MSc Thesis CME

Construction Management and Engineering

Optimizing Resource Recovery

Implementing Digital Product Passports to Improve Traceability in Dutch Infrastructure Projects

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dutch process innovators

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Implementing Digital Product Passports to Improve Traceability in Dutch Infrastructure Projects

By

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In partial fulfillment of the requirements for the degree of

Master of Science in **Construction Management and Engineering**

At the Delft University of Technology

to be defended publicly on Friday February 20th, 2026 at 14:30

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Cover: https://lca.no/en/gs1-mandatory-digital-product-passports-what-construction-needs-to-know/

Acknowledgements

While conducting this research, my family, friends, and the people of my hometown were facing one of the darkest periods of their lives. Over the past year, I lost many friends, and countless innocent people were killed simply because of their beliefs and identities. The province I come from, As-Suwayda, was surrounded by extremist jihadist groups supported by the new Syrian government and remained under siege and constant threat until the very moment I completed this research. Carrying out this work under such circumstances was emotionally overwhelming. For this reason, I am especially grateful to my study advisor, Anneloes Klapwijk, for her understanding and support.

I hope that the coming period will bring peace to the Middle East, and that the Druze community, along with all others, will be able to live in safety and dignity.

This research has been the most challenging academic project of my life. Completing it would not have been possible without the support of many people. I would like to express my deepest gratitude to my graduation committee, Paul Chan, Sander van Nederveen, and Hans Ramler. Without your guidance and feedback, I would not have been able to bring this work to completion.

I would also like to thank Dutch Process Innovators (DPI) and all my colleagues there for their support and motivation throughout this research. In particular, I wish to express my sincere thanks to my supervisor, Jasper Sonneveld, for his guidance, patience, and continuous support.

On a personal level, I am deeply grateful to my lovely wife, Rawan, whose love, strength, and unwavering support carried me through the most difficult moments.
To my family, whose strength and resilience continue to inspire me, and to my family-in-law, thank you for your warmth, love, and constant encouragement.

Finally, I express my deepest gratitude to UAF, the organization that supported me from the very first day I decided to pursue this path, and in particular, Carine Rozema and Joep van Kouwen, for their time, trust, and support.

Laith Emad Alzaher
February 2026

Abstract

The construction and infrastructure sector contributes significantly to environmental pressure through high material consumption, intensive use of primary resources, and substantial CO_2 emissions. Although the Netherlands recycles a large share of its construction and demolition waste, the reuse of components remains limited, often because essential information about materials, origin, performance, and condition is missing. When this information is fragmented or inaccessible, opportunities for circular strategies at the end-of-life stage are frequently lost. Strengthening traceability is therefore a critical foundation for national circularity ambitions and for the introduction of the Digital Product Passport (DPP) under upcoming European regulations.

This research examines how information gaps arise across the lifecycle of infrastructure assets in the Netherlands and how Digital Product Passport can address these gaps by improving data continuity, quality, and accessibility. A qualitative methodology was used, combining a structured literature review with fifteen semi-structured interviews involving asset owners, consultants, policy advisors, and specialists in information management. The study identifies where material information is lost, how current systems fail to maintain consistent traceability, and which organizational conditions influence long-term data reliability.

Findings show that weak traceability results mainly from fragmented systems, unclear responsibilities, inconsistent updating routines, and limited digital capacity. Based on these insights, a strategy guide was developed containing twelve strategies that support the practical implementation of DPP in infrastructure projects. The strategies focus on system integration, structured handovers, data ownership, verification mechanisms, and standardized information formats. The guide is illustrated through its application to a prefabricated concrete slab, demonstrating how lifecycle information can be structured in practice.

The research concludes that Digital Product Passport can strengthen traceability when embedded in existing workflows and supported by clear governance and shared data standards. While a DPP cannot resolve all information challenges, it provides a structured framework that reduces information loss and supports more reliable lifecycle data for future decisions.

Keywords: Traceability, Digital Product Passport, Infrastructure, Information Management, Circularity, Construction Sector.

Table of contents

Figures

Tables

Abbreviations

AI – Artificial Intelligence

BIM – Building Information Modelling

CE – Circular Economy

CDW – Construction and Demolition Waste

CO_2 – Carbon Dioxide

D-DAS – Disassembly and Deconstruction Analytics System

DBFM – Design, Build, Finance, Maintain

DfA – Design for Adaptability

DfD – Design for Disassembly

DfMA – Design for Manufacturing and Assembly

DPI – Dutch Process Innovators

DPP – Digital Product Passport

DR – Digital Record

EOL – End of Life

EPD – Environmental Product Declaration

GIS – Geographic Information System

IoT – Internet of Things

ISO/IEC/IEEE 15288 – International Standard for Systems and Software Engineering

KPI – Key Performance Indicator

LCA – Life Cycle Assessment

LCC – Life Cycle Costing

MKI – Milieukostenindicator (Environmental Cost Indicator)

MP – Material Passport

QR – Quick Response (code)

RFID – Radio Frequency Identification

RWS – Rijkswaterstaat

SE – Systems Engineering

1.Introduction

1.1 Background and Relevance

The construction and infrastructure sectors are among the largest contributors to global environmental pressures, responsible for massive material consumption, waste generation, and embodied carbon emissions across the life cycle of assets. Yet, at the end of service life, demolition followed by downcycling or disposal remains the dominant practice. This linear approach causes the premature loss of valuable structural capacity and creates unnecessary demand for primary raw materials, even when many components could technically be retained for future use (Lei, Yang, Yan, Tang, & Dong, 2023).

The environmental burden of this practice is substantial, especially because the end-of-life stage is often overlooked in project planning and decision making. In fact, this stage alone can account for up to 16% of total lifecycle CO_2 emissions in civil engineering projects, largely due to demolition activities (Tleuken et al., 2025). Recognizing and addressing end-of-life considerations differently therefore offers a major opportunity to reduce embodied carbon and resource demand (Lei et al., 2023).

Strategies have been developed to facilitate more sustainable end-of-life practices. Design for Disassembly encourages the use of modular systems, reversible joints, and design principles that enable assets to be dismantled without damaging components, thus increasing their potential for future applications (Roxas et al., 2023; Tsoka & Tsikaloudaki, 2024). Material Passports have been introduced to provide structured and standardized documentation of material and component properties, improving traceability and enabling informed decisions about the management of materials (Anastasiades et al., 2021). Advances in digital tools, such as BIM-based disassembly analytics and evaluation frameworks, further support the assessment of deconstruction options and lifecycle scenarios during the design and planning phases (Akanbi et al., 2019; Dams et al., 2021). From the client perspective, ambitions for sustainable end-of-life management only become effective when they are embedded in formal project requirements and supported by structured governance and monitoring mechanisms (Coenen, Visscher, & Volker, 2023).

Despite these developments, the application of advanced information management in infrastructure projects remains limited. Barriers include the perception of high upfront costs, uncertainty about the structural performance and safety of components, lack of reliable and accessible data, and unclear distribution of responsibilities among project actors (Karaca, Tleuken, Awan, et al., 2024; Coenen et al., 2023; Anastasiades et al., 2021). These obstacles persist because they are not systematically addressed in existing information and management processes. Without being captured in reliable data structures and supported by traceable digital systems, ambitions for circularity and resource efficiency often fail to materialize in practice.

At the policy level, the urgency of addressing these challenges is reinforced by ambitious national and European goals. The Dutch government aims to achieve a fully circular economy by 2050, with an interim target of reducing the use of primary raw materials by 50% by 2030, as outlined in its National Circular Economy Program (Government of the Netherlands, n.d.). Similar priorities are reflected in European initiatives such as the Ecodesign for Sustainable Products Regulation, which introduces the Digital Product Passport (DPP) as a new mechanism for product data transparency (European Commission, 2024).

DPP is expected to play a central role in the digital transition towards circular construction by recording material composition, origin, performance, maintenance history, and lifecycle potential throughout the lifecycle of components. Such a tool can improve traceability, enhance data continuity, and make lifecycle decisions more reliable (Jensen et al., 2023; Kühn et al., 2025). Recent studies highlight that DPP can act as a digital "memory" of materials, ensuring that critical information about products remains accessible for future decision-making (Psarommatis & May, 2024). However, the construction sector still lacks a clear understanding of how DPP can be practically implemented for infrastructure assets and which types of information are essential to enable circularity (Mankata, Antwi-Afari, Frimpong, & Ng, 2025).

In this context, strengthening traceability through the implementation of Digital Product Passports (DPP) offers a promising solution to address the persistent information gaps that challenge circular practices in infrastructure projects. By specifying the essential data requirements, establishing clear protocols for data updates, and defining stakeholder responsibilities for information management, this study aims to advance reliable traceability as a foundation for more circular and resource-efficient infrastructure systems.

1.2 Problem Definition

Although circular economy principles are increasingly promoted in the construction and infrastructure sectors, the practical implementation of data driven and circular practices remains limited. Bridges, viaducts, and other civil structures are still mainly demolished at the end of their service life, with materials often downcycled or discarded rather than managed through transparent and informed processes (Lei et al., 2023). This occurs despite growing awareness of the environmental and resource benefits associated with more circular approaches (Amarasinghe et al., 2025).

Several barriers continue to hinder the broader adoption of circularity in infrastructure projects. These barriers include uncertainty about the structural reliability of components, limited economic incentives, unclear roles and responsibilities, lack of standardized procedures, and weak traceability of information across the life cycle of assets (Coenen, Visscher, and Volker, 2023; Anastasiades et al., 2021; Karaca, Tleuken, Awan, et al., 2024). Among these barriers, the lack of traceable and consistent data is particularly significant. When essential information about material properties, origin, and condition is missing or fragmented, opportunities for circular decision making are often overlooked or rejected because of uncertainty.

Improving traceability is a key step toward enabling more resource efficient practices in infrastructure. Digital Product Passports have recently been introduced at the European policy level as part of the transition to a more sustainable and transparent product information system. Under the Ecodesign for Sustainable Products Regulation, Digital Product Passports will become mandatory for construction products and will serve as digital records that store verified information about materials and components throughout their life cycle (European Commission, 2024). This development creates an opportunity to explore how Digital Product Passports can strengthen traceability and make lifecycle decisions more transparent and reliable.

This research examines the potential of Digital Product Passports to improve traceability in infrastructure projects. By identifying the necessary information, update processes, and data management responsibilities, this study aims to contribute to the development of more reliable and resource efficient information practices in the Dutch infrastructure sector.

1.3 Research Objectives

The objective of this research is to examine how traceability of material information in infrastructure projects can be improved through the use of Digital Product Passports. The study focuses on identifying which types of information are required for accurate and continuous documentation of components, how this information should be structured and updated throughout the lifecycle of infrastructure assets, and which conditions determine whether information remains accessible and reliable in practice. Although decisions about future applications, including the possibility of reuse, are influenced by many factors, this study places primary emphasis on information continuity rather than on specific circular strategies.

To address this objective, the research combines findings from existing literature with insights from interviews involving professionals working in asset management, sustainability, and information and data management in the Dutch infrastructure sector. The interviews provide practical perspectives on current information gaps, limitations in existing data processes, and the challenges that restrict traceability in day to day project work. They also highlight opportunities for improving information quality and continuity through more consistent and structured data management practices.

The final goal of this study is to develop a set of strategies that describe how Digital Product Passports can be implemented in a realistic and workable manner for infrastructure assets. These strategies bring together the barriers identified in the literature and the insights gathered from interviews. They focus on responsibilities for updating information, governance structures, system alignment, and verification mechanisms. By linking traceability requirements with clear steps for implementation, the study aims to demonstrate how DPP can support more reliable material information flows and contribute to more informed lifecycle decisions in Dutch infrastructure projects.

1.4.Research Question

How can Digital Product Passports address information gaps and strengthen traceability in Dutch infrastructure projects?

SQ1: *What information gaps and missing data limit reliable traceability of materials and components in Dutch infrastructure projects?*

This question focuses on identifying where information is incomplete, inaccurate, or entirely missing within current infrastructure projects. It examines the points in the asset lifecycle where traceability breaks down, such as unclear material origins, limited documentation of changes, missing inspection records, or inconsistent data formats. By mapping these gaps, the question clarifies why current traceability systems struggle to provide continuous and trustworthy information. Understanding these missing data elements is essential, because they determine what Digital Product Passports must address in order to improve traceability.

