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Integration of the digital product passport into a PLM system

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Abstract

Within increasing regulatory and industrial attention to sustainability, the circular economy, and product transparency, the Digital Product Passport emerges as a key instrument for collecting, structuring, and sharing product-related information throughout the entire lifecycle. Under the European regulatory framework, and particularly the Ecodesign for Sustainable Products Regulation, the textile sector is a priority area for future DPP implementation due to its environmental impact, complex supply chains, and limited traceability.

This thesis investigates the integration of a Digital Product Passport model into a Product Lifecycle Management system using the Aras Innovator PLM platform. The research starts with a systematic analysis of the scientific literature on Digital Product Passports across multiple industrial sectors, with particular attention to textile applications. From the reviewed contributions, a broad set of information requirements is extracted, filtered, generalised, and reorganised into a structured framework. The resulting requirements are then compared with the simplified lifecycle-based model proposed by the EPRS study for the textile sector, leading to the development of an Integrated Lifecycle-Based DPP model.

The proposed model organises product-related information into lifecycle-oriented modules, including supply chain, product, evaluations, distribution, usage, and end-of-life. These modules are subsequently translated into a configurable data architecture within Aras Innovator PLM by redesigning the Forms and Tabs that collect all information on product identification, manufacturing, raw materials, traceability, environmental and social evaluation, documentation, after-sales services, repair, reuse, collection, and recycling.

To validate the model's applicability, a case study is conducted by comparing five real textile products already associated with corporate digital passports. The *Blue High Rise Putney Barrel Leg Jeans* by *Nobody's Child* is selected as the most suitable case due to the greater amount of available information that is subsequently transferred inside the Aras Innovator environment, demonstrating the ability of the PLM platform to manage heterogeneous data types, product structures, documents, lifecycle information, and component relationships.

The results show that Aras Innovator PLM provides a flexible and scalable environment for designing and managing Digital Product Passport structures. However, the case study also highlights the current limitations of corporate DPPs, especially regarding the availability of environmental, social, and performance-related data. Overall, the research confirms the potential of PLM systems as enablers of infrastructure suited to DPP implementation and provides a lifecycle-oriented reference model that can support future developments in the textile sector and can be adapted to other industrial contexts.

1. Introduction

In recent years, the European market has faced increasing environmental challenges, the depletion of natural resources, the growing complexity of supply chains, and persistent geopolitical crises, highlighting the need to enhance the transparency of product-related information. Origin, materials, environmental impacts, and end-of-life management have become key factors for an effective transition towards a circular and sustainable economic model, which is a central priority of European industrial policies.

The Ecodesign for Sustainable Products Regulation (ESPR), proposed by the European Commission in 2022 and adopted in 2024, is the regulatory framework formalising the objective of improving the sustainability and circularity of products placed on the European market. The Digital Product Passport (DPP) is an important component of this framework and serves as the standard digital system for storing and sharing product information throughout the entire lifecycle. It is a digital repository of records that collects and organises important product information, such as material composition, environmental impacts, repairability, and recyclability, as well as supply chain and traceability information, and will be progressively rolled out for products across different industrial sectors. Starting in February 2027, the battery industry will be the first to be affected; after that, the European Commission has also singled out textiles/apparel, tyres, furniture, mattresses, iron and steel, aluminium, electronics, and construction products for future implementation. The textile industry is a priority sector, and the Digital Product Passport is expected to be progressively implemented in it, with an initial roadmap around 2027.

The practical implementation of the Digital Product Passport faces several challenges, including identifying and structuring the information to be included in the passport. Previous studies have proposed a wide range of potential data needs for product identification,

material composition, environmental performance, circularity indicators, and supply chain transparency. However, these contributions are often fragmented across sectors and research areas, making it difficult to define a consolidated and interoperable set of information requirements.

This research aims at addressing this gap by identifying and structuring the information requirements for the development of Digital Product Passports through a systematic analysis of the existing academic literature. The study begins with a review of scientific literature concerning DPP systems across various industrial sectors. Subsequently, the information requirements in the literature are extracted and integrated to eliminate redundancy and normalise terminology. The defined set of requirements is further broken down into thematic groups, which are the core information elements of the Digital Product Passport.

The results of this analysis can serve as a starting point for considering the integration of DPP information structures into a Product Lifecycle Management (PLM) system, which provides a digital infrastructure for managing product data throughout the entire lifecycle. In particular, the research investigates the potential implementation of such an information structure in the open, low-code, and cloud-based PLM platform Aras Innovator, which offers flexible data modelling and a modular architecture for complex product information systems.

2. Theoretical background

2.1 European Regulatory Framework

2.1.1 European Green Deal

The European Union's policy agenda has placed global warming, environmental degradation, and the depletion of natural resources at the centre of its concerns, requiring an urgent response, which the European Commission has addressed by introducing the *European Green Deal* in 2019. It is a strategic policy framework aimed at transforming the European Union into a modern, competitive, resource-efficient, and climate-neutral economy. It is the main regulatory framework that guides the European Union towards an environmentally sustainable transition while also promoting economic growth, industrial competitiveness, social inclusion, and a gradual reduction in dependence on external energy partners (*European Commission, 2019; European Commission, 2024*).

In 2021, the European Union (EU) adopted the European Climate Law, in line with the 2015 Paris Agreement, and legally committed itself to achieve climate neutrality by 2050. This commitment is backed by intermediate targets, including a reduction of greenhouse gas emissions of at least 55% by 2030 compared to 1990 (*European Commission, 2021*) as part of the “Fit for 55” legislative package, and an additional target of at least 90% reduction by 2040, set by an amendment adopted in March 2026 (*European Commission, 2026*).

The European Green Deal is about more than climate targets, but it is also about making the transition to an economy that is sustainable, fair, and inclusive. The regulatory framework includes instruments such as the *Just Transition Fund* and the *Social Climate Fund*, which provide financial support to those regions, workers and communities most affected by the socio-economic impacts of the transition. These measures support workforce reskilling,

improve energy efficiency, refurbish buildings, and assist households experiencing energy and transport poverty (*European Commission, 2024*).

The changing energy system in Europe aims to accelerate the use of renewable energy sources, improve energy efficiency, and gradually reduce dependence on fossil fuels. To support green investments, develop clean energy technologies, and strengthen the Union's energy security, programmes such as *NextGenerationEU* and *REPowerEU* have been established.

The *European Emissions Trading System* (ETS), on the other hand, seeks to reduce and redistribute CO2 emission allowances through a market-based mechanism in which carbon quotas can be traded. It is being gradually extended to other economic sectors. The ETS's revenues are reinvested in innovative projects supporting the environment and climate, as well as social initiatives (*European Commission, 2024*).

One of the components of the European Green Deal is the *Circular Economy Action Plan* (CEAP), which sets out measures to develop a circular and resource-efficient economic model. The CEAP sets out actions to encourage the development of sustainable products, services and business models in the European market. The main priorities are to shift towards circular patterns of production and consumption, to reduce waste generation, to develop markets for high-value secondary raw materials, and to integrate sustainability principles throughout the product life cycle (*European Commission, 2020*).

2.1.2 Circular Economy Action Plan

The *Circular Economy Action Plan* (CEAP), published by the European Commission in 2020 as part of the European Green Deal, provides a strategic framework for the transition of the European economy from a linear to a circular model of production and consumption.

The main objectives are to decouple economic growth from resource use, promote sustainable economic development, increase the competitiveness of European enterprises, facilitate the achievement of climate neutrality by 2050, and reduce the consumption of natural resources.

This transition is urgent, as CEAP data show that global use of materials (biomass, fossil fuels, metals, minerals) is forecast to increase sharply over the next forty years, and annual waste output may increase by 70% by 2050. Resource extraction and processing contribute to approximately 50 % of global greenhouse gas emissions and more than 90 % of biodiversity loss and water stress, indicating that current production systems are strongly linked to environmental degradation.

CEAP calls for measures to change product design, production processes, consumer use, and waste management across the EU. A key aspect of the plan is the creation of a legislative framework for sustainable products, initially intended as an extension of the *Ecodesign Directive* to a broader range of products beyond energy-related ones. Given that the design phase accounts for up to 80% of a product's environmental impact, the proposed measures focus on improving durability, reusability, reparability, recyclability, and energy efficiency, as well as providing transparency regarding hazardous substances, recycled materials, and product information. The CEAP foresees the use of digital technologies, such as digital product passports, tagging, and watermarks, to improve product traceability and information management throughout the lifecycle.

The CEAP identifies several critical impact sectors, including electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction, and food systems. Of particular note is the textile industry, which ranks fourth for pressure on basic raw materials and water consumption, and fifth for greenhouse gas emissions. Furthermore, the sector's limited

circularity is demonstrated by the fact that less than 1% of textiles worldwide are recycled into new textile products. The CEAP suggests a dedicated *EU Strategy for Textiles* to improve product design, promote reuse and recycling, enable circular business models, and increase transparency across the textile value chain (*European Commission, 2020*).

The CEAP has set the stage for subsequent legislative initiatives on sustainable product development. The following step was the adoption of the *Ecodesign for Sustainable Products Regulation* (ESPR) as established in Regulation (EU) 2024/1781. The ESPR defines a framework for setting ecodesign criteria for sustainable products to improve their durability, reparability, recyclability, resource efficiency, and environmental performance throughout their lifecycle. It replaces the previous Ecodesign Directive and lays the basis for a more holistic regulatory framework for product sustainability, including the future roll-out of digital product passports to improve transparency and availability of product information (*European Parliament and Council of the European Union, 2024*).

2.1.3 Ecodesign for Sustainable Products Regulation and Digital Product Passport

The *Ecodesign for Sustainable Products Regulation* (ESPR) is a key EU legislative instrument to improve the environmental sustainability of products placed on the EU market. The new Regulation (EU) 2024/1781 replaces the old Ecodesign Directive 2009/125/EC, which was mainly focused on energy-related products and expands the ecodesign framework to a much broader range of physical goods. The regulation was published in the *Official Journal of the European Union* on 28th June 2024 and entered into force on 18th July 2024, directly applicable in all Member States without the need to be transposed into national law.

The ESPR establishes the general regulatory framework for defining ecodesign requirements and the product/sector-specific requirements to be laid down in delegated acts. Such requirements may concern several lifecycle aspects, including durability, reusability, reparability, upgradability, energy and resource efficiency, recyclability, recycled content, substances that may jeopardise circularity, and the environmental and carbon footprints of products.

The *Digital Product Passport* (DPP) is a key element of the regulation, an instrument to provide product-related information in a standardised and accessible manner. It can also make information on the composition, origin, environmental performance, and other characteristics relevant to product sustainability available to actors across the value chain, thereby increasing transparency, traceability, and circularity (*European Parliament and Council of the European Union, 2024*).

This regulatory development affects sectors like textiles. The future needs for ecodesign and the implementation of the Digital Product Passport are expected to enhance traceability, durability, repairability, recyclability, and the adoption of circular business models in the textile sector, in line with the goals already set out in the Circular Economy Action Plan (*European Commission, 2020*).

2.1.4 EPRS Study on the Implementation of the Digital Product Passport in the Textile Sector

The Digital Product Passport (DPP) is a structured digital tool that links a physical product to a standardised dataset of its lifecycle through a unique identifier, accessible via a digital carrier. It allows stakeholders to collect and store product-related information and share it with one another, supporting transparency, traceability, and circular economy practices.

However, persistent information gaps are a major barrier to implementing the DPP, especially in industrial sectors with complex global supply chains and fragmented data systems. Such conditions are a barrier to tracing products and restrict access to relevant information. This is especially evident in industries based on multi-level supply networks, the textile industry being a paradigmatic example.

In the study *Digital Product Passport for the Textile Sector* (2024), *Jérémy Legardeur* (ESTIA Institute of Technology) and *Pantxika Ospital* (Belharra), at the request of the Panel for the Future of Science and Technology (STOA) and under the management of the European Parliamentary Research Service (EPRS), pointed out that current practices enable only limited traceability at the product level. In most cases, the information available is limited to basic attributes such as country of manufacture and material composition, which are insufficient to support circularity and informed decision-making.

The study is based on a bottom-up grounded theory method and combines various sources of information, including solutions developed by textile brands, expert interviews, existing European regulations, and a systematic literature review. The objective is to define a DPP concept for the textile sector, define its implementation goals, identify the relevant information categories, and the stakeholders involved in its use. In this context, the Digital Product Passport is defined as "DPP is the combination of an identifier, the granularity of which can vary throughout the lifecycle (from a batch to a single product), and data characterising the product, processes, and stakeholders, collected and used by all stakeholders involved in the circularity process".

The authors list 11 main areas of contribution and objectives of the DPP: informing consumers and companies, managing resource flows, promoting circularity, supporting sustainability indicators, enabling market surveillance, ensuring post-sale traceability,

supporting regulatory compliance, supporting end-of-life management, increasing competitive advantage, and enabling product authentication. At the same time, eight stakeholder categories are identified. These are: supply chain companies, brands, retailers, public authorities, certification and assessment bodies, circularity operators, media, and consumers.

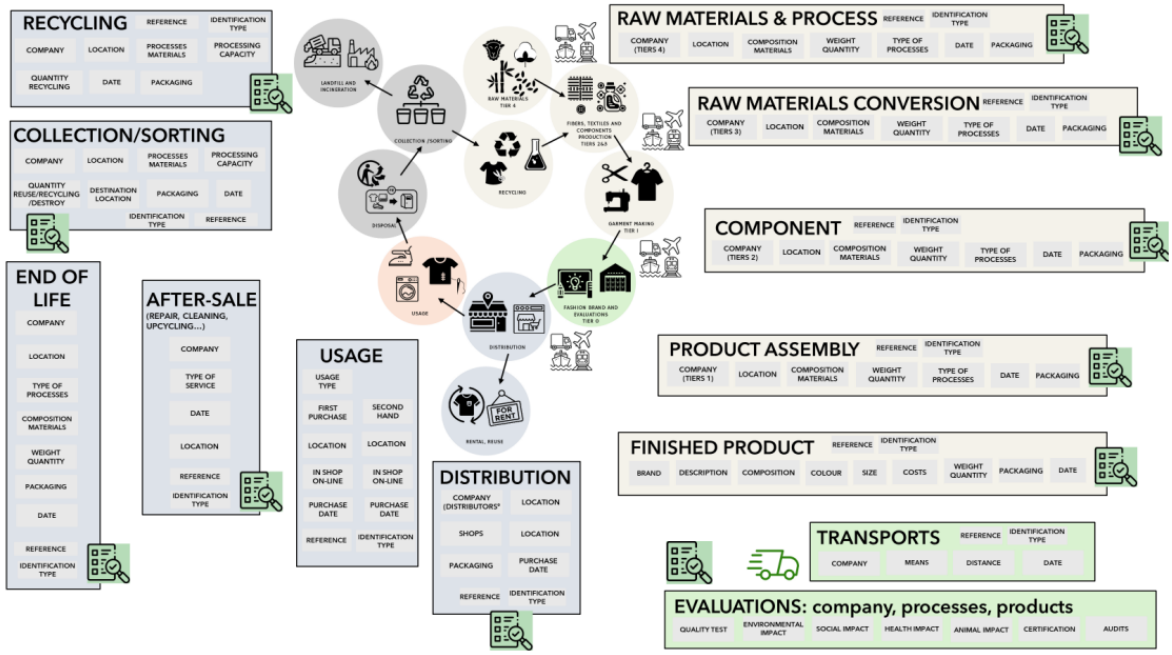
The study contributes significantly by identifying 16 categories of information and concepts that can be embedded within DPP and developing a generic DPP model based on a lifecycle representation to which these data categories are associated.

The researchers held consultations with 81 experts and stakeholders from 20 European countries to test the framework, which focused on product-level data categories and supply chain information. The study concludes with a three-phase roadmap for deploying the DPP in the textile sector: short-term deployment of a minimal, simplified DPP by 2027; mid-term deployment of an advanced DPP by 2030; and long-term deployment of a fully circular DPP for textiles by 2033.

2.1.5 Proposed DPP Model for the Textile Sector in the EPRS Study

In the study by *Legardeur et al. (2024),* 16 categories of information have been identified that may be associated with either individual products or production batches and can be incorporated into the Digital Product Passport (DPP) for the textile sector. These categories include product description, composition, supply chain, transport, documentation, environmental impact, social impact, impact on animals, circularity, health impact, information on the brand, communication/identification media, granularity, quantity, costs, after-sales tracking and tracing, and customer feedback.

Figure 1 – General model of DPP for textile. Source: Legardeur and Ospital (2024)



The general DPP model for the textile sector proposed in the study is based on a lifecycle-oriented representation, enabling the integration of all the aforementioned information throughout the different stages of the product life cycle, as shown in Figure 1.

The presented scheme illustrates the architecture of a lifecycle-based Digital Product Passport (DPP) for the textile sector, structured as an integrated data framework that collects and interconnects information across all stages of the product lifecycle.

The model is centred on a circular lifecycle approach that begins with raw material sourcing and extends through production, distribution, and use to end-of-life processes. Each of these phases is associated with a dedicated module containing information deemed appropriate for describing the product's characteristics in that specific context. The framework comprises thirteen modules corresponding to the following lifecycle stages: raw materials and processes, raw material conversion, components, product assembly, finished product,

distribution, usage, after-sales, end of life, collection and sorting, recycling, transport, and evaluations (covering company, processes, and products).

Each module includes multiple attributes that define the specific information relevant to its corresponding lifecycle phase. Table 1 summarises the modules and their attributes in the suggested DPP model.

Table 1 – Modules and attributes of DPP for textile

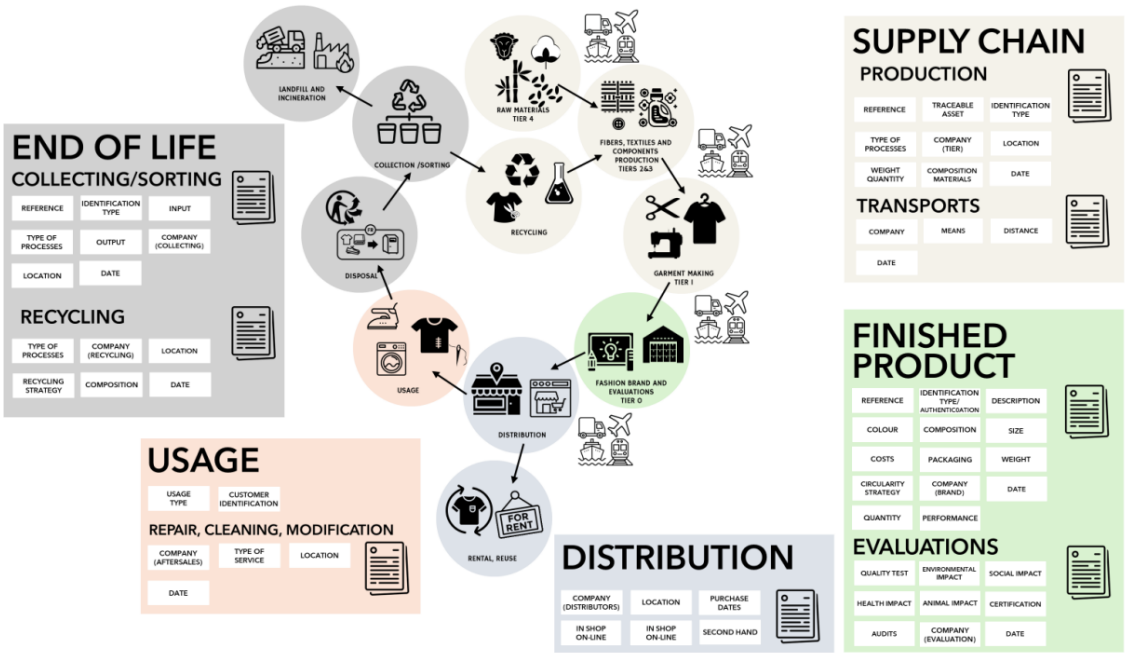
Module Name	Attributes
Raw materials & processes	Reference, identification type, company (tiers 4), location, composition materials, weight quantity, type of processes, date, packaging
Raw materials conversion	Reference, identification type, company (tiers 3), location, composition materials, weight quantity, type of processes, date, packaging
Component	Reference, identification type, company (tiers 2), location, composition materials, weight quantity, type of processes, date, packaging
Product assembly	Reference, identification type, company (tier 1), location, composition materials, weight quantity, type of processes, date, packaging
Finished Product	Reference, identification type, brand, description, composition, colour, size, costs, weight, quantity, packaging, date
Distribution	Company (distributors), location, shops, location, packaging, purchase, date, reference, identification type
Usage	Usage type, first purchase, location, in shop online, purchase date, second hand, location, in shop online, purchase date, reference, identification type
After-sale	Company, type of service, date, location, reference, identification type
End of life	Company, location, type of processes, composition materials, weight quantity, packaging, date, reference, identification type
Collecting/sorting	Company, location, processes materials, processing capacity, quantity reuse/recycling/destroy, destination location, packaging, date, identification type, reference
Recycling	Reference, identification type, company, location, processes materials, processing capacity, quantity recycling, date, packaging
Transports	Reference, identification type, company, means, distance, date
Evaluations	Quality test, environmental impact, social impact, health impact, animal impact, certification, audits

In addition to framework development, the study introduces a simplified model of the Digital Product Passport to ease consultation and validation with stakeholders. This simplified version consolidates supply chain information into a single template, eliminating redundancies across multiple lifecycle stages.

This model, visible in Figure 2, maintains a lifecycle-oriented structure while aggregating information and reducing the number of attributes per macro-category. In the simplified framework, the lifecycle is structured into only five main modules (supply chain, finished product, distribution, usage, and end of life) with a set of core attributes.

However, in some modules, specific sub-categories are introduced to capture more detailed information, thereby retaining a lifecycle-oriented structure while aggregating information and reducing the number of attributes within each macro-category. For instance, the supply chain module includes the subcategories “production” and “transport”; the finished product module incorporates an “evaluation” subcategory; the usage module includes “repair, cleaning, and modification”; and the end-of-life module encompasses “collection and sorting” and “recycling.”

Figure 2 – Simplified DPP for textile. Source: Legardeur and Ospital (2024)



Overall, the simplified model reduces data granularity while preserving a clear logical connection with the different lifecycle stages. The allocation of attributes across categories and subcategories is summarised in Table 2.

Table 2 – Modules and attributes of DPP for textile

Module Name	Subcategory Name	Attributes
Supply chain	*Production*	Reference, traceable asset, identification type, type of processes, company (tier), location, weight quantity, composition materials, date
	Transports	Company, means, distance, date
Finished product		Reference, identification type/authentication, description, colour, composition, size, costs, packaging, weight
	Evaluations	Quality test, environmental impact, social impact, health impact, animal impact, certification, audits, company (evaluation), date
Distribution		Company (distributors), location, purchase dates, in shop online, second hand, in shop online
Usage		Usage type, customer identification
	Repair, Cleaning, Modification	Company (after-sales), type of service, location, date
End of life	*Collecting/sorting*	Reference, identification type, input, type of processes, output, company (collecting), location, date
	Recycling	Type of processes, company (recycling), location, recycling strategy, composition, date

The simplified Digital Product Passport model proposed in the EPRS study serves as a valid and authoritative reference framework for the textile sector, particularly for prototypical DPP implementations.

By consolidating lifecycle information into a reduced set of modules associated with the different phases, the model achieves a balance between data comprehensibility and operational feasibility. This structure enables the identification of essential information categories and attributes while reducing both data granularity and complexity, thereby providing a coherent foundation for the textile sector in defining information requirements to be incorporated into DPP development.

Therefore, the simplified DPP model proposed in the EPRS study can be considered an important reference for designing and structuring the information architecture of the Digital Product Passport for the textile sector, ready for implementation in the Aras Innovator PLM software.

2.2 The role of PLM systems in the implementation of the Digital Product Passport

Product Lifecycle Management (PLM) systems are strategic software solutions for managing and integrating information, processes, and stakeholders across the entire product lifecycle.

In this sense, PLM platforms establish a common digital environment in which product-related data are generated, collected, and continuously updated, ensuring consistency and traceability across different lifecycle stages and actors. PLM systems also improve communication across the supply chain, allowing manufacturers, suppliers, and other

stakeholders to share data in controlled ways, thus improving coordination and reducing inefficiencies.

In this context, PLM systems are particularly important for implementing the Digital Product Passport (DPP). The DPP's aim is to collect and organise product-related information throughout the whole lifecycle.

