in Pakistan. Because textile supply chains are often fragmented across global regions, incorporating this international perspective ensures a diverse value chain structure even within the Swedish context, allows the phenomenon to be examined from varied viewpoints.

The target participants within selected organizations primarily comprise personnel directly involved with tracking, tracing, coordinating and disseminating lifecycle data for heterogenous reasons. Moreover, the sampling frame includes individuals who do not interact with lifecycle data directly but nonetheless play an operational role in capturing and/or forwarding relevant data to internal or external stakeholders. In one case company, an IT manager also participated as snowballed participant to understand organizational dynamics related to personnel designing and operationalizing explicit systems within an organization to handle lifecycle data including PLM.

Participant Profile	**C1 P1**	**C1 P2**	**C 2 P3**	**C2 P4**	**C3 P5**
Company Type	Manufacturer	Manufacturer	Retailer	Retailer	Recycler
Department	Manager EU Brands	Manager EU compliance	Sustainability & Product Quality & Safety	IT	Business Development
Years of Practice	16	10	17	15	15
Years in textile	16	4,5 years	17	5	4
Experience in other industries	No	Marketing & Advertising	Few years in workwear and the majority in fashion	Health	11 with SCT
Years in firm	16	4,5	12	5	4

Table 2: Participant Profile

Approximately seven organizations were invited to participate in this study. Out of these, four responded, three agreed to participate, while one declined, citing a lack of operational utility regarding the subject. Furthermore, retailer in Sweden added an additional participant citing relevance to the technical nature of explicit system in the study. One the other hand manufacturer from Pakistan referred participants responsible for managing EU retail clients and a manager overseeing compliance to EU regulations including the ESPR (2024).

Once the research questions were formulated, generic criteria was established to explore core phenomenon, specifically information flow for PLM using ACAP as a theoretical lens. Accordingly, priority was given to firms that are aware of incoming regulations, specifically ESPR, and are interested in engaging in studies related to it. Greater weight was given to the retailer in this context, as retailers are identified as one of the primary stakeholders placing products on the EU market under the ESPR (2024).

Furthermore, this study adopts the logic of small sample sizes, which is necessary for fine-grained, in-depth qualitative study (Coruch & Mckenzie 2006). Such an approach provides authentic and realistic insights into the relationship between individual cognitive perceptions

and their broader effects on organizational and inter-organizational dynamics. It enables an understanding of the qualitative attributes of feedback loops in a product's lifecyle and how lifecycle information moves within the textile value chain as compared to other industries explored in the literature review. This ensures a tight theoretical coupling between individual organizational experiences and the overarching constructs of ACAP and PLM.

Finally, as Geissdoerfer et al (2018) emphasize, circular business models enable circular supply chains to generate value at both organizational and network levels. Consequently, sample selection focuses on actors within the textile value chain that exhibit potential for organizational and network-level value creation through circular activities (Bocken et al. 2016; Sandberg 2023; Pal & Sanberg 2024)

4.3 Conceptual framing and construct alignment

The interview questions are formulated through a structured framework aligning concepts of PLM, PLF and ACAP. While feedback loops in PLM represent a research stream grounded in engineering that is essential for embedding continuous learning in iterative product development, this mechanism is equally relevant in the context of continuous learning loops within a circular economy (Ellen MacArthur Foundation 2016a) to support sustainable transition by radically increasing feedback-driven intelligence (Ellen MacArthur Foundation).

The theoretical framework and the sequential arrangement of PLM literature were aligned based on their similarities in acquiring, processing and utilizing knowledge, and interview questions were developed based on categorization interview questions generated from two research questions. For example, questions were structured to simultaneously address knowledge acquisition under ACAP and knowledge capture within PLM. Generating questions under such a frame allows them to be cohesive and logical for both the explicit systems and tacit structures of an organization's absorptive capacity. Subsequently, this enables responses to be analyzed both through the technical lens of PLM and through the organizational dynamics that interact with explicit knowledge flows. These organizational dynamics encompass interactions at both the collective institutional level and the individual level within a firm.

4.3.1 Thematic Consolidation and Guide Formulation

The final interview guide comprised of five core questions derived from the consolidation and second-order thematic categorization of the initial question pool. To ensure depth of response, the guide was later enriched with structured prompt questions and probes to be used if initial answers were unsatisfactory in breadth or depth or if responses required further elaboration for the author's understanding as shown in Annex 1. Given the semi-structured nature of the study, flexibility was maintained to allow emergent follow-up questions in real-time participant responses.

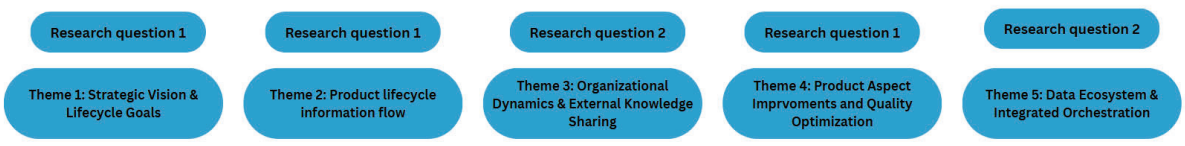

Figure 3 Thematic Areas and Corresponding Research Question

4.3.2 Interview Execution and Protocol Adaptation

While the full interview guide including probing and follow-prompts were withheld from the participants, core questions were visually displayed on screen during the interviews one at a time as sessions progressed. This dual visual and auditory approach ensured clarity for participants and minimalized potential miscommunication or misinterpretations. Minor adjustments were tailored depending on specific participant profile for example questions regarding information flow for retailer were more explicit system oriented towards IT personnel and organizational and cognition related for non-IT personnel. A complete sample of the interview guide is provided as Annex 1.

4.4 Principles of Qualitative Abstraction

In line with qualitative research principles, the formulation of interview questions was maintained at a level of abstraction that avoids over-specificity, ensuring that promising alternative avenues of inquiry emerging during fieldwork were not prematurely closed off (Bryman 2016, p. 469).

4.5 Data Collection

Data collection was conducted remotely via Microsoft Teams. Online interviewing offers distinct time and efficiency advantages by eliminating travel requirements which is a significant benefit when participants that have been engaged are geographically scattered in Sweden and in Pakistan (Bryman 2016, p. 473). Furthermore, empirical evidence indicates that an interviewer's ability to establish rapport is not significantly compromised in virtual environments compared to traditional face-to-face settings (ibid).

Interviews were recorded with participant consent using built-in Microsoft Teams functionality, which simultaneously generated initial automated transcripts. These transcripts were subsequently cross-verified against the audio-video recordings for accuracy before being segmented into analytical units for qualitative coding using frames in Microsoft Excel.

Participant Profile	Company	Actor	Department	Length of interview (mins)
C1 P1	Company 1	Actor 1	Manager EU Brands	57
C1 P2			Manager EU compliance	
C 2 P3	Company 2	Actor 2	Sustainability & Product Quality & Safety	35
C2 P4			IT	38
C3 P5	Company 3	Actor 4	Business Development	34
			Total Time	164

Table 3: Data Collection

The methodological usage of visually displaying questions during data collection was empirically reinforced during an interview when screen scrolling accidentally halted. Participant P4 explicitly noted that having the static question visually accessible was beneficial for processing the inquiry before responding. This observation suggests that visual aids paired with auditory delivery may enhance a participant's ability to engage in analytical processing during semi-structured qualitative interviews, highlighting a potential area for future methodological research.

4.6 Data Analysis

While interviews were conducted across five overarching thematic areas, the collected data was systematically segmented back into an analytical framework aligning themes, research questions, conceptual stages, and specific interview questions. Once the data segments were mapped into this framework, first order codes were extracted to reflect core concepts discussed by participants regarding the phenomenon under study. This included coding segments related to information flows from knowledge acquisitions through to reuse or exploitation across both underlying lenses of PLM and ACAP. This iterative coding cycle was executed to facilitate thematic emergence at a sufficient level of abstraction to address the primary research questions while keeping the contextual integrity intact.

Once initial interview questions were generated for each stage, they were evaluated for contextual similarities and consolidated. A total of 16 questions across two research question categories were re-categorized based on their contextual alignment with the study's primary objectives. This second-order categorization resulted in higher-level thematic questions designed to capture nuances relevant to overarching research questions. The level of abstraction was also raised for respondents to be able to explain in greater detail and not to constrain or narrow their responses which would otherwise risk missing relevant insight.

To ensure rigorous data processing, the selection of qualitative analysis methods aligns with guidelines established by Ritchie and Lewis (2003, pp. 210–211), who emphasize that analytical tools must extend beyond basic data organization to support in-depth, flexible thinking. Crucially, such analysis must remain grounded in the empirical data rather than forcing data into pre-conceived categories. The framework approach allows data to be organized into coherent blocks without excessive reduction, ensuring the participant's original narrative is preserved while maintaining a transparent audit paper trail for analytical traceability. Furthermore, it enables searching across thematic, individual, and comparative dimensions, mitigating the risk of narrative loss caused by over-fragmentation.

Finally, in accordance with Ritchie and Lewis (2003), all interviews were processed through a standardized, systematic analytical procedure while retaining sufficient flexibility for novel pattern recognition and creative interpretation. Selecting an analytical tool that embodies these characteristics ensures robust support for thematic searches, comparative evaluation, and theory elaboration.

4.7 Declaration of use of AI

The consolidation of these questions was executed using a Large Language Model (LLM) called Gemini operating in thinking mode. A meta-prompting technique was employed to first craft a dedicated prompt tailored only to merge questions in clusters identified. The resulting prompt was verified to ensure strict alignment with the study's analytical requirements.

The prompt contained explicit instructions to elevate the abstraction level of the clusters of questions while strictly preserving their semantic meaning and ontological relevance, barring the model from incorporating data from web or outside the session. These instructions functioned as a guardrail to maintain precise control over research parameters. The output of this AI-assisted consolidation was subsequently evaluated manually for interpretability, thematic cohesion and structural alignment with the original clustered question sets.

4.8 Quality of Research

In the criteria for evaluating quality in social research, reliability, replication, and validity are widely recognized as prominent benchmarks. Because this study adopts a qualitative approach, Bryman (2016) outlines four equivalent criteria designed for qualitative inquiry: credibility, transferability, dependability, and confirmability.

4.8.1 Trustworthiness

Pratt, Kaplan & Whittington (2020) highlight that standards built to foster transparency were originally designed for the replication crisis in experimental social psychology. They argue that while these standards are appropriate for deductive, quantitative research, they can be problematic or even dangerous when applied to qualitative research. Advocates for transparency often mistakenly equate replication with trustworthiness; however, qualitative research aims for theory building and elaboration rather than theory testing, making strict replication irrelevant to its core goals.

Regarding the scientific insight, Pratt, Kaplan & Whittington (2020) articulate two distinct ways research contributes to a field: vertical knowledge and horizontal knowledge. Vertical knowledge aligns with realism and positivism, building replicable "bricks" on top of one another under the assumption that a reliable, objective truth exists that can be confirmed through repeated testing (ibid.). Conversely, horizontal knowledge is grounded in transcendental realism and open systems, acknowledging that the social world is too complex and dynamic for exact replication (ibid.). Knowledge in this paradigm is viewed not as a vertical stack of bricks, but as a "stock of broad principles" comprising theories generated from unique positions. Under horizontal knowledge, if a theory fails to explain a new phenomenon, researchers draw upon alternative concepts from the same horizontal collection to navigate unique conditions (ibid.).

To reconcile these perspectives, Eisenhardt (2021) argues that vertical and horizontal knowledge represent orthogonal dimensions rather than mutually exclusive ends of a spectrum. A single study can possess qualities of both, offering unique situational insights (horizontal) while simultaneously contributing to cumulative broader theory (vertical) (.ibid). Whether a study leans towards vertical or horizontal knowledge depends on researchers' choices, such as the framing of research questions, decisions to link findings to prior literature, and the nature of the data collected (.ibid). Specific categorization processes and analytical decisions determine whether a researcher builds a vertical or horizontal knowledge, functioning effective whether the objective is expanding existing theory or exploring a unique phenomenon (.ibid).

According to Bryman (2016) dependability together with credibility, transferability, and confirmability should be used to show that qualitative research is realiable and trustworthy. This is done by drawing similarity in how reliability is used in quantitative research (.ibid).

4.8.2 Credibility

Credibility functions as the qualitative equivalent to internal validity to illustrate whether the research findings accurately represent the social reality of the participants (Bryman 2016; Abdalla et al. 2018). To establish credibility, the study utilizes triangulation by gathering data from various actors in the value chain. The strategic inclusion of Pakistani manufacturer provides significant methodological validity as it allows the student to examine inter-regional knowledge sharing tension and causal ambiguities that characterize information flow in global textile supply chain (Szulanski 1996; EPRS 2024).

The exclusion of sorters and consumers as direct participant is acknowledged as a potential validity risk. While the consumers exclusion is unavoidable due to time constraints the exclusion of sorter is framed as empirical finding itself highlighting perception divergence where downstream actors do not perceive the value of DPP or embedded QR/RFID enabled information flow.

4.8.3 Transferability

Because this study employs purposive sampling to examine a small group of organizational members at specific stages of a value chain, it possesses a unique and significant contextual orientation (Bryman, 2016). Conversely, Drisko (2025) notes that transferability relates to the process of abstraction, drawing information from specific individuals, settings, and eras to apply to unstudied contexts.

This study utilizes this form of abstraction by taking theoretical literature produced decades ago and applying it to the modern context of Product Lifecycle Feedback (PLF) in relation to Digital Product Passports (DPP). Rather than considering a universal positivist generalization, the inquiry in this study remains flexible to emergent, context specific findings within the applied framework. This allows the phenomenon to build and evolve within the theoretical frame, enriching core concepts and enabling the areas of inquiry to become more transferable to other value chains that are attempting to transition to circular economy.

4.8.4 Confirmability

Research becomes more reliable and rigorous when scholars maintain complete honesty regarding their analytic procedures, goals and evolving understanding throughout the categorization rather than projecting disconnected neutrality (Grodal, Anteby & Holm 2020). Stating these initial perspectives explicitly allows external readers to evaluate how researcher's standpoint may have influenced the analytical outcomes (.ibid). Achieving confirmability requires documenting every analytical step and demonstrating how those iterations informed theoretical development (ibid). Rather than concealing errors or confusing data points, researchers should transparently illustrate "messiness" of data categorization through both narrative accounts and visual displays (.ibid).
To ensure confirmability, the study transparently highlights the messiness of the data categorization process through narrative description and visual displays. An important instance of this is the handling of the exclusion of sorters and consumers. By acknowledging such validity risks and providing a clear audit trail of the analytical process, the research allows external reviewers to assess the link between the raw data and final conclusions.

When evaluating researcher objectivity, the presence of human prejudice and preconceptions is often inevitable, given that tests, questionnaires, and research protocols are designed by humans (Abdalla et al., 2018). Within qualitative research, confirmability directly addresses these concerns regarding the overall objectivity of the research process and findings (ibid.).