SQ2: *How is material traceability currently organized in infrastructure projects, and which challenges reduce its effectiveness?*

This question examines how material and component information is currently collected, stored, and transferred throughout infrastructure projects. It looks at the role of systems such as BIM, asset management platforms, and handover documentation to understand how traceability is supposed to function today. The question also identifies the challenges that weaken these systems, such as fragmented data, inconsistent updating practices, unclear responsibilities, or limited interoperability between tools. By analyzing how current traceability processes operate and where they fail, the question highlights the structural issues that Digital Product Passports will need to overcome.

SQ3: *What are the main benefits of a Digital Product Passport, and what challenges affect its implementation across the asset lifecycle?*

This question explores how the Digital Product Passport may improve information continuity and support long-term traceability in infrastructure projects. It considers the advantages the DPP is expected to offer from a lifecycle perspective, as well as the conditions and challenges that may influence its adoption and limit its ability to deliver these benefits.

SQ4: *What strategies can be developed to implement Digital Product Passports in infrastructure projects to enhance traceability?*

This question investigates what institutional, technical, and organizational measures are required for effective DPP adoption in infrastructure projects. It looks at implementation steps, stakeholder collaboration, and standardization processes that can enable DPPs to improve traceability and support circular use of materials.

1.5 Scope

This study examines how Digital Product Passports can address information gaps and improve material traceability in Dutch infrastructure projects. The focus is on understanding how Digital Product Passports can strengthen information quality, accessibility, and continuity across the life cycle of an asset. Although improved traceability can support future decisions about material recovery or potential reuse, reuse itself is not the main focus of this research. The emphasis lies on the information related conditions that allow traceability to function in a reliable way.

The scope is limited to issues related to data availability, data quality, documentation practices, and the transfer of information between phases of an infrastructure project. Broader economic, legal, social, and market related factors are acknowledged but remain outside the scope of this study. Highly technical subjects such as development of digital infrastructure, creation of complete information technology architectures, or detailed Digital Product Passport implementation plans are also excluded. The aim is to focus on realistic and foundational information needs that enable traceability in long lived assets.

Empirical insights were collected through semi structured interviews with professionals involved in asset management, sustainability, and information management within the Dutch infrastructure sector. Participants included representatives of national clients, regional asset owners, railway organizations, energy network operators, and consultants. These viewpoints provided a wide understanding of how material information is currently organized and where traceability often fails in practice. The perspectives of contractors and product manufacturers were only partly represented, which may limit insights related to production and supply chain related processes.

The study aims to develop a clear and structured set of strategies that describe how Digital Product Passports can be used in practice to support better traceability. This output is not intended to serve as a full technical implementation plan. Instead, the strategies focus on information that should be captured, responsibilities for updating information, and alignment with existing tools and processes. The strategies combine findings from the literature and interviews and are reviewed by experts for clarity and feasibility. Large scale validation, pilot projects, or sector wide implementation activities fall outside the scope of this research.

1.6 Methodology

This research adopts a qualitative and exploratory methodology aimed at understanding how Digital Product Passports can address information gaps and strengthen material traceability in Dutch infrastructure projects. The methodology consists of three phases: knowledge building, expert interviews, and synthesis and strategy formation. Each phase builds on the previous one to answer the sub-questions and ultimately develop a strategy guide that supports the practical use of DPP. The methodological structure is illustrated in Figure 1.

The first phase, knowledge building, establishes the theoretical foundation through a literature review on reuse, traceability, and DPP.
The second phase, expert interviews, gathers practitioner insights to explore current practices, barriers, and data management challenges.
The third phase, analysis and synthesis, integrates the findings into a set of steps and conditions for effective DPP implementation.

Phase 1: Knowledge building

Step 1: *Identifying information gaps and traceability limitations*

The research begins with examining academic papers, industry reports, and policy documents to identify where material and component information becomes incomplete, inaccessible, or inconsistent during the lifecycle of infrastructure assets. This includes gaps related to documentation, data reliability, change tracking, and information loss between project phases. These insights address SQ1 by clarifying the underlying issues that prevent continuous traceability.

Step 2: *Exploring current traceability practices and challenges*

The second step analyses how traceability is currently organized in infrastructure projects. It reviews existing digital tools such as Building Information Modelling, asset management systems, inspection reports, and handover documentation. Special attention is given to how information flows between stakeholders and which challenges reduce the effectiveness of these tools, such as fragmented data, unclear update responsibilities, and limited long term accessibility. This examination supports SQ2 by describing both the intended processes and the practical difficulties that arise.

Step 3: *Understanding Digital Product Passports and data needs*

The final step in this phase examines the concept of Digital Product Passports (DPP) in both construction and manufacturing contexts. The focus is on identifying what types of information are needed for reliable reuse decisions, such as material type, condition, provenance, and performance, and how such data could be structured and maintained. This supports SQ3 by defining essential data requirements for traceability and reuse..

Phase 2: Expert Interviews

Step 4: *Investigating current traceability practices in real projects*

Interviews were conducted with representatives from national clients, regional asset owners, railway organizations, energy network operators, and consultants. The interviews examined how material information is created, stored, and transferred in practice, which systems are used, and where information gaps typically occur. This step provides the primary empirical basis for SQ2 by examining how material traceability is organised in current infrastructure projects and which challenges reduce its effectiveness.

In total, 15 interviews were conducted, which is sufficient to reach thematic saturation (Guest, Bunce, & Johnson, 2006).

Step 5: *Analyzing The output from the interviews*

Interview data are analysed thematically to identify recurring patterns in how information is created, shared, and updated across project phases. The analysis examines how these practices influence information continuity across the asset lifecycle and where limitations may occur.

The findings are synthesised and compared with insights from the literature to examine the expected benefits of Digital Product Passport use and to support SQ3. This step aims to clarify the conditions that may enable these benefits in practice and those that may limit their effectiveness.

Step 6: *Defining Digital Product Passport information and process requirements*

This step focuses on translating the interview findings into specific data requirements for Digital Product Passports (DPP), addressing SQ 3, which examines what information is needed to support traceability and reuse in infrastructure projects. Patterns identified in the analysis are used to determine which types of information are most relevant for enabling reuse, such as provenance, condition, and environmental performance data. The step also considers how responsibilities for collecting, updating, and maintaining this information could be distributed among project stakeholders. The outcome is a structured overview of essential information categories and corresponding stakeholder roles that can inform the practical development of DPPs within the Dutch infrastructure sector.

Phase 3: Synthesis and Strategy Formation

Step 7: *Developing the strategy guide for DPP implementation*

This step synthesis the insights from the literature review and the expert interviews into a structured strategy guide that supports the practical implementation of the Digital Product Passport in infrastructure projects. The step addresses SQ 3 and SQ 4 by translating the identified barriers, enablers and information needs into clear strategies that strengthen information continuity across project phases. Patterns from theoretical and empirical findings are compared to determine where current practices align or conflict with the conditions required for effective DPP application.

The development process organizes these insights into coherent themes that reflect the essential elements of DPP implementation, including data governance, information responsibilities, update practices and system integration. Each theme is translated into practical guidance that indicates how relevant information should be recorded, shared and managed to support reliable reuse decisions. The resulting strategy guide provides a set of actionable recommendations that help organizations improve traceability and enable material reuse within Dutch infrastructure projects.

Step 8: *Mapping strategies onto the lifecycle of a product*

2This step maps the strategy guide onto the five lifecycle phases of a prefabricated concrete slab to demonstrate how Digital Product Passports can support structured and continuous information management. The mapping identifies the information typically required for traceability at each phase, highlights the gaps that commonly occur in current practice, and links these gaps to the strategies that can address them. By applying the strategies to a representative product, the analysis illustrates how the proposed measures align with existing workflows in Dutch infrastructure projects and how they respond to the information failures identified in the interviews and literature. This step functions as a synthesis of the research findings, showing how the strategy guide operates when placed within a realistic lifecycle progression. The outcomes clarify the practical relevance of the strategies and provide a foundation for the concluding discussion on improving traceability through Digital Product Passports

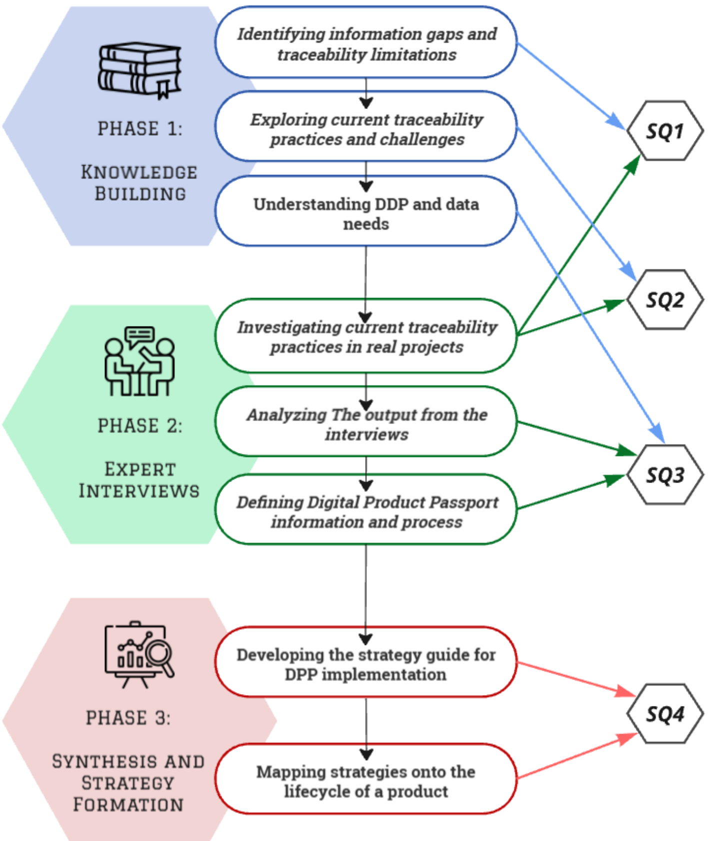

Figure 1 Research Methodology.

2. Literature Review

2.1 Traceability

The transition toward a circular built environment requires transparent information flows across the entire life cycle of infrastructure assets. Materials and components must be traced from production to reuse to enable informed decisions about maintenance, recovery, and recycling. In this context, traceability has emerged as a central mechanism linking digitalization and circularity. It ensures that data on products, materials, and processes remain accessible and verifiable throughout the asset's life, thereby supporting responsible resource management and compliance with circular economy goals (Davari et al., 2023).

2.1.1 Definition of Traceability

Traceability has become a key requirement for transparency and reliability in the construction and infrastructure sectors. It enables the tracking and linking of materials, information, and decisions across all life-cycle stages, which is essential for achieving circular and data-driven construction (Davari et al., 2023; Ranasinghe et al., 2024). Through traceability, stakeholders can follow how materials and data evolve and determine who is responsible for each choice or modification. According to ISO/IEC/IEEE 15288 (2023), traceability is the ability to identify and follow relationships among system elements throughout their life cycle, allowing information regarding their origin, status, and changes to be retrieved when needed. Rijkswaterstaat (2023) defines *traceerbaarheid* as the capability to follow the course of choices, decisions, and intentions clearly and unambiguously, and to trace the history, use, or location of an object. These perspectives show that traceability involves preventing data loss, improving information continuity, increasing transparency and accountability, and strengthening collaboration. They also highlight that traceability concerns not only data but also the decision-making process, linking technical and managerial dimensions in a unified framework. In addition, traceability can be viewed directionally, including forward and backward traceability across life-cycle stages, horizontal traceability across disciplines and organizational roles, and vertical traceability between project phases.

(Davari et al., 2023) describe several types of traceability that together establish a comprehensive foundation for information control in the built environment. These forms represent different dimensions of traceability, each addressing a specific aspect of how materials, information, and activities are monitored. Physical traceability refers to identifying and monitoring tangible elements, such as materials and components, allowing their location and condition to be known at every life-cycle stage. Informational traceability focuses on the flow and reliability of digital data across systems, ensuring that information remains accurate, verifiable, and accessible (Giovanardi et al., 2023). Process traceability captures the sequence of activities and responsibilities throughout design and construction, providing visibility on how decisions evolve. Event traceability documents specific actions, such as inspections, deliveries, or maintenance activities, as verifiable evidence of performance. Systemic traceability connects all other types across organizational and technical boundaries. A more recent development is hybrid traceability, which combines digital and physical tracking mechanisms, for example, linking sensor data from the physical environment to Building Information Modelling (BIM).