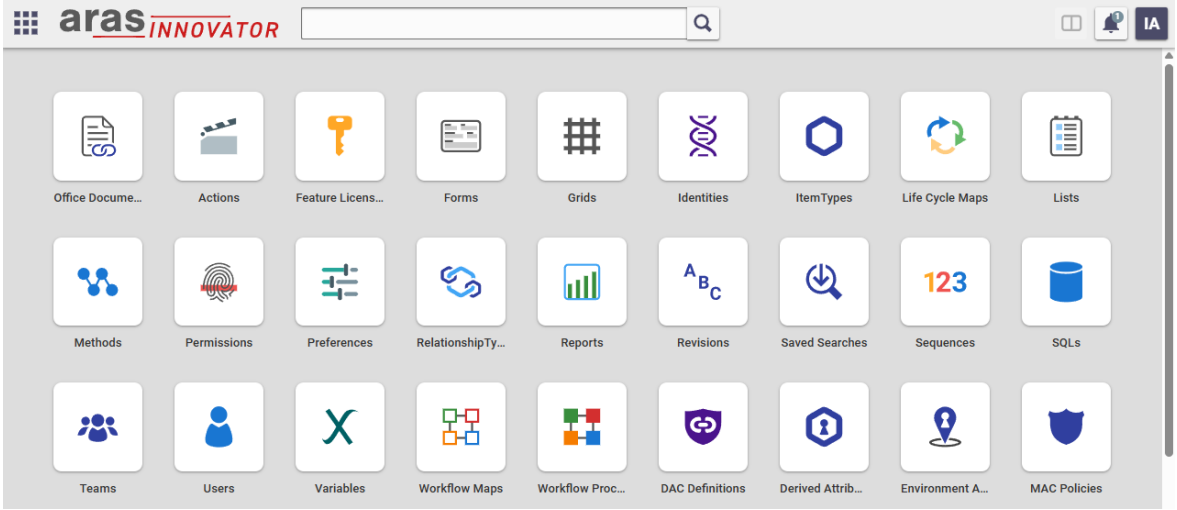
The integration of DPP requirements into PLM environments will help companies increase transparency among manufacturers, suppliers, regulatory bodies, and consumers, improve data traceability and regulatory compliance, and facilitate information exchange among stakeholders. PLM systems also support data standardisation and interoperability by centralising product information and implementing robust data governance.

In this context, the integration of DPP into PLM not only increases supply chain transparency but also supports circular economy strategies, enabling monitoring of environmental performance and promoting reuse, repair, and recycling.

2.2.1 Aras Innovator PLM

The open and low-code software solution Aras Innovator PLM offers significant advantages for implementing a Digital Product Passport (DPP) framework. These include its availability as a cloud-based platform, a modular architecture for reuse and scalability and a set of pre-configured applications that incorporate industry best practices. Furthermore, the intuitive and user-friendly interface, shown in Figure 3, allows customisation with relatively little programming effort and is therefore particularly well suited to extending existing functionality.

Figure 3 – Aras Innovator PLM's opening interface



An important contribution to the assessment of Aras Innovator's effectiveness for DPP integration has been made by *Bruno et al. (2025)* in a conference paper presented at the IFIP *International Conference on Product Lifecycle Management*. Rather than developing separate solutions, the authors embed a DPP framework into Aras Innovator by extending existing data structures.

The case study concerns a sliding door trolley, and in particular, the “Product” section is examined, where the relevant model is defined and accessible through the ItemType interface “Part”. This environment includes various DPP requirements such as Bill of Materials (BOM), after-sales and support information, end-of-life management, product performance, regulatory and sustainability data. The study highlights Aras Innovator's flexibility in meeting product-related requirements and the potential to successfully implement the Digital Product Passport framework, incorporating modifications and additions to the properties of these modules.

2.2.2 Standard Interface and Core Requirements

The standard interface of Aras Innovator is based on an architecture structured around ItemTypes, which represent the fundamental entities of the PLM system, such as Product, Part, and Document. This configuration enables a modular organisation of all information related to the product lifecycle.

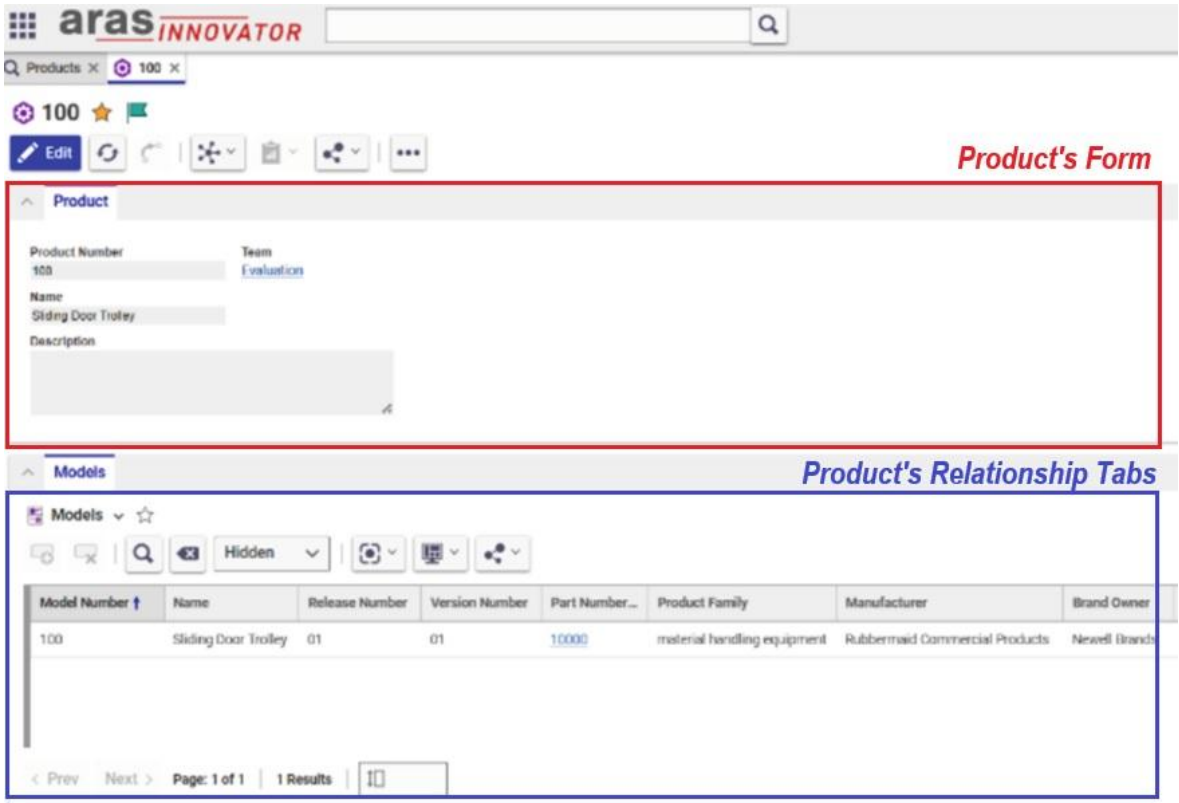
The user interface follows the typical structure of web-based enterprise systems and includes several core components:

- A navigation panel, defined as the Table of Contents (TOC), providing access to the different ItemTypes and PLM management functions.
- The Toolbar and Command Bar contain the main commands for creating, searching, and editing content.
- The central Workspace, which represents the area in which selected objects are displayed.
- Search and query tools, allowing users to interrogate the database and filter relevant information.

Each ItemType consists of multiple sections that can store data and associated elements defining the properties and lifecycle characteristics of the objects. In particular, the following can be identified:

- A Form, representing the main interface of the item, containing the object properties, which can be directly viewed and edited.
- Relationship Tabs, which connect the object to other PLM elements, such as documents, models, files, and additional ItemTypes (e.g. BOM, CAD Documents, Requirements).

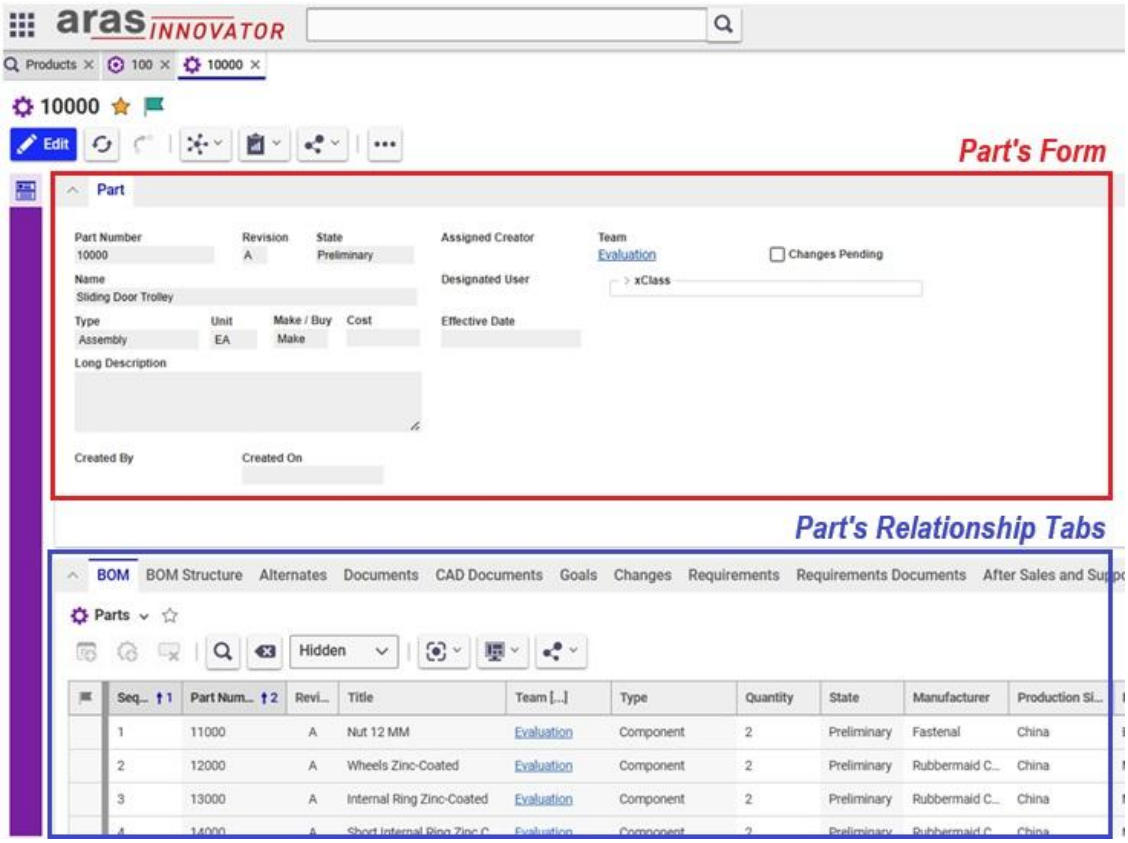
Figure 4 – ItemType Product's Form and Relationship Tabs



Within the Product ItemType interface, shown in Figure 4, the Form section includes preconfigured fields for product properties, such as Product Number, Team, Name, and Description. In the corresponding Relationship Tabs section, a predefined relationship with the Model ItemType is available, including associated properties such as Model Number,

Name, Release Number, Version Number, and Part Number. When a new model is created through the editor, a link to a Part ItemType is automatically generated in the Part Number field, which can then be accessed via the corresponding identifier.

Figure 5 – ItemType Part's Form and Relationship Tabs



The Part ItemType is the primary element for integrating DPP information requirements. Its interface, displayed in Figure 5, is similarly structured into a Form section and a Relationship Tabs section:

- The Form section includes pre-configured fields such as Part Number, Revision, State, Assigned Creator, Team, Changes Pending, Name, Designated User, Class, Type, Unit, Cost, Effective Date, Long Description, Created By, and Created On. Most of these fields are editable, while some are subject to default restrictions.

- The Relationship Tabs section includes several predefined relationships that are relevant to DPP requirements, such as BOM (Bill of Materials), BOM Structure, Alternates, Documents, CAD Documents, Goals, Changes, Requirements, Requirements and Documents, and Product Composition.

These elements constitute the baseline configuration provided by the software, serving as a foundation for further extensions and customisations to integrate tailored DPP structures. Such adaptations enable the system to accommodate sector-specific requirements and to progressively enhance the representation and dissemination of product information in alignment with European regulations and their future developments.

2.2.3 Implemented Functionalities in Previous Studies

In addition to the basic functionalities described previously, the Aras Innovator environment can implement modifications and extensions to enrich the informational content, enabling effective integration of the Digital Product Passport to meet the specific needs of different industrial sectors and changing regulatory frameworks.

Bruno et al. (2025) have made a relevant contribution in this regard with their conference paper at the PLM International Conference 2025, in which a conceptual framework is proposed for integrating DPP into PLM systems, and technical requirements, system architecture, and implications for product data management are analysed. After defining a set of requirements for a realistic implementation of the DPP, these are organised in six categories (General Information, Product Performance, After Sales and Support, End of Life Management, Environmental Impact, Regulation and Sustainability). Subsequently, the preconfigured core PLM modules in Aras Innovator are customised to extend the existing database associated with DPP-related information.

Through the development of a product case study, specifically a sliding door trolley, the example proposed by *Bruno et al.* enhances the Model ItemType by expanding its property section with additional requirements, such as Product Family, Manufacturer, Brand Owner, Production Site, Sustainability Certifications, and Regulatory Compliance.

At the level of the Part ItemType, further extensions are introduced:

- The addition of Relationship Tabs corresponding to the categories After Sales and Support, End of Life Management, and Regulation and Sustainability, modelled as Document relationships. These establish links to elements of the Document ItemType that contain information on product use and maintenance, end-of-life strategies, reuse and remanufacturing practices, recycling methods, and compliance with regulatory and sustainability standards, supported by appropriate documentation.

- The introduction of Null Relationship Tabs, namely relationships associated with other ItemTypes without explicit labelling but directly accessible for viewing and editing. These include Environmental Impact and Product Performance, within which specific indicators are defined, such as Carbon Footprint and Water Consumption for the former, and Durability and Estimated Number of Lifecycles for the latter.

- A further modification involves the extension of the BOM tab through the inclusion of additional properties containing general information, such as the manufacturer name, defined in the Manufacturer property, and the production location, specified in the Production Site property.

These interventions demonstrate how the standard PLM structure can be adapted and extended to support the integration of a broader set of DPP requirements, enabling a more comprehensive and structured representation of the information related to the product under analysis.

2.3 Concluding Remarks on the Theoretical Background

The analysis of the theoretical background has provided a comprehensive understanding of the context for the development and implementation of the Digital Product Passport. This includes the analysis of the European regulatory framework, the principles of the circular economy, the information models proposed in the literature and the operational role of PLM systems, with particular attention to the Aras Innovator platform.

The main features of the standard interface and the extensions to the pre-configured functionalities identified in the reviewed studies have demonstrated the system's flexibility in handling new information requirements structured at different levels of complexity. These elements form the basis for the following integration of an extended, structured DPP model within the Aras Innovator system to support the management of product-related information throughout its complete lifecycle in a comprehensive, modular, and interoperable way.

3. State of the art

3.1 Research Approach

The state-of-the-art analysis has been conducted to explore the current academic and industrial progress regarding Digital Product Passports (DPPs), their technological enablers, and their integration within PLM systems. The goal was to identify how DPPs are being conceptualised, implemented, and adapted across different sectors, with special attention to their potential application in the textile industry, which is one of the first product categories prioritised under the Ecodesign for Sustainable Products Regulation (ESPR), for which the integration of the Digital Product Passport (DPP) will become mandatory for all products placed on the market from 2030 onwards.

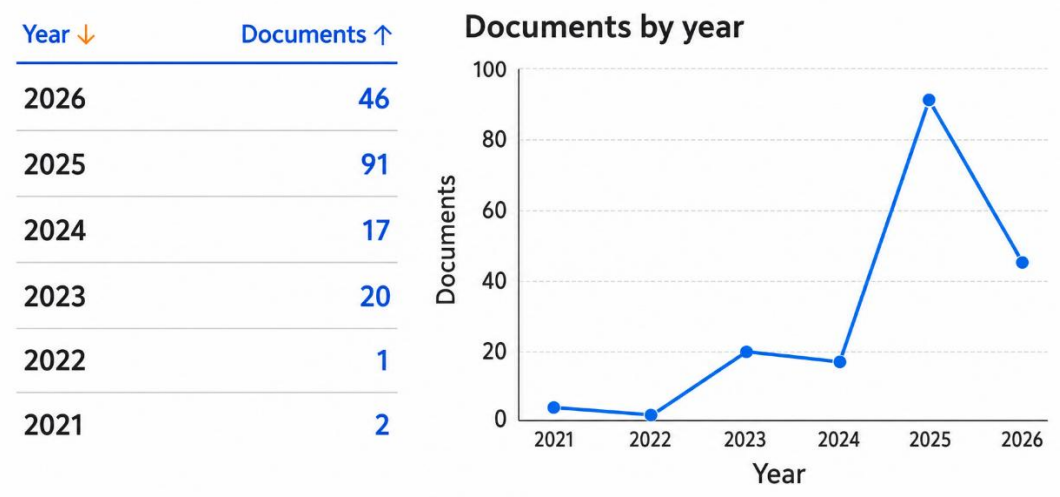
A systematic literature review has been performed using the *Scopus* search database, through the following query: “TITLE-ABS-KEY ("Digital Product Passport" OR "Digital Material Passport") AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English"))”.

The combination of keywords in the query limits the research to articles or reviews that include the keywords “Digital Product Passport” or “Digital Material Passport” and are written only in English. The search query yielded 177 academic contributions published between 2021 and 2026, which were subsequently screened.

The publication timeline in Figure 6 shows that the presence of topics related to the Digital Product and Material Passport has been growing in the scientific literature since 2022. A

significant increase is observed in 2025, the most productive year, with 91 publications. This upward trend is also confirmed in the first months of 2026.

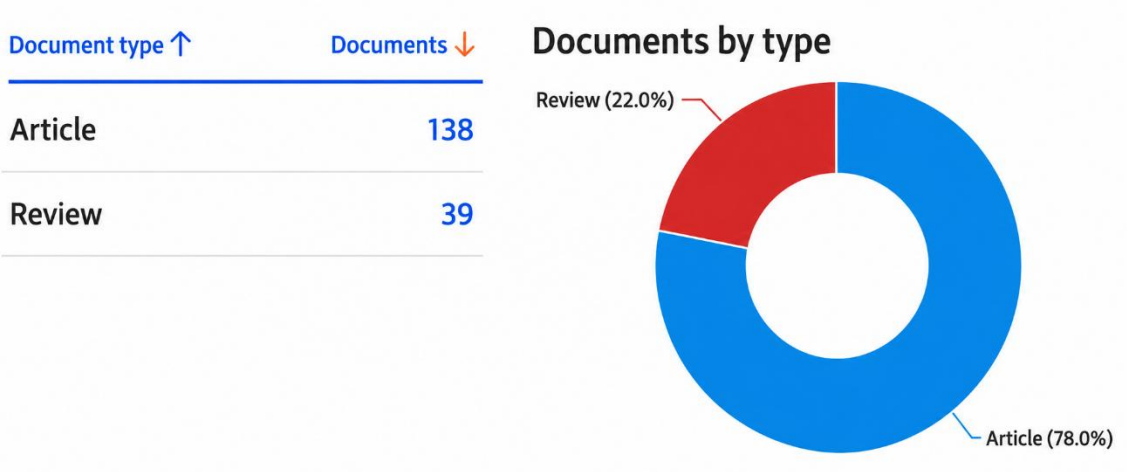
Figure 6 – Academic contribution over the years. Source: Scopus database



Year ↓	Documents ↑
2026	46
2025	91
2024	17
2023	20
2022	1
2021	2

The search query restricts the analysis to document types classified as articles and reviews. As shown in Figure 7, they are distributed as follows: the majority of articles account for 78% of the total (138 publications), while reviews account for 22% (39 publications).

Figure 7 – Types of academic documents. Source: Scopus database

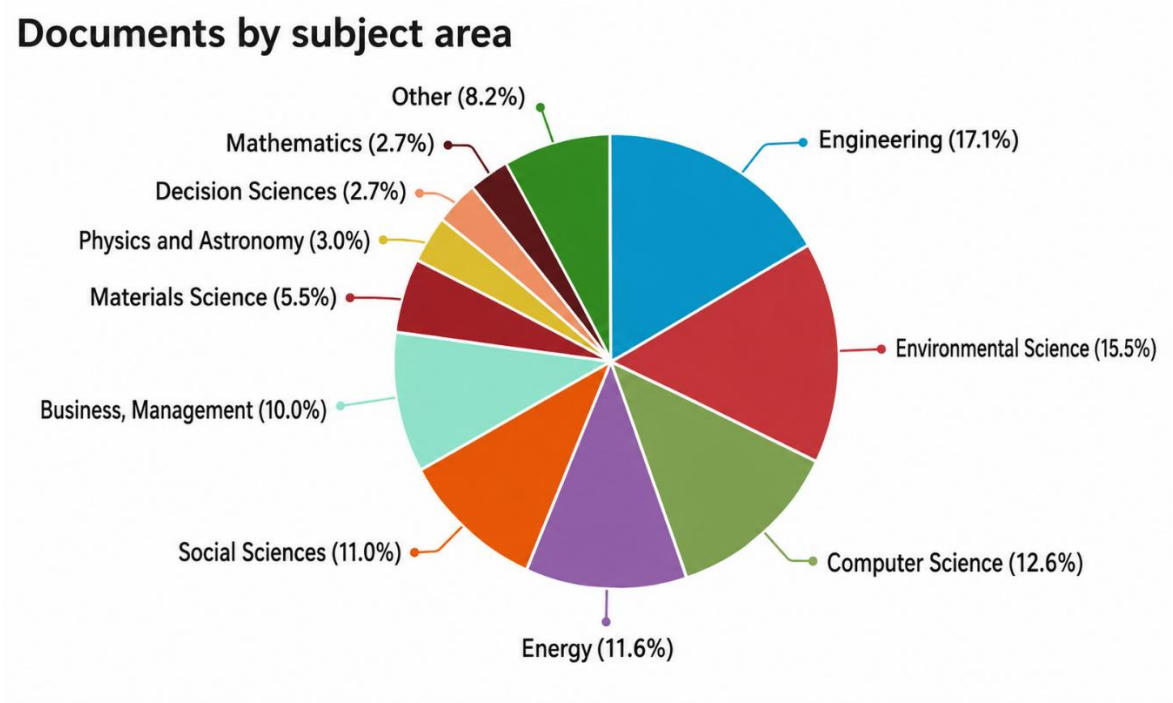


Document type ↑	Documents ↓
Article	138
Review	39

The DPP topic is distinctly interdisciplinary, as shown by the distribution in Figure 8, which indicates that most studies are from the field of Engineering (17.1%), a pattern attributable

to the strong focus on technical implementation aspects. It is followed by the field of Environmental Science (15.5%), often associated with assessing environmental impacts, and Computer Science (12.6%), which involves data analysis and software development. The Energy sector accounts for 11.6% and focuses on energy consumption and efficiency, while the Social Sciences represent 11% and have a major interest in evaluating social impacts. Publications in Business, Management, and Accounting constitute 10% of the total. The remaining 22% includes contributions from Material Science, Physics and Astronomy, Decision Sciences, Mathematics, and other fields of study.

Figure 8 – Subject areas of the scientific literature. Source: Scopus database



The screening process aimed to isolate papers that offered practical implementations of Digital Product Passports, such as case studies and product sector analyses, whose content presented a clear DPP structure, a data model definition, and indicator sets applicable to different industrial domains. The screening was conducted to extract sector-specific insights into data requirements, interoperability challenges, and information categories relevant to

DPP construction, resulting in the selection of 35 studies that collectively provide a comprehensive theoretical foundation for deriving a cross-sectoral indicator framework.

This framework is intended to serve as a reference model for developing a DPP architecture based on the Aras Innovator PLM platform. Special attention has been directed to identifying contributions that explore and discuss the textile industry, which will provide a target product on the market to develop a case study, as it represents one of the priorities in the ESPR roadmap. However, many indicators and data structures from other industries, such as electronics, batteries, and construction, have been examined and adapted where relevant through a comparative approach, enabling a versatile and extensible indicator set.

Table 3 categorises and summarises the content and main contributions of the 35 analysed papers, highlighting for each work the application sector, year of publication, specific research objectives, and key findings or results.