4.8.5 Dependability

Dependability serves as the qualitative parallel to reliability in quantitative research, acting as a key criterion for establishing the rigor and overall merit of qualitative inquiry (Bryman, 2016). The research process explicitly acknowledges and illustrates the messiness of data categorization through narrative accounts and visual displays to ensure that analytical outcomes are grounded in empirical data.

5 Findings

This chapter provides a theme-based findings from the data collected from actors in BOL and EOL phases as illustrated in figure 2. These themes are emerged from a pool of questions that was generated under each research questions based on the reviewed literature.

5.1.1 Strategic Vision and Lifecycle Goals

Manufacturer in Beginning-of-Life (BOL) Phase

The manufacturer in BOL reports a complete absence of structured, product performance-based feedback mechanisms originating from the downstream retailer in BOL regarding the MOL or EOL phases of the product lifecycle. The limited feedback currently received is strictly commercial-centric in the context of vendor managed inventory. This feedback restricted to demand forecasting and inventory optimization-based access to product-sales performance data given by the retailer to manufacturer.

Currently, manufacturer's overarching strategy centres primarily on product lifecycle transparency and carbon accounting, driven by impending regulatory mandates:

> *"We are currently developing an LCA tool inside... from ginning to the end at the final product... it is going to have scope one, scope two, scope three at each product level..."*

This strategic focus indicates a significant intensity of effort by the manufacturer to align with the regulatory compliance demand of downstream retailers. However, data indicates these initiatives are focused more on process, facility and infrastructure level transitions as opposed to product level or lifecycle-based feedback mechanisms from MOL and EOL. Data shows manufacturer has made strategic investments in renewable energy infrastructure such as solar and wind power which are triggered by customer requirements and long-term decarbonization commitments with immediate commercial alignment as P2 notes:

> *"…based on business decision as well…in Pakistan…major cost of production goes into energy…got the feedback from our customers to develop green energy system…we developed solar park…developed wind farms."*

Retailer and Consumer in Beginning-of-Life (BOL) and Middle-of-Life Phase (MOL)

Retail actor in the study shows prioritization of regulator compliance over near-term strategic shift viewing DPP as primarily a legal mandate than an enabler for post-sale tracking in MOL and EOL or secondary market value creation. Transition to circular business model is deferred until baseline regulatory framework and delegated act has stabilized as P3 notes

"…the starting point…comply to regulations and the legal requirements…do not know where they will land…we know the possibilities to increase circular business model or circularity of the product…at the moment…looking into first basic level of DPP…."

Data from participant suggests that their fast-fashion operational model seems to prioritize operational functions and consumer enablement over post-sale tracking due to participant's perceived product characteristics. As a result, post-sale product tracking in second or third lifecycle remains to the extent of facilitating initial consumer utility and circularity support as P4 notes:

"…more of a fast fashion company…even though aim for second perhaps third life…different projects looking into these aspects…not focused that much of tracking product…after we sell them…but want to achieve functionality for customers…help them without production, so they can give them a second life…"

The retailer in BOL reports internal lifecycle strategy remains focused on monitoring product quality to the extent of fulfilling immediate commercial objectives in the context of customer complaint. However, the organization demonstrates external engagement by participating in collaborative, inter-organizational pilot initiatives to acquire system-level knowledge regarding EOL product flows, mostly notably collaborating with local municipal actors in a project called system demonstrator.

Strategically, retailer appears to adopt a "wait-and-see" posture regarding product lifecycle infrastructure while actively monitoring regulatory developments as formalization and release of sector-specific delegated acts under ESPR is completed.

"once...delegated acts are settled…then…try to look at further options and possibilities...don't look at the moment…have that as a goal once we have settled the rest…"

Recycler in End-of-Life (EOL)

Recycler at EOL only describes important lifecycle information flow that can be fed to upstream actors that determine the technical recyclability of specific cellulosic materials for downstream value chain participants such as fibre producer as P4 notes:

"we can provide…the product and material we product…if its recyclable or not…both wood and recycle content from textile waste…I think they would be interested is to understand if viscose or lyocell is recyclable"

5.1.2 Product Lifecycle Information Flow.

Manufacturing in BOL:

While multi-directional feedback originating from the MOL and EOL phases back to the BOL remains severely restricted, the manufacturer in BOL is observed for actively engaging in proactive feedforward data architecture. This is primarily reflected in internal efforts to capture the push forward lifecycle data generated during the production phase:

"We are currently developing an LCA tool inside... from ginning to the end at the final product."

In contrast, the manufacturer's incoming feedback loop from downstream actors is confined to activities such as vendor managed inventory for never out of stock and process level efficiency requirements. As noted by the actor,

"There is no feedback or structured feedback or consumer feedbacks being done…other than sales or reorder feedback…when we are doing any big project at times, unstructured feedbacks are received…in a lifecycle assessment…make sure we reduce impact…design improvement within process[es]..."

While downstream retailers mandate strict compliance reporting regarding post-industrial waste generated during production, ensuring that *"... making sure we have everything…"*, a significant structural information gap persists regarding product performance during use and disposal, *"…brands are not sharing this kind of data."*

Internally, manufacturer's processes are data-driven and strictly data-gated through legacy Enterprise Resource Planning (ERP) software combined with barcode and QR-code scanning architectures. Production stages are systematically locked until a verified digital record is committed to the database. Automated process-level data capture is further enabled through shop-floor machine integration and further supplemented by manual procedures where legacy gaps exist:

"All our machines are connected to systems…some minor points where systems are not integrated, we teach our staff on a regular basis how to…maintain data, how to… keep the data with themselves."

Retail and customer feedback from MOL:

The information flow in retail is executed in a combination of tacit routines and explicit systems. In explicit systems the information flows in semi-structured formats like email. Whereas examples of tacit routines include conversations and meetings. Reliance on tacit routines and informal feedback mechanisms introduces exposure to firm's product improvement mechanism especially when employees leave the organization as P3 highlights

"…by conversations, meetings and so on…nothing complicated or structured...makes system fragile for internal knowledge…when that person…shifts position or starts working at another company, we lose that type of knowledge…a risk because we do not track it in system...a challenge..."

The information gap experienced at the manufacturing stage is observed to have stemmed directly from the retailer's lack of capability to track product behaviour once a product leaves the sale terminal. The retail organization has limited feedback loops which are reactive in nature and only convey highly divergent signal such as formal quality claims or negative webstore reviews:

"When we sell the product to a customer, we kind of lose all the information about the product… do not have feedback loops coming back when it comes to the product…we get from the customer either a negative one in customer

claim…also get it as…ratings…rate the product on our webstore…two feedback loops to our organization…don't have any strategic goals for these more than…to monitor them"

While there is no formalized tracking mechanism operational by the retailer, DPP in the form of QR code is being experimented for information dissemination to customers pertaining to care instructions and second life instructions. Conversely, retail actor is also experimenting the customer landing page of the QR code to drive additional sales:

"…. just now rolling out a QR label…so the customer scan the product…aim to fetch reasonable data…build a front end…they[customer] can fetch information regarding care instructions…also a second life…. add some kind of marketing…"

Despite this tracking blind spot during MOL and EOL, retailer identifies two primary passive feedback channels originating from end consumers. The first is a corrective or negative feedback loop operating through formal customer claim processes, whereas the second consists of voluntary customer review metrics (e.g. Likert-scale product ratings) captured on e-commerce platforms.

This flow of customer and post-sale feedback to upstream manufacturing relies heavily on informal, non-standardized communication channels. While structured quantitative data (e.g. return reason codes and customer claims) is collected, qualitative insights regarding a garment defect and necessary adjustment do not enter PLM systems or documentation. Product team communicate design modifications directly to suppliers via instant messaging or offline conversations as opposed to PLM sub systems as P3 highlights:

"[recurring material failure] not documented in the PLM system…discussion [is] face to face [or] on phone…other channels"

It also appears that when products have a lower price-point, it also causes data scarcity as consumers do not report minor defects or return lower-value items. As a result, organization do not have the operational data that is required to refine product design in high-volume lines as P3 highlights:

"…product that are…cheaper…there is a big gap of information…customers might not return or claim...or will not put effort into commenting…they believe or think it's too small amount to matter…a big information gap for us…the overall product experience…we don't know anything about…the overall use-phase…like washing and care for the products...we don't know anything about either…"

Empirical data also shows that the retail organization in this case has variation in terms of data accessibility and information flow between subunits. While historical quality data is stored within a specific subunit, other subunit such as product development does not interact directly or evaluate these metrics. Instead, the ingestion and initial analysis of lifecycle feedback are siloed with specialized subunits who act as intermediaries by sharing this processed contextualized knowledge to product designers as P3 notes

"We can find in our system quality claim data from years back... [but] this is done by us in the sustainability or quality product safety team... and we inform the product development teams...."

However, as participant P3 highlights, no structured feedback mechanism exists to capture continuous empirical data during the MOL and EOL phases. Furthermore, customer claims and rating data do not automatically enter the core PLM system. Instead, these feedback streams are directed into separate siloed repository. Relying on this siloed repository, participant P3 manually conducts analytical processes on customer claims. To make these claims actionable, the raw data undergoes qualitative transformation before being shared with internal organizational subunits such as production, supply chain management, and product design to inform decision-making and trigger corrective responses.

Recycler and Sorter in EOL:

The recycler provides information to its downstream partner such as fibre producers through external standards and platforms. This allows the recycler to conform to transparency and traceability practices for brands further downstream as P5 notes:

> *"we provide info to the fibre producer…RCS is handed over to the fibre producers…work with [platform name redacted] …to give transparency and or the traceability from fibre producer to brand owner."*

Whereas mechanisms for feedback loops comprise of semi-structured data and tacit knowledge transfer in the forms of e-mail and meetings

> *"…by email or by meetings that we share information back to sorters…"*

5.1.3 Organizational Dynamics & External Knowledge

Manufacturer in BOL:

Within the manufacturing stage, generation and management of static product lifecycle data remain internally fragmented across disparate operational roles:

> *"I reach out to the teams…[for] data about the energy uses, water uses, and all…[to] publish that to customer."*

Such an operational pattern shows that while individual subunits within the manufacturing firm generate and process process-level sustainability metrics, data transmission is not fully automated. Instead, cross-departmental data flows are manually initiated by specific coordination roles, representing a clear instance of mediated knowledge assimilation and transformation across organizational subunits.

At the same time manufacturer's client require independent third-party audits and certifications as a mechanism to validate internal manufacturer-reported evnvironmental and process data as P1 highlights:

> *"A brand asked us…verify this data with a third party…called third party, [who] validated...[authenticity]."*

Concurrently, manufacturer reports strict downstream transparency requirements imposed by retailers regarding the management of post-industrial garment leftovers within a hierarchical usability framework:

"About the leftover garments and how we are using those leftover garments that includes usable and non-usable garments…brands…are making sure that factories are adherent…"

However, the transparency mechanism seems operative in a one-way direction impeding the feedback process. As a result, post-sales, post-consumer, repair, recycling transparency lacks in the upstream direction.

Retailer in BOL and MOL

Within the retailer organization, specific organizational subunits demonstrate distinct ACAP routines, specifically, acquisition, assimilation, and transformation before passing refined knowledge to other functional units for internal exploitation. In this case, single subunit acts as the focal node for managing passive inbound feedback loops:

"We are already using the data…and have sort of continuous feedback to the production development, production offices, and to suppliers."

Participant P3 within its subunit is observed to function as an organizational mediator. This individual receives raw passive feedback data, identifies value relevant to other departments, and translates and disseminates this knowledge across the firm. This process appears to be enabled by a high degree of knowledge overlap between the subunits including P3 mediator's function as quality controller, supply chain function and product development function"

"We analyze sort of that data…the majority is useful for taking decisions and actions in the supply chains, but also in the product development."

Despite these functional knowledge bridges, participant P4 highlights organizational challenges stemming from uneven prior knowledge and varying baseline technological literacy across departments. Subunits exhibit variable willingness to adopt advanced information system capabilities such as artificial intelligence tools:

"Some of the departments are more willing to reach out and understand the capabilities of the agents and the AI…"

The difference in this heterogenous assimilation of technology between subunits indicates the presence of disparate level of knowledge overlap between technology and a specific subunit which has necessitated the embeddedness of domain-specific data analysts who can map requirements information flow or processing as P4 highlights:

"…reach out to our internal departments….have a one data analysis in every department…to find the problems or need for information…handout these kinds of functions to the department…a faster rollout"

Organizational dynamics at Point-of-Sale (POS) terminal further introduce friction into data acquisition routines. Front-Line Employees (FLEs) at POS terminals frequently experience tension between operational speed and comprehensive data capture:

"For example, when a customer…comes into physical store and makes a return, the shop employee doesn't have time to scroll through all of the different return causes…clicks 'other' or 'not applicable' or something…"

This operational shortcut reflects friction in internalizing technology-driven routines at the front line, service as an operational antecedent to an assimilation gap in lifecycle feedback collection.

While participant P4's individual perception is that the retailer's current product assortments are not engineered for a "third life", the organization participates in exploratory projects examining lifecycle extension. Consequently, establishing system-level infrastructure to track garments during second or third lifecycles has not historically been prioritized within core operational routines.

Additionally, long-term operational memory relies heavily on the individuals rather than explicit knowledge-based reporting systems. This demonstrates the firm's risk exposure to tacit knowledge loss when individuals leave the organization impeding the process of learning continuously as P3 notes

> *"…General knowledge... is very... linked to persons internally... We don't have that sort of data summarized in an easy and good way. And that is definitely a risk for the company."*

Recycler and Sorter in EOL

While recycler has expertise in chemical recycling but does not understand the operational knowledge across value chain such as the design phase in BOL. Recycler does not share the same vocabulary, knowledge and way of working regarding as actors from the BOL phase, design actor to be specific. Recycler has engaged in tacit knowledge transfer across the MOL phase and directly into BOL phase to understand actors that affect their process level viability in EOL phase

> *"…our knowledge…we only have it in…chemical recycling…we do not understand the full design phase…we have worked with designers from different global brands…to understand their language…their way of working…so that it resonates with the target group like the designer."*

Similarly, while tacit knowledge feedback loop jumps from EOL to BOL stage, the recycler perceives as having raised awareness as P5 highlights:

> *"…I think we have raised awareness…designers are more aware…I do not have evidence saying they [product composition] have improved"*

5.1.4 Product Aspect Improvement & Quality Optimization

Manufacturer in BOL:

Upstream process optimizations are actively triggered by downstream brand requirements focused on environmental and chemical impact metrics. For example, manufacturer reports a substantial shift from high-impact manual labor to technology-driven production processes. This includes replacing conventional "dry works" such as hand-sanding and Potassium Permanganate ($KMnO_4$) sprays for indigo reduction with laser-based technologies.

Downstream retail buyers routinely require manufacturer to submit Environmental Impact Measurement (EIM) scores (Jeanologia, n.d.) when evaluating new product designs.