(Watson et al., 2019) introduced the concept of the Digital Record to support a continuous golden thread of information connecting design intent, product data, and the as-built condition of assets. Their framework integrates information and supply chains to enable both backward and forward tracking of materials and decisions. This approach also appears in several engineering practices, where traceability is used simply as a means of checking whether requirements, design choices, and verification activities remain connected. It serves as an example of how structured processes can apply traceability without influencing the main concept described in this section.

(Ranasinghe et al., 2024) emphasized that data traceability is essential for achieving material circularity. Their review demonstrated that the lack of structured traceability hinders the reuse and recovery of materials, whereas digitalization of supply chains can overcome most of these barriers. Similarly, Santana and Ribeiro (2022) showed that traceability models and systems are fundamental for establishing coordination, control, and accountability within circular networks. These insights confirm that traceability is not limited to compliance documentation but forms a structural mechanism that connects technical, organizational, and environmental objectives.

Advances in digital technologies further enhance traceability capacities. Giovanardi et al. (2023) demonstrated that Internet of Things systems and digital twins enable continuous information exchange between physical assets and their digital representations, facilitating real-time monitoring and feedback. Such hybrid environments reflect the evolution toward Construction 4.0, which refers to the integration of advanced digital technologies into construction processes to create connected and data-rich project environments. Construction 4.0 encompasses tools such as BIM, IoT sensors, automated data platforms, and digital twins that synchronize information between physical assets and their digital models. These developments illustrate how digitalization can strengthen physical and informational traceability, supporting both operational reliability and long-term circular value retention in infrastructure projects.

Type	Main Focus	Description	Example
Physical	Materials and components	Follows tangible elements and their condition during the life cycle.	Using RFID tags to monitor prefabricated elements.
Informational	Digital data and documentation	Ensures that information is accurate, verifiable, and transferable.	Linking BIM data with material passports.
Process	Activities and responsibilities	Tracks how tasks and decisions are performed and updated.	Recording approval steps for design modifications.
Event	Specific actions	Captures and verifies critical occurrences for accountability.	Registering inspection or maintenance activities.
Systemic	Cross-system interaction	Connects information, materials, and workflows across organizations.	Integrating design, procurement, and operational data.
Hybrid	Physical–digital link	Combines physical and informational tracking for full visibility.	IoT sensors feeding real-time data into digital twin models.

Table 1 Traceability Types

2.1.2 Importance of Traceability

Traceability plays an important role in managing information within construction and infrastructure projects. After defining the concept, its importance becomes clear when considering the long life cycles of assets, the involvement of multiple stakeholders and the fragmented nature of data across project stages. Traceability supports the consistent connection of information, decisions and material characteristics, which aligns with the increasing focus on circularity and digitalization in the Dutch infrastructure sector. The following subsections outline why traceability is needed to maintain information continuity, improve technical assessments, strengthen transparency and enable digital information flows.

Traceability as a Foundation for Sustainability

Traceability strengthens circular construction because it preserves reliable information on the origin, transformation and condition of materials and components throughout their life cycle. Verified records of composition, performance and maintenance history allow engineers to evaluate components with greater certainty. When such information is incomplete or unavailable, materials lose their identity and are often treated as waste, which limits the opportunities for recovery (Ranasinghe et al., 2024).

The connection between traceability and broader sustainability objectives has also been highlighted in conceptual frameworks. (Katenbayeva et al.2016) position traceability within a sequence of related organizational concepts that include responsible sourcing, transparency, social responsibility, business ethics and sustainability. Figure 2 illustrates how these concepts expand in scope from operational practices toward strategic and societal aims. Within this structure, traceability provides the informational foundation that enables transparency and responsible sourcing, which in turn support wider sustainability ambitions.

The relevance of traceability becomes evident across lifecycle stages. During design, information must be organized in a way that supports later identification. During construction, materials and components need to be documented and linked to unique identifiers. At later stages, this information helps stakeholders understand past use, condition and compliance, which facilitates more informed decisions about maintenance, replacement or potential recovery (Watson et al., 2019). Digital technologies such as Building Information Modeling, material passports and shared data environments offer practical means to organize and exchange this information across actors and projects, although their effectiveness depends on data standards and clear responsibilities for updating information (ISO 15288, 2023).

As the construction sector moves toward more structured information practices, there is growing interest in instruments that can formalize and maintain traceability throughout the lifecycle. This provides the context for examining the concept of the Digital Product Passport in the next chapter, where the focus shifts to how traceability can be operationalized within infrastructure projects.

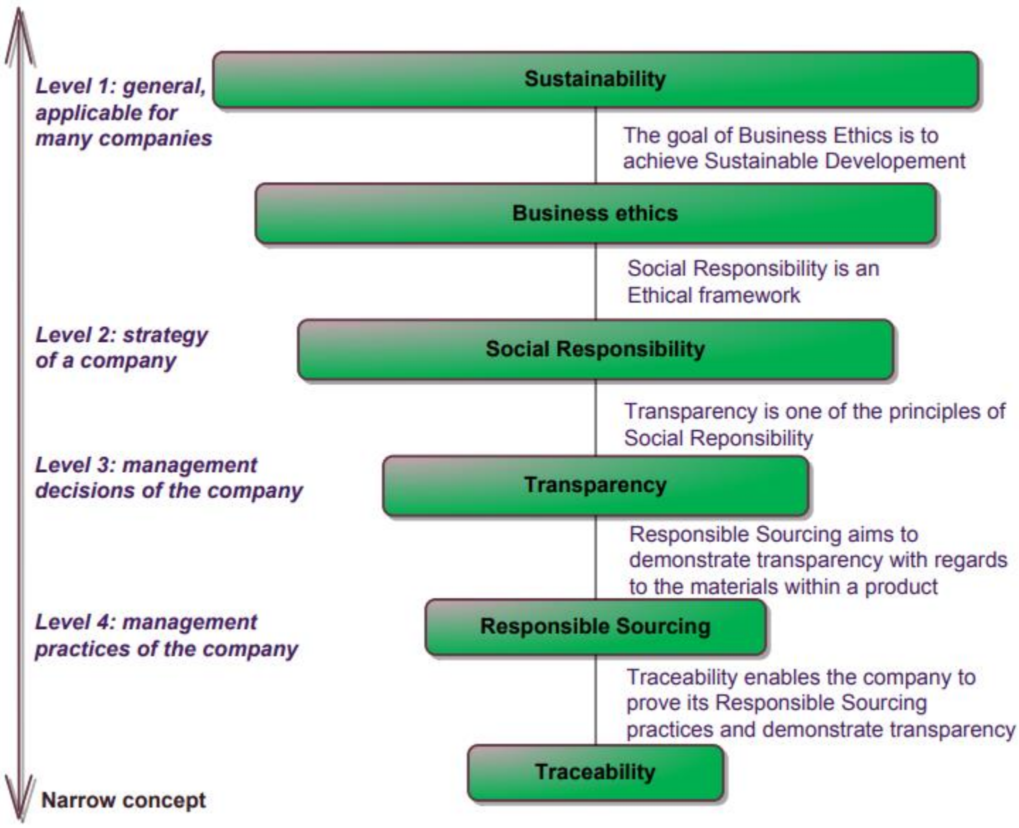

Figure 2 Diagram of the concepts related to traceability (Katenbayeva et al.2016)

Maintaining information across the Life Cycle

Traceability helps preserve reliable information throughout the life cycle of infrastructure assets. Construction projects often lose essential data during handovers between design, procurement, construction and operation, limiting the ability to identify material origin, condition and changes. (Davari et al., 2023) highlight that traceability reduces this fragmentation by linking information across phases and maintaining continuous access to material histories. Similarly, (Watson et al., 2019) explain that a Digital Record enables both backward and forward traceability, ensuring that information created early in the project remains available for later assessments. This positions traceability as a fundamental mechanism for life-cycle information continuity.

Improving reliability for reuse decisions

Reliable decisions about reuse depend on verified information on material quality, provenance and performance across the asset's lifecycle. Literature consistently shows that weak traceability is one of the most significant barriers limiting the feasibility of reuse. Research demonstrates that even when components appear physically suitable, the absence of documented production details, loading conditions and past interventions reduces confidence in their technical reliability (Akanbi et al., 2019). This uncertainty leads engineers to exclude reclaimed components from design options, regardless of their remaining performance capacity.

The importance of robust information becomes clear when assessing the technical identity of materials. Studies indicate that reuse is viable only when essential information on composition, manufacturing characteristics and service history remains available and verifiable (Assefa & Ambler, 2017). When such information is incomplete, the component cannot be evaluated with sufficient certainty, which restricts its use in safety-critical or performance-sensitive applications.

Additional research focusing on infrastructure shows that information gaps accumulate over long service periods. Many assets undergo undocumented repairs, alterations or exposure conditions, which makes it difficult to reconstruct a reliable material history at end-of-life (Lei et al., 2023). These gaps create significant uncertainty for engineers, who must rely on documented evidence to meet regulatory and liability requirements. As a result, risk perception becomes a decisive factor in reuse decisions.

Risk aversion is further reinforced by the absence of verifiable information. Studies show that where documentation is incomplete, stakeholders tend to prioritize new components with certified characteristics because they provide predictable performance and reduce perceived liability (Hart et al., 2019). This tendency persists even when inspections indicate that reclaimed materials are technically adequate.

Broader circularity research confirms that incomplete information flows restrict reuse more than physical degradation. Empirical studies identify missing documentation as one of the most frequent reasons why reusable components are rejected during planning processes, despite their potential to meet functional requirements (van den Berg et al., 2020).

Across these findings, weak traceability clearly emerges as a central barrier to enabling reuse in construction and infrastructure. Strengthening information continuity provides the basis for confident technical assessments, reduces uncertainty and supports higher-value reuse decisions.

Strengthening Transparency and Responsibility

Traceability supports transparency and accountability by documenting how information, decisions and responsibilities develop throughout the lifecycle of an asset. International systems engineering standards note that traceability provides structured links between requirements, design choices, verification activities and later updates, which allows organizations to demonstrate how decisions were formed and validated (ISO/IEC/IEEE 15288, 2023). Research also shows that traceability enhances coordination across project teams and supply chain actors. (Santana and Ribeiro, 2022) observe that clear information pathways improve visibility of responsibilities and reduce ambiguity during collaborative processes. Further evidence is provided by studies showing that structured traceability reduces uncertainty by clarifying which actors generated, modified or approved specific information (Katenbayeva et al., 201**6**). Their work demonstrates that transparent documentation strengthens accountability in complex projects by ensuring that actions and decisions can be followed, verified and justified. Together, these perspectives show that traceability contributes to reliable governance through clear documentation and consistent responsibility allocation.

Supporting Digital Information Flows

Digital technologies further enhance the importance of traceability. (Watson et al., 2019) demonstrate that digital recording structures support consistent information exchange and reduce the risk of data loss. (Giovanardi et al., 2023) show that integrating IoT sensors and digital twins strengthens the link between physical assets and their digital representations, enabling continuous updates and real-time monitoring. These digital environments improve both physical and informational traceability by ensuring that data remains accurate, verifiable and connected to the actual condition of the asset. This supports more reliable decision making throughout long infrastructure life cycles.

2.1.3 Current Practices and Data Systems in Infrastructure

In construction, traceability is applied to ensure that information about materials, components, and processes remains reliable throughout all life-cycle stages. The sector is characterized by fragmented responsibilities and separate information systems, which often result in the loss of essential data between design, procurement, and operation. This lack of information continuity makes it difficult to verify material origin or quality and limits the potential for reuse and circular construction (Ranasinghe et al., 2024).

A structured model for achieving information continuity was introduced by (Watson et al. 2019) through the concept of a Digital Record (DR). The framework, presented in *Figure 6*, organizes traceability across five interconnected chains: requirements, design, supply, construction, and in-use. Each chain represents a stage in which information is produced, transferred, or updated. The framework illustrates how data generated at one stage can be followed throughout the life cycle, allowing both backward traceability, which verifies material provenance and compliance, and forward traceability, which monitors how materials and systems are used, maintained, or replaced.