Table 3 - Categorisation of articles

Title	Year of publication	Application field	Objectives	Results	Journal or conference
Digital product passports for cleaner production: Economic evidence from producers and consumers in the fashion industry	2026	Textile industry	Exploration of the role of the Digital Product Passport (DPP) in the textile sector through an integrated analysis of producers' evaluations and consumer responses	A Multi-Criteria Decision Making (MCDM) framework analysed the dual producer and consumer perspectives within the DPP ecosystem. Ten experts evaluated nine sustainability criteria via Analytic Hierarchy Process (AHP), alongside 451 consumer questionnaires using a 10-point Likert scale. Producers prioritise traceability and circularity, while consumers, despite a higher willingness to pay for DPP-enabled products, remain driven by aesthetics and price. Findings confirm the DPP as a socio-technical enabler with implications for organisational strategy and sustainable consumer behaviour	Journal of Cleaner Production
Large-scale analysis of environmental and circularity metrics in construction products through automated data extraction using large language models	2026	Building industry	Analysis of construction product EPDs to extract and organise fragmented information on environmental impacts and circularity metrics	Large Language Models (LLMs) analysed 368 construction product Environmental Product Declarations (EPDs) from a dataset of 8,463 records, mainly from Europe and Italy. Barriers to DPP adoption include limited circularity standardisation and regulatory gaps. Most products lack circular end-of-life pathways, with landfill prevailing, while the product stage accounts for 80 to 98 per cent of total environmental impact. Reporting inconsistencies and the impact of mass-intensive products further hinder implementation. Design for disassembly is identified as a key sustainability lever.	Environmental Impact Assessment Review

Can Digital Product Passports become the next-generation eco-label? Analyzing consumer preferences for labeling using Digital Product Passports	2026	Multisectoral	Study aimed to analyse how the DPP affects consumers' information preferences and choice behaviour	Grounded in Random Utility Theory, the study estimates consumer preferences and marginal willingness to pay (MWTP) for Digital Product Passport (DPP) attributes through a survey of 500 respondents in South Korea. Consumers prefer cross-industry DPPs with detailed disposal and recycling information and favour government-led management. Full life cycle information increases Marginal Willingness to Pay (MWTP) by 27.3 per cent, highlighting the importance of aligning DPP design with consumer preferences	Journal of Cleaner Production
Textile Materials Information for Digital Product Passport Implementation in the Textile and Clothing Ecosystem: A Review on the Role of Raw Fibers in a Substantial Transition	2025	Textile industry	Exploration of the challenges and limitations in adopting DPP technologies to support the sustainable transition of the Textiles and Clothing (T&C) supply chain	A systematic literature review of 53 studies, following PRISMA methodology, examines material information requirements to support sustainable practices in the Textiles and Clothing sector, with a focus on supply chain transparency in Digital Product Passports (DPPs). Key barriers include high investment and IT costs, training needs, data privacy concerns, and lack of standardised formats. The study defines a minimum set of material information requirements and outlines future research toward scalable and implementable DPP frameworks	Sustainability (Switzerland)
Towards an International Digital Product Passport: The New Paradigm of a Worldwide Circular Economy	2025	Multisectoral	Investigation of the prominent factors influencing the adoption of DPPs, including requirements, enablers and barriers	Based on a literature review of 87 records, narrowed to 22 studies, the paper analyses the business impacts of Digital Product Passport (DPP) adoption, key data requirements, and main enablers and barriers. Requirements include product identification, supply chain transparency, and supportive policies, with issues in life cycle traceability, authenticity, and post-sale management. Enablers involve data pools, information integration, and design innovation, while barriers relate to accessibility, stakeholder understanding, and lack of data standardisation	Circular Economy and Sustainability
An Integrated Business Strategy for the Twin Transition: Leveraging Digital Product Passports and Circular Economy Models	2025	Textile industry	Study aimed to identify and prioritise the types of information that companies perceive as strategically valuable for the effective deployment of DPPs, with particular emphasis on the textile industry	Through a multi-criteria decision analysis (MCDA) integrating Analytic Hierarchy Process (AHP) and TOPSIS, ten textile experts identified and prioritised key data categories for Digital Product Passports (DPPs). Results highlight the importance of material traceability, reuse, repairability, recycling, end-of-life management, and environmental performance data. Differences among expert evaluations underline the need for modular, customizable, yet standardised DPP designs to ensure flexibility and interoperability	Business Strategy and the Environment
Environmental Concerns in the Fashion Industry: A Twin Transition with the Digital Product Passport	2025	Textile industry	Survey aimed at assessing consumers' willingness to pay for the DPP and their opinion on the importance assigned to its various attributes and functions	An online survey shows that DPP awareness is shaped by age, technology use, and income. Younger respondents exhibit higher technological literacy, while individuals aged 31 to 50, particularly women, display stronger fashion orientation. Purchasing decisions are mainly driven by price and aesthetics rather than sustainability, although respondents value information on locally sourced materials and show a willingness to pay over 17 per cent more for DPP-enabled products. Higher income groups demonstrate greater support for sustainability initiatives	Business Strategy and the Environment
Machine Learning-Based Data Quality Assessment for the Textile and Clothing Digital Product Passport	2025	Textile industry	Study on the use of machine learning algorithms for validating the quality of data used by each company in implementing the DPP	After processing a textile dataset, four Machine Learning algorithms were applied to detect anomalies, and their performance was evaluated and compared. The analysis assessed accuracy and adaptability across different data conditions. Results show the ability of these techniques to identify inconsistencies and improve data reliability. Overall, the findings confirm the effectiveness of Machine Learning in generating consistent and adaptable datasets, supporting data-driven decision-making in the textile sector	Applied Sciences
Sustainability Index in Apparel: A Multicriteria Model Covering Environmental Footprint, Social Impacts, and Durability	2025	Textile industry	Proposal for a multi-criteria method to assess the sustainability of clothing products with a score from A to E	The study applies a multi-criteria approach to assess textile product sustainability through a case study, integrating environmental and social life cycle assessments with durability testing to calculate a Product Sustainability Index. An A to E rating scale is proposed to support consumer communication and transparency. The case study demonstrates the practical applicability of the method, while also highlighting limitations related to the reliance on open-source environmental data	Sustainability (Switzerland)
Digital product passports for electric vehicle batteries: Stakeholder requirements for sustainability and circularity	2025	Battery industry	Identification of the level of importance, availability and accessibility on 40 criteria of information on EVBs and search for the most important actors for the implementation of the DPP	Sustainability and circularity emerge as the most important information categories, while social sustainability is considered less relevant. At the same time, key information related to sustainability, circularity, recycling, dismantling, and environmental and social assessments is perceived as the least accessible. This highlights a gap between importance and data availability. The most relevant actors for DPP development are battery manufacturers, designers, and raw material suppliers, reflecting their central role in enabling effective data integration and product transparency	Journal of Industrial Ecology Cleaner Production Letters

Exploring the value ecosystem of digital product passports	2025	Multisectoral	Analysis of the role of DPP in the implementation of the Circular Economy by means of an e3-value language model	The e3 value model is used to map the DPP value ecosystem and analyse how different actors interact within it. The model provides structured insights into value exchanges and supports the identification of key roles and relationships across the system. It also offers guidance for DPP implementation across different industries. Through the battery passport example, the model illustrates how coordinated actor interactions can optimise the product lifecycle and enhance overall system efficiency	Journal of Industrial Ecology
Circular Economy: Literature Review on the Implementation of the Digital Product Passport (DPP) in the Textile Industry	2025	Textile industry	Study on the implementation and potential of DPP in the transformation of the textile and clothing sector	The study identifies critical issues in the textile industry and their impacts, highlighting the adoption of the DPP as a key enabler of circularity. It outlines the main objectives and benefits of DPP implementation and defines the type of information to be included. An overview of initiatives by companies and government agencies is provided to illustrate current developments. The analysis concludes with a SWOT framework, summarising strengths, weaknesses, opportunities, and threats associated with DPP adoption	Sustainability (Switzerland)
Enabling a dynamic information flow in digital product passports during product use phase: A literature review and proposed framework	2025	Multisectoral	Construction of a DPP framework to bridge the research gap related to the updating of product information during the maintenance phase	The study examines technical solutions supporting DPP, including QR codes, RFID, and blockchain, together with information requirements across the four product life cycle phases: raw material sourcing and processing, manufacturing and design, use, and end of life. It proposes a framework to support the continuous updating of information, particularly during the product maintenance phase. Blockchain technology is highlighted as a key enabler to ensure data security, integrity, and system reliability	Sustainable Production and Consumption
Digital Product Passport Design Supporting the Circular Economy Based on the Asset Administration Shell	2025	Multisectoral	Analysis of a DPP model based on the Asset Administration Shell (AAS) framework to support the circular economy	An AAS-based DPP model is proposed to ensure flexibility and applicability across different industries. The DPP is structured into multiple submodels for the collection of diverse data, including parameters for KSI assessments such as ECI (end-of-use circularity indicator) and PCI (product composition circularity indicator). Based on the collected data, two scores are computed: one for circular design and one for depth of disassembly. The study concludes with a specific application of the model to the battery passport	Sustainability (Switzerland)
Blockchain-based digital product passport: design principles and demonstration	2025	Textile industry	Development of a blockchain-based DPP for the textile industry	Through the Hyperledger Fabric architecture, a Digital Product Passport (DPP) is developed as a blockchain-based solution for managing product lifecycle data. The approach enables secure, transparent, and tamper-resistant data storage across multiple stakeholders. Attention is given to privacy and controlled data access, ensuring the protection of sensitive information. The findings suggest that blockchain-supported DPP systems are a promising solution for improving data reliability and trust along the product lifecycle	International Journal of Production Research
Fostering lithium-ion battery remanufacturing through Industry 5.0	2025	Battery industry	Analysis of potential Industry 5.0 technologies to optimise the remanufacturing of lithium-ion batteries for electric vehicles (LIBs)	Using a hybrid AHP PROMETHEE approach, the analysis ranks Industry 5.0 solutions for lithium-ion battery regeneration, identifying the Digital Product Passport (DPP) as the most effective option, followed by Digital Twin and Internet of Everything (IoE). The evaluation considers multiple criteria related to sustainability and value creation. Sensitivity analysis further confirms the central role of DPP in enhancing value across the battery supply chain, in line with the European Union Ecodesign for Sustainable Products Regulation (ESPR) framework	International Journal on Interactive Design and Manufacturing
Modular Digital Twin–an approach for generating and exploiting product sustainability information towards service-oriented business models	2025	Multisectoral	Presentation of a Modular Digital Twin (MDT) prototype for the creation and use of product sustainability information (PSI) included in the DPP to support service-oriented business models (SBM)	A flexible Modular Digital Twin is proposed to support service-oriented business models, which are shown to be more eco-effective and efficient. The study introduces a framework to classify Product Sustainability Information based on material and energy use. Several use cases are presented to demonstrate applicability, including a plant-level application where the model is used to optimise the energy consumption of industrial robots. The results highlight the potential of the approach to enhance resource efficiency and support sustainable decision-making	International Journal of Production Research
CEF-DPP: A Circular Economy Framework Integrating Digital Product Passport for Improving Circularity of Sustainable Mechatronics Design	2025	Mechatronics and Electronics	Introduction of an integrated Circular Economy Framework to the DPP in support of the sustainable design of mechatronic components	The integration of the Circular Economy Framework (CEF) into the Digital Product Passport (DPP) is applied to the remanufacturing of an electric motor for bicycles. The results show a life cycle extension from 5 to 10 years, accompanied by a 45.2 per cent reduction in kg CO2 equivalent emissions. In addition, significant material recovery is achieved, with some materials, such as aluminium, reaching recovery rates of up to 100 per cent. These findings highlight the effectiveness of combining CEF and DPP approaches in enhancing resource efficiency and environmental performance	Circular Economy and Sustainability

An ecosystem orchestration framework for the design of digital product passports in a circular economy	2024	Manufacturing industry	Investigation of the practices that shape the DPP management ecosystem and development of a framework to assist the ecosystem that orchestrates DPP at the industry level	Through semi-structured interviews with five key stakeholders across the product life cycle in three Danish manufacturing case studies, the study identifies sixteen practices shaping the DPP orchestration ecosystem. These practices are consolidated into five core orchestration mechanisms and further organised into four stages of ecosystem development. The resulting framework is structured as an iterative process, distinguishing between an exploratory phase and an operational phase to guide DPP implementation	Business Strategy and the Environment
A modular ontology modelling approach to developing digital product passports to promote circular economy in the built environment	2024	Building industry	Development of a modular ontology in the built environment to explore its use in DPP to support the supply chain	Following a literature review and expert interviews, the study identifies the information requirements for the Digital Product Passport (DPP). The nomenclature of the proposed modules is then aligned with an existing ontology to ensure consistency and interoperability. Based on this alignment, eight modules are developed to structure and manage information within the DPP. The results provide a systematic approach to organising data and support the implementation of standardised and scalable DPP architectures	Sustainable Production and Consumption
Digital Product Passport Implementation Based on Multi-Blockchain Approach with Decentralized Identifier Provider	2024	Multisectoral	Using Hyperledger Fabric blockchain technology in the implementation of a DPP	Two blockchain-based technologies are employed: the Decentralised Identifier Technology (DID) Management Blockchain for creating decentralised and encrypted product identifiers, and the Hyperledger Fabric blockchain for managing product information. A DPP model is designed using a UML class diagram and supported by operational code implementation. The system is subsequently tested, demonstrating effectiveness and the capability to handle multiple operations in parallel with reliable performance	Applied Sciences (Switzerland)
How the Digital Product Passport Can Lead the Plastics Industry towards a Circular Economy—A Case Study from Bottle Caps to Frisbees	2024	Recycling sector	Case study of recycling plastic caps into frisbees. Data are collected and processed through a DPP on R-Cycle infrastructure based on GS1 open standards	A school competition dataset tracking the recycling of plastic closures into 2,192 HDPE frisbees is analysed across five processing stages: collecting, sorting, grinding, regranulation, and injection moulding. Data gathered at each stage is structured into five categories and integrated into a product tree architecture, forming the informational foundation of a Digital Product Passport (DPP). This approach enables the calculation of a comprehensive mass balance, tracing material flows from initial collection to the final product	Polymers
Digital product passports as enablers of digital circular economy: a framework based on technological perspective	2024	Manufacturing industry	Investigation and selection of potential technologies for the development and support of DPP	Three levels of data are identified: data collection, data curation and sharing, and data exploitation, together with a set of enabling technologies suitable for each level. Based on this structure, a two-level framework is proposed to first generate passport data and subsequently develop the Digital Product Passport (DPP). The DPP is designed in two formats: one tailored for manufacturing companies and their partners, and a user-oriented version intended for end customers	Telecommunication Systems
Data-driven and LCA-based Framework for environmental and circular assessment of Modular Curtain Walls	2024	Building industry	Development of a Semantic Data-driven Framework (SDF) based on LCA for assessing environmental and circular aspects of Custom prefabricated Modules for Curtain Walls (CMCW) in the building sector	A semantic data-driven framework (SDF) is proposed to bridge the gap between existing research and emerging EU regulations. Three data categories are defined: project, environmental, and circularity data. These are organised into two databases, one for commissioned works and one for environmental and circularity information, to support the framework. The study concludes with an analysis of the ontology and semantics of the SDF and an assessment of Global Warming Potential across the life cycle of CMCWs	Journal of Facade Design and Engineering
Digital Product Passport: A Pathway to Circularity and Sustainability in Modern Manufacturing	2024	Manufacturing industry	Definition of a standardised model and template as a guide for the design of DPPs	A DPP design scheme is proposed for single-component and assembled products, defining three connectivity types (local, cloud, hybrid), data storage and update categories, lifecycle stages, and key actors, with the OEM as owner. Seven data categories are mapped to their generation stages, with different levels of detail describing content, interdependencies, connectivity, update frequency, and actors involved. The framework also includes access modes, design templates, and internal variable specifications to support implementation	Sustainability (Switzerland)

Orchestrating a smart circular economy: Guiding principles for digital product passports	2023	Multisectoral	Transdisciplinary analysis aimed at defining guiding principles for DPPs and developing industry ecosystem orchestration in the transition to the EC through DPPs	A trans disciplinary analysis is conducted in three steps, involving experts from different fields, to define eight guiding principles for DPP adoption. These include analysis of regulatory requirements, design of DPPs as open and decentralised infrastructures, orchestration of available technologies, data governance and contractual relations, system implementation and definition of new business models, assessment of social, environmental and economic impacts, participation of regulators, and continuous improvement of DPPs through collaboration between stakeholders	Journal of Business Research
Designing a digital platform to foster data-enhanced circular practices in the European solar industry	2023	Mechatronics and Electronics	Conceptualisation for a digital platform for the exchange of information between the different stages and actors in the photovoltaic panel value chain	Through an analysis of existing digital platforms, a prototype is identified to support the exchange of information within the photovoltaic panel industry. An asset database for photovoltaics (PV) is proposed as a foundation for developing two key use cases. The first involves an information evaluation scheme to support the construction of a Digital Product Passport (DPP), while the second focuses on the design of an online marketplace for the reuse of photovoltaic panels, enabling effective matching between supply and demand	Journal of Cleaner Production
Integrating Absolute Sustainability and Social Sustainability in the Digital Product Passport to Promote Industry 5.0	2023	Multisectoral	Definition of indicators to integrate social sustainability in the DPP and assess absolute environmental impacts with thresholds. A cyber-physical systems framework is proposed to digitise the passport and support life cycle data collection	Two research gaps are identified, namely social impact assessment and the availability of absolute environmental impact information. The former is addressed through the application of the PSILCA method, which defines stakeholder categories, key social dimensions, and corresponding indicators. The latter is examined through LCA, enabling the identification of environmental impact categories with associated indicators and threshold values. The Cyber Physical Systems (CPS) framework is employed to support the systematic collection of environmental, social, and technical data for the Digital Product Passport (DPP)	Sustainability (Switzerland)
Data requirements and availabilities for a digital battery passport – A value chain actor perspective	2023	Battery industry	Empirical analysis of the data needs and requirements of EVB value chain actors in the context of sustainable battery management	Through a five-stage research process, including workshops with focus groups and interviews with industry experts, the study analyses the fifty-four data points identified by Berger et al. (2022), assessing their availability and criticality. The results highlight significant variability in data accessibility and relevance. In the Electric Vehicle Batteries sector, characterised by an evolving value chain, considerable uncertainty and lack of consensus persist, particularly regarding data standardisation and information sharing	Cleaner Production Letters
Digital product passports for a circular economy: Data needs for product life cycle decision-making	2023	Mechatronics and Electronics	Identification of the critical decision points and data needs of the different actors in the circular supply chain to support decision-making in the product life cycle	The study defines five decision-making contexts along the circular supply chain, including supplier, manufacturer, service provider, customer, and recycler, and organises twenty-eight data points into seven categories: use and maintenance, product identification, product and materials, guidelines and manuals, supply chain and reverse logistics, environmental data, and compliance. These data points are evaluated by the five actors in terms of importance, availability, and sensitivity, and the results are compared with findings reported in existing literature	Sustainable Production and Consumption
Stop Guessing in the Dark: Identified Requirements for Digital Product Passport Systems	2023	Multisectoral	Analysis of the requirements to be met by a DPP system, namely, the entire IT/software environment dedicated to data collection	A DPP system is required to meet eight categories of requirements, including legal obligations, functional stability, security and confidentiality with intellectual property protection, interoperability, modularity and modifiability, accessibility, availability and behaviour over time, and portability. However, two gaps remain in the current framework, specifically concerning the energy and resource consumption of the DPP system and issues related to data privacy	Systems
A Digital Product Passport for Critical Raw Materials Reuse and Recycling	2023	Critical raw materials (CRMs)	Design of a circular supply chain management system for Critical Raw Materials based on DPP	The study is grounded in the development of a management system to support the recovery and recycling of Critical Raw Materials (CRM). By analysing the needs and requirements of supply chain actors, fourteen product information management processes are identified and structured, operating with the support of the Digital Product Passport. These processes aim to enhance information flow and coordination across the supply chain. In addition, an IT architecture is proposed to enable the integrated and efficient management of the entire CRM supply chain	Sustainability (Switzerland)

Digital battery passports to enable circular and sustainable value chains: Conceptualization and use cases	2022	Battery industry	Construction of a prototype DPP for Electric Vehicle Battery (EVB)	An initial conceptual framework for Digital Product Passports (DPPs) in Electric Vehicle Batteries (EVBs) is developed, defining fifty-four data points grouped into four main categories: battery, sustainability and circularity, diagnostics, maintenance and performance, and value chain actors. The robustness of the model is assessed through four illustrative case studies, demonstrating potential DPP applications for different stakeholders, including manufacturers or OEMs, EV users, recyclers, and regulators	Journal of Cleaner Production
Digital Product Passports as Enabler of the Circular Economy	2021	Battery industry	Definition of the DPP concept and discussion of challenges and opportunities related to its development. The case of the EU battery passport is examined as an example	Following the identification of relevant policies, the study outlines industry initiatives toward circular economy adoption, highlighting associated economic benefits and barriers. Digitalisation is presented as a key enabler to address these challenges, with reference to existing tools such as IMDS and BIM. The Digital Product Passport (DPP) is identified as a critical instrument to standardise data on product origin, durability, composition, reuse, repair, dismantling, and end of life. The analysis concludes with the introduction of the EU battery regulation and the battery passport example	Chemie-Ingenieur-Technik
Towards a digital product passport fit for contributing to a circular economy	2021	Multisectoral	Introduction of the DPP concept and development of some DPP design options	The DPP is described as an integrated collection of data derived from existing regulatory frameworks provided by manufacturers, such as Energy Label, Material Passport, C2C, and AAS. The study outlines which actors along the value chain are responsible for providing specific information, how the data should be structured, and how access can be managed through a single interface for different stakeholder groups. The analysis concludes by highlighting the key benefits associated with the implementation of the DPP	Energies

Table 4 presents a classification of the industrial application domains addressed in the thirty-five reviewed papers. Eight of these contributions deal with applications in the textile sector, five with the battery industry, three with the building industry, three with cases in mechatronics and electronics, and three with the manufacturing industry. In addition, two papers are dedicated to other specific sectors: one reviews applications in recycling processes, and the other addresses critical raw materials management.

Table 4 - Number of articles by application field

Application Field	**Counter**
Multisectoral	11
Textile industry	8
Battery industry	5
Building industry	3
Manufacturing industry	3
Mechatronics and electronics	3
Recycling sector	1
Critical Raw Materials	1
Total	**35**

3.1.1 Multisectoral studies

The scientific literature on Digital Product Passport (DPP) information and models is still relatively immature and does not yet fully address integration with Product Lifecycle Management (PLM) systems. Most contributions adopt a general perspective, focusing on the broader DPP ecosystem rather than proposing detailed, implementable solutions. As a result, the majority of studies provide high-level guidelines that can be later adapted to specific industrial contexts. Among the 35 papers analysed, 11 adopt a multisectoral perspective, often considering additional digital technologies alongside the DPP.

Major themes in this literature are conceptual definitions of the DPP and the identification of guiding principles for its development. From the paper by *Adisorn et al. (2021),* the DPP emerges as a structured product-related dataset extracted from existing tools such as Energy Labels, Material Passports, and the Asset Administration Shell. Based on this definition, *Jansen et al. (2023)* point out the importance of a system of requirements for the integration of DPPs into IT infrastructures, such as interoperability, modularity, security, accessibility, and long-term availability. The contribution of *Langley et al. (2023)* also suggests some relevant guiding principles such as decentralised design, data governance, collaboration with stakeholders, and continuous improvement of the system.

Several studies focus on the technical architecture and the definition of the DPP's information content. *Kühn et al. (2025)* propose a model for evaluating the circular design and disassembly potential with circularity indicators such as the Product Composition Circularity Indicator (PCI) and the End of Use Circularity Indicator (ECI), both based on the Asset Administration Shell framework. *Wan and Jiang (2025)* deal instead with the lifecycle data management and propose a framework based on the integration of QR codes, RFID and blockchain technologies for the dynamic data update during the use phase.

On the other hand, *Panza et al. (2023)* investigate the integration of sustainability indicators by combining the Product Social Impact Life Cycle Assessment (PSILCA) for evaluating social impacts with Life Cycle Assessment (LCA) for environmental assessment, including the definition of absolute reference values.

Complementary technologies are also explored to support DPP implementation. *Werner et al. (2024)* introduce a Modular Digital Twin for managing product sustainability information, while *Hulea et al. (2024)* propose a dual-blockchain architecture to ensure secure product identification and data management. In addition, *Gieß and Möller (2025)* analyse the DPP value ecosystem using an e3-value model, highlighting interactions among stakeholders and the distribution of information flows.

The literature also highlights key drivers of the practical adoption of the DPP. From an industrial perspective*, Fares et al. (2025)* emphasise the importance of unique product identification, supply chain transparency, and regulatory facilitation, as well as the opportunities offered by data integration and design innovation. Conversely, from the consumers' perspective, *Joo et al. (2026)* reported that user acceptance is influenced by multisectoral applicability, lifecycle information (especially disposal and recycling), and government-led management.

3.1.2 Textile industry

The textile industry is the most addressed industrial sector in the selected papers. This prominence is largely due to the high complexity and fragmentation of textile supply chains, which limit transparency into the origins of materials and the sector's environmental and social impacts, and to the sector's heavy influence by fast-fashion dynamics and short product lifecycles. The Digital Product Passport (DPP) is considered a possible solution to

these challenges. Hence, the analysed studies focus on barriers to implementation, key attributes to be included in the DPP and supporting technologies to improve data quality and security.

The sector's complex nature underscores the importance of understanding how the DPP can effectively improve circularity and transparency. This line refers to two systematic literature reviews on challenges in adopting DPPs. For example, *Papile and Del Curto (2025)* identify key obstacles, including the cost of upgrading IT systems and training personnel, as well as issues related to intellectual property protection, data privacy, and the lack of uniform data formats. In the same spirit, *Carvalho et al. (2025)* highlight critical issues by analysing both private and governmental initiatives in each sector, defining strategic objectives and benefits through a SWOT analysis.

Equally important is identifying key attributes and sustainability criteria to include in textile DPPs. In a multi-criteria analysis based on expert evaluations, *D'Adamo et al. (2025)* identify material traceability, reuse, repairability, recycling, end-of-life management, and environmental performance as strategic priorities from an industrial perspective. From the consumer side, *Colasante et al. (2025)* show that users are more willing to pay for products associated with sustainability-related information, although purchasing decisions are still mainly driven by price and aesthetics. *Becchi et al. (2026)* offer a combined perspective by analysing both producers and consumers, confirming that the main priorities are traceability and circularity-related information. *Papile and Del Curto (2025)* and *Carvalho et al. (2025)* also suggest minimum information requirements to help the development of textile DPPs.