Additionally, manufacturer must commit to forward-looking sustainability targets mandated by retailers across Scope 1, Scope 2, Scope 3 emissions, as well as minimum recycler content thresholds resulting in internal initiatives such as establishment of "Circular Park" by manufacturer in 2022 to prepare for DPP compliance.

> *"So Jeanologia has a system of EIM which is called environmental impact measurement…if we use laser machine…that reduce[s] my worker impact of hand scrapping."*

Additionally, manufacturer reports flow of data in terms of 3D modelling and virtual fitting solutions streamlining product design iterations. This deployment assists in reducing the number of physical sample waste and resource consumption materially and temporally:

> *"…if sample count is three to four rounds to mature any order…we can start 3D rendering of fit model…scan fabric…share first 3d model fitting…brand gives comments…then we…just do one final sample…"*

Retailer and consumer in BOL

Data indicates that the retailer has corrective or negative feedback loops that originate from customer claims. This shows that feedback loops originating from retailer for product quality optimization relies on customer claims exceeding a quantifiable threshold. These improvements are made for the future similar iterations of the product. Additionally, P3 also notes that while corrective feedback loops are aimed primarily for future improvements, they are also used for products that are in production noting the potential of in-process corrections.

> *"…do our regular customer claims monitoring every month…when we see claims…above our reasonable limit and our internal limit…we take actions immediately…[for] future orders coming…maybe similar…take actions directly with the production team if its possible in supply chain…haven't already produced too much…"*

Retailer also engaged in a research and development project with potential circular supply chain partners to investigate end-of-life products that reach sorters. Such a field evaluation substantiated participants earlier held beliefs on expected product quality after long-use as P3 illustrates:

> *"…we could see there and information we got ourselves a bit sceptical...we see…doesn't look good…probably used a long time…they look slightly older…got feedback...products in general look good…"*

Recycler and Sorter in EOL

The observation mechanism for quality optimization at process level takes shape in the form of visual inspections and capturing photo. Feedback is then communicated with the upstream partner which is sorter in this case or the feedstock supplier in case material input does not meet the demand specifications highlighted by P5:

> *"...through visual inspections…if we are not happy with the quality…we take photos…send them back…not meeting our demand…specification."*

Additionally, recycler also have batch level traceability for recycling lots where they can track id numbers of base that goes into chemical recycling where impurities can be detected in terms of chemical composition. How ever the recycler is unable to pinpoint which base the impurity came from

> *"...we track the ID number of the base that goes into chemical recycling...we can do testing...can see if it is a lot of impurities...understand by contamination...but we cannot identify which supplier it is...but cannot understand which bail it come from..."*

Data also shows that the feedback mechanisms is most crucial in the beginning of relationship with the supplier when samples are continuously tested for conformity. The quality observations switches to visual method in large scale with bulk volume where final base quality is monitored to determined supplier performance on required parameters with high emphasis on improvements.

> *"we discuss how improvements can be made...normally happens...in the beginning...have a new supplier...do it carefully...they send small samples...we test it...in lab scale...when it comes to bigger volumes...we do visual inspections...we need to see improvements...otherwise...stop buying from this supplier...cannot continue... if it continues with this error or wrong specification in the base..."*

5.1.5 Data Ecosystem, Storage & Integrated Orchestration

Manufacturer in BOL:

Within the manufacturing stage, empirical data generation exhibits a high degree of automated machine integration. Process-level systems directly capture and log operational metrics, eliminating the need for external audit verification:

> *"And it is system generated...that is coming out of the EIM system, which is integrated in the machine...doesn't need any kind of audit report."*

While manufacturer reports receiving no downstream requests from retail customers requiring historical data recall, noting that *"on to the data to recall something, we as of now haven't received any such request"*. Whereas the manufacturer possesses the technical infrastructure to store and retrieve explicit lifecycle data for at least five years.

The manufacturer reports comprehensive barcode scanning and automated systems checkpoints that act as data gates to ensure continuous data capture throughout consecutive production stages as P1 notes:

> *"After cutting, the cutting cannot issue to stitching [until] data is not fed in the system. The stitching cannot dispatch to washing once data of that style...[until] every piece is fed into the system."*

Furthermore, to address an underlying trust deficit and overcome retailer scepticism regarding the manufacturer-reported data authenticity, manufacturer has proactively integrated diverse third-party traceability platforms since 2022 level.

"…for example [participant name redacted] mentioned…about [traceability platform name redacted] system for example if I am making any [garment]…a QR code…tells you…from where the cotton comes…from where trim comes…where garment was manufactured…and warehouse details."

Lastly, the manufacturer reports relying on external plat form technologies for exploring traceability capabilities and DPP frameworks before regulatory as P2 notes:

"…working on DPP since 2022…we [traced] around 1.2-1.3 million garments of [brand name redacted] with [platform name redacted]…"

Retailer and Consumer in BOL

Retailer reports utilization of PLM system that initiates with product designers and integrates with other subunits through Order Management Systems (OMS) and Product Information Management (PIM) platforms. PIM is utilized by purchasing teams to plan product assortments and execute procurement decisions. Crucially, the PIM system functions as a traceability repository, storing data to at least tier-3 suppliers:

"…also make enrichment on the purchase because here we really see that the country of origin and we see tier one, tier two, tier three and so on in this function"

Furthermore, retailer relies on approximation methods and prior tacit knowledge to estimate the product longevity. As participant P4 notes, "we know approximately the lifecycle of our products". This response aligns with empirical evidence from external collaboration projects the organization participates in. As participant P3 notes, *"the data we got from that repairer…gave us more or less the same or a confirmation of the information we get from the customer."* However, participant P4 acknowledges the lack empirical, structured post-sale feedback:

"But we don't really fetch the data after we have sold it. So, we don't know that much, we don't have structured data on these types of information…"

When assessing use-phase data capture, the willingness of consumers to provide feedback is strongly related to perceived financial value of the product by the consumers. As participant P3 observes:

"Products that customers might not return or clam or will not sort of put the effort into commenting because they kind of believe or think it a too small amount to matter. I would say that is a big gap of information for us."

This highlights a key structural limitation that while MOL feedback could provide crucial data for optimizing product quality parameters, consumers might forgo reporting product failures or performance successes when the garment's retail price is low.

Concurrently, another subunit within retailer represented by participant P4 reports ongoing research and development efforts regarding the DPP. The firm is actively experimenting with DPP landing pages to scan potential value and assess consumer engagement:

"The only thing we are experimenting, or we are aiming at right now is the DPP page. So, we will fetch as much information as we could. How many customers have scanned their product?"

At the retail level, data architecture is centralized around an enterprise data lake designed to aggregate heterogenous data streams from across the organization:

"And to reply to the other question here, we also send the information from all of our system to our data lake."

Participant P4 highlights that retailer possesses flexible acquisition capabilities capable of ingesting data from diverse channels such APIs, message queues, and file shares provided the external source permits data fetching. P4 notes that simple file sharing remains to be the most prevalent format from third-party services for data acquisition.

Furthermore, retail organizations rely on disparate enterprise systems such as PLM, Order Management System (OMS) and Product Information Management (PIM) to manage technical and operational data. This demonstrates that product data does not only reside within PLM systems but also other explicit systems within the organization. However, all this data is stored in a centralized data lake as P4 highlights

"…a product information flow…we have PLM system where design and the director works…send this product information to the order management systems where purchase works…plan assortment and make purchase to suppliers…send the data also to the product information master system where we have the digital experience and data assets modelling…marketing team make some enrichment…can see country of origin tier one, tier two, tier three,…spread info from these sources to point of sales....physical stores…e-comm…B2B…also send information from all system to data lake…"

However, while the static design information flows through the PLM, the feedback loops that the retail organization receives from the consumer does not flow back into the PLM system but is managed separately. Data is analysed and communicated to upstream suppliers through informal communication channels rather than feeding information back into the Bill of Materials (BOM) or automated tech packs according to P3:

"…it is not documented in the PLM system…discussion [takes place] face to face or phone, WhatsApp, through other channels…we send tech packs but do not have BOMs or fabric library…not so structured…when it comes to components in the product…"

While current operational routines rely on informal channels, retailer is deploying specialized Artificial Intelligence (AI) agents that are configured with automated schedules to feedback analytical insights directly back into internal management systems such as PLM from the central data lake. These agents are aimed to be designed to serve as decision-support tools for product designers by establishing statistical correlations between historical variables and commercial performance:

"We have some agents, but we want to build even more agents with different user scenarios or business cases...in some scenarios we have scheduled work for agents…giving feedback to…one of our system[s]"

The organization is amenable to applying the same AI-driven data lake framework to process MOL and EOL data streams as they become available.

To accelerate the adoption of these digital tools, retailers have implemented organizational mechanisms to transition tacit functional knowledge into explicit, system-supported routines. The IT department places dedicated embedded roles such as business developers or data analysis directly within functional subunits to identify operational needs to deploy data-centric tools:

> *"…identify problem or the need for information and just hand out these kind of function to the department so we can have a faster rollout…"*

Whereas AI agents are deliberately constrained to historical data spanning no more than three years. More importantly, the final-decision making authority on data processed by AI-agents remains through human-in-the-loop oversight mechanism:

> *"We will always use our data lake and agents for analysis…we will get reports…when an agent suggests a change…we will always use human approval."*

The data further highlights a human-in-the loop approval model that functions as an intra-organizational input generated by AI agents. While the system autonomously analyses data from PLM, OMS, Product Information Management, e-commerce customer reviews, and sales data from the data lake. However, it does not execute operational changes independently. Instead, the AI agents' suggestion requires manual verification and authorization by human decision-makers prior to implementation as highlighted by P4:

> *"…let's say that we will change a composition, then the director will get a suggestion…and then the human must approve that change…that's why we have this decision also with the human approval…"*

Additionally, the value of data in its ability to provide reliable predictions is also constrained temporally due to changing dynamics of the world in terms of economics, organization's operational environments and customer demographics where increase in temporality may result in unreliability of the prediction proportionally.

> *"…five years historical data…pretty good data quality…more than five years… isn't that good quality…agents rely on two-[to] three-year historical data…the world has changed…hard to rely on that data. Sales transactions…cant really compare this year's sales from five years ago…different markets that we are operational this year…different customers, different demographics."*

Moreover, the organization's data quality also depends on feeding the system with more data resulting in consumption of more resources, a process that also takes time. Additionally, inflating volume of data also results in better quality which affects decision-making positively. Moreover, due to the fast-changing macro-level patterns in the world including wars and weather anomalies, type of data required is also shifting with more focus on weather, politics and regional conflicts. Requirements for heterogenous data sources to keep predictive analytics relevant and robust is increasing proportionally with disruption happening across various domains. This result According to P4:

"…expand this and look at different type of data, weather data, world data in political views, hard to get structured data of this…if war in different locations of the worlds…. Should not rely on the data in the same way."

Requirements for heterogenous data sources and the volume required to maintain data quality to keep predictive analytics as accurate as possible is increasing proportionally with disruption happening across various domains in an organizational external environment as P4 notes:

"better data quality also relies on someone feeding our systems with more data…have weigh against feeding a system…more data takes more time…if we start to administer and get better data…have to feed more data into the system…don't know if we want to add more time to this…"

Data also shows that the retailer prefers collaboration over orchestration due to the financial viability at system level circulation. Additionally, from the retailer's perspective, sustainable operational viability requires financial responsibility and technological collaboration across sorters and manufacturers as well as consumer willingness to absorb system-wide circularity costs as P3 illustrates:

"…more about collaboration…cost of…changing an entire system with more circular material flows costs…do not see that big financial benefits at the moment…it is not profitable with these types of systems today…if we don't sort of put that surplus cost on the end-consumer…it will not work out.

Recycler and Sorter in EOL

Empirical data demonstrates the absence of item-level traceability when material is received. As a result, feedback in terms of process efficiency is diluted to batch level data where base (batch) is labelled by the sorting facility in terms of composition.

"on the base we get…material composition…how much cotton and how much polyester…have a specification of minimum 70% cotton and maximum 30% polyester…but on the bale we have the material composition of cotton and polyester..."

Additionally, the tracking and tracing capability of bales are further lost when chemical recycling permanently dissolves the product. As a result, this loses the ability of the recycler to trace a product's bale record:

"we track the ID numbers of the base that goes into the chemical recycling and then we can do testing and we can see and we can see if its a lot of impurities… but then we cannot understand which bail it comes from…"

5.2 Summary of Findings

This subsection illustrates the empirical results gathered from key participants, offering a focused though not comprehensive perspective on the diverse elements of the product lifecycle feedback within the textile value chain. The analysis categorizes these participants

based on their roles within the organization and their placement in the PLM framework. The manufacturer is situated in the BOL phase, while the retailer services direct representative of BOL and proxy for MOL phase, as consumers were excluded from direct participation. Furthermore, while sorter did not participate directly in the study, the recycler provides indirect insights into sorting-related issues while acting as a direct representative of the EOL stage. The findings are presented systematically, for each actor within the established thematic areas and their perspective from a subunit from an organization such Managers who participating from BOL manufacturing looking after EU customers and EU compliance. This is followed by the qualitative insights that was gained during the analysis.

Actor 1: Manufacturer

Themes	EU Customers and EU Compliance Managers
Strategic Vision and Lifecycle Goals	Commercially Driven Strategy
Product Lifecycle info flow	Product Lifecycle Feed-forward flow, Static feedback flow (no MOL feedback)
Org Dynamics & External Knowledge	High forward feed, low backward feed, High-explicit Low-tacit, internal and external fragmentation.
Product aspect improve and quality optimize	MOL to BOL decoupling, Asymmetric transparency
Data Ecosystem, Storage & Integrated Orchestration	High internal and upstream external ACAP (Process-level data automation, Data-gated production processing). Low external downstream ACAP. Third-party feed-forward integrations.

Actor 2: Retailer

Themes	Quality & Sustainability	Information Technology
Strategic vision and Lifecycle Goals	Commercial & Regulation Driven	Operational level strategy
Product Lifecycle info flow	Siloed Feedback Repository & Mediated Internal Diffusion	Static Split-feedback
Org Dynamics & External Knowledge	Data processing & sub-unit dissemination	Consumer-centric, behavioural.
Product aspect improve and quality optimize	Efficient tacit process, PLM disconnect. Cascading feedback loop	Agent-based and query-based feedback from Database.
Data Ecosystem, Storage & Integrated Orchestration	High-tacit Low-Explicit, Data Siloes.	BOL (Internal and External) Data, Unstructured data, Data quality.

Actor 3: Recycler

Themes	**Business Development & Policy**

Strategic vision and Lifecycle Goals	Commercially Driven
Product Lifecycle info flow	Uncodified/tacit feedback,
Org Dynamics & External Knowledge	High-tacit low-explicit, passive inter-organizational knowledge transfer for cognitive consonance.
Product aspect improve and quality optimize	process-based aggregated feedback.
Data Ecosystem, Storage & Integrated Orchestration	External standard driven data management

6 Discussion

This section discusses the findings from the interviews in relation to the literature reviewed and relevant literature. The study does this through the confluent lenses of Product Lifecycle Management (PLM) and an organization's Absorptive Capacity (ACAP) (Zahra & George 2002).