In Figure 3, the diamond shaped symbols represent traceable events, which are critical points at which information should be formally captured and documented. These events mark transitions where design decisions, material specifications, inspections or installation outcomes become fixed and should therefore be recorded in a verifiable manner. Their distribution across the requirements, design, supply, construction and in-use chains illustrates where information needs to stabilize before the asset progresses to the next stage. (Watson et al. 2019) emphasized that the systematic registration of such events creates a continuous trail of evidence, allowing both backward and forward tracing of component histories. When these traceable events are omitted or inconsistently recorded, information continuity weakens, leading to gaps that later hinder verification, maintenance planning and reuse assessments. The diamonds in the figure therefore function as anchors that connect activities across chains and support the creation of a coherent lifecycle record.

The Digital Record framework demonstrates that effective traceability depends on consistent and verifiable information flows rather than on isolated documentation. When information is captured in a structured and transparent manner, it becomes possible to reconstruct the full history of a component or decision. (Davari et al. 2023) emphasized that this kind of information traceability enables cooperation across organizational boundaries and supports decision-making about material reuse.

Digitalization provides the main mechanism for achieving such traceability. Systems such as Building Information Modelling (BIM), material passports, and digital product passports record material data, performance information, and ownership changes. These digital tools allow the stored data to be accessed in later stages of a project, enabling materials to be identified and assessed for potential reuse. (Katenbayeva et al. 2016) observed that this form of traceability also improves transparency and accountability, both of which are central to circular construction.

In the Netherlands, Rijkswaterstaat (RWS, 2023) integrates traceability into project management and procurement procedures to ensure that information on materials and maintenance is consistently documented and transferred. These practices align with European efforts to establish circular infrastructure systems supported by digital information. Through information traceability, construction projects can retain material knowledge, enable reuse, and contribute to a more resource efficient and transparent built environment.

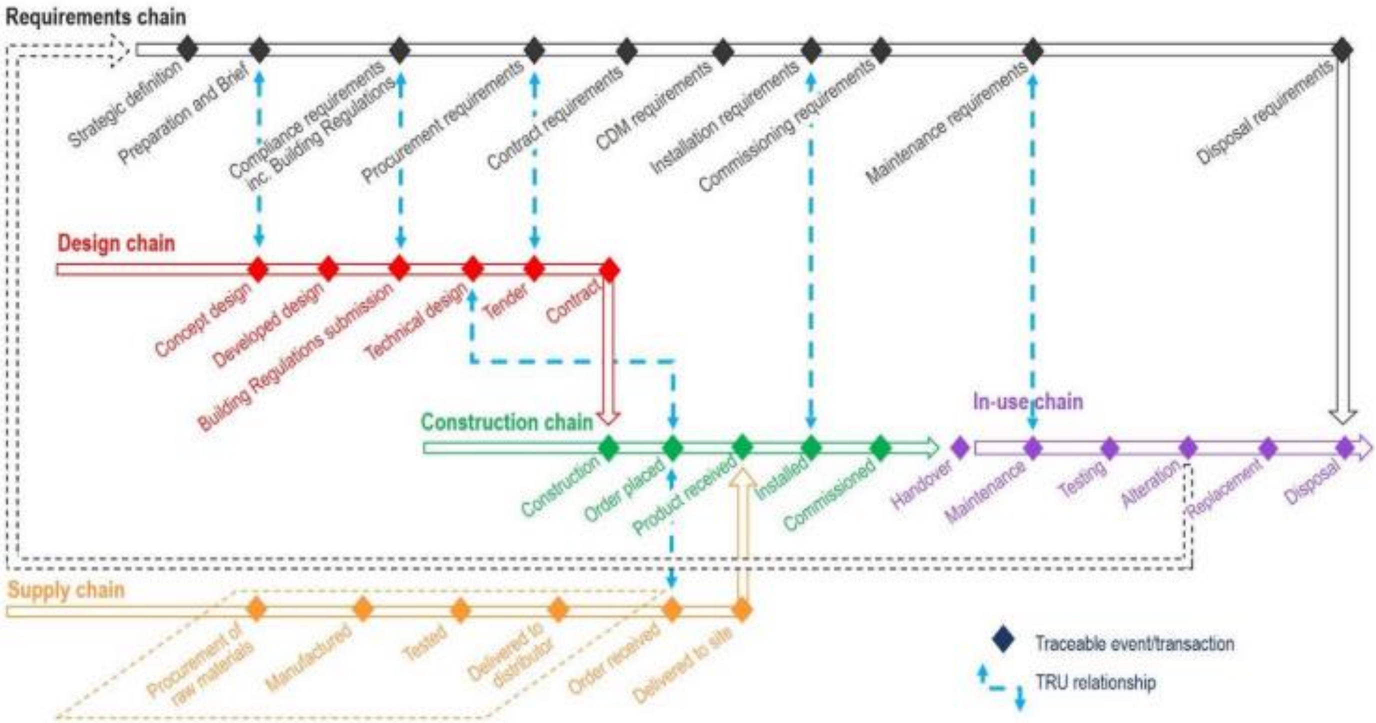

Figure 3 Framework for digital recording in construction (from Watson et al.)

2.1.4 Information Milestones and Lifecycle Gaps

Reliable traceability depends on maintaining continuous and accurate information across the life cycle of an asset. In practice, this continuity is often disrupted in infrastructure projects. Information is frequently produced for short-term project purposes, and the transitions between design, procurement, construction and operation are well-known points where documentation becomes incomplete, inconsistent or is lost entirely. These handovers weaken the information chain and reduce the ability to reconstruct the history, condition or characteristics of materials and components at later stages (Watson et al., 2019). As responsibilities shift between organizations, essential data becomes more difficult to retrieve or verify, even when partial records remain available.
Figure 4 illustrates the product lifecycle phases and the involvement of different stakeholders, highlighting typical locations where information gaps emerge across the lifecycle. The figure shows that information is generated by multiple actors at different stages, yet is often not transferred or maintained in a consistent manner as the asset progresses from creation and construction to use and end-of-life. This fragmented production and handover of information creates discontinuities that undermine reliable traceability over time.

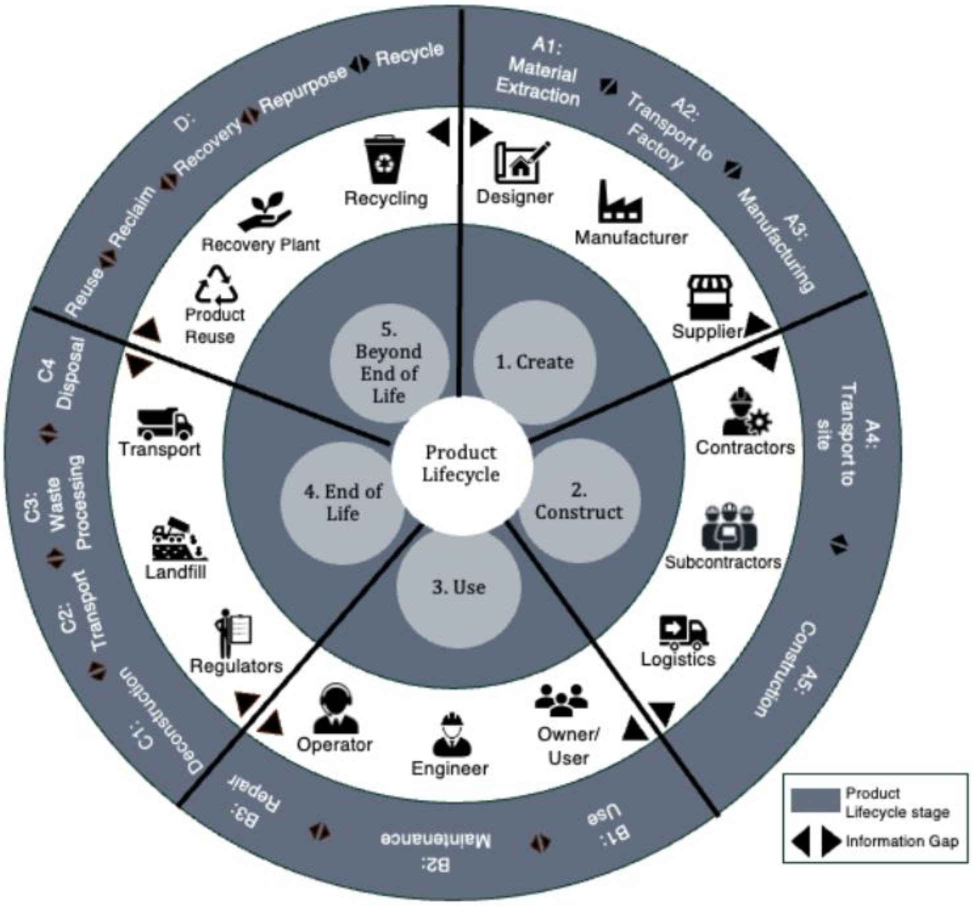

Figure 4 Product Lifecycle Phases

The information milestone model developed by Succar and Poirier (2020) provides a structured explanation for how these gaps emerge. Their framework, shown in Figure 5, illustrates the sequence of milestones that information passes through as it evolves from initial intent into digital representations and eventually into physical assets. At each milestone, the model distinguishes between the targeted information that should be delivered and the information that is actually produced. The figure presents this contrast across three domains, namely project purposes, deliverables and resources, and shows how ideal expectations frequently diverge from realized outcomes. Planned documentation, including detailed specifications, updated digital models and verified as-built records, often remains incomplete when it reaches the next phase.

This misalignment is a recurring pattern rather than an isolated exception. Succar and Poirier (2020) describe how information enters each milestone in a condition that does not meet what is required for reliable transfer. Time limitations, unclear responsibilities and insufficient verification routines contribute to this gradual deflection of information away from its intended trajectory. These deflection points align closely with the handover moments seen in infrastructure projects, where changes in actors, tools and documentation practices disrupt the continuity of information.

The effects of these misalignments become most visible when information must be transferred to the next stage. When design changes made during procurement are not included in digital models, or when construction deviations are not recorded in a structured manner, traceability becomes unreliable (Watson et al., 2019). Typical information gaps include missing material specifications, absent certificates, unrecorded installation conditions, inconsistent component identifiers and records stored in disconnected digital systems. Maintenance and inspection data are also often separated from earlier project information, which prevents the creation of a complete and connected lifecycle history. Even when information exists in archives, the absence of consistent identifiers or explicit links means it cannot be confidently associated with specific components or decisions.

These challenges reflect deeper characteristics of the construction sector. Project teams are temporary, information responsibilities are fragmented and organizations rely on heterogeneous tools and documentation practices. Once a project phase is completed, incentives to maintain or update records decrease significantly. Over the lifespan of an asset, this results in records that are incomplete, inconsistent or inaccessible. From a traceability perspective, materials and components cannot be followed with sufficient certainty across lifecycle phases, and stakeholders cannot determine where elements originated, how they changed or under which conditions they were used. Together, the lifecycle overview in Figure 4 and the milestone misalignment illustrated in Figure 5 demonstrate how structural patterns of information loss form the primary information gaps that limit reliable traceability in Dutch infrastructure projects.

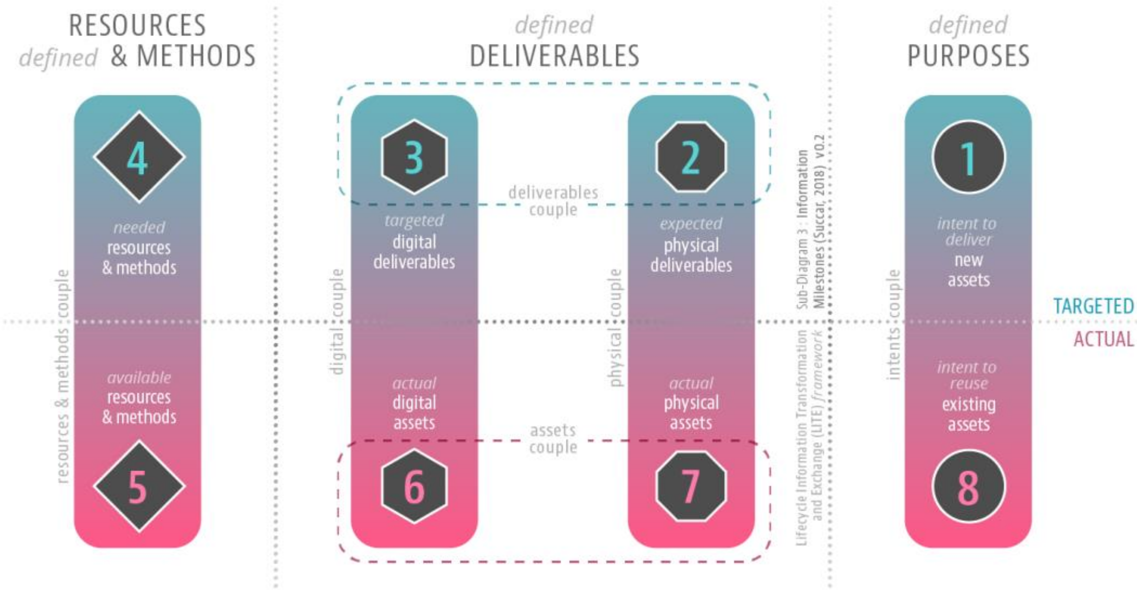

Figure 5 Information milestone (Succar and Poirier,2020)

2.1.5 Barriers and Limitations of Traceability

Although the value of traceability for transparency and circularity in construction is recognized in research and policy, its practical implementation remains limited. Several interrelated barriers, including technical, organizational, informational, and cultural factors, restrict effective traceability across the construction life cycle.