Lastly, some studies explore complementary models and technologies to assist the implementation of DPP. *Cruz et al. (2025)* employ machine learning algorithms to detect anomalies in textile datasets, thereby enhancing data quality for DPP applications.

According to *Abreu et al. (2025)*, blockchain architecture is a promising solution for ensuring data security and privacy. Moreover, *Gonçalves et al. (2025)* propose a multi-criteria sustainability index based on environmental and social Life Cycle Assessment (LCA) and durability to classify textile products from A to E, which can be integrated into the DPP.

3.1.3 Battery industry

The battery industry is the first industry to be subject to the mandatory implementation of the Digital Product Passport, in this case identified as the *Digital Battery Passport*, as established by the EU Batteries Regulation (2023), coming into force as of February 2027 for LMT batteries, electric vehicle batteries, and industrial batteries. This regulatory move has advanced research into DPP architectures, data requirements, and model development. The battery sector is strategically important for the energy transition and requires greater transparency and traceability given the complexity of its supply chains and the presence of critical raw materials. Consequently, the Battery Passport is widely considered a reference point for the development and future deployment of DPP systems across all sectors subject to regulatory requirements.

The literature on the battery sector shows strong research interest in the emerging segment of electric vehicle batteries (EVBs), with four of the five analysed papers focusing on this domain. This trend is closely linked to the European strategy for the electrification of transport, part of the European Green Deal, which aims to achieve a major reduction in emissions by 2050.

Walden et al. (2021) offer one of the first attempts to identify existing digital tools and to analyse industrial initiatives towards circularity, addressing the definition of the DPP

concept and the challenges and opportunities associated with its adoption in the European battery sector. The paper identifies the DPP as a principal tool for standardising battery-related information and tackling barriers that impede the battery sector's transition to circular-economy practices.

Batteries are complex systems composed of materials classified as critical raw materials, and their circularity requires assessing multiple informational attributes. *Pohlmann et al. (2025)* explore this by identifying 40 information criteria through questionnaires administered to EVB designers, actors involved in battery second use, and recycling stakeholders, followed by an assessment of their relative importance. Further studies help define the key data requirements for the Digital Battery Passport. A prototype DPP for EVBs is developed in *Berger et al. (2022)* based on a model comprising 54 data points, which are then analysed in *Berger et al. (2023)* through workshops and interviews with value chain actors. Results show uncertainty and a lack of consensus, reflecting the sector's emerging nature.

In addition to studies on DPP content, research is also conducted on complementary technologies within the Industry 5.0 paradigm for lithium-ion battery remanufacturing. *Neri et al. (2025)* evaluated several technological alternatives and concluded that the DPP is the best option for creating value in the battery supply chain, followed by the Digital Twin and the Internet of Everything.

3.1.4 Building industry

The construction industry is one of the most material-intensive industries in terms of the mass and volume of raw materials required. This makes it one of the most environmentally damaging sectors, with huge implications for resource use, waste generation and greenhouse gas emissions. The environmental impact of construction materials is more associated with

the production phase in comparison with the other life cycle phases. In addition, data in the sector is fragmented, and reporting practices are inconsistent, limiting transparency and the effective implementation of circular economy strategies.

Research work such as that of *Kebede et al. (2024)* has been driven by the need to structure and standardise lifecycle information for construction materials, particularly within the context of the DPP. The authors develop a modular ontology that identifies major information requirements for the DPP through a literature review and expert interviews. The proposed framework comprises eight information modules that will improve data organisation in the supply chain, as well as interoperability and information management. Also, *Vergés et al. (2026)* address fragmented data by using Large Language Models to analyse 368 Environmental Product Declarations (EPDs). Their findings confirm that 80-98% of total environmental impacts occur during the production phase and highlight design for disassembly as a key strategy to improve sustainability performance in the sector.

More specific analyses of applications are therefore needed to provide more accurate insights, given the heterogeneity of construction products in terms of materials, dimensions, and environmental impacts. From this perspective, *Morganti et al. (2024)* introduce a framework based on the Life Cycle Impact Assessment (LCIA) methodology for integrating project, environmental, and circularity data related to Customizable Modular Curtain Walls (CMCW). The data are then stored in two databases to manage the information and evaluate the Global Warming Potential throughout the life cycle of the analysed façade modules.

3.1.5 Manufacturing industry

The manufacturing industry is central to the transition towards a circular economy, since it is directly involved in managing product life cycles and data flows along the supply chain.

In this context, existing research investigates the adoption of the DPP, focusing on the benefits derived from interactions among actors in the industrial ecosystem and outlining the importance of effective orchestration and coordination models.

For example, *Jensen et al. (2024)* investigate three case studies in the Danish manufacturing industry and analyse the interactions among manufacturers, suppliers, service providers, third-party recyclers, and consumers. The study proposes an ecosystem orchestration framework grounded in these interactions and outlines the essential information requirements for implementing DPP.

Voulgaridis et al. (2024) further discuss the role of digital technologies in assisting with data collection, management, sharing and utilisation, and propose a two-level framework that addresses both data generation and DPP development. Their approach distinguishes between two types of DPP, one for interaction between companies and supply chain partners, and the other a user-friendly version for end consumers.

The manufacturing industry ranges from single components to complex assembled products; therefore, there is a need to develop standardised models and templates for use across a variety of production contexts. In this context, *Psarommatis and May (2024)* develop a comprehensive DPP model that defines connectivity modes (local, cloud, and hybrid), data management and update mechanisms, and a lifecycle structure comprising eight stages. The study also determines the key players in the DPP ecosystem and assigns the digital passport ownership to the Original Equipment Manufacturer (OEM). Moreover, it provides a classification of data into seven categories (material, environmental, manufacturing, value network, maintenance, circularity and end-user data) and describes different levels of data granularity in terms of their relevance for interoperability and update frequency in industrial processes.

3.1.6 Mechatronics and electronics

Research in the mechatronics and electronics sector shows a dual approach to analysing the Digital Product Passport. On the one hand, two contributions are related to specific applications, developing dedicated solutions for specific production systems to support circularity and reuse practices. This is the case of *Hammadi et al. (2025)*, who combine a Circular Economy Framework (CEF) with the DPP to allow remanufacturing of an electric bicycle motor and propose a conceptual DPP design for a mechatronic component of the system. Similarly, *Boukhatmi et al. (2023)* address data management challenges in the photovoltaic sector by developing a digital platform prototype comprising a well-organised product database that could be adapted to implement a DPP for solar panels.

On the other hand, another study is more general and aims to define datasets and information needs to support decision-making processes along the circular supply chain. In this paper, *Jensen et al. (2023)* differentiate between five decision-making contexts, i.e., supplier, manufacturer, service provider, customer and recycler, and map 28 data points to seven categories, i.e., use and maintenance, product identification, materials, technical documentation, supply chain and reverse logistics, environmental data and regulatory compliance. These data structures are available as a basis for DPPs in the mechatronics domain.

3.1.7 Recycling sector and Critical Raw Materials (CRM)

The other studies analysed in the literature review are related to two closely linked fields: material recycling and the management of Critical Raw Materials (CRMs). Recycling practices are present in all the industries studied previously, but the corresponding study is considered a separate category due to its specific methodological approach. In particular, a

case study on the recycling of plastic bottle caps into frisbees is presented by *Rumetshofer et al. (2024),* supported by data collection and management through a Digital Product Passport (DPP) used on the R-Cycle platform. The five stages of the recycling process (collection, sorting, shredding, regranulation, and injection moulding) are systematically linked to the acquisition of process-specific data, which are managed within the DPP. Results show the DPP's ability to provide traceability and enable calculation of the mass balance of materials in the final recycled product.

Koppelaar et al. (2023) adopt a more systemic, infrastructure-oriented view by analysing the information needs of supply chain actors involved in Critical Raw Materials (CRMs). The study identified 14 product information management processes and found that the DPP is a key tool for supporting efficient data management and coordination across the CRM value chain.

The analysis of the recycling and CRM sectors shows that the value of the Digital Product Passport is generated primarily downstream in the supply chain. These domains use upstream data to ensure traceability and material recovery, making the DPP a crucial link between product data and real-world circular economy outcomes.

4. Methodology and Requirements Identification

In parallel with the literature review of the 35 selected documents, within which the Digital Product Passport (DPP) is addressed with varying degrees of depth, alignment with framework development, sectoral focus, and scientific objectives, all information requirements mentioned, either explicitly or implicitly, were systematically collected. These were organised into a three-level structured list.

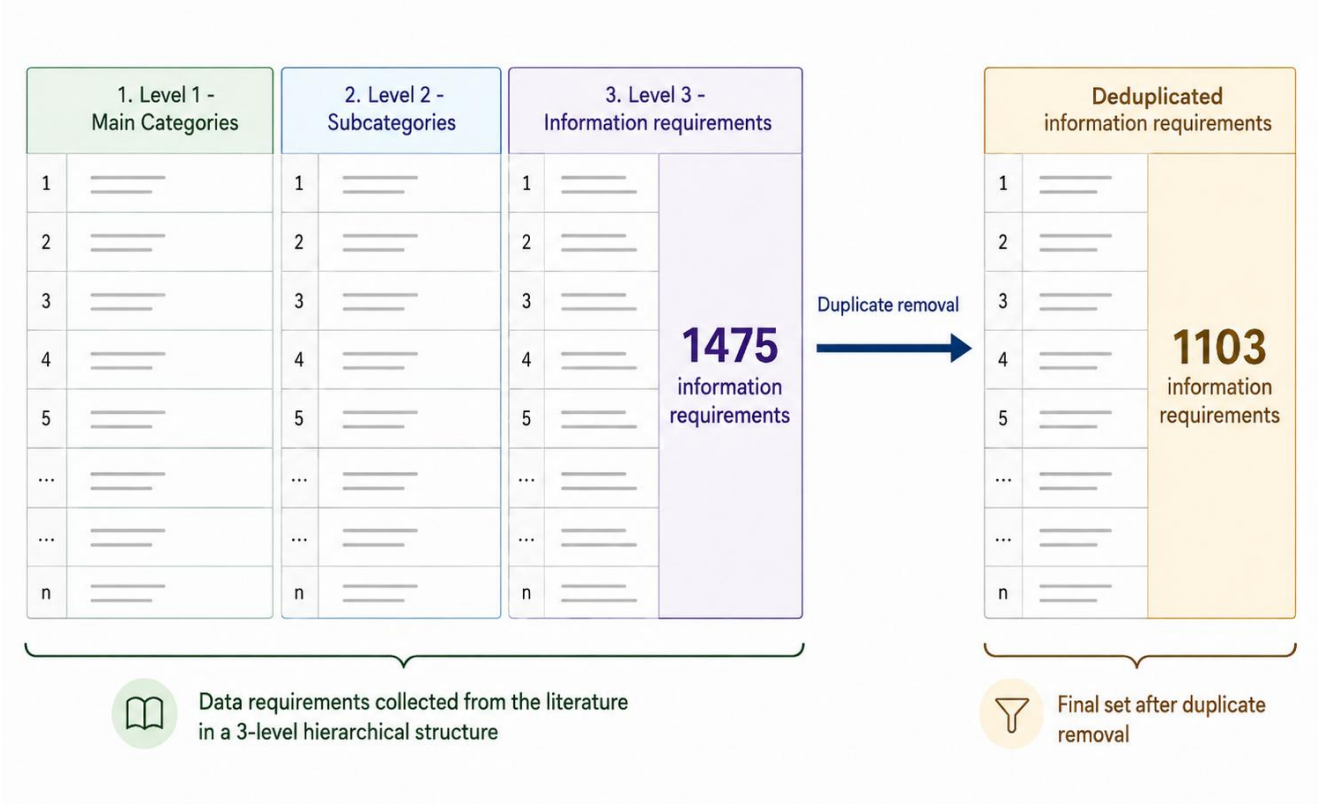
This choice is motivated by how data requirements are positioned within the analysed documents and, where applicable, within the frameworks proposed therein. In many cases, information is structured according to hierarchical schemes, beginning with macro categories of relevance and progressively branching into increasingly specific subcategories, ultimately leading to the identification of the final data point.

By way of example, in the work of *Panza et al. (2023)*, information is hierarchically organised starting from the overarching category (e.g. Manufacturing Data: environmental footprint impacts), followed by the descriptive category of the specific parameter to be assessed (e.g. climate change, water use, land use), and finally by the corresponding unit of measurement required for its quantification (e.g. global warming potential (GWP100) (kg CO_2 eq), user deprivation potential (m^3 world eq), soil erosion (kg soil loss)).

The aggregation of all information requirements defined and/or referenced across the analysed documents results, at the third level, which represents the most granular level of informational detail, in a total of 1,475 terms. This number is relatively high because the compiled list includes duplicate entries and semantically equivalent terms expressed in different formulations. An initial filtering operation to remove duplicate entries reduces the

total number of requirements from 1,475 to 1,103. Figure 9 illustrates the operations performed to identify the information requirements.

Figure 9 – Information requirements identification process



4.1 Requirements Filtering Process

The identification of 1,103 requirements highlights the need for further selection, refinement, and filtering based on criteria to ensure a clear and unambiguous interpretation of their content. Moreover, a significant share of the selected requirements contains highly specific references to the industrial sector from which they originate, whereas the final objective is to obtain a set of requirements suitable for developing a DPP adaptable to multiple industrial contexts. Particular attention is paid to the textile sector, given its prominence in the analysed literature and the forthcoming regulatory push to adopt the Digital Product Passport, expected in 2027.

The methodology adopted for filtering the list of data requirements is structured into three main steps.

1. **Selection and generalisation**: the first step involves the identification of requirements that can be generalised when originally defined within a specific sector, and their subsequent reformulation into requirements potentially applicable across different industries (e.g. battery manufacturer information → manufacturer information; battery type → product type). This step also includes the removal of overly specific and non-generalisable requirements (e.g. power capability (W), voltage limits (V)), while retaining those specifically relevant to the textile sector.
2. **Redefinition and consolidation**: This step consists of the renaming of requirements that share the same semantic meaning but were originally expressed using different terminology by assigning a single unified definition (e.g. materials breakdown, raw materials composition, types or quantity of materials → material composition).

3. **Unique term extraction**: the last step focuses on the deduplication of the resulting list through the extraction of unique terms, ensuring that each requirement appears only once and eliminating all repetitions. The outcome of this step is a non-redundant set of requirements.

The application of these three filtering steps significantly reduces the number of terms, transitioning from the initial 1,103 requirements to a more concise set of 80 data requirements, either generalised or specifically relevant to the textile sector, as illustrated in Figure 10.

However, the resulting list still presents some limitations. In particular, certain terms encompass DPP-related themes at a very broad level, resulting in overlaps in which information from more specific requirements is effectively subsumed within broader categories. For this reason, an additional step of domain-based reorganisation and hierarchical structuring is required to organise the list into structured categories and establish a coherent reference framework to support subsequent modelling of the DPP.

Figure 10 – Data requirements filtering operation



4.2 Filtered Requirements List

The list of the 80 information requirements obtained through the filtering process described in the previous section is presented in Table 6. This set consists of a generalised, redefined and deduplicated selection of data elements, consolidated and refined for use.

Furthermore, each requirement is connected to its respective source in the analysed literature. Each requirement is identified by a numerical reference to the papers in Table 5. The cross-referencing enables traceability of the information requirements, providing visibility of their provenance and allowing for a better understanding of their distribution among the reviewed documents.

Table 5 – Reference number to paper attribution

Number	Title	Author
1	Digital product passports for electric vehicle batteries: Stakeholder requirements for sustainability and circularity	Pohlmann et al., 2025
2	Exploring the value ecosystem of digital product passports	Gieß et al., 2025
3	Circular Economy: Literature Review on the Implementation of the Digital Product Passport (DPP) in the Textile Industry	Carvalho et al., 2025
4	Enabling a dynamic information flow in digital product passports during product use phase: A literature review and proposed framework	Wan et al., 2025
5	Digital Product Passport Design Supporting the Circular Economy Based on the Asset Administration Shell	Kühn et al., 2025
6	Blockchain-based digital product passport: design principles and demonstration	Abreu et al., 2025
7	Fostering lithium-ion battery remanufacturing through Industry 5.0	Neri et al., 2025
8	Modular Digital Twin–an approach for generating and exploiting product sustainability information towards service-oriented business models	Werner et al., 2024
9	CEF-DPP: A Circular Economy Framework Integrating Digital Product Passport for Improving Circularity of Sustainable Mechatronics Design	Hammadi et al., 2025
10	An ecosystem orchestration framework for the design of digital product passports in a circular economy	Jensen et al., 2024
11	A modular ontology modeling approach to developing digital product passports to promote circular economy in the built environment	Kebede et al., 2024
12	Digital Product Passport Implementation Based on Multi-Blockchain Approach with Decentralized Identifier Provider	Hulea et al., 2024
13	How the Digital Product Passport Can Lead the Plastics Industry towards a Circular Economy—A Case Study from Bottle Caps to Frisbees	Rumetshofer et al., 2024

14	Digital product passports as enablers of digital circular economy: a framework based on technological perspective	Voulgaridis et al., 2024
15	Data-driven and LCA-based Framework for environmental and circular assessment of Modular Curtain Walls	Morganti et al., 2024
16	Digital Product Passport: A Pathway to Circularity and Sustainability in Modern Manufacturing	Psarommatis et al., 2024
17	Orchestrating a smart circular economy: Guiding principles for digital product passports	Langley et al., 2023
18	Designing a digital platform to foster data-enhanced circular practices in the European solar industry	Boukhatmi et al., 2023
19	Integrating Absolute Sustainability and Social Sustainability in the Digital Product Passport to Promote Industry 5.0	Panza et al., 2023
20	Data requirements and availabilities for a digital battery passport – A value chain actor perspective	Berger et al., 2023
21	Digital product passports for a circular economy: Data needs for product life cycle decision-making	Jensen et al., 2023
22	Stop Guessing in the Dark: Identified Requirements for Digital Product Passport Systems	Jansen et al., 2023
23	A Digital Product Passport for Critical Raw Materials Reuse and Recycling	Koppelaar et al., 2023
24	Digital battery passports to enable circular and sustainable value chains: Conceptualization and use cases	Berger et al., 2022
25	Digital Product Passports as Enabler of the Circular Economy	Walden et al., 2021
26	Towards a digital product passport fit for contributing to a circular economy	Adisorn et al., 2021
27	Machine Learning-Based Data Quality Assessment for the Textile and Clothing Digital Product Passport	Cruz et al., 2025
28	Sustainability Index in Apparel: A Multicriteria Model Covering Environmental Footprint, Social Impacts, and Durability	Gonçalves et al., 2025
29	Environmental Concerns in the Fashion Industry: A Twin Transition With the Digital Product Passport	Colasante et al., 2025
30	An Integrated Business Strategy for the Twin Transition: Leveraging Digital Product Passports and Circular Economy Models	D'Adamo et al., 2025
31	Towards an International Digital Product Passport: The New Paradigm of a Worldwide Circular Economy	Fares et al., 2025
32	Textile Materials Information for Digital Product Passport Implementation in the Textile and Clothing Ecosystem: A Review on the Role of Raw Fibers in a Substantial Transition	Papile & Del Curto, 2025
33	Can Digital Product Passports become the next-generation eco-label? Analyzing consumer preferences for labeling using Digital Product Passports	Joo et al., 2026
34	Large-scale analysis of environmental and circularity metrics in construction products through automated data extraction using large language models	Vergés et al., 2026
35	Digital product passports for cleaner production: Economic evidence from producers and consumers in the fashion industry	Becchi et al., 2026

Table 6 – DPP Requirements and Reference numbers to literature

Requirement	Reference numbers
manufacturer information	1, 2, 3, 4, 7, 11, 12, 16, 17, 18, 20, 24, 27
durability	1, 2, 7, 8, 9, 11, 15, 17, 18, 19, 20, 21, 23, 24, 25, 30, 31
supply chain actor	1, 2, 3, 4, 7, 11, 12, 15, 17, 20, 21, 24
product dimensions	1, 4, 11, 15, 17, 18, 20, 21, 23, 24, 26, 31, 32
product family	1, 4, 7, 11, 12, 13, 16, 30, 32
product identifier	1, 2, 3, 5, 6, 7, 9, 10, 11, 12, 17, 18, 20, 21, 23, 24, 30, 31, 32
Bill Of Materials	1, 2, 3, 4, 5, 6, 11, 12, 15, 16, 17, 18, 19, 20, 21, 23, 24, 26, 27, 30, 31
warranty	1, 3, 15, 16, 18, 26, 31, 32
transport information	1, 3, 4, 9, 11, 15, 28
circularity information	1, 5, 7, 8, 11, 14, 18, 20, 30, 31, 34
material composition	1, 2, 3, 4, 7, 9, 10, 11, 12, 15, 16, 17, 18, 20, 21, 22, 23, 24, 26, 27, 29, 30, 31, 32, 33
repair instructions	1, 2, 3, 7, 9, 11, 16, 17, 18, 24, 26, 31, 32, 35
regulatory compliance	1, 2, 3, 7, 9, 11, 20, 21, 35
care and maintenance instructions	1, 7, 9, 10, 11, 15, 16, 17, 18, 19, 24, 30
labels and certifications	1, 2, 4, 7, 9, 11, 18, 25
health and safety information	1, 2, 4, 7, 11, 20, 21
remanufacturing instructions	1, 4, 9, 16, 18, 19, 32, 34
environmental impacts	1, 3, 4, 9, 10, 11, 12, 17, 20, 21, 24, 25, 26, 30
disassembly instructions	1, 2, 4, 5, 7, 8, 9, 11, 16, 17, 18, 19, 20, 21, 23, 24, 26, 30, 32, 34
social impacts	1, 9, 19, 20, 25, 30, 35
recycling instructions	1, 2, 3, 4, 7, 12, 18, 21, 22, 29, 31, 32, 33, 34
manufacturing processes	2, 3, 4, 6, 11, 12, 13, 16, 19, 22, 27, 29, 35
disposal and designed collection points	2, 3, 7, 9, 10, 11, 12, 15, 21, 22, 26, 29, 30, 32, 33, 34, 35
reuse information	2, 4, 7, 9, 11, 15, 16, 18, 19, 26, 31, 32, 34, 35
user and service manual	2, 7, 11, 16, 21, 26, 30
air emissions	2, 9, 19, 28
materials origin	2, 3, 4, 5, 11, 12, 15, 18, 21, 26, 30, 31, 32, 33

product information	2, 9, 11, 12, 17, 20, 21, 23, 24
waste type and amount	2, 4, 9, 11, 12, 13, 19, 26, 27, 28, 32
packaging information	2, 3, 4, 11, 13
input resources	2, 4, 9, 11, 13, 14, 15, 18, 19, 23, 25, 27, 28, 31, 32, 35
responsible actor and activity	2, 11, 17, 18, 20, 24, 31
recycled input content	2, 9, 10, 15, 18, 21, 25, 32, 34
hazardous substances	2, 9, 11, 12, 17, 18, 19, 24, 27, 28, 30, 32
CO2 footprint and GWP	2, 4, 5, 7, 8, 9, 11, 15, 19, 25, 26, 28, 31, 32, 33, 34
product performances	2, 3, 4, 5, 9, 11, 22, 25, 29, 31
product map and tracking	3, 5, 7, 11, 16, 21, 26, 30, 32, 33, 35
manufacturing location	3, 4, 6, 7, 11, 12, 13, 15, 17, 18, 20, 24, 31, 32, 33
chemicals	3, 4, 7, 9, 17, 18, 19, 20, 22, 24, 27, 28, 29, 31, 32, 35
documents and certificates	3, 15, 18, 30
energy consumption	3, 4, 5, 8, 9, 11, 15, 17, 19, 20, 24, 26, 27, 28, 35
certified service providers	3, 10, 17, 24, 32
quality test reports	3, 4, 11, 16, 23, 31
record of ownership history	3, 11, 16
refurbishment instructions	3, 7, 9, 16, 18, 32
service history	3, 4, 5, 6, 11, 15, 16, 20
intellectual property	3, 35
percentage of children employment	4, 19, 28
living wage	4, 19
minimum wage	4, 19, 28
sector average wage	4, 19, 28
women employment rate	4, 19, 28
gender wage gap	4, 19
labour conditions and job safety reports	4, 9, 10, 19, 21, 28
manufacturing date	4, 7, 12, 15, 16, 18, 21
recyclability	4, 9, 11, 12, 15, 22, 23, 25, 26, 29, 33

recycling rate	4, 9, 15, 19, 23, 26, 27, 33
technical documentation	5, 7, 9, 11, 15, 22, 26, 29, 30
product weight	5, 11, 15, 18, 23, 24, 31, 32
return options	5, 7, 11, 12, 32, 35
product name	6, 7, 9, 11, 12, 13, 15, 18, 30
SVHC in product	7, 11, 21, 22, 25, 27, 28, 29
water footprint	9, 11, 19, 26, 27, 28, 32, 34
acidification emissions	9, 19, 26, 28, 34
eutrophication emissions	9, 19, 27, 28, 32, 34
rate of job accidents	9, 19, 28
tensile strength	11, 19, 28
customer feedback	11, 30, 31, 35
end of life options	12, 22, 33
product colour	6, 13, 32
fossil fuel consumption	15, 19, 27, 28, 34
particulate matter	19
land use	19, 28, 32
frequency of forced labour	19, 28
shift working hours	19
average weekly working hours	19, 28
ozone depletion	19, 26, 28
dimensional stability	28
surface durability	28
colour stability	28

4.3 Domain-Based Reorganisation and Hierarchical Structuring

The set of 80 information requirements obtained does not consist of fully independent elements. This limitation arises partly from the initial generalisation process applied to sector-specific terms, which in their final form tend to represent broader categories of information rather than clearly defined individual requirements. In addition, some of the requirements exhibited a certain degree of vagueness or lack of specificity already at the stage of literature analysis; therefore, even prior to the generalisation phase, they were more appropriately interpreted as groups of related requirements rather than as single, well-defined data elements.