The transition from linear to circular systems in the Swedish textile value chain requires focus on both intra and inter-organizational information loops. As demonstrated in empirical findings, the shift towards CE requires more than the physical circulation of materials. It requires a complex, information driven approach to bridge structural gaps across the value chain. These loops function as underlying mechanisms for endogenous responses through transformation of product into information rich assets comprising both technical and operational tracking (Harkonen, Guerrero Rodriguez & Mustonen 2024). This transition is currently impeded by a more dominant commercial logic that prioritizes exploitation at short distances in value chains. Thus, limiting the scope of feedback systems at chain level that may uncover artifacts which can be used for aligning dual-use lifecycle-centric feedback systems that enable both exploration and exploitation models in near and distant locations on chain (Lane & Lubatkin 1998).

6.1 Acquisition

Manufacturer in BOL

The findings reveal that actors in BOL interact with and respond to external environmental stimulus, specifically regulatory requirements under the EU's ESPR and DPP mandate therein. As highlighted by Tsoukas and Chia (2002), subunits within these manufacturing organizations interpret these external signals to condition an endogenous response that is compliant in nature. While manufacturer initiatives such as development of LCA tools suggest early-stage acquisition of regulatory data, the incoming information flow from downstream retail actors remains primarily commercial-centric and limited to Vendor Managed Inventory (VMI) sales and demand forecasting.

A geographically distant manufacturer in this case relies significantly on third-party digital platform to manage data authenticity and compliance reporting feed forward information. From an ACAP perspective, third party platforms can strengthen internal ACAP provided the

manufacturer maintains foundational internal technical know-how (Im & Ahuja 2023; Lane & Lubatkin 1998; Szulanski 1996). As Keller (1996) highlights, mere access to external technological platforms does not drive sustained capability building unless knowledge is transferred to internal human capital to build technical skills. Relying on long-term vendor relationships to handle data can create an operational dependency trap, which reduces organizational learning over time.

Concurrently, retailers demand third-party audits and strict tracking of post-industrial garment leftovers from manufacturers. However, this transparency initiative also operates as a one-way information flow. While manufacturers perceive requirement of transparency to communicate process-level and post-industrial waste metrics, real-world post-sale product lifecycle performance feedback from downstream phases remains absent. Furthermore, manufacturer investments in renewable infrastructure such as solar parks and wind farms represent infrastructure-level responses to client decarbonization targets rather than product- and process-level lifecycle-based aspect optimization stemming from feedback mechanisms.

While product lifecycle data feedback can be valuable for improving a products aspect. Findings show that currently there is no mechanism for manufacturer in BOL to acquire PLF field data. Furthermore, geographically distant manufacturers need to leverage EU data format framework such as CWA 18291:2025 to align their data schema with EU firms to achieve baseline interoperability. As downstream actors prepare to deploy digital links, manufacturers can begin internalization of the necessary technological and knowledge overlap required to identify and interpret feedback data points. This will enhance manufacturer capability for material level analysis to allow insight into how the fabric and other component's construction parameters have performed and how can it be further optimized by analysing cause-and-effect patterns from raw feedback data. It is pertinent to highlight the need for manufacturers to account for feedback delay based on their distance in the value chain and the estimated lifecycle duration of the garment they produce based on LCA studies and related proposed delegated acts (Apparel and Footwear PEFCR Technical Secretariat 2025; JRC 2025).

Retailer and Consumer in MOL

The findings indicate that the retailer's data ecosystem is not formalized in direction by the uncertainty surrounding regulatory delegated acts, leading the organization to adopt a wait-and-see posture. In terms of ACAP, when faced with external technological disruption, firms may use strategic delay to avoid committing capital to unstandardized regulatory driven data architectures. However, this posture limits the firm's capacity to absorb external changes early and build capabilities for circular value creation.

The empirical data highlights that the retailer's perceived fast-fashion operational model prioritizes operational speed and consumer utility over post-sale product tracking across second or third lifecycles. This demonstrates a fundamental divergence in dominant logics (Lane & Lubatkin 1998), between fast-fashion business models and EU circular economy policy framework.

Although the digital link with the garment is lost post-sale, reactive feedback loops are observed to be operational through formal customer claims and webstore (ratings-based) ratings. The acquisition of this negative feedback is directed by specialized gatekeeping subunits such as sustainability and quality teams. This aligns with Cohen & Levinthal (1990),

where boundary spanning individuals can identify external value for internal subunits based on their prior knowledge that creates this knowledge overlap.

Additionally, the retailer experiments with DPP QR codes on physical garments as dual-purpose channel such as relaying static product information as care label and second life instructions while tracking customer landing pages for customer demographic analysis for sales and marketing. This shows a dual explorative and exploitative approach to technology acquisition. However, low garment price points create an operational challenge for retailer's feedback mechanisms. Because consumers rarely raise formal claims or return for cheap defective items, the retailers feedback loop from MOL could become redundant for high-volume, low-cost product lines. As a result, this may impede the retailer's ability to collect data required from use-phase to optimize the durability and repairability of the garments.

To acquire system-level EOL insights, the retailer participates in exploratory inter-organizational pilot projects such as "System Demonstrator" project. These collaborative initiatives allow the firm to acquire knowledge regarding post-consumer product flows without committing core internal IT infrastructure. Furthermore, by engaging in inter-organizational projects, retailer can further identify the underlying determinants such as pre-existing technological and knowledge overlaps required to engage in collaborative, inter-organizational and whole-lifecycle operations with manufacturer, sorter and recycler (Mowery, Oxley & Silverman 1996; Keller 1996).

Recycler and Sorter in EOL

The EOL recyclers approach to transmitting feedback is primarily centred around the commercial viability and raw material costs based on composition accuracy. The recycler exhibits a reliance on backward tacit feedback loops through emails and meetings with upstream sorting facilities to optimize feedstock purity and process viability. This shows that the recycler engages frequently with preceding actor in the value chain for proximate exploitation cycles (Zahra & George

Furthermore, recycler as an actor in EOL phase also engages with BOL actors, specifically designers to understand their vocabulary and design process. This demonstrates that the recycler engages in activities where it identifies external knowledge that is distant in the value chain but is critical for its operations (Zahra & George). By bridging this cognitive distance to understand design vocabulary and routine, the recycler attempts to realign the value chain that is compatible to process parameter constrains but at the same time signifies a state transition towards CE. Consequently, it cannot be determined if this activity is exploration or exploitation, meaning further investigation is required to determine if the recycler perceives the returns as uncertain, distant and negative or positive, proximate and predictable (March 1991).

However, incoming feedback stock at the EOL stage arrives aggregated at batch level identification rather than at item level. Unlike BOL manufacturing, where production batches consist of uniform garments, post-consumer recycling batches originating from sorters have heterogenous technical and operational traceability parameters. While aggregated composition data satisfied the baseline input requirements, the recycler lacks item-level traceability to feed material recyclability performance back to upstream retailers or original clothing manufacturers as a PLF source (Xu et al. 2009).

Additionally, leveraging embedded tags to acquire static technical traceability data for acquired batches can allow analysis of batch-level data coupled with item-level traceability and its corresponding process performance. As the only underlying determinant for the batches is product composition, it can allow anomalous pattern recognition of fault detection over large number of batch data sets together with item-level technical and operational traceability. This can help remove causal ambiguities by narrowing the origin of process failure to specific categories, styles, trims or producer. A digitally linked batch can also facilitate in defect traceability within the feedstock in terms of erroneous composition data or sorting classification error further removing causal ambiguity at chain level. By standardizing data exchange protocols and domain ontologies, recycler can effectively bridge the cognitive distance continuously with BOL actors in explicit systems as opposed to one-time tacit knowledge transfers in the form of best practices which have been linked to knowledge decay (Bindi et al. 2018; PESCO-UP n.d.). Thus, by deploying and adapting enterprise explicit knowledge management systems such as PLM, recycler can enable both inra- and inter-organizational acquisition of PLF for process improvement.

6.2 Assimilation

Manufacturer in BOL

Within the manufacturing stage, generation and management of static product lifecycle data remains internally fragmented across disparate operational roles. Cross-departmental information flow is manually initiated by specific coordination roles in comparison to automated systems. This mediated knowledge assimilation illustrates that while individual subunits generate process-level data, the firm lacks the automated intra-organizational integration where any individual can access data for reuse.

This assimilation gap can be bridged by leveraging cross-functional data modelling and metadata management. Combined with master data management and data governance, these practices transform fragmented data into structured information within the manufacturing facility (Kalluri et al. 2025). Additionally, to further reduce the assimilation gap, the manufacturing facility can utilize NLP and semantic parsing to reduce search time by enabling users, specifically non-IT users to query required information with ease using natural language (Abramovici et al. 2016). Through such techniques the subunits within organizations can access the organizations explicit knowledgebase to achieve better assimilation of stored data.

Furthermore, as the manufacturer mostly generates static data after design phase, it can leverage whole lifecycle product data models (Xu et al. 2009; Modelio n.d.). Such domain specific comprehensive data models in textiles with MOL and EOL classes that can aggregate product data failure modes and frequencies can be utilized to analyse and improve performance of future iterations by better design, construction and process optimization (Xu et al. 2009).

Retailer (BOL) and Consumer (MOL):

The retailer relies on a combination of tacit and explicit routines such as conversations, face-to-face meetings and explicit systems (emails, PLM, PIM, OMS) when processing feedback data. This creates fragmentation between tacit knowledge residing in individual cognitive structures and explicit knowledge codified in organizational repositories. As Volberda, Foss, and Lyles (2010) and Zhang et al. (2009) emphasize that organizational memory that remains

uncodified risks being lost when key personnel leave the firm, leading to recurring design and material failure. Systematic codification through lifecycle data modelling within enterprise ecosystem is necessary to prevent operational learning loss.

Product teams frequently communicate material defects directly to suppliers via informal channels such as WhatsApp or phones calls rather than logging instance events within the core PLM platforms. While informal channels facilitate rapid local understanding, circumventing explicit PLM systems prevents feedback from entering explicit organizational memory as well as ingestion of raw data into the data lake for automated pattern analysis.

Subunits within the retail firm exhibit varying level of technological and prior knowledge overlap. As Boynton, Zmud, and Jacobs (1994) argue, managerial IT knowledge is a major factor that drives IT utilization. Extending the concept by Lane & Lubatkin (1998) to from inter-organizational level to intra-organizational level between subunits, this study hypothesises that assimilation capacity is guided by the compatibility between lower-level knowledge structures where subunits like marketing exhibit higher routine compatibility with modern IT/AI tools than other operational units. To bridge this intra-organizational learning gap, the retailer embeds dedicated analysts directly within disparate subunits or departments to identify information gaps and formalize data workflows resolving assimilation gap between cognitive structures and data-centric workflows in explicit systems.

Information captured in document form such as spreadsheets or customer relationship management systems by service teams can be incompatible with complex CAD and PLM systems used by designers. As a result, this can cause internal stickiness in knowledge transfer between subunits in an organization and between inter-organizational boundary spanning individuals (Szulanski 1996). However, the development of ACAP is

Organizations are unable to analyse and interpret incoming field data because it is not formatted to align with the existing cognitive systems of designers. As a result, raw field data is not transformed into design intelligence, slowing the organizational learning required for circular design. This limitation can be reduced by transforming UML based data models in PLM systems into ontologies to enable reasoning and DSS for designers as well as other organizational functions (Matsokis & Kiritsis 2011).

At the point of sale (POS), Front-Line Employees (FLEs) experience friction between speed of routine transaction and comprehensive data capturing requirements during returns. When processing these returns, FLEs routinely select operational shortcuts by clicking other or N/A to maintain transaction throughput in rush hours. This assimilation gap (Fichman & Kemerer 1999) illustrates how the speed of operational routine acts as antagonistic determinant for technology assimilation in a routine and its intended data acquisition pipeline. As a result, this impedes the ability of the organization insert new data pipelines in existing routines. On the other hand, the friction also reduces the quality of the data and makes it unreliable for use in analysis, knowledge transformation and predictive analytics.

Recycler and Sorter in EOL

While the recycler possesses specialized expertise in chemical processing, it lacks foundational knowledge regarding BOL clothing design routines. To overcome this inter-organizational cognitive distance at the chain level, the recycler engages in direct tacit knowledge exchange with BOL garment designers. By attempting to learn the “Language” and design routines of the fashion brands, the recycler hinges on its prior knowledge to

recognize external knowledge first as student firm and subsequently act as a teacher firm when issuing guidelines or best practices about choosing compatible recyclable fibre composition driven by dominant logic of CE (Lane & Lubatkin 1998).

6.3 Transformation

Manufacturer in BOL

The lack of post-sale feedback from MOL and EOL phases creates an information deficit for BOL manufacturers, impeding their ability to analyse real-world stress factors, duty cycles and failure rates. Upstream optimizations are triggered by downstream buyer requirements which are focused on EIM scores. Manufacturers transform production processes and routines by replacing high-impact manual labour (Such as KMnO4 sprays and hand-sanding) with laser technologies and adopting 3D virtual fitting models to minimize physical prototyping waste, highlighted by Casciani, Chkanikova and Pal (2022).

However, if downstream retailers lack the operational capacity to process detailed manufacturer LCA data, these comprehensive disclosure investments risk producing inflated data volumes that are not processed in explicit systems and destined to be failed venture from the onset (Kessler, Bierly & Shanti 2001). Ingesting uncontextualized LCA data into corporate data lake without relative transformation capability can create redundant data. To transform LCA into useful data it can be coupled with the product's field data. Downstream actors can structure manufacturer's product LCA data with field instance master data and design specifications in PLM system to analyse when, where and why the product failure has occurred (Dienst et al. 2011; Fichman & Kemerer 1999). This demonstrates another challenge in developing data sources and maintaining whole lifecycle data pipelines and data volume over a product's LCA for example in the case of denim products which are four years (Apparel and Footwear PEFCR Technical Secretariat, 2025).

Retailer and Consumer MOL

The retailer's central data lake aggregates data from disparate systems (PLM, OMS, PIM, and e-commerce reviews). However, retail actors perceive that the predictive value of historical data decays over time due to shifting economic conditions, consumer demographics, and supply chain disruptions. Consequently, the firm constrains its AI predictive models to 2-3 years of historical data, revealing temporal disparity in data preference and governance between short-term commercial forecasting as compared to long-term product lifecycle tracking for feedback.

Furthermore, findings from retail actors indicate raw field data transformation is subject to resource tradeoffs. These tradeoffs exist between the heterogenous sources of data required due to turbulent external environment versus the cost and time it takes to process the ingested data. Some of these heterogenous external data sources exemplified are weather patterns and geopolitical metrics. Organizations must balance the operational overhead costs of expanding data pipelines against the analytical and monetary value gained.