A major limitation results from the fragmented and project-based structure of the construction industry, which prevents continuous information exchange between actors and project stages. (Davari et al. 2023) observed that temporary project organizations and short-term contracts cause information discontinuities once phases end or new participants are introduced. Data about material origin, specification, and maintenance history are often lost at handover, which limits the potential for reuse. Watson et al. (2019) similarly noted that the complex supply chains and frequent ownership changes in construction disrupt data continuity and make accountability difficult to establish.

Another persistent barrier is the absence of common data standards and interoperable systems. (Ranasinghe et al. 2025) reported that although digital tools such as Building Information Modelling (BIM), material passports, and Internet of Things applications can enhance traceability, they are rarely used in a coordinated manner. The coexistence of isolated data formats and proprietary software systems prevents consistent information exchange between design, procurement, and operation. This limitation corresponds with (ISO 15288 ,2023), which states that effective system traceability depends on uniform identification methods and structured configuration management, both of which are rarely applied in practice.

Low data quality and incomplete information present additional challenges. In many projects, products lack unique identifiers or are recorded through manual processes, which results in inconsistent or unreliable data. (Katenbayeva et al. 2016) pointed out that traceability in construction is often treated as simple documentation rather than as a continuous information process, leading to partial or inaccurate records. Davari et al. (2023) explained that when data cannot be trusted, the entire traceability system becomes unreliable, reducing its usefulness for reuse assessments.

Organizational and cultural factors further limit implementation. Contractors and suppliers often hesitate to share information because of commercial sensitivity and uncertainty about data ownership (Davari et al., 2023; Ranasinghe et al., 2025). In many cases, project clients do not include traceability requirements in contracts, leaving adoption to voluntary initiatives. (Katenbayeva et al. 2016) noted that without formal incentives or policy frameworks, cooperation across supply chains remains weak.

Technological and financial constraints also play a role. (Ranasinghe et al. 2024) found that establishing digital traceability systems involves high investment and operational costs, while many organizations lack the technical expertise to manage complex data platforms. Multiple parallel initiatives, such as BIM, digital product passports, and blockchain pilots, have emerged without alignment, creating uncertainty about which systems should be adopted.

Finally, traceability is often poorly integrated with circular economy objectives. (Davari et al. 2023) and (Ranasinghe et al. 2025) showed that information flows frequently end at the construction or delivery stage, with little attention to the use, maintenance, and end-of-life phases. When material data are not available at these later stages, the identification and recovery of reusable components become nearly impossible.

These limitations indicate that the barriers to traceability in construction arise not from a lack of technology but from systemic fragmentation, inconsistent data management, and weak governance. Addressing these issues requires shared standards, reliable data exchange mechanisms, and stronger alignment between traceability and circularity goals.

2.2 Digital Product Passport (DPP)

2.2.1 Concept and Background of the Digital Product Passport

The Digital Product Passport (DPP) is increasingly defined as a digital system for storing verified information across all relevant life-cycle stages of a product. It supports transparency, strengthens traceability and improves material management by linking physical products to structured digital information. This function is essential for reducing long-standing information gaps that limit circular practices, as demonstrated in recent research (Oteng et al., 2025).

Figure 6 situates the Digital Product Passport within the broader product lifecycle and illustrates the multiplicity of actors involved in generating, updating and using product-related information. As shown in the figure, information is produced at different stages, ranging from material extraction and manufacturing to use, recovery and end-of-life processing, and by actors with heterogeneous roles and interests. (Ducuing and Reich., 2023) emphasize that DPPs are expected to function as a shared digital infrastructure that coordinates these dispersed information flows and mitigates the loss of data that typically occurs at phase transitions and organizational handovers. From this perspective, the lifecycle representation highlights why DPPs must extend beyond a single project phase and support both static and dynamic information over time, while accommodating differentiated access for stakeholders across the value chain.

The specific structure of a DPP varies between product groups. Some remain static, while others are continuously updated during use. This flexibility reflects differing regulatory obligations and industry needs. Access is typically provided through automated identification methods, such as QR codes or barcodes, which connect the physical product to its digital record and ensure that information remains available to relevant actors. The practical implications for value-chain coordination are further illustrated in studies on information accessibility and collaboration (Illán García et al., 2024).

European sustainability regulations increasingly define expectations for digital product information. Requirements introduced through the Ecodesign for Sustainable Products Regulation and the Circular Economy Action Plan emphasize consistent documentation of composition, origin and environmental performance. Their impact on construction-specific data is expected to grow, particularly as revisions to the Construction Products Regulation introduce new obligations for performance declarations and environmental reporting (Ruismäki et al., 2025).

A key motivation behind the DPP is the persistent fragmentation of material information. When data on composition, treatment or life-cycle performance becomes inaccessible, opportunities for reuse and high-value recovery decline. Research on standardized DPP data structures shows how consistent formats help maintain essential information across project phases and support informed decisions in design, construction and end-of-life processing (Vangelova et al., 2025).

The role of the DPP in supporting circular construction is also shaped by ongoing pilot projects in Europe. These initiatives explore how digital information systems can fulfil regulatory requirements, enable transparency and strengthen resource efficiency in material-intensive sectors. Their observations provide insights relevant to future construction templates and potential integration with tools such as Building Information Modelling (Wautelet & Ayed, 2024).

The development of the DPP builds upon earlier approaches, particularly material passports, which introduced systematic methods for recording product-related information in the built environment. This continuity is reflected in analyses that compare emerging DPP practices with earlier schemes and identify how new regulatory frameworks accelerate their adoption (Honic et al., 2024).

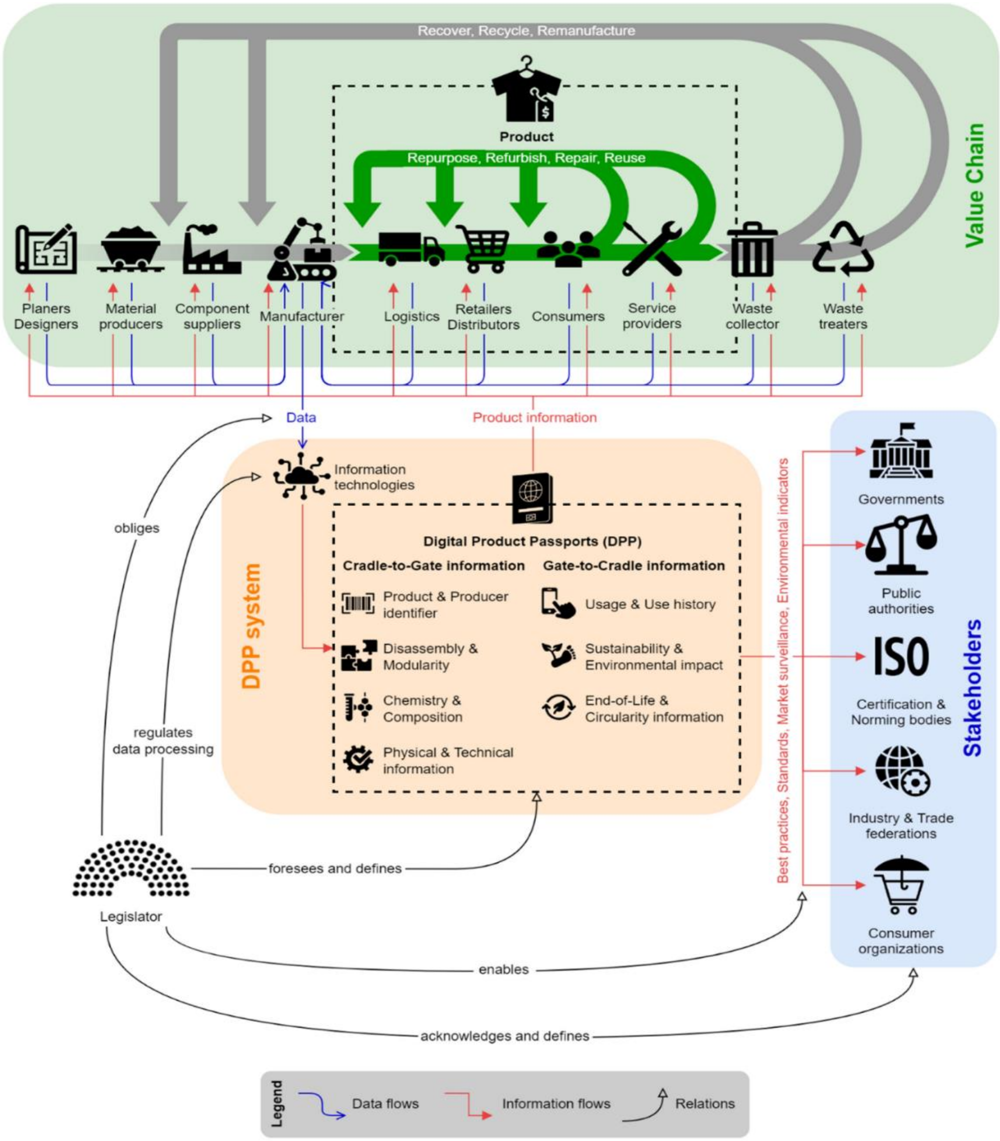

Figure 6 Overview of the DPP ecosystem. Adapted from (Ducuing and Reich., 2023)

2.2.2 Digital Product Passport and Material Passport

The Digital Product Passport (DPP) builds on earlier approaches developed for the construction industry, particularly the Material Passport (MP). Both instruments aim to improve material transparency and traceability by organizing information that supports circular use. Their differences can be understood across several aspects.

Material Passports were introduced as voluntary tools to support circularity at the level of buildings or specific construction components. MPs provide information on material composition, environmental performance, and reuse potential, mainly to guide activities during renovation, deconstruction, or end-of-life planning (Honic et al., 2021). Their application is largely project-based and remains concentrated in the construction sector. MPs are usually created during design or demonstration phases and are often linked to BIM environments or local databases (Costa and Hoolahan, 2024). Due to the absence of a standardized format, MP structures vary widely across projects, which limits their interoperability and broader scalability (Mankata et al., 2025).

The DPP extends this idea beyond the construction sector and introduces a regulated, harmonized approach to product information. The DPP is expected to become a mandatory requirement under EU legislation, with the aim of improving data quality and ensuring consistent information across all regulated product groups (Oteng et al., 2025). Unlike MPs, which are mainly used at later stages of the building life cycle, the DPP follows the entire product life cycle. It includes data on composition, origin, manufacturing, repair, maintenance, and end-of-life pathways (Ruismäki et al., 2025). This broader scope reflects the need for shared and verifiable information across value chains.

Another key distinction is timing. MPs are often generated during the design phase of a project, whereas the DPP begins before products are placed on the market and continues throughout their use and disposal. This shift introduces a more consistent and traceable pattern of information that supports regulatory compliance and monitoring of sustainability targets (Honic et al., 2024). The DPP also relies on harmonized EU data models and unique identifiers to ensure that information can be exchanged between systems, organizations, and digital tools.

Differences also appear in the type of information included. MPs focus on reuse potential and environmental performance indicators relevant to construction. The DPP includes broader datasets covering repairability, durability, safety information, and recycling options, which reflect its cross-sector scope (Ruismäki et al., 2025). Access to the DPP is provided through digital carriers such as QR codes, which connect physical products to their digital records and enable information exchange throughout the supply chain (Oteng et al., 2025).