To address potential interdependencies among requirements, the 80 elements were reorganised into thematic clusters, defined as domains. Ten domains were identified, namely: product identification, manufacturing information, supply chain and traceability, product composition, environmental sustainability, social sustainability, product performance, circularity and end-of-life, after-sales and support, and regulation, certification, and documentation.

The resulting domain-based reorganisation is presented in Table 7.

Table 7 – DPP Requirements collected by Domains

Domains	Requirements
Product Identification	product information, product name, product family, product identifier, product weight, product dimensions, product colour
Manufacturer Information	manufacturer information, manufacturing processes, manufacturing location, manufacturing date
Supply Chain and Traceability	materials origin, supply chain actor information, product map and tracking, transport information
Product Composition	Bill of Materials, materials composition, chemicals, packaging information, input resources

Environmental Sustainability	environmental impacts, air emissions, CO2 footprint and GWP, water footprint, acidification emissions, eutrophication emissions, energy consumption, fossil fuel consumption, particulate matter, land use, waste type and amount, hazardous substances, SVHC in product, ozone depletion
Social Sustainability	social impacts, children employment, living wage, minimum wage, sector average wage, women employment rate, gender wage gap, labour conditions and job safety reports, rate of job accidents, frequency of forced labour, shift working hours, average weekly working hours
Product Performances	durability, warranty, dimensional stability, surface durability, colour stability, product performances, tensile strength
Circularity and End-of-Life	remanufacturing instructions, disassembly instructions, recycling instructions, disposal and designed collection points, reuse information, recycled input content, recyclability, recycling rate, return options, end of life options, repair instructions
After Sales and Support	warranty, care and maintenance instructions, user and service manual, certified service providers, service history, customer feedback, health and safety information, responsible actor and activity
Regulation, Certification and Documentation	Regulatory compliance, labels and certifications, documents and certificates, technical documentation, quality test reports, intellectual property, record of ownership history

Following the domain-based reorganisation, a further step is to identify requirements that, from a semantic perspective, overlap with their domain of reference or with other individual or grouped requirements. Such elements can be removed from the list, as their information is already captured elsewhere, thereby avoiding redundancy. In particular, requirements such as product information, environmental impacts, social impacts, product performances, and circularity information were found to coincide with the meaning of their respective domains, while air emissions and customer feedback represent aggregations of more specific indicators.

An additional operation aimed at reducing redundancy consists of the consolidation of two or more requirements whose informational content is complementary by merging them into a single term capable of including the information contained in both original requirements.

The outcome of this merging process is summarised in Table 8.

Table 8 – Convergence of complementary requirements

Original requirements	Merged requirements
product map and tracking	product tracking and transport
transport information	
hazardous substances	hazardous substances and SVHC
SVHC in product	
care and maintenance instructions	use, maintenance and service manual
user and service manual	
labels and certifications	certification, labels and IP
documents and certificates	
intellectual property	

At the end of the reorganisation of the requirements identified in the literature according to a domain-based logic, and of the subsequent phase of redundancy elimination, carried out by removing duplicate elements and consolidating semantically similar ones, the structure is further refined.

In this phase, a hierarchical organisation is introduced between information requirements and their associated metrics, understood as data expressed through appropriate units of measurement. The units of measurement adopted are derived from the analysed literature in order to ensure methodological consistency and alignment with established standards.

Table 9 presents the final structure of the requirements, along with the corresponding information types and associated units of measurement.

Table 9 – Domain-based list of DPP Requirements and associated units of measurement

Domain/Requirements	Unit of Measure
Product Identification	
Product Name	
Product Family	
Product Identifier	
Product Weight	kg
Product Dimensions	mm
Product Colour	
Manufacturing Information	
Manufacturer Name	
Manufacturing Location	
Manufacturing Processes	
Manufacturing Date	dd/mm/yyyy
Supply Chain and Traceability	
Materials Origin	
Supply Chain Actor Information	
Product Tracking and Transport	
Product Composition	
Bill of Materials	
Material Composition	%
Input Resources	kg (or m^3)
Environmental Sustainability	
GHG emissions	kg CO_2 eq
Particulate Matter	kg PM10
Photochemical Ozone Formation Potential	kg NMVOC eq

Acidification Potential		kg SO_2 eq
Ozone Depletion		kg CFC-11 eq
Eutrophication Potential	Terrestrial	kg N eq
	Freshwater	kg P eq
Energy Consumption	Total	MJ
	Fossil	MJ
Water Footprint		m^3
Land Use		kg
Hazardous Substances and SVHC		
Waste		kg (or m^3)
Social Sustainability		
Human Rights and Ethical Practices	Children Employment	%
	Forced Labour Frequency	%
Economic Conditions and Compensation	Living Wage	€/month
	Minimum Wage	€/month
	Sector Average Wage	€/month
	Gender Wage Gap	%
Employment Inclusion	Women Employment Rate	%
Working Conditions	Shift Working Hours	hours/day
	Average Weekly Working Hours	hours/week
Occupational Health and Safety	Rate of Job Accidents	$\frac{\text{N°accidents}}{\text{N°workers}} * 10^5$
	Labour Conditions and Safety Reports	
Product Performances		
Durability	Expected Lifetime	N° of cycles (or years)
Dimensional Stability	Dimensional Variation	%
Surface Durability	Surface Pilling	Scale (1-5)

	Colour Change	Scale (1-5)
Mechanical Properties	Tensile Strength	MPa
Circularity and End-of-Life		
Circularity Metrics	Recycled Input Content	%
	Recyclability	%
	Recycling Rate	%
R-strategies Instructions	Reuse Instructions	
	Repair Instructions	
	Remanufacture Instructions	
	Recycle Instructions	
Disassembly Instructions		
Collection Points		
End-of-Life Pathways		
After Sales and Support		
Use, Maintenance and Service Manual		
Certified Service Provider		
Warranty		
Service History		
Health and Safety Information		
Product Life Cycle Responsibility		
Regulation, Certification and Documentation		
Regulatory Compliance		
Certifications, Labels and IP		
Technical Documentation		
Record of Ownership History		
Quality Test Reports		

The hierarchical reorganisation of information within the domain-based framework yields a total of 66 requirements distributed across 10 domains. Among these, 35 are associated with quantitative values and corresponding units of measurement, while the remaining requirements consist of qualitative information, expressed as textual data such as strings, documents, and lists.

4.4 Comparison between domain-based DPP and EPRS study model

The Digital Product Passport model proposed in the EPRS study by *Legardeur et al. (2024)* for the textile sector serves as a useful reference for translating the domain-based classification of information requirements extracted from the literature into a structure built around the product life cycle. The EPRS model organises DPP data into modules corresponding to the main stages of the product lifecycle, namely supply chain, finished product, distribution, usage, and end of life. Within these modules, the data requirements selected following consultations with experts are then placed into specific subcategories, as they are considered essential and of primary importance for the future development of the DPP in the textile sector across three consecutive time phases, each involving the progressive completion and refinement of the digital tool, starting from a minimal format to be introduced in 2027 up to the advanced and final model expected in 2033.

By comparing the two approaches adopted in the construction of the two models, it is possible to observe that the EPRS model, although adopting an operational and simplified perspective for representing the flow of information along the lifecycle of the textile product, appears to be less complete and to have a lower level of detail. Conversely, the domain-based model derived from the literature analysis provides a broader and more granular representation of the DPP requirements, including environmental and social impacts, product performance, regulations, and information on technical documentation and related

reports. However, the domain-based organisation does not allow explicit indication of where each requirement is located within the product lifecycle.

The integration of the two approaches could therefore enable the development of a more complete and clearer information model, maintaining the lifecycle readability present in the solution obtained by *Legardeur et al. (2024)* and incorporating the informational depth of the model extracted from the literature review.

To create a hybrid model combining the two solutions, it is useful to start with a comparative analysis of the two structures, highlighting similarities and differences between the modules defined in the EPRS study and the associated requirements derived from the domain-based model, as shown in Table 10.

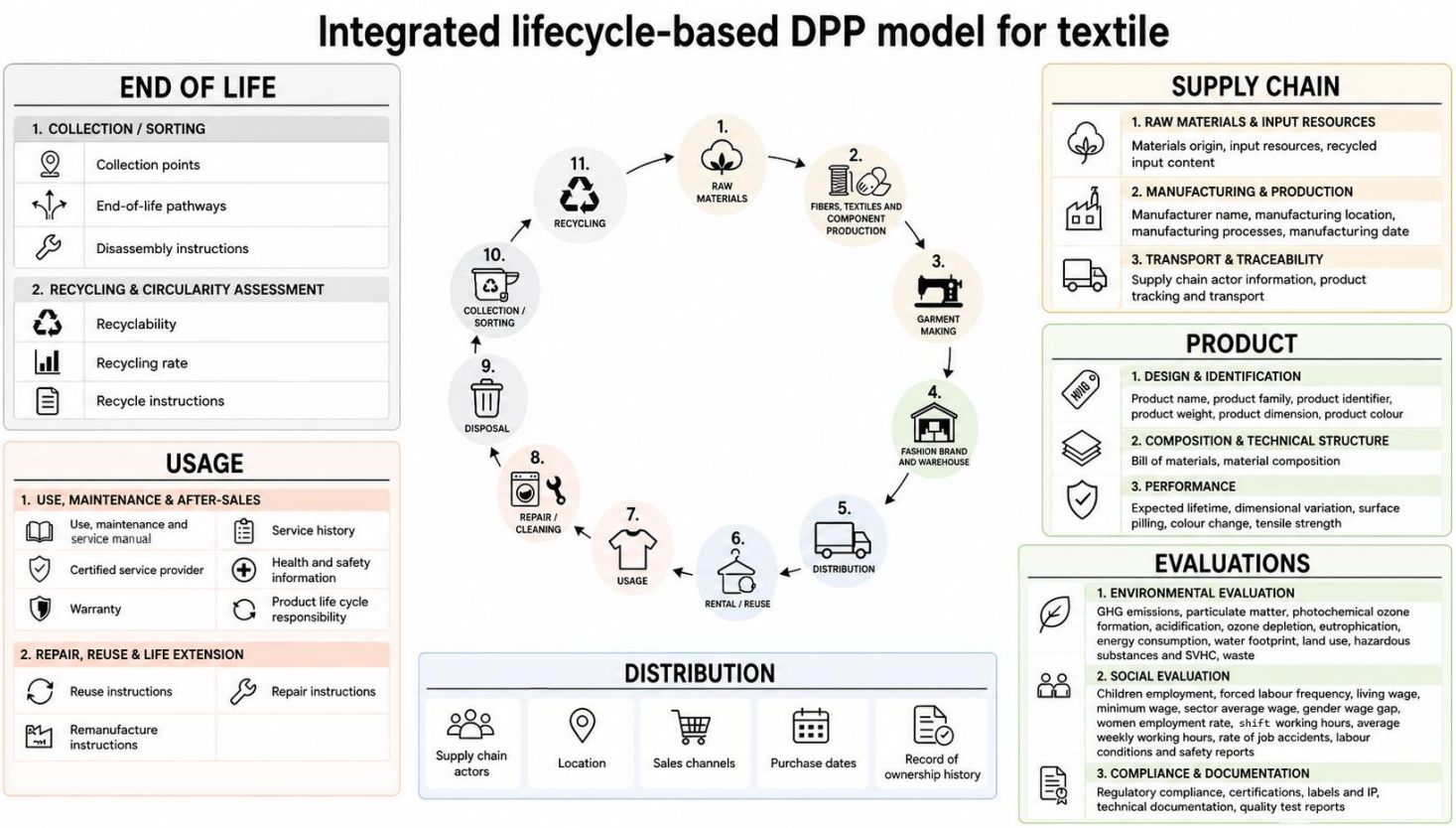
Table 10 – Comparison between EPRS model and domain-based list of DPP requirements

EPRS module	Corresponding literature - based requirements	Main observation
Supply chain - Production	Manufacturer Name; Manufacturing Location; Manufacturing Processes; Manufacturing Date; Materials Origin; Supply Chain Actor Information; Input Resources	The EPRS model includes production-related information such as processes, company tier, location, material composition, quantity, and date. The literature-based model expands this area by explicitly distinguishing manufacturers, actors, material origin, and input resources.
Supply chain - Transports	Product Tracking and Transport; Supply Chain Actor Information	Transport is present in both models. In the literature-based structure, however, it is included within the broader domain of supply chain traceability.
Finished product	Product Name; Product Family; Product Identifier; Product Weight; Product Dimensions; Product Colour; Bill of Materials; Material Composition	The EPRS model includes reference, authentication, description, colour, composition, size, packaging, cost, and weight. The literature-based requirements provide a more structured description of the product and its technical composition.
Finished product -Evaluations	Environmental Sustainability; Social Sustainability; Product Performances; Certifications, Labels and IP; Quality Test Reports	The EPRS model groups quality, environmental, social, health, animal impact, certifications, and audits under the evaluation area. The literature-based model allows these aspects to be detailed through specific indicators and measurement units.
Distribution	Product Tracking and Transport; Supply Chain Actor Information; Record of Ownership History	The EPRS model explicitly includes distributors, location, purchase dates, and sales channels. The literature-based model does not include distribution as an autonomous domain, but related data can be linked to traceability and ownership history.
Usage	Use, Maintenance and Service Manual; Health and Safety Information; Product Life Cycle Responsibility	The EPRS model includes usage type and customer identification. The literature-based model extends this phase by including manuals, safety information, and lifecycle responsibility.
Usage - Repair, Cleaning, Modification	Repair Instructions; Certified Service Provider; Warranty; Service History	Both models include after-sales activities, but the literature-based structure provides a more detailed representation of service-related information.
End of life – Collecting/Sorting	Collection Points; End-of-Life Pathways; Disassembly Instructions; Waste	The EPRS model includes input, output, processes, company, location, and date. The literature-based requirements strengthen this phase by adding disassembly instructions and end-of-life pathways.
End of life – Recycling	Recycled Input Content; Recyclability; Recycling Rate; Recycle Instructions	The EPRS model includes recycling processes, company, location, strategy, composition, and date. The literature-based model incorporates quantitative circularity metrics to assess recycling potential.

4.5 Integrated Lifecycle-based model of DPP requirements

Based on the previous comparison, it is possible to reorganise the requirements identified in the literature review into an integrated lifecycle model. In this model, the logic adopted in the EPRS study is maintained, with the product lifecycle placed at the centre, while the surrounding modules include additional requirements derived from the domain-based model derived from the literature.

Figure 11 – Integrated lifecycle-based DPP model for textile products



From the integration of the two models, it was possible to derive a structure oriented towards the representation of the main lifecycle phases of a textile product, which preserves the readability of the simplified model proposed in the EPRS study and, at the same time, is able to capture the level of detail required by the requirements identified through the literature review.

In the *Integrated Lifecycle-based (ILB) DPP model for textiles*, shown in Figure 11, six modules are built to identify the main stages of the product lifecycle, namely: supply chain, product, evaluations, distribution, usage, and end of life. The supply chain module includes the categories of requirements related to raw materials and input resources, manufacturing and production, and transport and traceability. The product module, instead, contains the requirements for product design and identification, its composition and technical structure, and, finally, its performance. The evaluations module significantly expands the requirements of the model proposed in the EPRS study and, in this case, includes information on environmental and social evaluation, compliance, and documentation, while the distribution module contains requirements related to product sales. This is followed by the usage module, with two subcategories: maintenance and after-sales, and repair, reuse, and life extension. The model concludes with the end-of-life module, which includes information concerning collection/sorting, recycling and circularity assessment.

The modules and their subcategories were populated by including all 66 requirements from the domain-based model, appropriately redistributed according to their corresponding life-cycle phase. Moreover, the presence of the distribution module is derived from the model proposed by *Legardeur et al.* and extends the list of requirements to 70 by including, in addition to the record of ownership history derived from the literature, supply chain actors, locations, sales channels, and purchase dates.

This *Integrated Lifecycle-based* (ILB) model will serve as the foundation for designing the DPP model to be implemented in Aras Innovator PLM.

5. Design of the DPP Model in Aras Innovator PLM

This chapter describes the implementation of the ILB DPP model for textiles within the PLM platform Aras Innovator. The implementation begins with the redesign of the Form sections to introduce Products and their associated Parts, then proceeds to modify and create the Relationship Tabs for the *Product ItemType* and the *Part ItemType*.

During this process, a preliminary assessment was carried out to determine which predefined elements needed to be preserved, either because they were already optimised and compatible with the new model to be developed, or because they were mandatory, as they were associated with predefined relationships required for the correct functioning of some of the fundamental features of the PLM system.

The following sections describe the Forms and Relationship Tabs associated with the Product and Part sections in their newly designed versions, intended to host the informational content of the ILB DPP model. This includes the presentation of the new RelationshipTypes and their related properties, within an architecture aimed at harmonising the integration of informational content with the usability of the PLM system.

It should be noted that the Aras PLM software provides access to information about the product, its materials, and components through a hierarchical structure, starting from the Product section and linking to the Part element within the relationship with the *Model ItemType*. Once inside the Part section, it is possible to access all DPP information associated with the product, including links to subcomponents and materials in the Bill of Materials.

For the design of the ILB DPP model, a test product is therefore created, named TEST and containing no associated information. In addition, within the Relationship Tab related to the

Model ItemType, a Part-type element named TEST PART is created, through which the product DPP can be accessed.

5.1 Elements Preserved from the Original PLM Configuration and Previous Studies

Starting from the Relationship Tab of the Product section, the functional relationship with the Model ItemType is retained, as it is required to establish the connection with the Part section, where most of the information concerning the product, its subcomponents, and its constituent materials is concentrated. More specifically, within the Model ItemType, the default properties Model Number, Name, and Part Number are preserved, with the latter being renamed Part Number/ID. In addition, the properties introduced by *Bruno et al. (2025)* are also retained, namely Product Family, Manufacturer renamed Manufacturer Name, Production Site renamed Manufacturing Location, Brand Owner, Sustainability Certification, and Regulatory Compliance. Finally, the Version Number and Release Number properties are hidden through the dedicated function, as they are considered redundant for the purposes of the present modelling activity.

In the Relationship Tabs associated with the Part section, the relationships with the BOM ItemType (renamed Bill of Materials), BOM Structure, and CAD Documents are retained, with appropriate modifications to their associated properties, as discussed in the following sections.

The elements described in this paragraph are therefore preserved in order to maintain the native functionalities already provided by the PLM software, as well as because they qualitatively correspond to the requirements defined by the ILB DPP model.

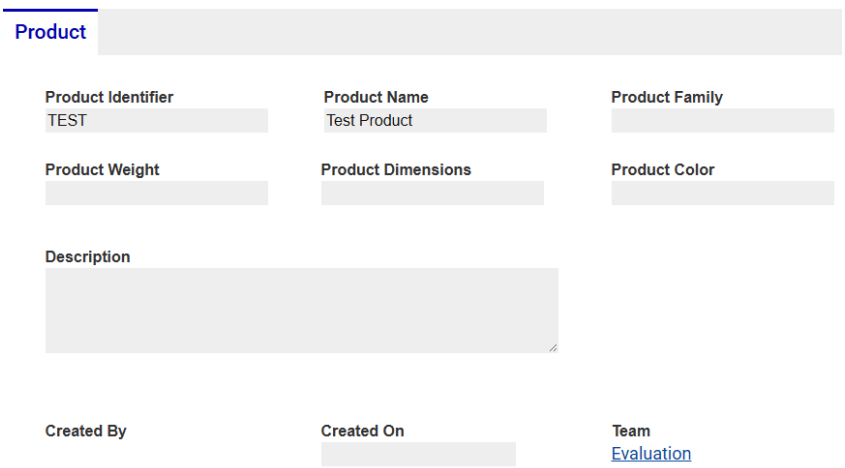
5.2 ILB DPP Product's Form

The Form dedicated to the product has been redesigned to collect the information required to identify the product and define its fundamental characteristics. The six information elements belonging to the Design & Identification category of the ILB DPP model, namely Product Identifier, Product Name, Product Family, Product Weight, Product Dimensions, and Product Colour, are included in the Form, thereby expanding its informational content, which was previously limited to the object nomenclature.

Compared with the default version, the section related to the product's Description is retained, along with the information concerning the product's creation within the software, namely Created On and Created By, which identify the creation date and the user responsible for creating the element. The Team element is also preserved, as it serves as a mandatory identifier for the user category and defines the corresponding usage permissions.

Compared with the original version, the new Product Form, visible in Figure 12, is more comprehensive and serves as a valid reference for identifying basic general information about the product's physical characteristics, as well as the key information required to create and identify the digital passport within the PLM software.

Figure 12 – New Product's Form Section



5.3 ILB DPP Product's Relationship Tab - Model

The Relationship Tab associated with the Product section includes, by default, a single relationship with the Model ItemType, to which the properties intended to define the Part ItemType related to the product subject to the DPP are associated. The list of properties and their corresponding data types is reported in Table 11 in the display order shown in the interface (see Figure 13), with the last two added as an informational expansion consistent with the ILB DPP model.

Figure 13 – Product's Relationship Model

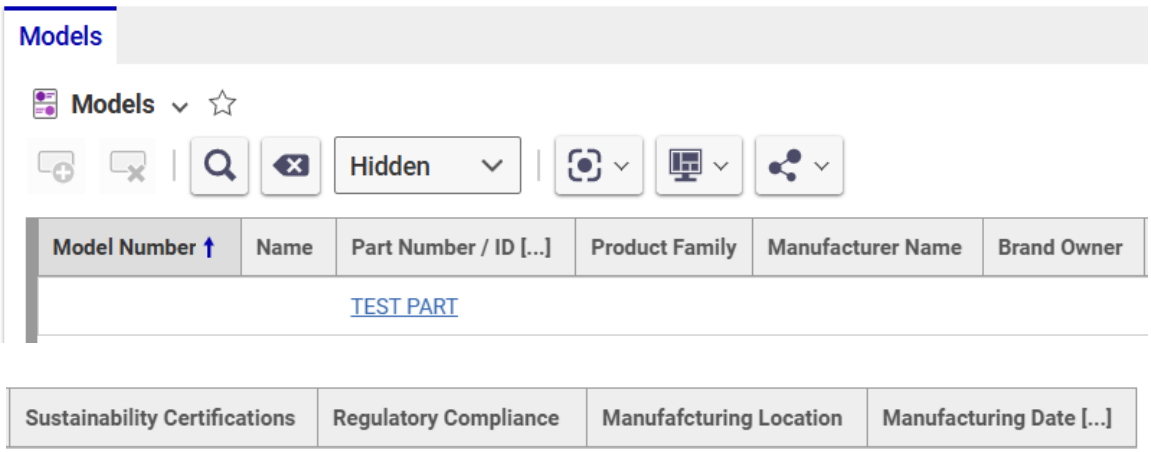


Table 11 – Item Type Model properties list

Item Type	Name	Label	Data Type	Data Source	Length
Model	item_number	Model Number	String		32
Model	name	Name	String		64
Model	part_number	Part Number/ID	Item	Part	
Model	family	Product Family	List	Product Families Textiles	128
Model	mfg_name	Manufacturer Name	String		128
Model	brand_owner	Brand Owner	String		32
Model	sust_cert	Sustainability Certifications	Multi Value List	Sustainability Certifications	128
Model	reg_comp	Regulatory Compliance	Multi Value List	Regulatory Compliance	128
Model	mfg_loc	Manufacturing Location	String		128
Model	mfg_date	Manufacturing Date	Date		

The choice of data types for the properties associated with the Model ItemType is determined by the type of information to be managed. In particular, the String data type is preferred for entering free-text lines without specific input constraints, whereas List and Multi Value List are best suited for selecting, respectively, one or multiple values from the associated lists. Date enables guided date selection through a calendar interface, while Item represents the internal links between elements of the Part ItemType, thereby establishing parent-child relationships.