Recycler and Sorter in EOL

Transformation at the EOL stage is critically hindered by causal ambiguity (Lane & Lubatkin 1998). Because recyclers receive post-consumer garments in aggregated, heterogenous batches, chemical testing can detect impurities in a batch but cannot pinpoint which specific

garment or supplier blend introduced the contaminant. This lack of item-level causal clarity prevents the transformation of EOL process failures into targeted design revisions for upstream BOL actors across MOL phase. Through access to shared knowledge management systems in PLM, recycler can both retrieve advanced knowledge required to streamline pre-process preparations including anomalous detection. By retrieving technical traceability information of the batch through EPCs (Shih, Sun & Lin 2005), recycler or sorter can validate and verify content in comparison to requirements of batch-level parameters against other measurement techniques (Specim 2026) before chemically processing feedstocks.

6.4 Exploitation

Manufacturer in BOL

Commercial exploitation at the manufacturing stage occurs primarily through process efficiency, energy optimization (e.g. Circular Park Investments), and digital sample reduction via 3D rendering. By integrating automated barcode scanning and machine-level data gates, manufacturers ensure strict data execution across manufacturing process stages. To overcome brand scepticism regarding data authenticity, manufacturer exploits third-party traceability platforms to prove provenance and process compliance. Similarly, Hyundai's case of inverted R&D approach highlighted by Kim (1998) also demonstrates that firm may acquire explicit knowledge via licensing and hiring in the context of migratory knowledge to achieve higher levels of learning through proactive crisis construction.

Retailer and Consumer in MOL

To exploit stored lifecycle data, the retailer configures AI agents to anlayse data in data lake and deliver optimization suggestions directly into enterprise systems such as PLM. However, the firm enforces a mandatory human-in-the-loop approval routine before any autonomous suggested modification such as altering material composition in a BOM can be executed. While this human oversight prevents algorithmic error, it acts as an operational bottleneck in realized ACAP, slowing down the exploitation of field data into product updates.

Furthermore, economic parameters constrain the exploitation of circular feedback loops. High costs reported in findings in relation to the circular systems combined with low consumer willingness to absorb this surplus circularity costs prevent the retailer from exploring circular exploitation. As March (1991) describes the tendency of firms to exploit short-term commercial returns. As findings highlight the negative impact of low-priced products affect the consumer perception and willingness to provide feedback. This impedes the PLF information flow required from active-duty cycles on various MOL parameters.

Overall, retail firm exhibits reactive behaviour as illustrated by Cohen & Levinthal (1990), acting on dynamic feedback when customer claims exceed internally established thresholds or in the event of compliance as findings indicate. Transitioning to proactive firm behaviour would require the firm to systematically leverage dynamic PLF and reverse information flow to design for durability, repairability and recyclability (DfX) (Kiritsis 2011). Consequently, shifting its focus to identifying value throughout the entire lifecycle of the product in both high-volume, low value and low-volume, high-value configuration by leveraging internally benchmarked product durability LCA data to calculate residual lifetime specific to the firm products.

Recycler and sorter in EOL

Commercial exploitation for EOL recyclers is driven by achieving alignment in value chain to the recycling process parameters in terms of fibre composition requirements and sorting accuracy. While the recycler utilizes batch-level testing data to enforce strict feedstock requirements, this exploitation remains isolated to intra-organizational process viability.

As Iyengar, Sweeney, and Montealegre (2015) and Kohli & Grover (2008) note, information technology does not generate competitive advantage in isolation. Value creation is mediated through ACAP and realized through cross-organizational alignment, process changes, and shared strategic logic. Until such dominant logics (Lane & Lubatkin), data schemas, and financial responsibility are aligned across the consumer divide, PLF cannot be fully exploited to close the loop between EOL, MOL actors and BOL actors (Jun, Kiritsis & Xirouchakis 2007).

6.5 Inter-organizational feedback loops

Closing these loops is crucial to move beyond fragmented material flows and toward closed information loops where information generated during MOL and EOL returns to BOL to inform strategic redesign. By feeding this data back into early design, organizations can build multi-level learning artifacts embedded in operational routines that can execute single-loop routine corrective actions, double-loop structural and strategic redesigns and deutero-learning to increase their long-term temporal capacity for systematic adaptation or transition to the desired state (Argyris & Schön 1997) which in this case is CE.

Moreover, asymmetric information flow was observed in the value chains where feed-forward dataflows tend to be high in information density. In contrast, product lifecycle feedback data flows were nearly absent. This feedforward flow is also disrupted post-sale when retailers lose link between the organization and its ability to monitor product's actual performance. This information blackout prevents the industry from validating the standardized tests for durability and repairability proposed in EU policy (ESPR 2024; JRC 2025). Without real world performance data, design standards will only be shaped by theoretical assumptions rather than empirical field evidence.

Feedback loops that do occur in the chain only take place with immediate supply chain partners. These feedback loops are limited to address commercial performance of products rather than lifecycle performance of products. Where B2B corrective feedback loops are observed to have threshold levels before they are triggered by the focal firm. This corrective feedback loops as illustrated in figure 4 stem from ensuring acceptable standards for process viability or acceptable quality parameters for sales performance. Additionally, viewing these quality parameters collectively through feedback mechanisms to hear the voice of the product (Stark 2015) throughout its lifecycle can radically automate the optimization process (Xu et al. 2009; Jun & Kiritsis 2012). Organizations can leverage information technology to make outcomes of inter-organizational information flows more predictable and improve competitive position (Marche 1991).

Furthermore, the gap between EOL recycler and BOL designer represents an anomaly in inter-organizational feedback loop that results in causal ambiguity regarding product failures (Szulanski 1966). Recyclers face cognitive distance in know-how and know-why of design choices and routines in BOL. While recycler possesses composition-based batches for chemical recycling prepared by sorters. It lacks the digital link required to connect any batch failure to a specific garment model or BOL design choice. This cognitive distance can be bridged by deployed interoperable explicit systems (Xu et al 2009). Additionally, stemming

from findings of cognitive distance between distant value chain actors, the phenomena of PLF delay across the consumer divide in MOL is also observed.

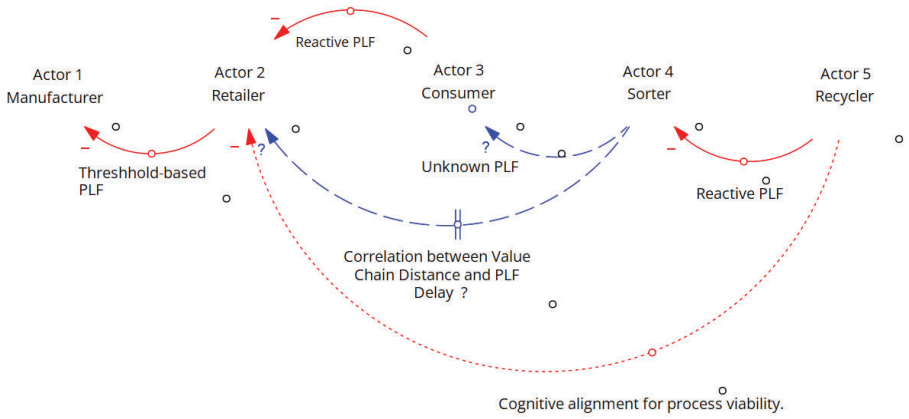

Figure 4: PLF Causal Loop Diagram

6.6 PLF as a 4-stage sequential process

A textile value chain is often complex and fragmented, both in terms of value addition and geography. Textile supply chains are frequently spread across continents, where cotton may be grown in one country, spun in another, woven in third, and sewn in a fourth. Such structures are the result of decades of supply chain evolution, where agriculture, expertise and cost in specific stages of the value chain became more efficient in certain regions in comparison to others.

Digital solutions such as PLM systems enable efficient communication between design and production teams even when they are spread across the globe as BOL actors. Figure 6 illustrates the author's view of feedback within this value chain which focuses on the flow of information from the product's lifecycle location originating from MOL and EOL lifecycle stages. The orange boxes in figure 5 represent components of PLF feedback mechanism. Simple integers represent the stages of ACAP in Zahra & George (2002) visualized together within a PLM system where S1 is knowledge capture, S2 & S3 represent knowledge organization and S4 represents knowledge reuse. This layered approach addresses both tacit and explicit facets of the mechanism. This process is further visualized in figure 6. where numbers on circular arrows represent the staged of ACAP embedded within PLF to enable closed-loop PLM grounded in organizational learning framework.

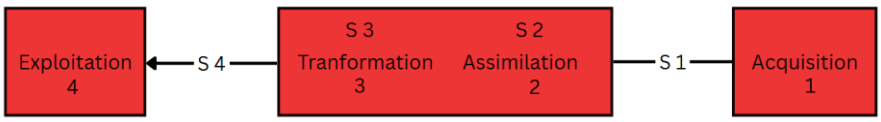

Figure 5 PLF framework adapted from ACAP and PLM.

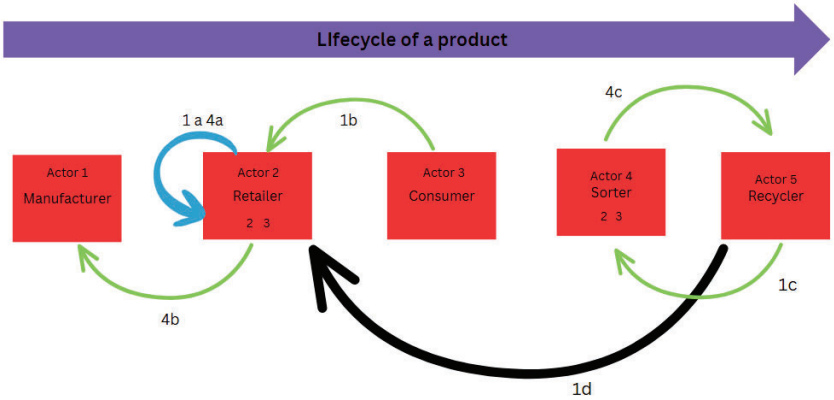

Figure 6: PLF as a routinization process for building data pipelines.

Feedback loop #	Description
1a4a	This causal loop is identified and represents the acquisition and exploitation in an intra-organizational setting
1b 4b	Reactive PLF that originates from consumers and cascades to the manufacturer under certain conditions such as a variable in excess of control threshold.
1b 4a	A reactive PLF that originates from consumer but is exploited in intra-organizational setting.
1 c 4c	A reactive and negative PLF that is exploited by sorter to improve quality of the batches specifically with respect to composition requirement at aggregate levels.
1d	Causal 1d is a one-off tacit knowledge transfer observed codified in the form of a document called guide. Pertains to the acceptable compositions and materials. This can also be an example for transfer of best practices or routines in inter-organizational setting.

6.7 PLF in 3-phase PLM for a Textile Value Chain

The current textile value chain information structure critically lacks backward information flow. This absence of feedback information can be bridged by embedded RFID and QR codes in the product. At the same time this study proposes backward information flow across the three stages in configured for a textile value chain's product lifecycle in addition to forward information flow. This can effectively achieve a bi-directional information flow in the value chain that informs processes ahead and offers insights backward in chain to evaluate process and material performance in real-world.

By sourcing dynamic MOL and EOL data, a firm can conduct a whole lifecycle-based analysis on the products it produces and places on the EU market. This also allows automatic calculations of emissions data that are incurred or avoided through valorization in automated way. It further refines the industry level LCAs to be adapted to organizations' products depending on the material, supplier, geographical and other variables. While information flows occur at both technical and operational traceability level, the PLM is largely observed to contain technical traceability parameters which is vital at process levels in sorting as well as recycling stages.

A conceptual closed-loop PLM for a textile value chain is illustrated in figure 7. Below. The figure includes phase transitions zones where product leaves an organization and boundary and enters an organizational boundary on the other side of the consumer divide. The material flow in MOL (shown in purple color) illustrates that material in this direction can move linearly or in circular direction through Third-Party Circular Services (TPCS) such as Dvala (n.d.). The purpose of giving access to TPCS in PLM is to provide the necessary technical information that may be required by repair, remanufacturing, reprinting, redyeing etc. to determine products compatibility and performance with the process.

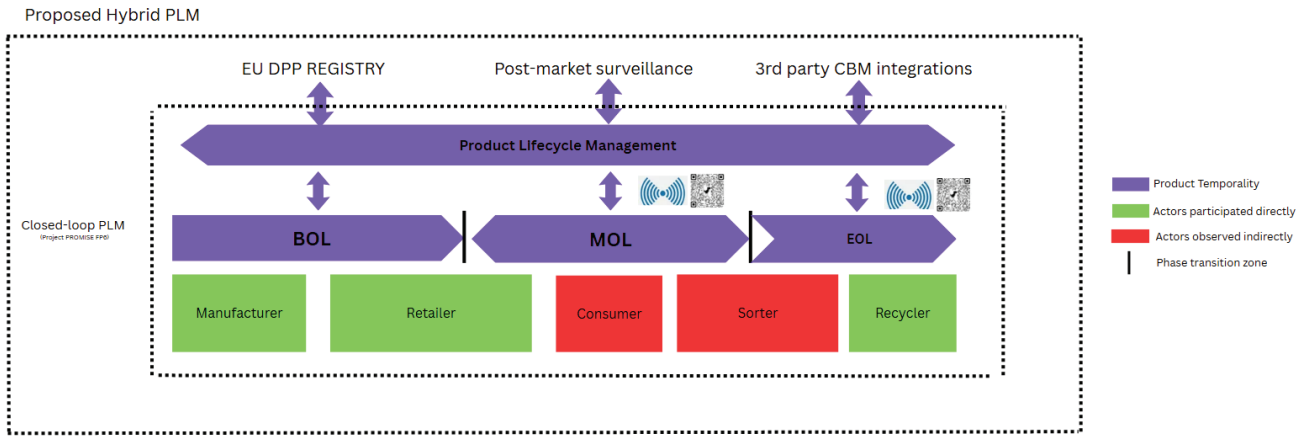

Figure 7: Closed-loop PLM in Textile Value Chain

7 Conclusion

The Swedish textile industry currently operates in fast changing regulatory environment, in this case, ESPR (2024) which contains impending mandates including DPP. This shift requires transition from linear information streams to joined lifecycle centric information flows across T&C value chain. Within the context of Swedish textile value chain, there is a strategic need to move beyond compliance-driven data models to one where PLF acts as the extension of human cognition in terms of circularity. This research applies qualitative empirical method to address to crucial questions:

RQ1: How are Product Lifecycle Feedback (PLF) loops currently structured and practiced in Swedish textile value chain?

RQ2: What organizational capabilities are required for textile firms in Sweden to operationalize product lifecycle feedback?