The user groups also differ. MPs are primarily used by designers, builders, demolition contractors, and asset owners because they support project-specific circularity decisions (Mankata et al., 2025). The DPP engages a wider set of actors, including manufacturers, suppliers, regulators, market surveillance authorities, and consumers, since it is intended to function across entire value chains (Chu et al., 2023). This wider user base reflects the DPP's role as a cross-sector system rather than a construction-specific tool.

Although differences exist, MP experience provides useful input for developing construction-specific DPP templates. The knowledge gained from MP initiatives helps clarify which data are needed to support reuse, how product information can be linked to BIM, and what challenges arise when datasets are not standardized. These insights support the development of DPPs that meet regulatory requirements but also respond to the practical needs of the construction sector (Vangelova et al., 2025).

Aspect	Material Passport (MP)	Digital Product Passport (DPP)
Regulation	Voluntary	Mandatory under EU policy
Sector	Construction sector	Cross-sector system
Life cycle	Focus on end-of-life and reuse	Covers the full product life cycle
Data model	Non-standard formats	Harmonised EU data model
When created	During design or demonstration phase	Before market entry
Type of data	Reuse potential, material composition, environmental info	Composition, origin, repair, maintenance, recycling info
Stakeholders	Architects, builders, asset owners, demolition teams	Manufacturers, suppliers, regulators, consumers
System integration	Often linked to BIM or project platforms	Designed for interoperability across supply chains
Scalability	Project-specific and difficult to transfer	Standardised and suitable for large-scale adoption

Table 2 MP vs DPP

2.2.3 Data Requirements of Digital Product Passports

The data requirements of the Digital Product Passport (DPP) define the information that must be collected, maintained, and updated throughout the life cycle of a product. The DPP functions as a structured digital record that supports traceability, transparency, and circular use by linking physical products to reliable and accessible data. To enable repair, reuse, and recycling, the information included must cover both technical and material-related aspects and remain available across project phases and organizational boundaries (Ruismäki et al., 2025).

Beyond defining what information is stored, DPPs also require clarity on *who* records, manages, and uses this information. Figure 7 illustrates the main stakeholders involved in recording and using DPP data and shows how passport data is connected to identification systems, BIM environments, and asset management systems. The figure highlights that DPP data governance is distributed across multiple actors rather than centrally controlled. Manufacturers and owners provide detailed product information, BIM systems store spatial and functional data, and asset managers use passport data during operation. Persistent identifiers form the linking mechanism between these systems, enabling information continuity over time (Platform CB'23, 2022).

This structure emphasizes that reliable traceability depends not only on data availability but also on coordinated responsibilities for data creation, updating, and access. Information gaps may arise when responsibilities are unclear or when data generated in one system is not properly linked to the passport through consistent identifiers.

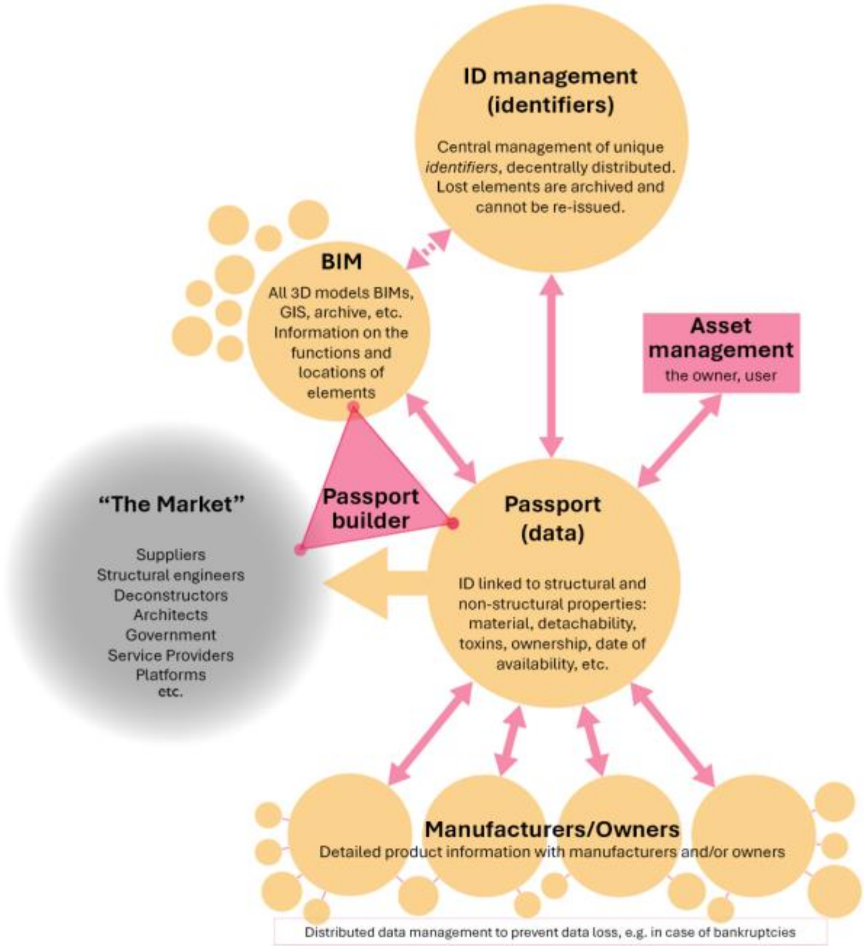

Figure 7 Stakeholder and their roles in recording and usign data (Platform CB'23, 2022)

Across the literature, DPP information is commonly organized into structured information groups that cluster related data fields. This supports consistency, comparability, and interoperability between digital systems such as BIM models, asset management platforms, and material databases used in construction projects (Vangelova et al., 2025). While specific data fields vary by product type, several recurring information groups are consistently identified in construction related DPP frameworks.

The main information groups relevant to construction Digital Product Passports and representative data fields are summarized in Table 3.

Physical properties

describe the basic characteristics of a product that support identification and handling. Typical data include dimensions, weight, density, geometry, and quantity, which influence logistics, installation, and end-of-life processes.

Circular use information

captures how a product can be reused, recycled, or dismantled. This includes reuse possibilities, recycling options, disassembly possibilities, potential future use, and end-of-life routes, supporting decision-making related to value retention and recovery.

Material information

focuses on the composition and origin of materials. Common data fields include material type, material composition, presence of hazardous substances, origin of materials, and recycled content. This information supports regulatory compliance, safe handling, and circular processing.

Product details

enable clear identification across digital systems and supply chains. These typically include product name, manufacturer, product number, article or serial number, production date, and the location of the product within a building (Protokol, 2024).

Additional information

supports long-term use and management. Examples include building or project location, update history, date and time information, condition status, maintenance information, and disassembly instructions. Such data improves lifecycle decision-making during use, renovation, and end-of-life stages .

Across all information groups, data quality and continuity are critical. DPP data must remain accurate, validated, and machine readable to ensure long-term usability and interoperability (European Commission, 2022–2024). Clear responsibilities for data updates, controlled access rights, and the use of product-linked identifiers such as QR codes are essential to maintain information availability throughout the full life cycle.

By structuring DPP information into coherent data groups and embedding them within a governance framework that defines stakeholder roles and system connections, Digital Product Passports provide a foundation for transparent, traceable, and circular product management in construction and infrastructure projects.

Physical Properties	Circular Use	Material Information	Product Details	Additional Information
Dimensions	Reuse possibility	Material type	Product name	Building or project location
Quantity	Recycling possibility	Material composition	Manufacturer	Update history
Density	Disassembly possibility	Hazardous substances	Product number	Date and time information
Geometry	Possible future use	Origin of materials	Article or serial number	Condition information
Weight	End-of-life option	Recycled content	Production date	Maintenance information
			Location	Disassembly instructions

Table 3 Core information groups in Digital Product Passport

2.2.4 Barriers and challenges for implementation

The implementation of Digital Product Passports in construction is affected by several interconnected challenges. These barriers extend beyond technology and relate to technical, organizational, economic, regulatory, and collaborative conditions across the value chain.

Technical barriers

Technical barriers are mainly linked to fragmented and incompatible digital environments. Construction product data are stored across multiple systems that follow different structures, identifiers, and formats, which complicates the creation of a unified DPP. Studies emphasize that current data practices lack common templates and harmonized vocabularies, making it difficult to connect the DPP with BIM models, supply-chain software, or digital identification frameworks (Vangelova et al., 2025; Honic et al., 2024). Decentralized identity and verification methods are still emerging, and most organizations do not yet have stable infrastructures for secure, interoperable data exchange (Illán García et al., 2024). This fragmentation reduces system compatibility and limits the reliability of information flows across the value chain.

Data quality and responsibility barriers

The DPP requires accurate, validated, and continuously updated product information. However, responsibilities for maintaining and verifying data remain unclear in many organizations. Ruismäki et al. (2025) show that information is often entered only at the manufacturing stage, while subsequent changes during installation, use, or maintenance are not recorded. Without defined governance roles, validation routines, or version-control procedures, the credibility and usability of DPP data are weakened. These gaps also reflect limited organizational readiness to manage structured digital information, as noted in construction and other sectors experimenting with DPP systems (Chu et al., 2023; Oteng et al., 2025).

Economic and capacity barriers

Economic and capacity-related barriers arise from the resources required to collect, structure, and update DPP information. Compliance demands ongoing administrative effort, and many small and medium-sized enterprises lack the financial and technical capacity to implement new digital processes or maintain detailed product records (Oteng et al., 2025). The cost of upgrading systems, training staff, and adapting internal workflows contributes to uneven readiness across the value chain. Broader DPP pilot studies in other industries, such as batteries and textiles, similarly report disparities in digital maturity, indicating that capacity gaps may slow down adoption in construction as well (Wautelet & Ayed, 2024).

Regulatory and legal barriers

Regulatory barriers are linked to the evolving nature of the DPP framework. The detailed requirements under the Ecodesign for Sustainable Products Regulation and the revised Construction Products Regulation are still being developed, which creates uncertainty about future obligations, reporting duties, and verification procedures (Jousse, 2024; Ruismäki et al., 2025). Legal concerns also relate to intellectual property rights and data protection. Manufacturers are hesitant to disclose detailed information on material composition, performance, or production processes due to competitive sensitivity and GDPR constraints. These issues reduce willingness to share data and highlight the need for transparent access-control mechanisms and clear governance structures (Protokol, 2024; Chu et al., 2023).

Collaboration and awareness barriers

Collaboration barriers arise from limited coordination, low trust, and uneven awareness of DPP requirements. Many actors in the construction sector are still unfamiliar with the purpose, benefits, and implications of the DPP, which reduces motivation to participate in shared data environments (Ruismäki et al., 2025). Communication across manufacturers, contractors, clients, and regulators remains inconsistent, and stakeholders often lack shared incentives for contributing to a common information system. Insights from cross-sector DPP pilots suggest that successful implementation requires clear value propositions and stronger alignment of expectations across supply chain partners (Oteng et al., 2025; Wautelet & Ayed, 2024).

2.3 Literature Findings and Connection to the Sub-Questions

The literature review identifies clear patterns that shape the conditions for traceability, and the role of Digital Product Passports in Dutch infrastructure projects. Across the reviewed studies, three recurring issues emerge:
(1) fragmented information systems,
(2) limited continuity of material data across the life cycle, and
(3) a lack of shared standards or responsibilities for updating and verifying information.

At the same time, the literature highlights several enabling factors, such as structured data governance, early design consideration for recovery, component standardization, and digital systems capable of maintaining verified material data.
The following subsections summarize the literature-based answers to each sub-question.

SQ1: *What information gaps and missing data limit reliable traceability of materials and components in Dutch infrastructure projects?*

The literature shows that information gaps arise throughout the entire asset life cycle. Missing material characteristics, incomplete production records, outdated drawings, and inconsistent documentation from design to maintenance weaken the traceability chain. These gaps frequently originate at handovers, where responsibilities shift and information is reformatted or reduced. As a result, essential lifecycle data, including material composition, installation conditions and changes made during service life, is often unavailable or unreliable for later use. The literature therefore positions information gaps not as isolated issues, but as structural outcomes of fragmented processes and inconsistent data responsibilities.

SQ2: *How is material traceability currently organized in infrastructure projects, and which challenges reduce its effectiveness?*

Existing traceability practices rely on disconnected systems such as BIM, asset registers, inspection databases and Systems Engineering documentation. Although these tools support project delivery, they do not provide a continuous information chain across the life cycle. The literature cites incompatible formats, non-standard identifiers and inconsistent updating routines as major causes of fragmentation. Information often becomes static after delivery, while assets continue to change. These conditions prevent the formation of a coherent material or component history, limiting the reliability of traceability across phases.