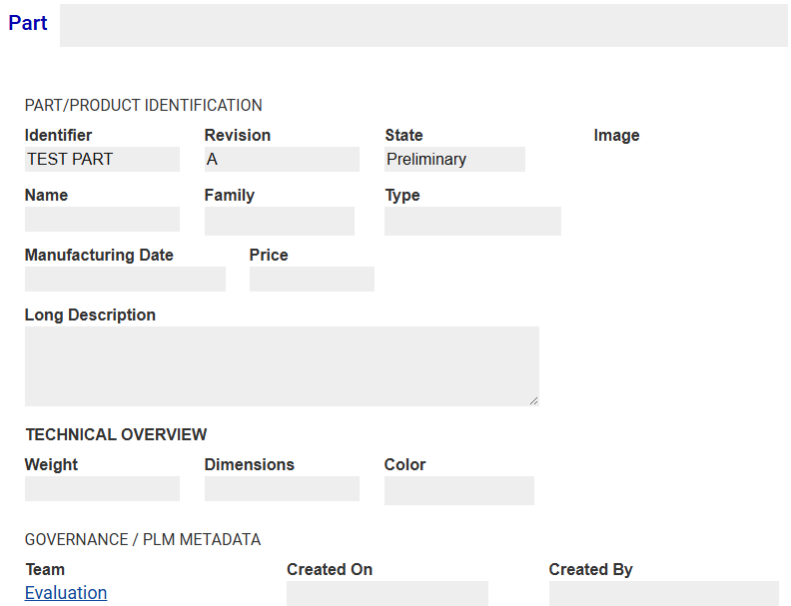
The length assigned to the newly created properties is set to 128 characters, which is considered suitable for ensuring both descriptive completeness and limited impact on the software data structure. For properties created in previous implementations or already present in the standard software configuration, their original lengths are left unchanged to preserve functionality and maintain consistency with the working environment's original setup.

5.4 ILB DPP Part's Form

Through the link to the TEST PART element included within the Part Number/ID property, access is provided to the Part section, which, like the Product section, is divided into two areas: the Form and the Relationship Tab. The Form contains general information about the component or material under examination and is structured into three relevant groups.

As shown in Figure 14, the first group visible from the top is named Part/Product Identification, and it includes the default elements Identifier, previously Part Number, Revision, State, Name, Type, Manufacturing Date, previously Effective Date, Cost, and Long Description, together with the additional elements Family, Image, and Price. This is followed by the Technical Overview group, in which the elements Weight, Dimensions, and Color are added to describe the product's basic physical characteristics. Finally, the last set of information, named PLM Governance/Metadata, completes the information set with administrative data, namely Team, Created On, and Created By, which are already present by default.

Figure 14 – New Part's Form Section



5.5 ILB DPP Part's Relationship Tab

Most of the content of the ILB DPP model is hosted within the Relationship Tab corresponding to the Part section of the object under examination. To cover the entire set of indicators related to the product lifecycle, 19 RelationshipTypes are associated with this section, whose contents define their types, visualisation, and editing methods. Table 12 lists the newly adopted relationships, including their specific name, label, and associated source ItemType, in the order they appear in the software interface.

Table 12 – Part's section RelationshipType list

Relationship Type	Relationship Name	Tab Label	Source ItemType	Related ItemType
Null	SC	Supply Chain	Part	
Null	MP	Manufacturing & Production	Part	
Null	RM	Raw Materials & Input Resources	Part	
Null	TT	Traceability & Transport	Part	
Null	PF	Performances	Part	
Part-to-Part	Part BOM	Bill of Materials	Part	Part
Tree View	Part MultiLevel BOM	BOM Structure	Part	
CAD Document	Part CAD	CAD Documents	Part	CAD
Null	EE	Environmental Evaluation	Part	
Null	SE	Social Evaluation	Part	
Document	JSR	Job & Safety Reports	Part	Document
Document	CD	Compliance & Documentation	Part	Document
Null	Distrib	Distribution & Sales	Part	
Document	UM	Use, Maintenance & Service Manuals	Part	Document
Null	AS	After-Sales Service	Part	
Null	SH	Service History	Part	
Null	RR	Repair, Reuse & Life Extension	Part	
Null	CS	Collection/Sorting	Part	
Null	RCA	Recycling & Circularity Assessment	Part	

Among the RelationshipTypes included in the Part section, five typologies with different functions can be distinguished. The Null RelationshipType is a relationship without a Related ItemType and is used to create informational tabs containing properties that are not associated with other databases. The Document RelationshipType links a source item to a Document and is useful for associating certificates, reports, and manuals; similarly, the CAD Document RelationshipType connects the item to a CAD Document containing technical drawings, CAD models, and project files.

A Part-to-Part RelationshipType instead establishes a link from a Father-Part element to one or more Child-Part elements, enabling the representation of product structures such as a Bill of Materials. Finally, the Tree View RelationshipType provides a multi-level hierarchical view of the relational structure between parent and child elements, as in the BOM.

Almost all the introduced relationships are newly created elements intended to ensure alignment with the contents of the ILB DPP model. The only elements retained from the default software configuration are the three relationships: Bill of Materials, BOM Structure, and CAD Documents, which are already optimised and functional for representing the relational structures between parts and are compatible with the indicators already included in the ILB model.

At this stage, the description of the properties associated with each RelationshipType is provided, together with an explanation of the operating logic adopted both for the visualisation and for the modification of the information associated with them.

5.5.1 Null Relationship - Supply Chain

The first Null Relationship in the Part Tab concerns the item's *Supply Chain*. It includes six properties designed to identify the role and contribution of each actor in the product supply chain. The Supply Chain Actor property identifies the entity involved in the supply chain, such as a supplier, manufacturer, or logistics operator. The Role property specifies the function the actor performs within the supply chain by defining its activity, while the Tier property classifies the level the actor occupies within the supply chain structure.

The Location property records the geographical position of the actor's site or of the facility where its operations are carried out. Supplied Input indicates the type of input associated with the actor's supply activity and may refer to materials, resources, or services. Finally, the Process/Activity property enables indicating the process the actor performs on the product, thereby linking the actor to the specific operational phase of the product lifecycle.

Table 13 then provides the technical definition of the previously identified properties within the PLM software.

Table 13 – ItemType Supply Chain properties list

ItemType	Name	Label	Data Type	Data Source	Length
SC	supply_chain_actor	Supply Chain Actor	String		128
SC	actor_role	Role	String		128
SC	tier	Tier	Integer		
SC	location	Location	String		128
SC	supplied_input	Supplied Input	String		128
SC	process_activity	Process/Activity	String		128

For most elements in the property set, the String data type is preferred for its greater flexibility during data entry. Indeed, String enables the insertion of textual values without

specific constraints that could limit their customisation. Only the Tier property is defined as an Integer, as it is intended to contain whole numbers. For all properties, the standard length of 128 characters is adopted, as it strikes a balance that ensures sufficient formal completeness while avoiding excessive burden on the system.

5.5.2 Null Relationship - Manufacturing & Production

The *Manufacturing & Production* Null Relationship is configured by creating four properties that contain the main information related to production activities in the textile sector. The Manufacturer Name property identifies the name of the company or organisation responsible for manufacturing operations, while Manufacturer Location identifies the corresponding production site. Manufacturing Processes presents a list of the most common production processes used in textile manufacturing. Finally, the Manufacturing Date property allows recording the date associated with the specific manufacturing phase via the calendar integrated into the PLM software. Table 14 reports the technical configuration of the previously identified properties.

Table 14 – ItemType Manufacturing & Production properties list

ItemType	Name	Label	Data Type	Data Source	Length
MP	mfg_name	Manufacturer Name	String		128
MP	mfg_location	Manufacturing Location	String		128
MP	mfg_processes	Manufacturing Processes	Multi Value List	MFG Textiles	128
MP	mfg_date	Manufacturing Date	Date		

The four properties included in the list use the String, Multi Value List, and Date data types. For the definition of the manufacturer's name and the location of the operations, the use of a text line provided by the String data type is considered appropriate. Conversely, the selection of manufacturing processes from the corresponding list included in the MFG Textiles list is implemented through a Multi Value List. Finally, the manufacturing date is defined using the Date data type and can be selected through the calendar interface. As in the previous cases, the length assigned to the properties corresponds to the standard value of 128 characters.

5.5.3 Null Relationship - Raw Materials & Input Resources

For the construction of the Null Relationship dedicated to *Raw Materials & Input Resources*, eight properties are configured to capture information on the resources and materials used throughout the production process. The Resource Type property allows selection of the resource type used in the process, while Resource Name uniquely identifies the specific raw material or resource. Resource Quantity records the numerical amount of the resource employed, whereas Unit provides the list of the most common units of measurement to be associated with it.

The Recycled Content (%) property indicates the possible percentage of recycled input related to the corresponding resource. Origin and Supplier/Provider, respectively, identify the raw material's geographical origin and the entity responsible for its supply. Finally, Additional Information provides a text area for supplementary information that cannot be represented by the previous properties.

The technical characteristics of the aforementioned properties are reported in Table 15 below.

Table 15 – ItemType Raw Materials & Input Resources properties list

ItemType	Name	Label	Data Type	Data Source	Length
RM	res_type	Resource Type	List	Resource Type	128
RM	res_name	Resource Name	String		128
RM	res_quantity	Resource Quantity	Float		
RM	unit	Unit	List	Unit of Measure	128
RM	recycled_cont	Recycled Content (%)	Float		
RM	origin	Origin	String		128
RM	supplier_provider	Supplier/Provider	String		128
RM	add_info	Additional Information	Text		128

The data type assigned to the properties varies according to the type of information to be described. For Resource Name, Origin, and Supplier/Provider, the data type is String; therefore, a text line is available for data entry. Resource Type and Unit are single-selection elements based on the lists named Resource Type and Unit of Measure and are therefore defined using the List data type. Decimal numerical values, obtainable through the Float data type, are assigned to the Resource Quantity and Recycled Content (%) properties. Finally, for the Additional Information property, a text box is made available through the Text data type. The character length for the entire set of properties is consistently set to 128.

5.5.4 Null Relationship – Traceability & Transport

The management of logistical traceability and transport processes for the textile product throughout the phases of its lifecycle is implemented in the PLM software via the Null Relationship named *Traceability & Transport*. This relationship supports transparency and the reconstruction of logistical flows, as required by the ILB DPP model.

Within the relationship, ten properties are organised. These properties enable identifying the sequence of transport phases by Step Number, associating each operation with the corresponding lifecycle phase by Lifecycle Stage, determining the current geographical position and departure date by Current Location and Departure Date, and defining the subsequent location and arrival date by Next Location and Arrival Date. In addition, the Transport Distance (km), Transport Mode, and Tracking ID properties provide information concerning the distance covered during transport, the means used to perform it, and a unique identification code for the shipment. The section concludes with the Transport Description property, which is dedicated to including additional information related to transport operations.

Table 16 lists the properties of this section and their configuration specifications.

Table 16 – ItemType Traceability & Transport properties list

ItemType	Name	Label	Data Type	Data Source	Length
TT	step_number	Step Number	Integer		
TT	lifecycle_stage	Lifecycle Stage	Multi Value List	Life cycle stages	128
TT	current_location	Current Location	String		128
TT	departure_date	Departure Date	Date		
TT	next_location	Next Location	String		128
TT	arrival_date	Arrival Date	Date		
TT	transport_distance	Transport Distance (km)	Float		
TT	transport_mode	Transport Mode	Multi Value List	Transport Mode	128
TT	tracking_id	Tracking ID	String		128
TT	transport_descr	Transport Description	Text		

The properties included in this section require numerical, textual, and date-based information depending on the specific case. More specifically, the 128-character String data type is used for the Current Location, Next Location, and Tracking ID properties, while the Date configuration is preferred for the Departure Date and Arrival Date properties, enabling access to the calendar interface. The properties containing numerical values are Step Number, which is assigned the Integer data type for whole numbers, and Transport Distance (km), which is defined using the Float data type for decimal values.

For checkbox-based selection, the Multi Value List data type is defined for both Lifecycle Stage (associated with the Life Cycle Stages list) and Transport Mode (associated with the list named Transport Mode). For both Multi Value List properties, the standard length of 128 characters is maintained. Finally, the Transport Description property is configured as a text box using the Text data type available in the PLM software.

5.5.5 Null Relationship - Performance

The configuration of the *Performance* Null Relationship, dedicated to collecting information on the technical performance, durability, and functional behaviour of the textile product, is carried out by creating seven properties within the dedicated section. The Part/Component/Material property identifies the specific element to which the performance characteristics are associated. This is followed by Expected Lifetime (years) and Expected Lifetime (use cycles), which provide two valid alternatives for measuring product durability according to two different criteria: service life in years and use cycles.

Dimensional Variation (%) records any change in the product's volume relative to its original dimensions after use or following washing and drying. Surface Pilling (1 Good - 5 Bad) and Color Change (1 Good - 5 Bad) contain the numerical value, on a scale from 1 to 5, related to the product’s performance in terms of surface pilling formation or chromatic variation of the material. The section concludes with the Tensile Strength (MPa) property, which measures the material's or component's tensile resistance under consideration, expressed in megapascals. This property is particularly useful for high-quality applications or products with specific technical features.

Table 17 describes the technical configuration of the Performance properties.

Table 17 – ItemType Performance properties list

ItemType	Name	Label	Data Type	Data Source	Length
PF	prod_component	Part/Component/Material	String		128
PF	exp_lifetime	Expected Lifetime (years)	Float		
PF	exp_lifetime_cycle	Expected Lifetime (use cycles)	Integer		
PF	dim_variation	Dimensional Variation (%)	Float		
PF	surface_pilling	Surface Pilling (1 Good - 5 Bad)	Integer		
PF	color_change	Color Change (1 Good – 5 Bad)	Integer		
PF	tensile_strength	Tensile Strength (MPa)	Float		

The first property, Part/Component/Material, is the only one in the set that can be described through a text line and is therefore the only property assigned the String data type, with a length of 128 characters.

The following properties are instead characterised by numerical values, either integer or decimal, depending on the case. More specifically, Expected Lifetime (years), Dimensional Variation (%), and Tensile Strength (MPa) are assigned the Float data type, as they are intended to contain decimal values, whereas Expected Lifetime (use cycles), Surface Pilling (1 Good – 5 Bad), and Color Change (1 Good – 5 Bad) are assigned the Integer data type, as they are intended to contain whole numerical values.

5.5.6 Part-to-Part Relationship - Bill of Materials

The Part-to-Part RelationshipType named *Bill of Materials* (BOM), included in the Part Tab, is fundamental for constructing the relationships between the assembly and its component elements. In this section, most of the existing properties stem from the original structure and are essential to the proper functioning of the PLM system. Among these, the Sequence, Part Number, Name, Type, Quantity, and Make/Buy properties are functional for managing and identifying the BOM elements.

The main modifications in this section include adding the Manufacturing Date, Manufacturer Name, Origin, and Percentage properties. These are included to expand the informational content by providing an overview of the component or material's production date, the associated manufacturer, its geographical origin, and its mass percentage relative to the finished product of which it forms part.

The additional properties included in the original system configuration are hidden from the system interface to improve readability, while placing greater emphasis on the information considered a priority by the ILB model.

Table 18 describes the technical configuration of the new properties.

Table 18 – ItemType Bill of Materials list of the additional properties

ItemType	Name	Label	Data Type	Data Source	Length
Part BOM	mfg_date	Manufacturing Date	Date		
Part BOM	manufacturer	Manufacturer Name	String		128
Part BOM	material_origin	Origin	String		128
Part BOM	percentage	Percentage	Float		

The Manufacturer Name and Origin properties, which can be described through a text line, are assigned the String data type, with a length of 128 characters. Conversely, the Manufacturing Date and Percentage properties are defined using the Date and Float data types, respectively, to accurately represent their information.

5.5.7 Tree View Relationship – BOM Structure

The Tree View RelationshipType named *BOM Structure* is left unchanged relative to the original PLM software configuration to preserve its native functionality for hierarchical and graphical representation of the Bill of Materials (BOM). This structure enables intuitive visualisation of the relationships among the finished product, subcomponents, materials, and other constituent parts, supporting multi-level navigation of the bill of materials through a tree-based representation.

Within the dedicated Tab, the following properties can be distinguished: Part Number, which enables the unique identification of components; Name, which defines their main designation; Quantity, which represents the numerical value describing the amount of each component within the assembly; Sequence, which determines the hierarchical and logical order of the components within the structure; State, which monitors their status within the lifecycle; and Revision, which identifies the revision associated with the element, supporting future controls and modifications. Finally, the Claimed By, Effectivity, and Reference Designator properties complete the set of elements related to the management of responsibilities associated with BOM elements, their validity, and their functional identification within the overall assembly.

Maintaining the original configuration of the Tree View therefore preserves the advanced functionalities of the PLM system for managing the BOM structure, while also ensuring a clear and navigable representation of the technical information associated with the elements of the ILB DPP model.

The interface representation for the Tree View is shown in Figure 15. It shows the elements that compose the final product, such as the jeans material (organic cotton), the button, and the button material (brass). It should be noted that the information on the components is not derived from the original product passport but is included based on plausibility-based criteria.

Figure 15 – BOM Structure Relationship properties overview

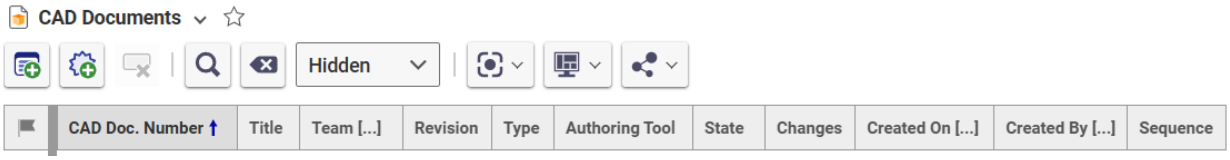
Part Number	Rev...	State	Sequence	Quantity	Claimed By	Name
UK 16R 01	A	Preliminary	1	1	Innovator Admin	Organic Cotton
UK 16R 02	A	Preliminary	2	1		Button
UK 16R 03	A	Preliminary	1	1	Innovator Admin	Brass

5.5.8 CAD Document Relationship – CAD Documents

As in the previous case, the *CAD Documents* Relationship is also left unchanged relative to the original configuration of the PLM software, as it is already fully consistent with the requirements of the ILB DPP model. This relationship enables the association and management of technical documents related to the product and its components, such as technical drawings, CAD models, and project files.

The properties defined within it (see Figure 16) allow for document identification, revision, and state management, author and tool traceability, as well as the organisation and monitoring of the modifications applied to them.

Figure 16 – CAD Documents Relationship properties overview



5.5.9 Null Relationship – Environmental Evaluation

The Null Relationship, called *Environmental Evaluation*, is introduced to collect and organise information on the environmental impacts associated with the textile product or one of its components throughout its entire lifecycle. This relationship therefore supports the assessment of the product's environmental performance by completing thirteen properties derived from the environmental requirements defined within the ILB DPP framework, together with one additional property to identify the corresponding lifecycle stage.

In Table 19, the properties are listed together with their respective configuration methods within the PLM software.

Table 19 – ItemType Environmental Evaluation properties list

ItemType	Name	Label	Data Type	Data Source	Length
EE	lifecycle_stage	Lifecycle Stage	List	Item Life Cycle	128
EE	ghg_emissions	GHG Emissions (kgCO2eq)	Float		
EE	pm10	Particulate Matter (kgPM10)	Float		
EE	nmvoc	Photochemical Ozone Formation Potential (kgNMVOCeq)	Float		
EE	energy	Total Energy Consumption (MJ)	Float		
EE	fossil_energy	Fossil Energy Consumption (MJ)	Float		
EE	water	Water Footprint (m^3)	Float		
EE	acidification	Acidification Potential (kgSO2eq)	Float		
EE	ozone	Ozone Depletion (kgCFC11eq)	Float		
EE	eutroph_land	Eutrophication Terrestrial Potential (kgNeq)	Float		
EE	eutroph_water	Eutrophication Freshwater Potential (kgPeq)	Float		
EE	land	Land Use (kg)	Float		
EE	waste	Waste (kg)	Float		
EE	hazard	Hazardous Substances and SVHC	Multi Value List	hazardous and svhc	128

In most cases within the Environmental Evaluation Relationship, the Float data type is assigned to properties associated with environmental impacts that can be measured

numerically, as it is suitable for decimal values. For the remaining cases, namely Lifecycle Stage and Hazardous Substances and SVHC, the List data type is selected for the former, while Multi Value List is adopted for the latter. The associated data sources for these two properties are the Item Life Cycle and the Hazardous and SVHC lists, respectively. In this case as well, the properties associated with lists maintain a length of 128 characters.

5.5.10 Null Relationship – Social Evaluation

The Null Relationship named *Social Evaluation* is created to collect key information on social impacts and working conditions associated with the textile product supply chain. The assessments of social performance linked to production and the various phases of the product lifecycle are therefore listed in relation to the corresponding supply chain actor, enabling identification of the critical element of social impact and the actor responsible for that phase.

The relationship is configured with a total of fourteen properties, dedicated to recording social indicators concerning wage conditions, employment equity, working hours, safety, and the presence of critical phenomena such as child exploitation and forced labour, as required by the ILB DPP model. Table 20 summarises the properties included in this relationship and specifies their technical configuration in the software.

Table 20 – ItemType Social Evaluation properties list

ItemType	Name	Label	Data Type	Data Source	Length
SE	s_chain_actor	Supply Chain Actor	String		128
SE	tier	Tier	Integer		
SE	location	Location	String		128
SE	lifecycle_stage	Lifecycle Stage	List	Life cycle stages	128
SE	children_emp	Children Employment (%)	Float		
SE	forced_lab	Forced Labour Frequency (%)	Float		
SE	living_wage	Living Wage (€/month)	Float		
SE	min_wage	Minimum Wage (€/month)	Float		
SE	sect_avg_wage	Sector Average Wage (€/month)	Float		
SE	g_wage_gap	Gender Wage Gap (%)	Float		
SE	women_rate	Women Employment Rate (%)	Float		
SE	shift_hours	Shift Working hours (hours/day)	Integer		
SE	avg_week_hours	Average Weekly Working Hours (hours/week)	Integer		
SE	rate_of_accidents	Rate of Job Accidents (N°Accidents/N°Workers)*10^5	Float		

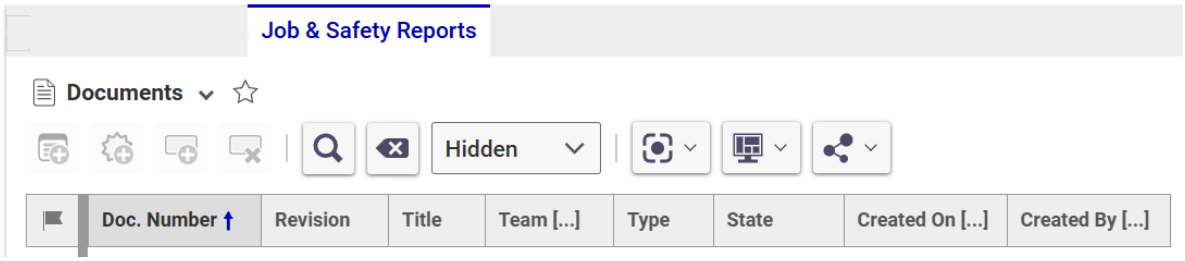
For the completion of areas dedicated to measuring social impacts that require integer or decimal numerical values, the Integer or Float data types are assigned, respectively. Conversely, for identifying the Supply Chain Actor and Location, the 128-character String data type is selected, given the need for textual input. Finally, to define the Lifecycle Stage property, a connection is established to the Life Cycle Stages list via the List data type, enabling checkbox-based selection. In this latter case as well, the 128-character length is maintained.

5.5.11 Document Relationship – Job & Safety Reports

Following the Social Evaluation Relationship, creating a dedicated section to collect documentation related to *Job & Safety Reports* is considered appropriate. This objective is therefore achieved through a Document RelationshipType, which enables the attachment, storage, and management of document-type files.

The decision to construct the relationship by exploiting the native functionality of Aras Innovator PLM is consistent with the design requirements of the ILB model, as it enables document identification, control of revisions and approval status, and traceability of authors and the modifications applied, as shown in Figure 17.

Figure 17 – Job & Safety Relationship properties overview

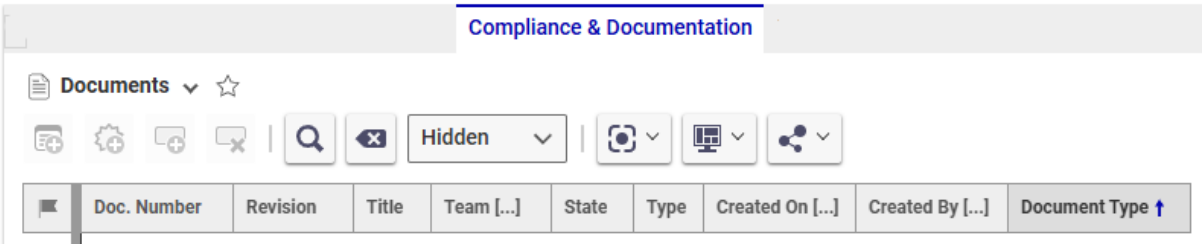


5.5.12 Document Relationship – Compliance & Documentation

Similar to the previous relationship, creating a Document-type relationship is also preferred for the tab dedicated to the *Compliance & Documentation* section. In this case as well, by leveraging the native functionalities of the PLM software, an area is associated with the ILB DPP for the collection and management of certifications, declarations of conformity, regulatory reports, and further documents useful for demonstrating compliance with legislative requirements and standards applicable to the textile sector.