By utilizing absorptive capacity framework to product lifecycle management architectures, this study demonstrates that circular transition is impeded no only by technological shortcomings, but also by lack of lifecycle-centric explorations. The following synthesis bridges these structural and capability gaps, beginning with addressing socio-technological divergence in lifecycle data flows

RQ1:
The structure and practice of PLF loops in observed configuration of the Swedish textile value chain clearly shows information bottleneck that impedes tracking ability of organizations to adapt standardized durability and recyclability testing in real-world performance data. Information asymmetry is observed along the entire chain especially in reverse flow the feedback from MOL and EOL phases is almost non-existent especially across the consumer divide or between distant value chain actors.

Data integration is limited to BOL phase, where design specifications are treated as final. Once a product exits the point-of-sale terminal, firms experience a near-total blackout except for product claims feedback and experience rating on webstore. The current state of information flow can be characterized as a one-way forward flow in nature. MOL and EOL actor interactions are decoupled from the BOL designers and manufacturers. This keeps the system limited to performance metrics based on theoretical lab assumptions rather than real-world data.

The study identifies a significant divide between the structured potential of PLM systems and the fragmented reality of daily operations. While the literature shows potential PLF channels through integrated PLM and BOM relational databases, actual practice is limited to reactive customer claims and returns. Similarly, while DPP event logs can capture MOL or use-phase data effectively, practice relies on web reviews and social media. Furthermore, where RFID data can be observed for maintenance and other process instances such as sorting and recycling, actual PLF channels are in informal channels or semi-structured format.

Such a structural fragmentation is a possible explanation of why textile waste that is redirected from landfills converts to incineration rate. A shift of material flow towards energy recovery as compared to high-value recycling could be a direct lack of lifecycle data-centric workflows. Additionally, the lack of item-level traceability in recycling impedes the PLF information to provide garment-level recyclability assessments at the EOL. Similarly, this loss

of knowledge prevents the recovery decision feedback to BOL required to inform the recyclability of a garment.

RQ2:

To transform lifecycle data into organizational knowledge requires high level of ACAP. The ACAP framework applied in this study identifies the organizational mechanism required to internalize signals from external environment to form an endogenous response as an innovative pathway to CE in harmony with EU regulations.

Firms must transition from passive regulatory posture to active digital linkage via QR and RFID technologies to enable information flow across the value chain. Technological overlap between value chain partners can bridge the know-how and know-why regarding product performance failures or improvisation by capturing the voice of the product (Stark 2015; Lane & Lubatkin 1998).

Assimilation gaps between departments or subunits within each organization are prevalent, especially in BOL Phase. This stems from both rigid and siloed enterprise systems that not only lack interoperability within organization but also in inter-organizational settings such as CAD and ERP systems. Additionally, tacit, person-dependent knowledge needs to be formalized into explicit databases through adaptive, relational and contextual data models for improved knowledge diffusion within organization resulting in reduced risk of knowledge or learning loss.

Transformation requires re-alignment between explicit technological tools or data ecosystems as extension of organizations individual cognitive structures grounded in lifecycle-centric approach to reduce friction with forthcoming EU regulations. By mapping data points in MOL and EOL in relation to BOL, these disparate data sets can provide insight into a firm's product over longer temporal horizons. In doing so, firms may engage in tracking capabilities that may give them further capabilities that cross-functional (Arthur 1996). Furthermore, by accumulating PLF from disparate sources, firms can optimize their product aspects based on their target market and market dynamics.

Organizations must explore long-term exploitation opportunities in addition to short-term exploitation. These long-term exploitations can vary in time and distance in the value chain ranging from actors in MOL, EOL and back in BOL. Whole lifecycle PLFs will provide supplementary knowledge required. To exploit the knowledge that exists within the routines of the organization by embedding individuals from one subunit to another may create the necessary knowledge overlap required to transition tacit routines into data-centric workflows to the extent where it is possible. Overall, the need of re-orientation is observed at the strategic, operational and tactical levels of organizations.

7.1 Limitations

While this study provides valuable insights into Product Lifecycle Feedback (PLF) within Sweden's textile sector, several critical limitations must be acknowledged.

Firstly, the primary empirical subjects, Actor 1 (Manufacturer), Actor 2 (Retailer), and Actor 5 (Recycler) do not share direct commercial or operational relationships. As these insights are drawn from parallel, unlinked value chains rather than a single interconnected supply network, the study cannot directly observe end-to-end, interorganizational feedback loops

within a single commercial ecosystem. As a result, the findings reflect unique, lateral chain dynamics rather than the direct flow of feedback across interlinked supply chain partners.

Secondly, as noted in the study's delimitation, certain key actors within the broader lifecycle were excluded, such as dedicated sorting and collection facilities. This exclusion limits the ability to analyse the necessary temporal dynamics, such as the time taken from initial placement on market and the products arrival at a sorting facility after completing its first or final use cycle. These time delays are influenced by variables such as the category product belongs to, inherent durability and technical parameters of product and its failure, all of which offer avenues for future research.

8 Theoretical Contribution

This study advances the intersection of PLM, ACAP and Circular Economy theory by identifying gaps at the strategic, operational and tactical levels of organizations in the T&C value chain of the Kingdom of Sweden. The research addressed the underexplored management of information feedback by operationalizing the concept of product lifecycle feedback in PLM systems denoted as voice of the product by Stark (2015). By linking feedback loops to optimize product-aspects the study moves beyond technical traceability to operational traceability where feedback systems drive organizational learning which in turn mitigate the risk of being trapped in linear economy. Additionally, by exploring feedback systems the study also extends the concept of potential orchestration capabilities to remote orchestration operations.

9 Managerial Implication:

Managerial implication includes transition of document-oriented information flow to product-data oriented systems replacing manual spreadsheet tracking to applying the concepts of relational databases in a whole-lifecycle format and real-time updates for decision support systems. Moreover, the study highlights the presence o f data exchange protocols and data standardization that can be leveraged for more automated and interoperable systems to feed directly into design software and other cross-functional use-cases.

The study highlights the importance of investing in collaborative knowledge sharing across the value chain to enable know-how, know-why and know-where understanding amongst stakeholders. Such chain level knowledge sharing also bridges the gap in cognitive distance and creates semantic cohesion for better understanding of routines and data ecosystem. Furthermore, the study also demonstrates how dominant logic is necessary to align value chain actors towards achieving a common goal of CE, even if it is encapsulated in commercial gains and regulatory compliance.

Lastly, the competitiveness of Swedish textile ecosystems in regulated circular market depends on transition from data acquisition to knowledge exploitation in a bi-directional information flow. As stricter mandates emerge within circular economy action plan, the ability to transform the voice of the product into organizational knowledge will offer sustained competitive advantage in the circular economy as compared to those trapped in linear paradigm.

10 Future Research

Building on the proposed hybrid PLM framework adapted from Project PROMISE (Kiritsis, Bufardi & Xirouchakis 2003) for the T&C value chain, several directions for future empirical and theoretical inquiries emerge.

Expanding upon the established framework theories of supply chain orchestration (Sandberg 2023; Sandberg, Pal & Hemilä, 2018), future research should explore the and test the concept of remote orchestration capabilities (Chien, Shih, & Huang, 2025; Shih et al., 2005). Researchers are encouraged to identify the architectural mechanisms, triggered data-centric workflows, decision-support algorithms, and organizational capabilities necessary for focal actors, meaning any actor in focus that remotely configures or demands resource routing in MOL and EOL. This can be explored by leveraging light weight IoT protocols within high-volume, low-margin and low-volume high-margin business model configurations. Additionally, the concept of fused, hybrid or collaborative decision support system should be explored in intra-organizational and extra-organizational configuration.

While this study highlights the role of ESPR in feedback systems, the role of extended producer responsibility should also be explored in conjunction. This exploration involves potential role of Swedish Producer Responsibility Organization (PRO) to mediate as data and information broker between producing firms, municipality collection, sorting, TPCS and recycling actors. This may ensure data privacy for all actors involved and equitable participation of all stakeholders to benchmark baseline circularity. Topics to be explored in this setting include, sensorized, connected, orchestrated and, optimized collection and routing in MOL for re-everything (logistics cost reduction) and end-of-use. Similarly, Connected, sensorized and, orchestrated sorting and recycling in EOL should also be explored (Refashion 2026). When exploring this direction, emphasis must be placed on economic viability through cross-phase single-actor or multi-actor demand and routing capabilities. Further exploration is also required in phase-transition zones to understand and bridge the distant value chain stages of BOL and EOL material and information flow with emphasis on implications of feedback delay in correlation with LCA results from PEFCR as initial baseline delay.

References:

Abdalla, M. M., Oliveira, L. G. L., Azevedo, C. E. F. & Gonzalez, R. K. (2018). Quality in qualitative organizational research: Types of triangulation as a methodological alternative. *Administração: Ensino e Pesquisa*, 19(1), pp. 66–98. doi:10.13058/raep.2018.v19n1.578

Abramovici, M., Gebus, P., Göbel, J. C. & Dang, H. B. (2016). A Semantic Information Retrieval Framework within the Scope of IPS2-PLM. *Procedia CIRP*, 47, pp. 294-299. doi:10.1016/j.procir.2016.03.083

Abramovici, M. & Lindner, A. (2011). Providing product use knowledge for the design of improved product generations. *CIRP Annals*, 60(1), pp. 211-214. doi:10.1016/j.cirp.2011.03.103

Abramovici, M., Neubach, M., Schulze, M. & Spura, C. (2009). Metadata reference model for IPS² lifecycle management. In *Proceedings of the 1st CIRP Industrial Product-Service Systems (IPS2) Conference*. Cranfield University, p. 268. https://dspace.lib.cranfield.ac.uk/server/api/core/bitstreams/2cf810cb-d7cf-4d57-b3c1-3f52a5f9818b/content [Accessed May 2026]

Acevedo, L. I., Pigosso, D. C. A. & McAloone, T. C. (2024). Exploring the Landscape of Contemporary Sustainability Philosophies: Origins, Synergies and Corporate Applications. *Circular Economy and Sustainability*, 4(4), pp. 2675-2711. doi:10.1007/s43615-024-00399-x

Alavi, M. & Leidner, D. E. (2001). Review: Knowledge Management and Knowledge Management Systems: Conceptual Foundations and Research Issues. *MIS Quarterly*, 25(1), pp. 107-136. doi:10.2307/3250961

Apparel and Footwear PEFCR Technical Secretariat (2025). *Product Environmental Footprint Category Rules (PEFCR) for Apparel and Footwear (Version 3.1)*. https://pefapparelandfootwear.eu/wp-content/uploads/2025/05/AFW_PEFCR_v3.1_final.zip [Accessed April 2025]

Argyris, C. & Schön, D.A. (1997). Organizational learning: a theory of action perspective. *Reis*, (77/78), pp. 345–348. https://doi.org/10.2307/40183951

Arthur, W. B. (1996). Increasing returns and the new world of business. *Harvard Business Review*, 74(4), pp. 100–109. https://sites.santafe.edu/~wbarthur/Papers/HBR.pdf [Accessed April 2026]

Avery Dennison (n.d.). *AD TexTrace connected textiles*. https://rfid.averydennison.com/en/home/products-solutions/connected-textiles.html

Bates, A., Vavricka, R., Carleton, S., Shao, R. & Pan, C. (2025). Unified modeling language code generation from diagram images using multimodal large language models. *Machine Learning with Applications*, 20, 100660. doi:10.1016/j.mlwa.2025.100660

Baxter, D., Gao, J., Case, K., Harding, J., Young, B., Cochrane, S. and Dani, S. (2007). An engineering design knowledge reuse methodology using process modelling. *Research in Engineering Design*, 18(1), pp. 37–48. doi:10.1007/s00163-007-0028-8

Bindi, B., Fani, V., Bandinelli, R., Massa, G., Ciaccio, G., Brutti, A. & De Sabbata, P. (2018). Barriers and drivers of eBIZ adoption in the fashion supply chain: Preliminary results. In *2018 5th International Conference on Industrial Engineering and Applications (ICIEA)*. IEEE, pp. 555-559. doi:10.1109/IEA.2018.8387163

Bocken, N. M. P., de Pauw, I., Bakker, C. & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, 33(5), pp. 308-320. doi:10.1080/21681015.2016.1172124

Booch, G., Rumbaugh, J. & Jacobson, I. (1999). *The unified modeling language user guide*. Addison-Wesley. http://meusite.mackenzie.com.br/rogerio/the-unified-modeling-language-user-guide.9780201571684.997.pdf [Accessed May 2026]

Boynton, A. C., Zmud, R. W. & Jacobs, G. C. (1994). The Influence of IT Management Practice on IT Use in Large Organizations. *MIS Quarterly*, 18(3), pp. 299-318. doi:10.2307/249620

Brydges, T. (2021). Closing the loop on take, make, waste: Investigating circular economy practices in the Swedish fashion industry. *Journal of Cleaner Production*, 293, p. 126245. doi:10.1016/j.jclepro.2021.126245

Bryman, A. (2016). *Social research methods*. 5th ed. Oxford University Press.

Bufardi, A., Edler, A., Frey, M., Kiritsis, D., Metin, A. & Smith, B. (2007). Improving Product Development by Design-for-X (DfX) Support. In Krause, F.-L. (ed.) *The Future of Product Development*. Springer, pp. 91-100. doi:10.1007/978-3-540-69820-3_10

Casale, G., Ardagna, D., Artac, M., Barbier, F., Branitski, E., Brataas, G., Di Nitto, E., Ferguson, D., Perez, J.F., Ruiz, D.G., Sfakianakis, E., Spais, I. & Tamburri, D.A. (2015). DICE: quality-driven development of data-intensive cloud applications. In: *2015 IEEE/ACM 7th International Workshop on Modeling in Software Engineering (MiSE)*. Florence, Italy, 16-17 May 2015. Piscataway: IEEE, pp. 78–83. https://doi.org/10.1109/MiSE.2015.21

Chien, H.Y., Shih, A.T. & Huang, Y.M. (2025). Leveraging hierarchical asymmetry for efficient resource discovery in Message Queuing Telemetry Transport. *Symmetry*, 17(10), p. 1722. https://doi.org/10.3390/sym17101722

CISUTAC (n.d.). *Deliverables*. https://www.cisutac.eu/deliverables [Accessed May 2026]

Cohen, W. M. & Levinthal, D. A. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly*, 35(1), pp. 128-152. doi:10.2307/2393553

Cooper, A. C. & Schendel, D. (1976). Strategic responses to technological threats. *Business Horizons*, 19(1), pp. 61-69. doi:10.1016/0007-6813(76)90024-0

Creswell, J. W. & Creswell, J. D. (2023). *Research design: Qualitative, quantitative, and mixed methods approach*. 6th ed. SAGE Publications.