SQ3: *What are the main benefits of a Digital Product Passport, and what challenges affect its implementation across the asset lifecycle?*

Digital Product Passports are described as structured information instruments capable of maintaining verified data throughout the asset lifecycle. The literature highlights that DPPs can support traceability by organizing essential fields within harmonized templates, providing rules for updates and verification, and linking product information to stable identifiers. When aligned with existing digital environments and standardized schemas, the DPP reduces information loss and improves the consistency of lifecycle data.

The literature also notes several challenges that may limit the effectiveness of DPPs. These include the absence of shared data standards across organizations, uncertainties about roles and responsibilities for updating information, concerns about data ownership, and the difficulty of integrating DPP routines into established project processes. Limited interoperability, insufficient incentives for consistent data entry, and varying levels of digital maturity further complicate implementation.

SQ4: *What strategies can be developed to implement Digital Product Passports in infrastructure projects to enhance traceability?*

The literature identifies several conditions for effective DPP implementation:

Shared data standards and uniform terminology
Clear allocation of information responsibilities across lifecycle phases
Integration with existing digital workflows and asset management tools
Verification mechanisms to ensure data accuracy
Governance structures that coordinate updates over long service periods.

These conditions are reflected in strategies that focus on system integration, structured handovers, standardized data models and clear roles. The literature emphasizes that DPPs become effective only when embedded within coordinated organizational processes that prevent information fragmentation and ensure long-term reliability.

3. Interviews

Semi-structured interviews were conducted to collect expert perspectives on how Digital Product Passports (DPP) can improve traceability in Dutch infrastructure projects. The interview guide (Appendix A) included six main themes: current circularity practices, data management, benefits of DPP, required information content, implementation barriers, and final reflections.

Questions were adapted to each participant's background but followed a consistent order from general circularity topics to specific discussions on data responsibilities and implementation feasibility. Each interview lasted between 45 and 60 minutes and was conducted online.

The results mainly contribute to Sub-question 3, which focuses on identifying information needs for DPP, and to Sub-question 4, which explores the practical and organizational conditions for implementation. Insights related to Sub-question 1 and Sub-question 2 also help contextualize barriers and current traceability practices.

3.1 Interview Participants

To explore how Digital Product Passports (DPP) can support traceability and material reuse in Dutch infrastructure projects, 15 semi-structured interviews were conducted with professionals representing different roles and stakeholder groups across the sector. The participants were purposefully selected to capture a balanced range of perspectives from consultants, contractors, asset owners, and policy advisors involved in design, construction, and maintenance processes.

This diversity provided complementary insights into technical, organizational, and governance-related aspects influencing the practical application of DPP. Each interview lasted between 45 and 60 minutes and followed the structure outlined in the interview guide. Table 4 presents an overview of the interview participants.

Code	Organization	Role	Experience	Familiar with DPP	Type of Infrastructure
P1	DPI Consultancy	Asset management advisor	15	No	Tunnels and existing infrastructure
P2	DPI Consultancy	Information manager	10	No	Roads, bridges, tunnels
P3	DPI Consultancy	Environmental advisor	9	Limited	Urban and energy infrastructure
P4	Royal HaskoningDHV	Sustainability / LCA advisor	15	Yes	Regional and national infrastructure
P5	ProRail	Sustainability advisor	6	Yes	Rail infrastructure
P6	Circulair Bouw	Circularity advisor	29	Yes	Circular and reuse-oriented infra projects
P7	Municipality of Eindhoven	Policy advisor	3	Yes	Urban and public-space infrastructure
P8	RWS	Asset manager	7	Yes	National roads and tunnels
P9	RWS	Innovation & transition advisor	4	Limited	Bridges, viaducts, hydraulic structures
P10	Royal HaskoningDHV	Bridge design advisor	30	Yes	Bridges and reuse-oriented infrastructure
P11	Underground-infrastructure contractor	work preparer	*2*	No	Cable routes, wind farms, underground energy infrastructure
P12	TenneT	Supply Chain Advisor – Sustainability	4.5	Yes	High-voltage stations, transmission lines, cables
P13	Royal HaskoningDHV	Sustainability advisor	13	Yes	Dikes, bridges, tunnels, water-safety infrastructure
P14	Province of Zuid Holland	Coordinator Sustainable Infrastructure	10	Yes	Roads, asphalt works, regional infrastructure
P15	Province of Zuid Holland	Senior Advisor Asset Information Management	8	Limited	Roads, civil structures, asset management of provincial infrastructure

Table 4 Interviews participants

3.2 Interview Topics and Questions

The interviews were structured using the topics and question blocks presented in the interview guide (Appendix A). The guide was developed to align with the research sub-questions and the theoretical concepts introduced in the literature review, particularly those related to traceability, information management, and circularity in infrastructure. The structure ensured consistency across interviews while allowing participants to introduce additional perspectives based on their professional background.

Each interview began with introductory questions about the participant's role, organizational context, and experience in the infrastructure sector. These questions supported a clear understanding of each participant's position within the asset lifecycle and their exposure to circularity practices or Digital Product Passports (DPP).

The next theme focused on circularity and the reuse of materials. Participants were asked whether circularity forms part of their organization's strategy, how reuse is currently applied or encouraged, and which barriers make reuse difficult in practice. These questions aimed to identify how reuse is interpreted operationally and which constraints arise before discussing traceability systems.

The interviews then moved to questions on data and material traceability. Participants reflected on how material and component information is currently recorded within projects or existing assets, which systems are used (for example BIM, GIS, Relatics, or asset management databases), and who is responsible for keeping such data up to date. Additional questions explored differences in traceability across materials or project phases, gaps in current data, and what adaptations to existing systems could support better traceability.

After establishing the current situation, the concept of the Digital Product Passport was introduced. Participants were asked whether DPP is expected to be adopted in their organization, which material streams could benefit most, and whether they anticipate long-term advantages in terms of time, cost, or resource savings. Further questions addressed how DPP could support collaboration between project partners and how it should be integrated into existing digital environments.

A dedicated part of the interview addressed the information content of the DPP. Using the predefined list of fourteen data categories, participants were asked which types of information they considered most valuable for supporting traceability and reuse. Follow-up questions examined when DPP data should be updated, who should be responsible for maintaining it, and which characteristics are essential to ensure reliable long-term use.

The final topic focused on barriers and conditions for implementation. Participants reflected on challenges related to data sharing, process integration, digital capability, workload, and the absence of standards. They were also asked to consider potential risks if these issues are not addressed, and to identify measures that could support effective implementation of DPP, such as clearer responsibilities, standardized data formats, or improved coordination among stakeholders.

All questions in the guide were open-ended, enabling participants to provide detailed and context-specific insights. The interview guide served as a flexible structure: although the same thematic blocks were used across all interviews, deviations were allowed when participants introduced relevant examples or elaborated on topics specific to their organizational context.

3.3 Data Analysis Approach

The interview material was analyzed using a thematic analysis to identify recurring patterns and shared interpretations related to circularity, traceability and the implementation of Digital Product Passports in Dutch infrastructure projects. This approach allowed the qualitative data to be examined in a structured manner while remaining open to insights that emerged directly from participants.

All interviews were recorded and automatically transcribed using the transcription function in Microsoft Teams. The transcripts were reviewed for accuracy and clarity before being used in the analysis. The use of AI-supported transcription improved the efficiency of processing the material and provided a consistent textual basis for interpretation.

The coding followed a combined deductive and inductive approach. The deductive structure was based on the six main topics included in the interview guide. These topics concern circularity and reuse, data and traceability, expected advantages of the Digital Product Passport, required information, implementation barriers and possible opportunities. In parallel, inductive coding was used to capture additional insights that did not directly follow from the interview guide but were mentioned repeatedly by participants, such as differences in digital capabilities, uncertainty about data updates and practical constraints in daily project work.

After coding, the material was examined for recurring views, shared concerns and common experiences across participants. This process ensured that the analysis accurately reflected how professionals interpret circularity, information management and traceability in practice, without forcing the data into predefined categories.

3.4 Findings from the Interviews

The interviews provide practical insights into how professionals across the Dutch infrastructure sector experience circularity, traceability and the potential role of Digital Product Passports. The following sections present the main patterns that emerged from their perspectives.

3.4.1 Circularity and Reuse in Infrastructure

Circularity and reuse were described as important drivers in Dutch infrastructure projects, shaped by organizational ambitions, data availability and the practical realities of design and construction. Participants from both public and private organizations portrayed circularity as something that increasingly informs decisions rather than a separate environmental agenda. A sustainability advisor from the rail sector explained that *"a large part of our impact sits in concrete, asphalt and steel, so whenever we apply circular measures it nearly always reduces our environmental costs as well"* (P5). This link between circularity and measurable performance was recognized across several interviews, especially among asset owners who must balance long term stewardship with operational constraints.

A recurring insight was that successful reuse depends on knowing what materials contain, how they were produced and how they have changed through maintenance. A circularity expert emphasized that *"reusable components only remain valuable when you know their history, their quality and their condition, otherwise they end up treated as waste even if the material itself is still perfectly usable"* (P6). Participants repeatedly pointed to missing or outdated data as a barrier, particularly for infrastructure built in periods when documentation standards were less rigorous. An asset manager within a national authority described this challenge by noting that *"many of our structures were built decades ago, so we often do not know the exact number of beams, the mixtures that were used or how elements have changed over time"* (P8). Uncertainty about what is present in existing assets complicates planning for reuse and limits the possibilities for high value recovery.

Bridge engineers added that insufficient documentation not only restricts reuse but can also create technical surprises during refurbishment. A consultant with extensive experience in reusing structural components explained that *"you sometimes discover hidden modifications only when you remove the deck, so good archiving of what was originally built and what was changed later is essential for safe reuse"* (P10). This concern reflects a broader need for consistent information flows across the entire lifecycle, from design to operation.

Municipal perspectives highlighted a different aspect of circularity. Cities aim to reuse available materials, yet responsibilities are spread across departments and external contractors, which makes it difficult to track whether materials return, where they originate and how they will perform. As one municipal advisor noted, *"we try to reuse what is already available, but once materials move outside our direct control it becomes much harder to know what returns, where it goes and how long it will last"* (P7). The ambition exists, but the organizational structure often limits what can be practically achieved.

Energy infrastructure professionals pointed to technical specifications as a fundamental limitation. A supply chain advisor described that *"many components require very pure metals, and for our stations and lines that purity is essential for performance and safety"* (P12). The strict material demands of high voltage assets mean that recycling is often possible, while direct reuse is more constrained.

Consultants working across sectors emphasized the importance of synchronizing material availability with project schedules. One advisor observed that *"materials need to be available at the right moment and in the right condition, otherwise you end up designing from what you wish you had instead of what is realistically there"* (P13). Timing, verified quality and cross project coordination were therefore seen as decisive conditions for making reuse viable at scale.

3.4.2 Data and Traceability

Participants described data and traceability as the foundation on which reuse decisions rely. Across sectors, practitioners noted that the ability to recover materials is strongly linked to how well information about those materials has been captured, maintained and transferred between project phases. A sustainability advisor from the rail sector explained that *"we record deliveries and locations, but the level of detail still varies, and for complex assets the information is often too limited to support confident reuse"* (P5). This difference in data richness influences both the quality of assessments and the reliability of future applications.

Circularity experts stressed that the absence of consistent data increases risk and reduces the value of materials that might otherwise be reusable. One interviewee reflected that *"traceability quickly declines when projects update drawings, repair parts or replace elements without storing that information in a central place"* (P6). Without a clear and continuous record of modifications, even structurally sound components become difficult to evaluate for new applications.

National asset owners highlighted that many existing structures predate contemporary data standards, which complicates efforts to implement more systematic traceability. An asset manager described that *"we sometimes know the condition of a viaduct but not how many beams are underneath or what exact blends were used, because those details were never recorded digitally"* (P8). Such gaps hinder decisions about which elements can be dismantled, transported and certified for reuse.

Bridge engineers emphasized that reliable archival information is essential for safe adaptation. One consultant noted that *"hidden welds or undocumented repairs often emerge only when a structure is opened, and without earlier records those findings can delay or even block reuse"* (P10). This reinforces the need for traceability systems that extend throughout the entire lifespan, not only during design or construction.