The only difference, also visible in Figure 18, compared with the previous case, concerns the addition of a single property named Document Type. This property is configured with the List data type and linked to the Document Type list, enabling selection of the document typology via a checkbox, with a maximum length of 128 characters.

Figure 18 – Compliance & Documentation Relationship properties overview



5.5.13 Null Relationship – Distribution & Sales

For the lifecycle stage related to the *Distribution & Sales* phase, a Null RelationshipType with the same name is created to collect and structure the main information on the product's distribution and commercialisation activities. The relationship is configured through seven properties: Distribution Stage specifies the phase of the distribution process; Supply Chain Actor and Actor Role identify the entity involved in the distribution or sale of the product; Location geographically locates the place where distribution activities are carried out; Sales Channel defines the sales channel used; and finally, Purchase Date and Ownership Record, respectively, the date of product purchase and the list of ownership transfers throughout the lifecycle of the asset.

Table 21 summarises the properties and their associated software configurations.

Table 21 – ItemType Distribution & Sales properties list

ItemType	Name	Label	Data Type	Data Source	Length
Distrib	distrib_stage	Distribution Stage	List	Distribution	128
Distrib	supply_actor	Supply Chain Actor	String		128
Distrib	actor_role	Actor Role	Multi Value List	Actor Role	128
Distrib	location	Location	String		128
Distrib	sales_channel	Sales Channel	List	Sales Channel	128
Distrib	purchase_date	Purchase Date	Date		
Distrib	owners_record	Ownership Record	Text		

For the Distribution & Sales properties, the Supply Chain Actor and Location properties are defined using the 128-character String data type. Conversely, Distribution Stage, Sales Channel, and Actor Role are made selectable through checkboxes associated with the Distribution, Actor Role, and Sales Channel lists, respectively. Among these, only Actor

Role allows multiple selections and is therefore configured using the Multi Value List data type, while the others are defined using the List data type with a length of 128 characters.

Finally, the Purchase Date property is configured with the Date data type to enable date selection, while the Ownership Record property is assigned the Text data type to create a text box for ownership transfer information.

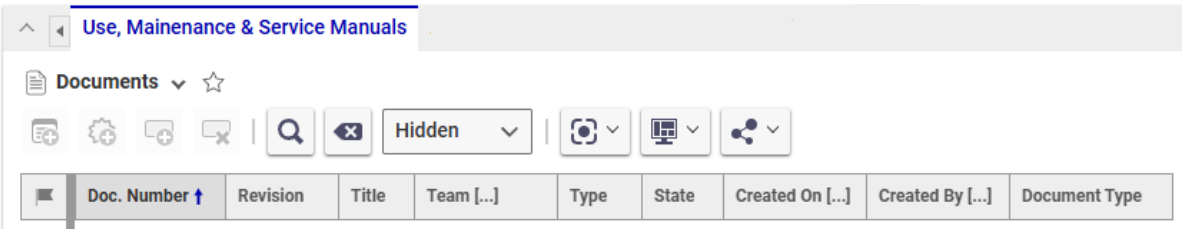
5.5.14 Document Relationship – Use, Maintenance & Service Manuals

The *Use, Maintenance & Service Manuals* Relationship is the last relationship configured as a Document type. In this case as well, as in the previous ones, the native functionality of the software associated with this relationship makes it possible to collect, manage, identify, revise, and trace external documentation, such as user manuals, maintenance instructions, repair guidelines, and service technical documents supporting the correct use of the product and the extension of its lifecycle.

The novelty relative to the default properties is the addition of the Document Type property, defined as a List with a length of 128 characters. This property is associated with the Document Type UM list, which collects a set of document typologies that can be selected through checkboxes.

Figure 19 is provided to visualise the interface related to the Use, Maintenance & Service Manuals tab.

Figure 19 – Use, Maintenance & Service Manuals Relationship properties overview



5.5.15 Null Relationship – After-Sales Service

The *After-Sales Service* Null Relationship collects information related to post-sales services associated with the product, enabling traceability and managing information useful to the consumer. The relationship is configured with five properties: Service Type, which describes the type of service offered; Service Provider, which identifies the entity responsible for providing the service; Provider Location, which geographically locates the service provider; Email Info, which associates the corresponding e-mail contact; and finally, Expiration Service Date, which records the possible expiry date of warranties or the validity period of services associated with the product.

The technical configuration of the properties is shown in Table 22.

Table 22 – ItemType After-Sales Service properties list

ItemType	Name	Label	Data Type	Data Source	Length
AS	service_type	Service Type	Multi Value List	After Sales Service	128
AS	service_provider	Service Provider	String		128
AS	provider_location	Provider Location	String		128
AS	email_info	Email Info	String		128
AS	exp_service_date	Expiration Service Date	Date		

For the configuration of properties related to the After-Sales Service Relationship, the String data type is selected for the Service Provider, Provider Location, and Email Info properties. For these properties, a 128-character text field is available to enter the corresponding information. The Service Type property uses a different configuration, as it is associated with a Multi Value List linked to the After Sales Service list, which contains a set of available services that can be selected through the dedicated checkbox. The only Date-type information is configured via the Expiration Service Date property, allowing the date to be selected directly from the software's integrated calendar.

5.5.16 Null Relationship – Service History

To collect and manage information related to the history of assistance, maintenance, and support interventions performed on the product throughout its lifecycle, the *Service History* Null Relationship is created. It contains the following six properties: Service Date, for recording the date of the intervention performed; Service Type, for identifying the type of activity carried out; Service Provider, which identifies the entity responsible for the service; Service Location, for geographical localization; Service Status, for monitoring the progress status of the service-related procedures; and finally, Description, which provides a brief description of the activities performed, including any additional information.

Table 23 summarises the software configuration and the data type assigned to each property.

Table 23 – ItemType Service History properties list

ItemType	Name	Label	Data Type	Data Source	Length
SH	service_date	Service Date	Date		
SH	service_type	Service Type	Multi Value List	Service Type	128
SH	service_provider	Service Provider	String		128
SH	service_location	Service Location	String		128
SH	service_status	Service Status	List	Service Status	128
SH	description	Description	Text		

The properties intended for text-line completion, such as Service Provider and Service Location, are configured with the 128-character String data type. Conversely, for the Service Type and Service Status properties, the Multi Value List and List data types are preferred, respectively, both with a length of 128 characters and associated with the Service Type and Service Status data sources. Finally, selecting the Service Date via the calendar is done by assigning the Date data type, while the text box for the Description property is created with the Text data type.

5.5.17 Null Relationship – Repair, Reuse & Life Extension

The ILB DPP model also includes a section dedicated to collecting information on interventions aimed at product repair, possible reuse, and extension of its lifecycle. The modelling of this information within the software is carried out by creating the Null Relationship named *Repair, Reuse & Life Extension*, to which two properties are associated. The first, Intervention Type, identifies the type of intervention performed on the product, such as repair or reconditioning. The second, Description, outlines the expected ways these interventions can be carried out according to the official guidelines.

For their configuration, see Table 24. The List data type is assigned to the Intervention Type property, linked to the corresponding Intervention Type element. Conversely, for the Description property, the configuration is performed using the Text data type, creating a text box.

Table 24 – ItemType Repair, Reuse & Life Extension properties list

ItemType	Name	Label	Data Type	Data Source	Length
RR	intervention_type	Intervention Type	List	Intervention Type	128
RR	description	Description	Text		

5.5.18 Null Relationship – Collection/Sorting

The Null Relationship named *Collection/Sorting* is introduced to organise information related to the collection, sorting, and management of the product at the end of its lifecycle, thereby supporting material recovery processes and the circularity models envisaged by the ILB DPP model. Four properties are configured within this relationship: Collection Point, for identifying the collection points designated for the textile component or product under examination; Location, for the geographical localization of the collection point; End of Life Pathways, for indicating the possible pathways envisaged for product management after the collection phase; and finally, Disassembly Instruction, which informs the consumer about the methods for product disassembly, with the aim of facilitating material separation and appropriate allocation to the aforementioned collection points.

Table 25 – ItemType Collection/Sorting properties list

ItemType	Name	Label	Data Type	Data Source	Length
CS	collection_point	Collection Points	String		128
CS	location	Location	String		128
CS	eol_pathways	End of Life Pathways	Multi Value List	EOL Path	128
CS	disassembly	Disassembly Instructions	Text		

Table 25 summarises the configuration of the four properties associated with the Collection/Sorting module. Specifically, the Collection Point and Location properties are intended for text-line completion and are therefore configured using the 128-character String data type. End of Life Pathways is instead associated with the EOL Path list via the Multi Value List data type, which also has a length of 128 characters. The section concludes with the Disassembly Instruction property, configured as a text box using the Text data type.

5.5.19 Null Relationship – Recycling & Circularity Assessment

The final relationship configured within the Aras PLM software, dedicated to collecting information related to the recyclability of the product and its parts and intended to support the assessment of the level of circularity envisaged by the ILB DPP model, is the *Recycling & Circularity Assessment* Null Relationship. Four properties are configured within it: Component/Material, for identifying the material or component to which the recycling information refers; Recycling Rate (%), for recording the actual percentage of recyclable material from the component; Recyclability (%), which estimates the target percentage of material that could potentially be recycled; and finally, Recycle Instruction, which contains instructions or indications related to the methods of recycling, separation, and treatment of the material at end of life.

Table 26 – ItemType Recycling & Circularity Assessment properties list

ItemType	Name	Label	Data Type	Data Source	Length
RCA	comp_material	Component/Material	String		128
RCA	recycling_rate	Recycling Rate (%)	Float		
RCA	recyclability	Recyclability (%)	Float		
RCA	recycle_instr	Recycle Instructions	Text		

The properties included in the Recycling & Circularity Assessment tab present three different data configuration methods, as shown in Table 26. More specifically, the 128-character String data type is selected for the Component/Material property, enabling the creation of a text line intended to contain its informational content. For the Recyclability and Recycling Rate percentages, the Float data type is used, as it allows the insertion of decimal values. Finally, the Recycle Instruction property is configured with the Text data type, allowing the generation of a text box.

5.6 ILB DPP Model Final Design Overview

The design of the ILB DPP model, developed within the Aras Innovator PLM software, enables the creation of a modular and hierarchical information architecture that collects and manages information on the key aspects of the entire lifecycle of a textile product. The structure is based on the connection between the Product and Part ItemTypes, thereby allowing access to the various informational sections envisaged by the Digital Product Passport.

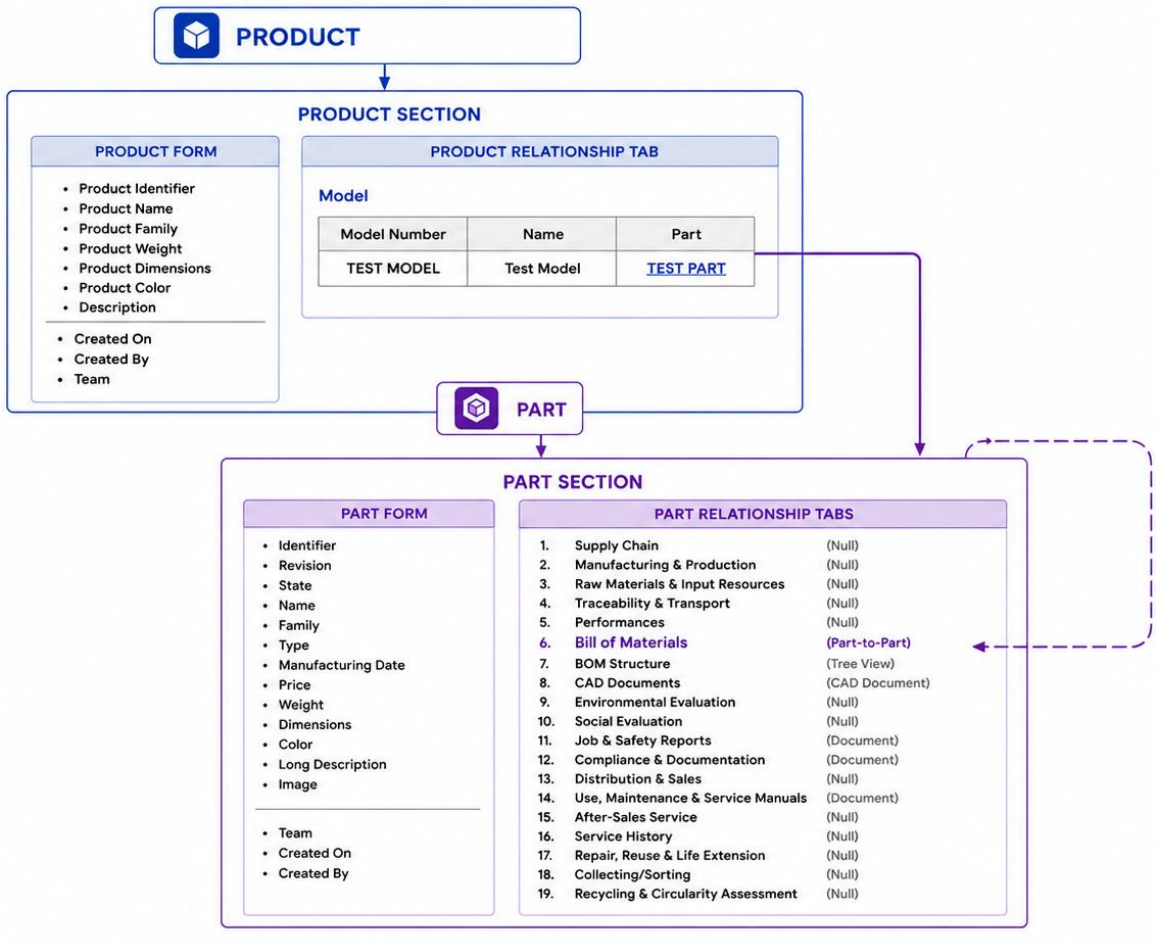
In the implemented model, a clear distinction is made between the Form and Relationship Tab sections, related either to the Product or to the Part. Within these sections, it is possible to integrate the information requirements previously defined during the construction of the ILB model, most of which are organised through relationships associated with the Part Tab. Among these, the Bill of Materials, BOM Structure, and CAD Documents relationships are substantially maintained in their original configuration, as they are associated with the native functionalities for linking the Parts of the assembly with its subcomponents and materials, visualising the BOM structure through a tree-based scheme, and connecting technical documents to the DPP of the textile product.

The main innovation compared with the default software configuration consists in the creation of sixteen new relationships within the Part Tab, which, together with the three native relationships, bring the total number to nineteen. Through these new relationships, it is possible to populate the PLM environment with information about the entire product lifecycle via the properties associated with them.

The design of the ILB model implemented in Aras PLM can therefore be schematized as shown in Figure 20, where the two sections dedicated to the Product and the Part are

distinguished and connected through the Model Relationship located in the Product Relationship Tab. Within the Part section, all nineteen created relationships are visible together with their respective typologies. Among them, particular emphasis is placed on the Part-to-Part RelationshipType Bill of Materials, which enables a closed-loop connection between the Part associated with the overall assembly and the Parts related to its components.

Figure 20 – Design overview of the integrated lifecycle-based DPP model for textile



The ILB DPP model developed within Aras Innovator PLM therefore represents a scalable structure consistent with the principles of the Digital Product Passport. It is capable of integrating information from different domains and related to different phases of the product lifecycle, including technical data, assessments of environmental and social impacts, measurements of product performance in terms of both quality and circularity, and the identification of the actors responsible for the supply chain, services, production, sales, and end-of-life management of the textile product.

6. Implementation of a Case Study

This section is dedicated to the identification of a set of products belonging to the textile sector for which a digital passport model has already been provided by their parent companies, followed by a comparative assessment aimed at selecting the most suitable object for the implementation of a Digital Product Passport case study based on the Integrated Lifecycle-Based model designed within the Aras Innovator PLM software environment.

The analysis evaluates the number of information items available in real-world cases and compares them with the information requirements already included in the ILB DPP model. The textile product associated with the highest number of relevant information items is selected and subsequently analysed in terms of its components, with the aim of implementing its digital passport within the model developed in the PLM software.

The section then presents the implementation procedure for the case study, defines any adjustments and modifications aimed at improving the compatibility of the ILB model with the information set acquired from the selected product, and evaluates the quality of the final result. This evaluation highlights the strengths and weaknesses of the framework developed in this research.

6.1 Product Information Benchmarking for Case Study Selection

Through a web-based search on the websites of some of the main apparel manufacturers that already provide customised versions of Digital Product Passports, it is possible to identify five products currently available on the market and associated with links and QR codes that can be used to access the digital environment dedicated to the collection and presentation of their related information.

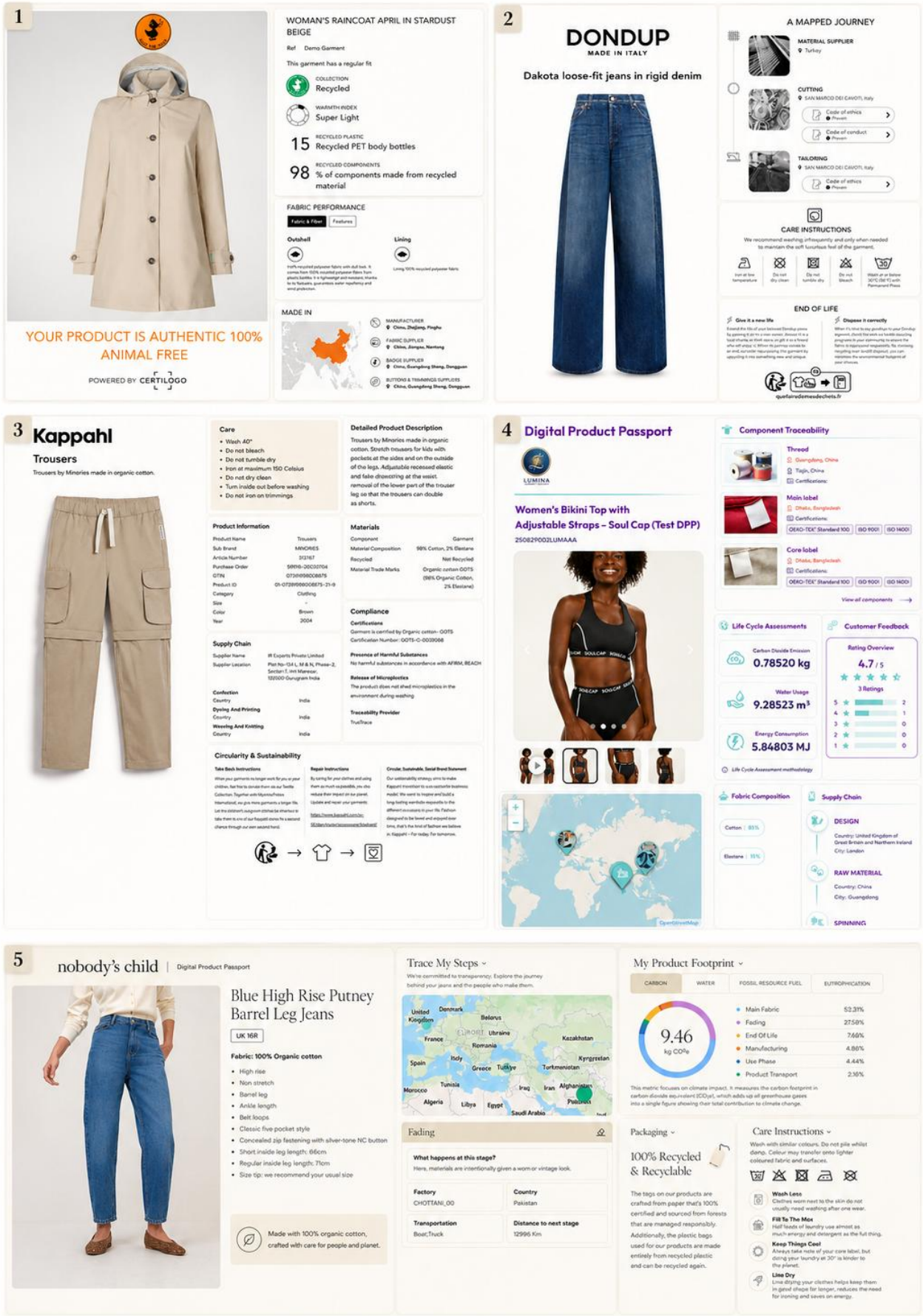
Although these products belong to the same industrial sector, they fall within different clothing categories. More specifically, the products under consideration are:

- Product 1: Woman’s raincoat – Save The Duck
- Product 2: Dakota loose-fit jeans – Dondup
- Product 3: Trousers – Kappahl
- Product 4: Women’s bikini top with adjustable straps – Soul Cap
- Product 5: Blue High Rise Putney Barrel Leg Jeans – Nobody's Child

The list therefore includes two pairs of jeans, one pair of trousers, one swimwear item, and one raincoat. Four of the garments under examination are intended for female customers, whereas the trousers represent the only menswear item within the selected group.

In Figure 21, a graphical representation, specifically adapted to improve readability, shows how the corporate Digital Product Passports of the analysed products appear after accessing their interfaces via the corresponding QR codes, following the same order as the previously presented list.

Figure 21 – Representation of the five corporate Digital Product Passports



At this stage, with reference to the ILB DPP model framework for textile products, Tables 27, 28, 29, 30, 31, and 32 list the information requirements and relate them to the selected set of apparel products. This makes it possible to determine whether information that meets the same requirements is present in the DPPs provided by their respective companies.

It should be specified that the set of information requirements is kept almost entirely consistent with the one previously derived from the study. However, for analytical completeness and to improve the qualitative identification of the relationships between requirements and product DPPs, the Supply Chain Actor Information requirement is divided into two more specific sub-requirements: Supply Chain Actor Name and Supply Chain Actor Location. Similarly, Product Tracking and Transport is divided into Product Map/Tracking and Travel Distance & Means of Transport.

Table 27 – Supply Chain information – product DPP relationships

Supply Chain	Product 1	Product 2	Product 3	Product 4	Product 5
Raw Materials & Input Resources					
materials origin	x	x	x	x	x
input resources	x	x	x	x	x
recycled input content	x		x		
Manufacturing & Production					
manufacturer name			x		x
manufacturing location	x	x	x	x	x
manufacturing processes	x	x	x	x	x
manufacturing date					
Transport & Traceability					
supply chain actor name	x		x		x
supply chain actor location	x	x	x	x	x
product map/tracking	x	x	x	x	x
travel distance & means of transport					x
Total	8	6	9	6	9

Table 28 – Product information – product DPP relationships

Product	Product 1	Product 2	Product 3	Product 4	Product 5
Design & Identification					
product name	x	x	x	x	x
product family	x	x	x	x	x
product identifier	x	x	x	x	x
product weight				x	
product dimension					x
product colour	x	x	x	x	x
Composition & Technical Structure					
Bill of Materials				x	
material composition	x	x	x	x	x
Performance					
Expected lifetime					
dimensional variation					
surface pilling					
colour change					
tensile strength					
Total	5	5	5	7	6

Table 29 – Usage information – product DPP relationships

Usage	Product 1	Product 2	Product 3	Product 4	Product 5
Use, Maintenance & After-Sales					
use, maintenance and service manual	x	x	x		x
service history					
certified service provider					x
health and safety information					
warranty					
product life cycle responsibility					
Repair, Reuse & Life Extension					
reuse instructions					x
repair instructions	x		x		x
remanufacturing instructions					
Total	2	1	2	0	4

Table 30 – Evaluations information – product DPP relationships

Evaluations	Product 1	Product 2	Product 3	Product 4	Product 5
Environmental Evaluation					
GHG emissions				x	x
particulate matter					
photochemical ozone					
acidification					
eutrophication					x
energy consumption (total)				x	
energy consumption (fossil)					x
water footprint				x	x
land use					
hazardous substances and SVHC	x		x		
waste					
Social Evaluation					
children employment					
forced labour frequency					
living wage					
minimum wage	x				
sector average wage					
gender wage gap					
women employment rate					
shift working hours					
average weekly working hours					
rate of job accidents					
labour conditions and safety reports	x				
Compliance & Documentation					
regulatory compliance	x	x	x	x	
certifications, labels and IP	x	x	x	x	
technical documentation					
quality test reports					
Total	5	2	3	5	4

Table 31 – Distribution information – product DPP relationships

Distribution	Product 1	Product 2	Product 3	Product 4	Product 5
supply chain actors	x	x	x	x	x
location	x	x	x	x	x
sales channels					
purchase dates					
record of ownership					
Total	2	2	2	2	2

Table 32 – End of Life information – product DPP relationships

End of Life	Product 1	Product 2	Product 3	Product 4	Product 5
Collection/Sorting					
collection points	x	x	x	x	x
end-of-life pathways		x		x	
disassembly instructions					
Recycling & Circularity Assessment					
recyclability					x
recycling rate					
recycle instructions	x	x		x	x
Total	2	3	1	3	3

Overall Total	24	19	22	23	28

From the analysis of the Digital Product Passports associated with the selected products, it emerges that the type of information available, and therefore attributable to the requirements of the ILB model, is, in most cases, similar across the products. This information primarily falls into categories related to the supply chain, product design and identification, product composition and technical structure, regulatory compliance and documentation, product care and maintenance, and collection and recycling channels.