Crouch, M. & McKenzie, H. (2006). The logic of small samples in interview-based qualitative research. *Social Science Information*, 45(4), pp. 483-499. doi:10.1177/0539018406069584

d'Avolio, E., Bandinelli, R. & Rinaldi, R. (2015). Improving new product development in the fashion industry through product lifecycle management: a descriptive analysis. *International Journal of Fashion Design, Technology and Education*, 8(2), pp. 108-121. doi:10.1080/17543266.2015.1005697

David, M. & Rowe, F. (2016). What does PLMS (product lifecycle management systems) manage: Data or documents? Complementarity and contingency for SMEs. *Computers in Industry*, 75, pp. 140-150. doi:10.1016/j.compind.2015.05.005

De Sabbata, P., Scalia, M. & Baker, M. (2008). eBIZ-TCF: An initiative to improve eAdoption in European textile/clothing and footwear industry. In Cunningham, P. & Cunningham, M. (eds.) *Collaboration and the knowledge economy: Issues, applications, case studies*. IOS Press, pp. 1169–1176.

Dienst, S., Fathi, M., Abramovici, M. & Lindner, A. (2011). A conceptual data management model of a feedback assistance system to support product improvement. In *2011 IEEE International Conference on Systems, Man, and Cybernetics*. IEEE, pp. 446–451. doi:10.1109/ICSMC.2011.6083706

Dodgson, M. (1993). Organizational Learning: A Review of Some Literatures. *Organization Studies*, 14(3), pp. 375-394. doi:10.1177/017084069301400303

Drisko, J. W. (2025). Transferability and Generalization in Qualitative Research. *Research on Social Work Practice*, 35(1), pp. 102-110. doi:10.1177/10497315241256560

Dvala (n.d.). *dvala.se: circular fashion for the event industry*. Available at: https://dvala.se/ [Accessed 19 August 2026].

EEA (2024). *Reuse flows according to the implementing decision (EU) 2021/19, 2024, ver 1.2*. European Environment Agency. https://sdi.eea.europa.eu/data/d3f8d201-854e-4863-bac8-f6ad0f4769ed [Accessed 2nd February 2026]

EEA (2025). *Circularity Metrics Lab. Share of textile waste sent to incineration or landfill in the EU*. European Environment Agency. https://www.eea.europa.eu/en/circularity/sectoral-modules/textiles/share-of-textile-waste-sent-to-incineration-or-landfill-in-the-eu?activeTab=658e2886-cfbf-4c2f-a603-061e1627a515 [Accessed 2nd February 2026]

Eisenhardt, K. M. (2021). What is the Eisenhardt Method, really? *Strategic Organization*, 19(1), pp. 147-160. doi:10.1177/1476127020982866

Ellen MacArthur Foundation (2016a). *Continuous learning loops*. https://www.ellenmacarthurfoundation.org/continuous-learning-loops

Ellen MacArthur Foundation (2016b). *Embed feedback mechanisms*. https://www.ellenmacarthurfoundation.org/embed-feedback-mechanisms [Accessed April 2026]

Ellen MacArthur Foundation (2017). *A new textiles economy: Redesigning fashion's future*. http://www.ellenmacarthurfoundation.org/publications [Accessed 9th February 2025]

Ellen MacArthur Foundation (2021a). *Circular business models: Redefining growth for a thriving fashion industry*.

https://content.ellenmacarthurfoundation.org/m/60926fc64dbab81d/original/Circular-business-models.pdf [Accessed April 2026]

Ellen MacArthur Foundation (2021b). *Universal policy goals: Overview*. https://www.ellenmacarthurfoundation.org/universal-policy-goals/overview [Accessed April 2026]

European Commission (2024a). *Ecodesign for Sustainable Products Regulation*. https://environment.ec.europa.eu/strategy/circular-economy/ecodesign-sustainable-products-regulation_en [Accessed May 2024]

European Commission (2024b). *Ecodesign for Sustainable Products Regulation (ESPR) online information session*. https://commission.europa.eu/document/download/c5db3b9e-23ae-42c8-a50a-b549f20a377d_en?filename=2024_05_22_EC%20Presentation%20ESPR%20Webinar_final.pdf [Accessed April 2024]

European Committee for Standardization (2025). *CWA 18291:2025: TRICK – Guidelines on data collection from textile supply chains for the Digital Product Passport*. https://www.cencenelec.eu/media/CEN-CENELEC/CWAs/RI/2025/cwa18291_2025.pdf [Accessed May 2026]

European Parliamentary Research Service (2024). *Digital product passport for the textile sector (PE 757.808)*. European Parliament. https://www.europarl.europa.eu/RegData/etudes/STUD/2024/757808/EPRS_STU(2024)757808_EN.pdf [Accessed April 2024]

Expósito-Langa, M., Molina-Morales, F.X. & Tomás-Miquel, J.V. (2015). How shared vision moderates the effects of absorptive capacity and networking on clustered firms' innovation. *Scandinavian Journal of Management*, 31(2), pp. 293–302. https://doi.org/10.1016/j.scaman.2015.06.001

Fichman, R. G. & Kemerer, C. F. (1999). The Illusory Diffusion of Innovation: An Examination of Assimilation Gaps. *Information Systems Research*, 10(3), pp. 255-275. doi:10.1287/isre.10.3.255

Gardner, T. A., Benzie, M., Börner, J., Dawkins, E., Fick, S., Garrett, R., Godar, J., Grimard, A., Lake, S., Larsen, R. K., Mardas, N., McDermott, C. L., Meyfroidt, P., Osbeck, M., Persson, M., Sembres, T., Suavet, C., Strassburg, B., Trevisan, A. & Wolvekamp, P. (2019). Transparency and sustainability in global commodity supply chains. *World Development*, 121, pp. 163-177. doi:10.1016/j.worlddev.2018.05.025

Geissdoerfer, M., Morioka, S. N., de Carvalho, M. M. & Evans, S. (2018). Business models and supply chains for the circular economy. *Journal of Cleaner Production*, 190, pp. 712-721. doi:10.1016/j.jclepro.2018.04.159

Geissdoerfer, M., Savaget, P., Bocken, N. M. P. & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, 143, pp. 757-768. doi:10.1016/j.jclepro.2016.12.048

Grieves, M. (2011). *Virtually Perfect: Driving Innovative and Lean Products through Product Lifecycle Management*. Space Coast Press.

Grodal, S., Anteby, M. & Holm, A. L. (2020). Achieving Rigor in Qualitative Analysis: The Role of Active Categorization in Theory Building. *Academy of Management Review*, 46(3), pp. 591-612. doi:10.5465/amr.2018.0482

GS1 (n.d.). *EPCglobal*. https://www.gs1.org/epcglobal [Accessed May 2026]

Gupta, S., Chen, H., Hazen, B. T., Kaur, S. & Santibañez Gonzalez, E. D. R. (2019). Circular economy and big data analytics: A stakeholder perspective. *Technological Forecasting and Social Change*, 144, pp. 466-474. doi:10.1016/j.techfore.2018.06.030

Harkonen, J., Guerrero Rodriguez, J. M. & Mustonen, E. (2024). The Role of Productization in End-To-End Traceability. *Eng*, 5(4), pp. 2943-2965. https://www.mdpi.com/2673-4117/5/4/153

Halstenberg, F. A., Lindow, K. & Stark, R. (2017). Utilization of product lifecycle data from PLM systems in platforms for Industrial Symbiosis. *Procedia Manufacturing*, 8, pp. 369–376. doi:10.1016/j.promfg.2017.02.047

Horn, S., Mölsä, K.M., Sorvari, J., Tuovila, H. & Heikkilä, P. (2023). Environmental sustainability assessment of a polyester T-shirt – Comparison of circularity strategies. *Science of the Total Environment*, 884, 163821. https://doi.org/10.1016/j.scitotenv.2023.163821

Interior Cluster Sweden (n.d.). *Data till Business*. Available at: https://interiorcluster.se/dtb [Accessed 8 Aug. 2026]

Iyengar, K., Sweeney, J. R. & Montealegre, R. (2015). Information Technology Use as a Learning Mechanism: The Impact of IT Use on Knowledge Transfer Effectiveness, Absorptive Capacity, and Franchisee Performance. *MIS Quarterly*, 39(3), pp. 615-642.

Jäger-Roschko, M. & Petersen, M. (2022). Advancing the circular economy through information sharing: A systematic literature review. *Journal of Cleaner Production*, 369, 133210. doi:10.1016/j.jclepro.2022.133210

Jeanologia (n.d.). *EIM software: Environmental impact measuring*. https://www.jeanologia.com/eim/

Joint Research Centre (2025). *Summary of working document on the 3rd milestone: Preparatory study on textiles for product policy instruments*. European Commission. https://susproc.jrc.ec.europa.eu/product-bureau/sites/default/files/2025-12/Textile-Prep-Study_3rd-Milestone_SUM_20251212.pdf [Accessed July 2026]

Jun, H.-B. & Kiritsis, D. (2012). Several aspects of information flows in PLM. In Rivest, L., Bouras, A. & Louhichi, B. (eds.) *Product lifecycle management: Towards knowledge-rich enterprises*. Springer, pp. 11–20. doi:10.1007/978-3-642-35758-9_2

Kalluri, R.R., Surasani, V.R., Rellu, N.S.H. and Devarakonda, N. (2025). Evolution of Master Data Management and Data Governance: A Two-Decade Review of Advancements and Innovations. *Journal of Informatics Education and Research*, 5(2), pp. 258–268.

Kedia, B. L. & Bhagat, R. S. (1988). Cultural Constraints on Transfer of Technology across Nations: Implications for Research in International and Comparative Management. *The Academy of Management Review*, 13(4), pp. 559-571. doi:10.2307/258375

Keller, W. (1996). Absorptive capacity: On the creation and acquisition of technology in development. *Journal of Development Economics*, 49(1), pp. 199-227. doi:10.1016/304-3878(95)00060-7

Kessler, E. H., Paul E. Bierly, III & Shanthi, G. (2001). Vasa Syndrome: Insights from a 17th-Century New-Product Disaster. *The Academy of Management Executive (1993-2005)*, 15(3), pp. 80-91.

Kim, L. (1998). Crisis Construction and Organizational Learning: Capability Building in Catching-up at Hyundai Motor. *Organization Science*, 9(4), pp. 506-521.

Kiritsis, D., Bufardi, A. & Xirouchakis, P. (2003). Research issues on product lifecycle management and information tracking using smart embedded systems. *Advanced Engineering Informatics*, 17(3), pp. 189-202. doi:10.1016/j.aei.2004.09.005

Kiritsis, D. (2011). Closed-loop PLM for intelligent products in the era of the Internet of things. *Computer-Aided Design*, 43(5), pp. 479–501. doi:10.1016/j.cad.2010.03.002

Kohli, R. & Grover, V. (2008). Business value of IT: An essay on expanding research directions to keep up with the times. *Journal of the Association for Information Systems*, 9(1), pp. 23–39. doi:10.17705/1jais.00147

Kurilova-Palisaitiene, J., Lindkvist, L. & Sundin, E. (2015). Towards facilitating circular product life-cycle information flow via remanufacturing. *Procedia CIRP*, 29, pp. 780-785. doi:10.1016/j.procir.2015.02.162

Lane, P. J. & Lubatkin, M. (1998). Relative absorptive capacity and interorganizational learning. *Strategic Management Journal*, 19(5), pp. 461-477. doi:10.1002/(SICI)1097-0266(199805)19:5<461::AID-SMJ953>3.0.CO;2-L

Li, H., Pour, M. A. N., Li, Y., Lindecrantz, M., Blomqvist, E. & Lambrix, P. (2023). A survey of general ontologies for the cross-industry domain of circular economy. In *Companion Proceedings of the ACM Web Conference 2023 (WWW '23 Companion)*. Association for Computing Machinery, pp. 731–741. doi:10.1145/3543873.3587613

Lindkvist Haziri, L., Sundin, E. & Sakao, T. (2019). Feedback from Remanufacturing: Its Unexploited Potential to Improve Future Product Design. *Sustainability*, 11(15), 4037. doi:10.3390/su11154037

MacCarthy, B. L. & Pasley, R. C. (2021). Group decision support for product lifecycle management. *International Journal of Production Research*, 59(16), pp. 5050-5067. doi:10.1080/00207543.2020.1779372

Maitre-Ekern, E. & Dalhammar, C. (2016). Regulating Planned Obsolescence: A Review of Legal Approaches to Increase Product Durability and Reparability in Europe. *Review of European, Comparative & International Environmental Law*, 25(3), pp. 378-394. doi:10.1111/reel.12182

March, J. G. (1991). Exploration and exploitation in organizational learning. *Organization Science*, 2(1), pp. 71–87. doi:10.1287/orsc.2.1.71

Mason, J. (2002). *Qualitative research*. 2nd ed. SAGE Publications.

Matinheikki, J., Pesonen, T., Artto, K. & Peltokorpi, A. (2017). New value creation in business networks: The role of collective action in constructing system-level goals. *Industrial Marketing Management*, 67, pp. 122–133. doi:10.1016/j.indmarman.2017.06.011

Matsokis, A. & Kiritsis, D. (2010). An ontology-based approach for Product Lifecycle Management. *Computers in Industry*, 61(8), pp. 787-797. doi:10.1016/j.compind.2010.05.007

May, G., Cho, S., Correia, A. T., Siafaka, R., Stokic, D. & Kiritsis, D. (2022). Toward a reference terminology for product-service systems in the manufacturing domain. *Computers in Industry*, 142, 103729. doi:10.1016/j.compind.2022.103729

Milios, L. (2018). Advancing to a Circular Economy: three essential ingredients for a comprehensive policy mix. *Sustainability Science*, 13(3), pp. 861-878. doi:10.1007/s11625-017-0502-9

Miller, R. L. (2000). Analysing life histories. In *Researching life stories and family histories*. SAGE Publications, pp. 113–154. doi:10.4135/9781849209830.n5

Modelio (n.d.). *Modelio: open modeling environment*. http://www.modelio.org/index.htm [17 July 2026]

Morshedzadeh, I., Oscarsson, J., Ng, A., Jeusfeld, M. & Sillanpaa, J. (2018). Product lifecycle management with provenance management and virtual models: an industrial use-case study. *Procedia CIRP*, 72, pp. 1190-1195. doi:10.1016/j.procir.2018.03.157

Mowery, D. C., Oxley, J. E. & Silverman, B. S. (1996). Strategic alliances and interfirm knowledge transfer. *Strategic Management Journal*, 17(S2), pp. 77-91. doi:10.1002/smj.4250171108

Nazeer, N., Rasiah, R. & Furuoka, F. (2021). Technology Transfer, Technological Capability, Absorptive Capacity and Firm Performance: An Investigation of the Textile and Clothing Firms in Pakistan. *Malaysian Journal of Economic Studies*, 58(1), pp. 99–124. https://doi.org/10.22452/MJES.vol58no1.6

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T. & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment*, 1(4), pp. 189-200. doi:10.1038/s43017-020-0039-9

Noy, N. F. & McGuinness, D. L. (2001). *Ontology development 101: A guide to creating your first ontology* (Technical Report No. SMI-2001-0880). Stanford Medical Informatics.