Information concerning environmental and social impacts is less frequently provided and, in many cases, is entirely omitted. Only the *Woman's Raincoat by Save The Duck* includes information related to the assessment of working conditions within production facilities, referring to the adoption of a minimum wage as well as protections and benefits for workers. By contrast, the impact assessment provided for the *Women's Bikini Top with Adjustable Straps by Soul Cap* and the *Blue High Rise Putney Barrel Leg Jeans by Nobody's Child* excludes the social dimension but reports two lifecycle assessments aimed at evaluating environmental impacts related to CO_2 emissions, energy and water consumption, and freshwater eutrophication.

The final count of information items associated with the ILB DPP model highlights the Blue High Rise Putney Barrel Leg Jeans by Nobody's Child as the leading product, with twenty-eight associations, followed by the raincoat by *Save The Duck* and the bikini by *Soul Cap*. At the bottom of the ranking are the trousers by *Kappahl* and the blue jeans by *Dondup*.

Based on the analysis conducted so far, one product appears to be the most suitable option. However, during the collection of information from the product DPPs, additional items are identified that, although not included in the ILB model requirement set, prove useful for implementing the case study within the PLM software. More specifically, these include the brand owner's name, product image and description, additional product performance information, customer feedback, and a description of the company's sustainability strategy.

In Table 33, these additional information items are collected and once again related to the corporate DPPs of the selected products.

Table 33 – Additional information – product DPP relationships

Additional Information	Product 1	Product 2	Product 3	Product 4	Product 5
brand owner	x	x	x	x	x
image	x	x	x	x	x
product description	x	x	x		x
customer feedback				x	
additional product performances	x				
sustainability strategy description	x		x	x	
Total	**5**	**3**	**4**	**4**	**3**

Overall Total (with additional info)	**29**	**22**	**26**	**27**	**31**

Following the inclusion and counting of the additional information items, the total number of relationships increases for all the products examined. However, the previous ranking remains unchanged and again identifies the *Blue High Rise Putney Barrel Leg Jeans by Nobody's Child* as the leading product with a total of thirty-one correspondences. This product is therefore selected as the case study for implementing the Integrated Lifecycle-Based DPP model in Aras Innovator PLM.

6.2 Implementation of the Case Study in Aras Innovator PLM

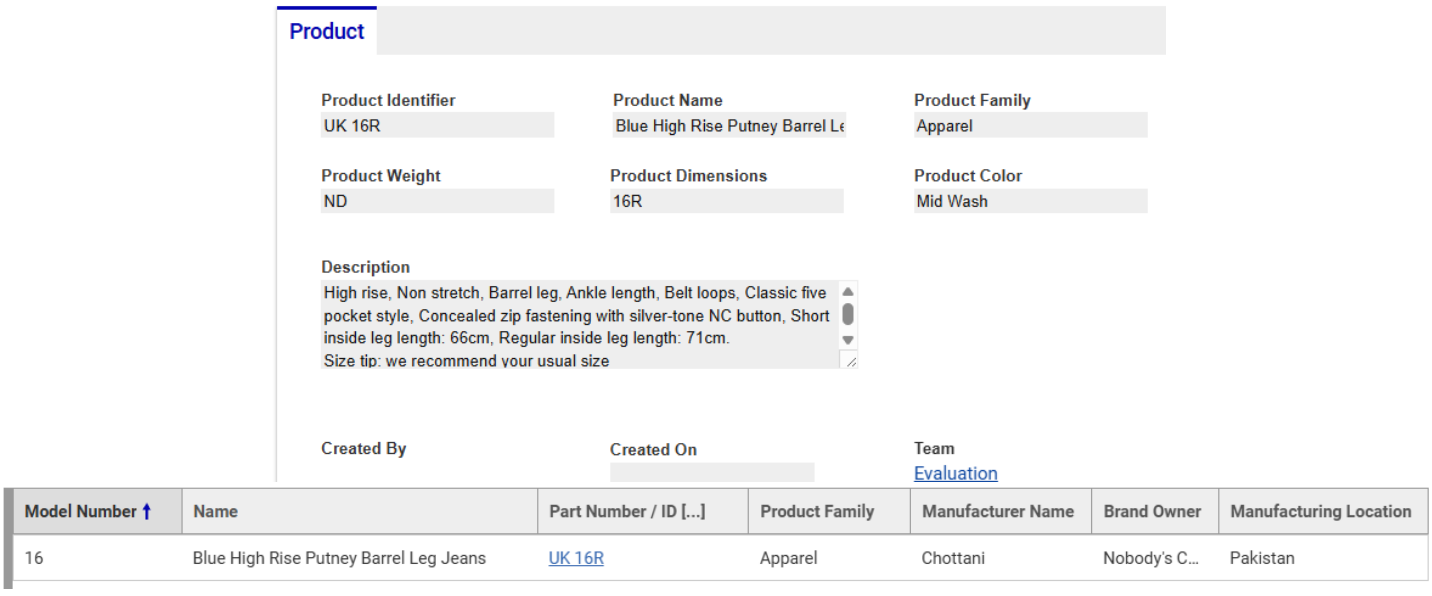
As highlighted in the previous section, the Digital Product Passports for products currently on the market still display a limited amount of information relative to the number of requirements considered in the ILB DPP model. Nevertheless, through the structure defined within the PLM software, it is possible to populate several sections of the DPP with information related to the *Blue High Rise Putney Barrel Leg Jeans by Nobody's Child.*

6.2.1 Product's Section

In the Product section, both the Form and the Model RelationshipType are populated with the official characteristics derived from the company's official digital passport. Once all the information applicable to this section is entered, the Part dedicated to the product is created and associated with the Model Relationship, which establishes the connection with the Bill of Materials of the assembly.

The software interface, populated with the manufacturer's data and configured to hide empty sections, is shown in Figure 22.

Figure 22 – Case Study's Product's Form and Relationship Tab



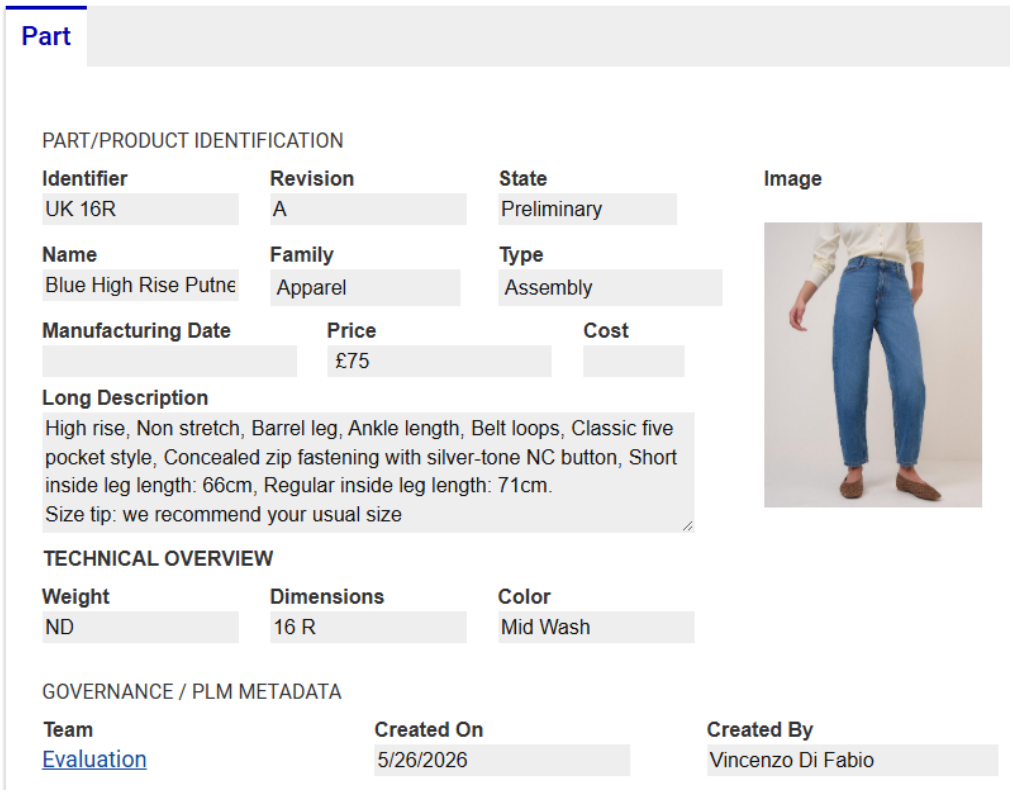
6.2.2 Part's Section

Once the connection with the Part related to the product, identified by the code *UK 16R*, is established through the Model RelationshipType, it is possible to access the area dedicated to the Part of the product under examination. Within this area, the Form and the Relationships are populated with information obtained from the official product passport, where available.

The application of the case study successfully enables the completion of a limited portion of the properties related to the Supply Chain, Manufacturing & Production, Raw Materials & Input Resources, Traceability & Transport, Bill of Materials, BOM Structure, Environmental Evaluation, Distribution & Sales, Use, Maintenance & Service Manuals, After-Sales Service, Collection/Sorting, and Recycling & Circularity Assessment relationships. The absence of further information prevents the framework from being completed; consequently, the model appears overextended relative to the current state of the art in applying corporate DPPs.

The PLM software interface, including the information entered, is shown in Figures 23-36, respectively, dedicated to the Form and the individual Relationship Tabs previously constructed. Empty sections and areas without data are appropriately hidden using the Hide Column command to improve the clarity and readability of the information displayed in the interface.

Figure 23 – Case study's Parts Form



In Figure 23, the form related to the *Nobody's Child* product is shown. It includes the original product identification code *UK16R*, the full product name, the price reported on the official website, and the description provided in the native Digital Product Passport.

In addition, it is possible to select one of the standard dimensions available for the product, together with the description of the original colour, which is also provided within the brand's passport. The remaining information is instead completed in accordance with the procedures defined by the native Aras Innovator PLM model.

Figure 24 – Case study's Part's Supply Chain relationship

Supply Chain Actor	Actor Role	Tier	Location	Supplied Input	Process/Activity
unnamed	Raw Material Supplier	5	Pakistan	Organic Cotton	Materials Sourcing
Docotton Group	Raw Material Processer	4	Turkey		Processing
Kassim	Yarn Mill, Dye House, Fabric Mill	3	Pakistan		Spinning, Dyeing, Weaving, Knitting
Chottani	Manufacturer	2	Pakistan		Manufacturing, Fading
Nobody's Child	Seller	1	United Kingdom		Advertising, Marketing, Retailing, Reselling

Figure 25 – Case Study's Part's Manufacturing & Production relationship

Manufacturer Name	Manufacturing Location	Manufacturing Processes
Chottani	Pakistan	Cutting, Sewing, Packaging

Figure 26 – Case study's Part's Raw Materials & Input Resources relationship

Resource Type	Resource Name	Origin
Raw Material	Organic Cotton	Pakistan

Figure 27 – Case study's Part's Traceability & Transport relationship

Step Number	Lifecycle Stage	Current Location	Next Location	Transport Distance (km)	Transport Mode	Tracking ID
1	Raw Materials	Pakistan	Turkey	3995	Truck	5056780339385
2	Raw Materials Processing	Turkey	Pakistan	3983	Truck	5056780339385
3	Fibers Production, Dyeing	Pakistan	Pakistan	1026	Truck	5056780339385
4	Manufacturing, Finishing	Pakistan	United Kingdo...	12996	Truck, Ship	5056780339385

Figures 24, 25, 26, and 27 provide information on the Supply Chain, Manufacturing & Production, Raw Materials & Input Resources, and Traceability & Transport of the product.

From the brand's DPP, five actors are identified within the supply chain, located in three different countries: Pakistan, Türkiye, and the United Kingdom. The raw material, namely organic cotton, is produced in Pakistan, as shown in Figures 24 and 26, and then undergoes its first processing stage in Türkiye at the *Docotton Group* factory.

The subsequent fabric processing and manufacturing phases are again carried out in Pakistan by the companies *Kassim* and *Chottani*. The latter, in addition to cutting and sewing operations, is responsible for packaging the product, as shown in Figure 25.

The product-related operations are completed in the United Kingdom, where the *Nobody's Child* brand is responsible for marketing, distribution, and sales.

The product traceability steps are clearly shown in Figure 27, which identifies its movements, including distances and modes of transport. More specifically, the product travels a total of twenty-two thousand kilometres, mainly by truck and ship.

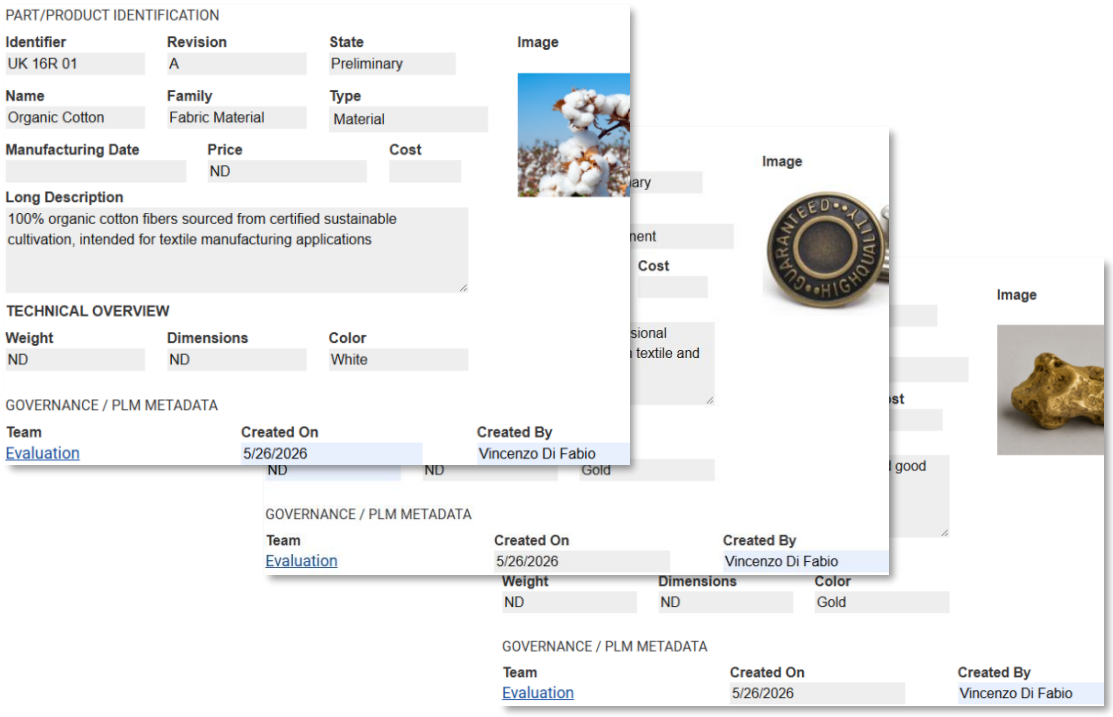
Figure 28 – Case study's Part's Bill of Materials relationship

Sequence ↑	Part Number / ID	Name	Type	Quantity	Manufacturer Name	Origin
1	UK 16R 01	Organic Cotton	Material	1	Docotton Group	Turkey
2	UK 16R 02	Button	Component	1	Chottani	Pakistan

Figure 29 – Case study's Part's BOM Structure relationship

Part Number	Revision	State	Sequence	Quantity	Claimed By	Name
UK 16R 01	A	Preliminary	1	1	Innovator Admin	Organic Cotton
UK 16R 02	A	Preliminary	2	1		Button
UK 16R ...	A	Preliminary	1	1	Innovator Admin	Brass

Figure 30 – Case study's sub-components Forms



Figures 28 and 29 show how the Bill of Materials and BOM Structure Relationships enable the creation and visualisation of the entire assembly structure and its components through a Tree View representation.

Furthermore, through the Bill of Materials, it is possible to access the Part sections of the components themselves, which can then be modified and used to create dedicated digital passports.

Figure 30 shows the Forms visible after accessing the Part sections of the components of the textile product under examination, namely organic cotton, the button, and the metal (brass) used for the production of the button.

Figure 31 – Case study's Environmental Evaluation relationship

Lifecycle Stage	GHG Emissions (kgCO2eq)	Fossil Energy Consumption (MJ)	Water Footprint (m^3)	Eutrophication Freshwater Potential (kgPeq)
Total	9.46	188.75	28.68	11.7
Main Fabric	4.95	70.56	28.6	11.27
Fading	2.61	42.51	-0.025	0.29
End of Life	0.72	-0.43	0	0.005
Manufacturing	0.46	7.33	-0.02	0.045
Use Phase	0.43	64.82	0.12	0.088
Product Transport	0.19	2.75	0.005	0.002
Distribution	0.08	1.21	0	0

The product lifecycle assessment included in the product DPP enables identification of environmental impacts related to CO_2 emissions, fossil fuel consumption, water consumption, and freshwater eutrophication potential across all lifecycle stages.

The data retrieved from the website, expressed as percentages of the total, are reported in the Environmental Evaluation Relationship table, converted into their absolute values and corresponding units of measurement, as shown in Figure 31.

The most relevant impacts for each assessment category are consistently identified in the lifecycle stage related to main fabric production, with significant values also associated with material fading operations for GHG emissions and fossil energy consumption. Furthermore, with regard to fossil energy consumption, the use phase also appears critical, representing the second most impactful stage.

It is evident that in some lifecycle stages, energy is generated and water is recovered, as indicated by negative impact values in the LCA.

Figure 32 – Case study's Distribution & Sales relationship

Distribution Stage	Supply Chain Actor	Actor Role	Location	Sales Channel
Retail	Nobody's Child	Retailer	United Kingdom	Retail Store
E-Commerce	Ebay	E-Commerce Platform	Luxembourg	Marketplace

Figure 33 – Case study's Use, Maintenance & Service Manuals relationship

Doc. Number ↑	Title	Team [...]	State	Created On [...]	Created By [...]	Document Type
UK 16R Care	Care Instructions	Evaluation	Preliminary	5/26/2026 12:47:17 PM	Innovator Admin	Maintenance Instructions

Figure 34 – Case study's After-Sales Service relationship

Service Type	Service Provider	Provider Location	Email Info
Rental Partner	Nobody's Child	United Kingdom	heretohelp@nobodyschild.com
Takeback Service	Reskinned	United Kingdom	takeback@reskinned.clothing
Repairs & Alteration Service	Sojo	United Kingdom	heretohelp@nobodyschild.com

Figure 35 – Case study's Collection/Sorting relationship

Collection Point	Location	End of Life Pathways
Reskinned	London, United Kingdom	Reuse, Recycling

Figure 36 – Case study's Recycling & Circularity Assessment relationship

Component/Material	Recycling Rate (%)	Recyclability (%)	Recycle Instructions [...]
Packaging	100	100	The tags on our products are crafted from paper that's 100% certified ...

Figures 32 to 36 summarise the activities carried out by *Nobody's Child* as both a physical retailer and an online seller through *Ebay*, as shown in Figure 32. They also report the after-sales services provided in collaboration with *Reskinned* and *Sojo*, including rental, take-back, repairs, and alterations, see Figures 34 and 35. Finally, Figures 33 and 36 present the recycling instructions for the product and its packaging, together with the related circularity performance.

6.3 Case Study Results and Model Validation

The case study on the *Blue High Rise Putney Barrel Leg Jeans by Nobody's Child* represents the first practical application to validate the Integrated Lifecycle-Based DPP model within the Aras Innovator PLM environment. Starting with the benchmarking of five real textile products associated with their respective corporate Digital Product Passports, this product emerges as the most suitable for implementation, as it contains the highest number of information items aligned with the ILB model, totalling 31 correspondences after the inclusion of additional relevant information.

The PLM structure proves capable of organising heterogeneous product information according to a lifecycle-oriented logic. In particular, the forms dedicated to the Product and Part sections are populated with information concerning product identification, description, and technical data, while the relationship tabs enable the integration of information related to the supply chain and its actors, raw materials, manufacturing processes, traceability and transport, the Bill of Materials, environmental impacts, distribution, use and maintenance instructions, after-sales services, collection pathways, and recycling performance. Through the Bill of Materials and BOM Structure relationships, it is also possible to represent the product assembly by establishing links with its components, namely the organic cotton used for the jeans, the button, and the brass metal used for the same button.

At the same time, the case study highlights significant gaps between the level of completeness proposed by the ILB DPP model and the information currently made available by companies through their digital passports. Several areas, including social evaluations, various environmental impacts, product performance, compliance documents, service history, health and safety information, warranty and product lifecycle responsibility, recycling rate, as well as much of the information concerning distribution and the

instructions for remanufacturing and disassembly, cannot be completed due to the absence of available data. Therefore, the framework appears more comprehensive than the current state of the art in implementing corporate DPPs, while remaining scalable for future regulatory and industrial developments.

Overall, the study's results confirm the suitability of the Aras Innovator PLM digital environment for organising and managing lifecycle-based Digital Product Passport information. The adopted tool enables the collection, integration, and visualisation of product-related information across the different phases of its lifecycle, while also highlighting the need for greater data availability, standardisation, and transparency from companies in the sector to fully exploit the potential of the DPP framework.

7. Conclusions

The lack of a standardised framework for the development of Digital Product Passport models, together with the forthcoming application of European regulations requiring their mandatory adoption, is driving research towards the analysis of data from major industrial sectors and the definition of general guidelines for the design of digital structures capable of collecting and managing large volumes of product-related information in a simple and efficient manner.

The objective of this thesis is therefore aligned with this need. Through analysis of the currently available scientific literature, the study confirms that the implementation of the digital passport in industry remains at a preliminary stage, although it is undergoing ongoing evolution and development. Among the industrial sectors most frequently addressed in the scientific literature, the textile industry stands out as a priority area, both in terms of environmental impacts and regulatory relevance, with the mandatory adoption of the digital passport expected by 2027.

Following the analysis of scientific papers and a comparison with the European EPRS study by *Legardeur et al. (2024)*, which proposes a general model for implementing the DPP in the textile sector, a set of the most common information requirements in the apparel industry is extracted. This set is then appropriately modified and filtered to identify the essential information to be included in the sector-specific DPP. Based on the resulting information requirements, a general lifecycle-based Digital Product Passport framework is subsequently defined, named the Integrated Lifecycle-Based DPP model, to establish a valid standard that can be adapted to future industrial applications using either proprietary or open-source software.

For the assessment of the validity and applicability of the ILB DPP model, and at the same time to test the capabilities provided by the use of Aras Innovator PLM, which is presented as an open-source, cloud-based tool with a flexible and scalable modular structure, a DPP model based on the lifecycle-based framework principles is designed within the same software environment and subsequently intended for implementation through a case study.

To identify the textile product from which the most useful information could be extracted for the construction of the case study, the websites of official retailers that are already adopting or experimenting with digital passports for their garments are examined. Five products from five different apparel retailers meet the information requirements proposed by the ILB model; however, for the case study selection, a comparative analysis is conducted to identify the product with the most complete information set in terms of both quantity and quality. The product that stands out in the comparative assessment is the *Blue High Rise Putney Barrel Leg Jeans* from the brand *Nobody's Child*.

Through the implementation of the case study within Aras Innovator, it is therefore possible to construct, within the PLM environment, a digital passport based on the ILB model, capable of comprehensively collecting the information available from the original product DPP and of linking the product with each of its components through the native Bill of Materials management functionality provided by the platform.

This operation highlights the strengths of the PLM software, which, thanks to the full customisation of its internal sections, proves suitable for collecting different types of information, including text, numerical values, enumerations and lists, images, files, and documents. The modification of existing relationships and the creation of new properties enable the extension of the informational content of the configured digital passport model

without compromising the software's native functionalities, which are useful for establishing relationships between items and other components.

The basic, predominantly tabular graphical interface appears intuitive for business users with elementary IT skills. However, the data collection method and the complex use of relationships among the various elements may be difficult for consumers and users without prior knowledge of PLM software environments.

A limitation encountered during the use of Aras Innovator is the near-complete absence of warnings that clearly alert the user when interventions or modifications are being performed on elements with active relationships, whose alteration could compromise the proper functioning expected by the native software configuration.

Overall, Aras Innovator PLM proves to be a valid tool, as its modular structure enables the configuration and customisation of sections dedicated to data collection and management. It therefore enables the design of a DPP model and validates the quality of the results obtained from processing the information requirements and creating the Integrated Lifecycle-Based DPP model for textiles. Finally, through the implementation of a case study, it is possible to construct a Digital Product Passport by associating it with the information of a real textile product, the *Blue High Rise Putney Barrel Leg Jeans by Nobody's Child*, directly within the model configured in the PLM software, thereby further confirming its validity in collecting and managing textual information, documents, numerical values, files, and images.

The results achieved in this research provide a foundation for future developments of Digital Product Passport models based on a lifecycle-oriented methodology. Further studies could focus on acquiring and integrating more detailed, phase-specific information requirements for each stage of the product lifecycle, enabling a more comprehensive and scalable DPP structure. Moreover, the proposed model could be adapted and extended to different

industrial sectors by analysing domain-specific information requirements. Finally, the adoption of Aras Innovator demonstrated the potential of PLM systems for DPP implementation, although future software updates aimed at improving functionalities, usability, and graphical interface are strongly encouraged.

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