Pal, R. (2016). Extended responsibility through servitization in PSS: An exploratory study of used-clothing sector. *Journal of Fashion Marketing and Management*, 20(4), pp. 453–470. doi:10.1108/JFMM-12-2015-0100

Pal, R. (2017) Value creation through reverse logistics in used clothing networks. *The International Journal of Logistics Management*, 28(3), pp. 864–906. Available at: https://doi.org/10.1108/IJLM-11-2016-0272

Pal, R. & Sandberg, E. (2024). Circular supply chain valorisation through sustainable value mapping in the post-consumer used clothing sector. *The International Journal of Logistics Management*, 35(5), pp. 1373–1416. doi:10.1108/IJLM-01-2023-0023

Patel, S., Choudhary, J. & Patil, G., 2023. Revolution of Database Management System: A literature Survey. *International Journal of Engineering Trends and Technology*, 71(7), pp. 189–200. https://doi.org/10.14445/22315381/IJETT-V71I7P218

PESCO-UP (n.d.). *Deliverables*. https://www.pesco-up.eu/deliverables [Accessed May 2026]

Porter, M. E. & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. *Harvard Business Review*, 92(11), pp. 64–88. https://hbr.org/2014/11/how-smart-connected-products-are-transforming-competition [Accessed March 2025]

Pratt, M. G., Kaplan, S. & Whittington, R. (2020). Editorial Essay: The Tumult over Transparency: Decoupling Transparency from Replication in Establishing Trustworthy Qualitative Research*. *Administrative Science Quarterly*, 65(1), pp. 1-19. doi:10.1177/0001839219887663

Primo1D (n.d.). *Retailers & brands: RFID tags for apparel and footwear*. https://www.primo1d.com/retailers-brands/

Product Environmental Footprint (PEF) Apparel and Footwear (n.d.). *Technical secretariat & governance*. https://pefapparelandfootwear.eu/who-is-involved/#members [Accessed April 2025]

Psarommatis, F. & May, G. (2024). Digital Product Passport: A Pathway to Circularity and Sustainability in Modern Manufacturing. *Sustainability*, 16(1), p. 396. doi:10.3390/su16010396

Puglieri, F. N., Salvador, R., Romero-Hernandez, O., Escrivão Filho, E., Piekarski, C. M., de Francisco, A. C. & Ometto, A. R. (2022). Strategic planning oriented to circular business models: A decision framework to promote sustainable development. *Business Strategy and the Environment*, 31(7), pp. 3254-3273. doi:10.1002/bse.3074

RAIN Alliance (2026). *How RAIN RFID Enables Textile Digital Product Passport Compliance and Circularity*. Available: https://therainalliance.org/digital-product-passports-how-rain-rfid-enables-textile-compliance-and-circularity/ [Accessed 8 August 2026]

Refashion (2026). *State of the art of automated sorting and disassembly technologies for textile and footwear in Europe*. Available at: https://media-pro.refashion.fr/2026/08/state-of-the-art-of-automated-sorting-and-disassembly-technologies-for-textile-and-footwear-in-europe-refashion-version-2026.pdf [Accessed 18 August 2026].

Repenning, N. P. (2002). A Simulation-Based Approach to Understanding the Dynamics of Innovation Implementation. *Organization Science*, 13(2), pp. 109-127.

Ritchie, J. & Lewis, J. (eds.) (2003). *Qualitative research practice: A guide for social science students and researchers*. SAGE Publications.

Russell, S. & Norvig, P. (2022). *Artificial intelligence: A modern approach*. 4th ed., Global ed. Pearson Education.

Sandberg, E. (2023). Orchestration capabilities in circular supply chains of post-consumer used clothes – A case study of a Swedish fashion retailer. *Journal of Cleaner Production*, 387, 135935. doi:10.1016/j.jclepro.2023.135935

Scheidt, L. & Zong, S. (1994). An approach to achieve reusability of electronic modules. In *Proceedings of 1994 IEEE International Symposium on Electronics and the Environment*. IEEE, pp. 331–336. doi:10.1109/ISEE.1994.337237

Schildt, H., Keil, T. & Maula, M. (2012). The temporal effects of relative and firm-level absorptive capacity on interorganizational learning. *Strategic Management Journal*, 33(10), pp. 1154-1173. doi:10.1002/smj.1963

Shih, D. H., Sun, P. L. & Lin, B. (2005). Securing industry-wide EPCglobal Network with WS-Security. *Industrial Management & Data Systems*, 105(7), pp. 972-996. doi:10.1108/02635570510616148

Science Park Borås (2024). *System demonstrator for a sustainable textile system*. Available: https://scienceparkboras.se/2024/01/systemdemonstrator-for-ett-hallbart-textilsystem/ [Accessed 8 August 2026].

Specim (2026). *Retex_Webinar_05_26*. https://www.specim.com/wp-content/uploads/2026/05/Retex_Webinar_05_26.pdf (Accessed 2026-08-10).

Sreepathy, H. V., Rao, D. B., Jaysubramanian, M. K. & Rao, D. B. (2024). Data Ingestions as a Service (DIaaS): A Unified Interface for Heterogeneous Data Ingestion, Transformation, and Metadata Management for Data Lake. *IEEE Access*, 12, pp. 156131–156149. doi:10.1109/ACCESS.2024.3479736

Stark, J. (2015). Product Lifecycle Management. In Stark, J. (ed.) *Product Lifecycle Management (Volume 1): 21st Century Paradigm for Product Realisation*. Springer International Publishing, pp. 1-29. doi:10.1007/978-3-319-17440-2_1

Stelmaszczyk, M., Pierscieniak, A. & Abrudan, D. (2023). Managerial decisions and new product development in the circular economy model enterprise: absorptive capacity and a mediating role of strategic orientation. *Decision*, 50(1), pp. 35–49. doi:10.1007/s40622-023-00336-1

Szulanski, G. (1996). Exploring internal stickiness: Impediments to the transfer of best practice within the firm. *Strategic Management Journal*, 17(S2), pp. 27-43. doi:10.1002/smj.4250171105

Tai, Y.-M. (2017). Effects of product lifecycle management systems on new product development performance. *Journal of Engineering and Technology Management*, 46, pp. 67-83. doi:10.1016/j.jengtecman.2017.06.001

Tayaran, E. & Schiffauerova, A. (2012). The role of internal and external sources of knowledge in the product lifecycle in biotechnology sector. In Rivest, L., Bouras, A. & Louhichi, B. (eds.) *Product lifecycle management. Towards knowledge-rich enterprises*. Springer, pp. 48–57. doi:10.1007/978-3-642-35758-9_5

Thomas, K., Durrani, H., Brady, J., Ludwig, K., Yatvitskiy, M., Clarke-Sather, A. R., Cao, H. & Cobb, K. (2024). Fundamental Challenges and Opportunities for Textile Circularity. *Sustainability*, 16(24), 11117. doi:10.3390/su162411117

Timmermans, S. & Tavory, I. (2012). Theory construction in qualitative research: from grounded theory to abductive analysis. *Sociological Theory*, 30(3), pp. 167–186. https://doi.org/10.1177/0735275112457914

Todorova, G. & Durisin, B. (2007). Absorptive Capacity: Valuing a Reconceptualization. *The Academy of Management Review*, 32(3), pp. 774-786.

TRICK (n.d.). *Project documents*. https://www.trick-project.eu/project-documents [Accessed May 2026]

TRICK Consortium (2023). *Data model and domain-specific ontologies implementation (Deliverable D2.2)*. TRICK Project. https://policycommons.net/artifacts/21526412/data-model-and-domain-specific-ontologies-implementation/22426612/

Trinidad, J. E. (2025). Mapping Organizational Theory With SCRIPTS. *Sociology Compass*, 19(4), e70059. doi:10.1111/soc4.70059

TrusTrace (2025). *The data advantage playbook*. https://trustrace.com/hubfs/TrusTrace-The-Data-Advantage-Playbook-June-2025.pdf [Accessed 12th February 2026]

TrusTrace & Trace4Value (2023). *Digital product passport in textile data protocol*. https://trustrace.com/hubfs/Whitepapers/TrusTrace%20and%20Trace4Value%20Digital%20Product%20Passport%20in%20Textile%20Data%20Protocol.pdf [Accessed 11th February 2026]

Tsoukas, H. & Chia, R. (2002). On organizational becoming: Rethinking organizational change. *Organization Science*, 13(5), pp. 567–582. doi:10.1287/orsc.13.5.567.7810

University of Borås (2025). *System demonstrator for a sustainable textile system*. Available: https://www.hb.se/forskning/forskningsportal/projekt/systemdemonstrator-for-ett-hallbart-textilsystem/ [Accessed 8 August 2026].

Uriarte, F. A. (2008). *Introduction to Knowledge Management: A Brief Introduction to the Basic Elements of Knowledge Management for Non-practitioners Interested in Understanding the Subject*. ASEAN Foundation.

Veugelers, R. (1997). Internal R & D expenditures and external technology sourcing. *Research Policy*, 26(3), pp. 303-315. doi:10.1016/S0048-7333(97)00019-X

Volberda, H. W., Foss, N. J. & Lyles, M. A. (2010). Absorbing the Concept of Absorptive Capacity: How to Realize Its Potential in the Organization Field. *Organization Science*, 21(4), pp. 931-951.

Walter, B., Jolevski, I., Garnizov, I. & Arsovic, A. (2023). Supporting Product Management Lifecycle with Common Best Practices. In M. Yilmaz, P. Clarke, A. Riel & R. Messnarz, eds. *Systems, Software and Services Process Improvement: EuroSPI 2023*. Communications in Computer and Information Science, vol. 1891. Cham: Springer, pp. 219–230. doi:10.1007/978-3-031-42310-9_15

Walton, A. L. J., Tomovic, C. L. & Grieves, M. W. (2013). Product lifecycle management: Measuring what is important – Product lifecycle implementation maturity model. In Bernard,

A., Rivest, L. & Dutta, D. (eds.) *Product lifecycle management for society*. Springer, pp. 32–41. doi:10.1007/978-3-642-41501-2_4

Wan, P. K. F. & Jiang, S. (2025). Enabling a dynamic information flow in digital product passports during product use phase: A literature review and proposed framework. *Sustainable Production and Consumption*, 54, pp. 362-374. doi:10.1016/j.spc.2025.01.014

Wellsandt, S., Hribernik, K. & Thoben, K.-D. (2015). Sources and Characteristics of Information about Product Use. *Procedia CIRP*, 36, pp. 242-247. doi:10.1016/j.procir.2015.01.060

Wellsandt, S. & Thoben, K.-D. (2016). Approach to Describe Knowledge Sharing between Producer and User. *Procedia CIRP*, 50, pp. 20-25. doi:10.1016/j.procir.2016.04.193

WRAP (2024). *Extending product lifetimes: WRAP's work on clothing durability*. Waste & Resources Action Programme. https://www.wrap.ngo/resources/case-study/extending-product-lifetimes-wraps-work-clothing-durability [Accessed 12th February 2026]

Xu, D. F., Li, Q., Jun, H. B., Browne, J., Chen, Y. L. & Kiritsis, D. (2009). Modelling for product information tracking and feedback via wireless technology in closed-loop supply chains. *International Journal of Computer Integrated Manufacturing*, 22(7), pp. 648-670. doi:10.1080/09511920701675755

Zagan, E. & Danubianu, M. (2019). From data warehouse to a new trend in data architectures - Data lake. *IJCSNS International Journal of Computer Science and Network Security*, 19(3), pp. 30–35.

Zahra, S. A. & George, G. (2002). Absorptive Capacity: A Review, Reconceptualization, and Extension. *The Academy of Management Review*, 27(2), pp. 185-203. doi:10.2307/4134351

Zhang, D., Hu, D., Xu, Y. & Zhang, H. (2012). A framework for design knowledge management and reuse for Product-Service Systems in construction machinery industry. *Computers in Industry*, 63(4), pp. 328-337. doi:10.1016/j.compind.2012.02.008

Zou, B., Guo, F. & Guo, J. (2016). Absorptive capacity, technological innovation, and product life cycle: a system dynamics model. *SpringerPlus*, 5(1), 1662. doi:10.1186/s40064-016-3328-5

Zou, T., Ertug, G. & George, G. (2018). The capacity to innovate: a meta-analysis of absorptive capacity. *Innovation*, 20(2), pp. 87-121. doi:10.1080/14479338.2018.1428105

ANNEX 1: Interview Guide

Product Lifecycle Feedback & Information Systems

Theme 1: Strategic Vision & Lifecycle Goals (Time limit 10 minutes)

Core Question: When designing feedback loops for a product's lifecycle, what are the primary strategic goals and values your organization aims to achieve?

Theme 2: Information Flow & Technical Architecture (Time limit 10 Minutes)

Core Question: How does raw information regarding a product's lifecycle and feedback currently flow into your technical systems?
Final Probes (Apply only when necessary or for short answers):

- Connectivity: How is lifecycle data connected to the Digital Product Passport (DPP)

Theme 3: Organizational Dynamics & Knowledge Sharing (Time limit 10 minutes)

Core Question: How does your organization organize and interpret feedback received from external partners to ensure it is useful for decision-making?
Final Probes (Apply only when necessary or for short answers):

- External Contributors: Who are the key external actors (e.g., repair shops, sorters, or recyclers) and do they have the technical tools to contribute effectively?
- Knowledge Relay: What specific information does your organization "push" back to the ecosystem (e.g., disassembly manuals for recyclers or care guides for consumers)?
- Human Literacy: Does your current workforce possess the data-literacy skills required to interpret and act on this input data of lifecycle feedback? (for IT interview question was altered to, what level of IT-knowledge overlap do other subunits in your opinion have to effectively engage with available IT tools and understand the IT capabilities the organization has ?

Theme 4: Product Aspect Improvements & Quality Optimization (Time limit 10 minutes)

Core Question: In what ways does product lifecycle feedback specifically alter or improve the "aspect groups" (such as durability, repairability, or chemical safety) of your products?
Final Probes (Apply only when necessary or for short answers):

- Design Transformation: How is feedback turned into a technical specification change for future product versions?
- Resource Efficiency: Can you provide examples of where feedback has directly reduced waste or improved material choice in the manufacturing phase?

Theme 5: Integrated Orchestration & Data Ecosystem (Time limit 10 minutes)

Core Question: How is lifecycle knowledge reused across the broader ecosystem to direct material flows and inform future development cycles?

Final Probes (Apply only when necessary or for short answers):

- Active Routing: Can your systems provide real-time instructions to external actors to ensure products reach their "next best use"?
- Organizational Memory: How easily can your current systems recall failure logs or historical data from several years ago to assist with new product development?

THE SWEDISH SCHOOL
OF TEXTILES
UNIVERSITY OF BORÅS

Visiting address: Allégatan 1 · Postal address: 501 90 Borås · Phone: 033-435 40 00 · E-mail: registrator@hb.se · Webb: www.hb.se