A senior asset information advisor added that "*the real problem is the handover between phases, that's where information gets lost or stuck in separate systems, and once it drops out, it rarely comes back in*" (P15). This highlights that gaps in documentation are not only historical, but also arise from fragmented processes and disconnected information flows.

The energy sector added another dimension. High voltage infrastructure requires precise material data, especially for components where purity affects performance. A supply chain advisor explained that *"we rely on suppliers to provide accurate records, but once something is installed it often stays in service for decades without being updated, so information becomes static while the asset changes"* (P12).

A provincial sustainability coordinator confirmed this issue from an asset-owner perspective, noting that "*we often do have the information, but it is buried in old project handover files that no one consults again, and by the time we need it, it has become difficult to locate or has* *effectively disappeared*" (P14)This disconnect between long service lives and static datasets limits the traceability of components that might be reused in the future.

Consultants working across infrastructure domains described how data fragmentation restricts circular strategies. One advisor summarized that *"if information is scattered across drawings, spreadsheets and project folders, no one has the complete picture needed to judge whether a material can return into a new design"* (P13). The challenge is therefore not only collecting data but ensuring that it remains accurate, accessible and aligned with the evolving state of the asset.

3.4.3 Advantages and Future Use of Digital Product Passports (DPP)

Across the interviews, many participants described the Digital Product Passport as a practical way to bring structure to the currently fragmented information landscape in infrastructure projects. They explained that data now moves through projects in separated formats, which makes it difficult to keep track of what materials contain and how assets change over time. Several interviewees expected that a DPP could create a more continuous flow of information. One participant noted that *"a passport that stays with the material would stop information from disappearing when projects move on"* (P6). This idea appeared across multiple conversations, especially among those who regularly face missing or outdated documentation.

Participants also pointed to the advantage of having supplier information in one consistent structure. A sustainability advisor explained that *"using the same format for material data would make decisions much easier, because you can compare everything without rebuilding it each time"* (P5). Others confirmed that a shared format could support procurement and long term assessments by reducing uncertainties and preventing repeated work.

Engineers working with reused components described that a DPP could reduce uncertainty during inspections. One interviewee explained that *"earlier changes become clear much faster when they are logged somewhere reliable"* (P10). They viewed this as important for safe reuse, since many issues arise from undocumented repairs or adjustments made in older projects.

Consultants working with asset owners highlighted that long lifespans require data that can be updated. One participant explained that *"our current systems freeze information at the delivery date, while the asset keeps changing afterwards"* (P8). Participants in the energy sector recognized the same issue, noting that a DPP could help information stay accurate even after decades in operation.

A final recurring advantage was cooperation. Participants explained that many difficulties in reuse arise because information is scattered across drawings, spreadsheets and folders. A consultant summarized this by saying that *"a shared structure prevents every organization from recreating the same information again and again"* (P13). They believed that a DPP could make collaboration between clients, designers, contractors and suppliers more efficient and more reliable.

3.4.4 Content and Reliability of DPP

Interviewees were asked to select the most relevant information categories from the fourteen items shown in table 6 in appendix A. This question was included because a Digital Product Passport must follow the principle that only necessary information should be stored. By selecting from the table, participants had to decide which data is essential for reuse while keeping the passport concise. Several interviewees emphasized this need. One participant explained that *"you should not make it too big, because then people lose sight of what really matters"* (P13). Another pointed out that *"if it becomes too complicated, everyone stops using it"* (P11).

The graph below shows clear preferences. Environmental performance data was chosen most frequently, followed by inspection and maintenance records, remaining service life, condition assessments and verification of data quality. These categories were selected because they offer the strongest basis for safe and reliable reuse. As one engineer stated, *"you want to know what the material has been through, otherwise you cannot decide if it can be used again"* (P10).

Participants also prioritized information that helps understand how an object was built and changed over time. Categories such as modification history, connection details and dismantling instructions were considered important because these details are often missing today. One interviewee highlighted this by saying that *"we sometimes do not even know which changes were made during the lifetime of a structure"* (P10). Without this information, assessing strength, condition or reuse potential becomes difficult.

Another commonly selected category was the link with existing Dutch systems such as BIM, Relatics and GIS. Interviewees stressed that the DPP should not become a new isolated tool. One participant noted that *"information is now stored everywhere and nowhere, so it needs to fit into one shared structure"* (P8). Others mentioned that Excel-based approaches are not suitable for information that must be updated throughout the asset lifecycle, explaining that *"Excel cannot support dynamic data in a reliable way"* (P12).

Interviewees also discussed concerns about long term data quality. Infrastructure assets often remain in service for decades, and participants described that information can quickly become outdated. One participant explained that *"data freezes at the moment an object is installed, while the object itself continues to change"* (P8). This is why many interviewees argued that updates should follow moments where trustworthy information is already collected, such as inspections, major maintenance or refurbishment.

Across the interviews, the selected categories show a shared expectation that a DPP must stay practical and focused, while still providing the essential technical and environmental information needed for reuse. The choices reflect a preference for clarity, accuracy and long term usability, in line with the requirement to keep the passport as lean and reliable as possible.

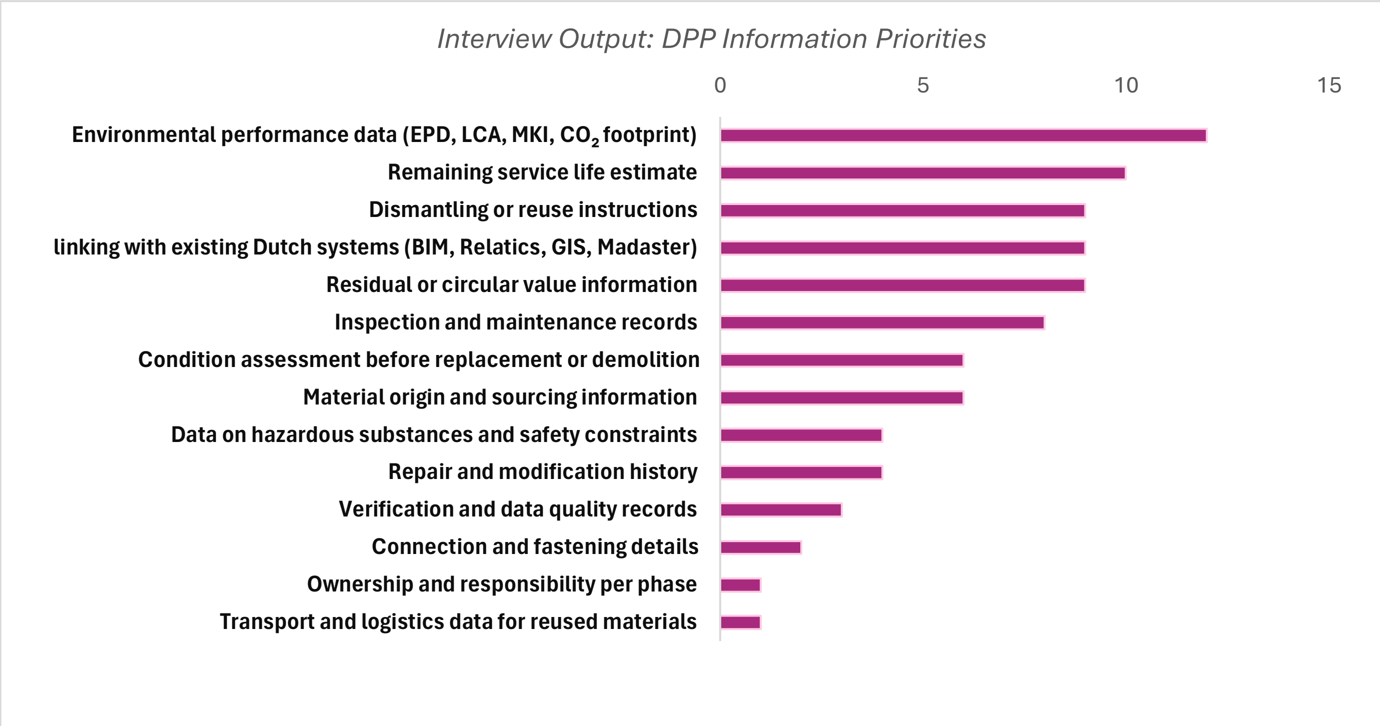

Figure 8 Interview Output: DPP Information Priorities

3.4.5 Barriers to DPP Implementation

The interviews revealed several recurring barriers that influence whether a Digital Product Passport can function effectively in infrastructure projects. Participants described practical, organizational and informational challenges that currently limit consistent data use and restrict the feasibility of implementing a shared passport structure.

1. Inconsistent data practices between organizations

Interviewees explained that organizations all use different ways of structuring information, which makes it difficult for a DPP to work. People described that data sits in BIM, Relatics, GIS, Ultimo or Excel, and none of these systems speak the same language. One participant said that *"everyone uses a different structure, so you cannot bring the data together in a normal way"* (P13). Another added that *"information is everywhere and nowhere"* (P8). Without a shared structure, a DPP cannot be filled consistently.

2. Gaps and uncertainty in existing asset information

Many assets were built long before digital systems existed. Interviewees said that basic information is missing, unclear or outdated. One participant noted that *"data freezes when something is installed, but the object keeps changing"* (P8). Others explained that drawings, revisions and repairs often disappear during the lifetime of an asset. Participants said this makes a DPP difficult because *"we sometimes do not even know what changes were done over the years"* (P10). This limits confidence when reusing materials.

3. Limited time and resources for data management

A strong pattern across interviews was the lack of time and capacity. People said that although they see the value of a DPP, daily work makes it hard to record or update information. One interviewee said that *"people think it is important, but they simply do not have the time to do it properly"* (P10). Another mentioned that *"during construction everything goes fast, so information is not always captured"* (P7). This barrier affects both creating and maintaining DPP data.

4. Unclear responsibility for keeping the passport updated

Interviewees described uncertainty about who is responsible for the passport once an asset is handed over. Some said the contractor should update it, while others said the asset owner must do it. One participant explained that *"you need one clear owner, otherwise nobody keeps the data up to date"* (P9). Because responsibilities are unclear, updates often stop after delivery.

5. Limited sharing of sensitive material information

Several interviewees said that suppliers do not want to share detailed material information because it contains business secrets. One participant explained that *"producers do not want to give away their mix or their recipe"* (P7).

A provincial sustainability coordinator described the same challenge, noting that "*sometimes they do have the information, but they refuse to share it because they say it is commercially sensitive*" (P14)
Others mentioned that environmental data or technical information is sometimes kept internal. This limits how complete the DPP can be.

6. Lack of a common approach for introducing DPP

Participants said that there is no single approach that everyone follows. Without guidance, organizations make their own versions, which increases fragmentation. One interviewee stated that *"without joint direction, every organization creates its own version, and that does not work"* (P6). Others said they are waiting for European or national rules before starting. This slows down DPP implementation across the sector.

3.4.6 Opportunities and Success Factors for DPP Implementation

Interviewees identified several opportunities that could support meaningful adoption of Digital Product Passports in the infrastructure sector. A key opportunity mentioned across roles was the potential to improve insight into how materials have performed throughout their lifetime. Participants described that reliable lifecycle information makes reuse decisions safer and more predictable. As one interviewee stated, *"if we know what materials went through during their lifetime, we can make smarter decisions about reuse"* (P10). A DPP was also seen as a way to prevent information from disappearing after project completion or staff changes. One participant highlighted that *"you prevent information from getting lost when a project ends or when people change roles"* (P6). Interviewees explained that this continuity is crucial for long lived assets. Participants further emphasized that using one shared format can improve cooperation between parties, since *"using the same format makes it much easier to exchange information without rebuilding it every time"* (P5).

A second group of success factors relates to data responsibilities, updating practices and system integration. Interviewees stressed that a DPP needs a clearly defined owner to remain reliable. One participant stated that *"there must be one owner who checks the information and makes sure it stays accurate"* (P9). Participants also explained that information should not be updated constantly, but during existing activities where trustworthy data is already collected, such as inspections or major maintenance. As one interviewee noted, *"you update it when you already have the right information, not every week"* (P13). They saw this as a realistic way to keep the passport aligned with actual asset conditions. Several interviewees added that the DPP must integrate with current digital tools to avoid unnecessary extra work. One participant explained that *"it must fit into the systems we already use, otherwise nobody will keep it up to* *date"* (P8). Linking the passport with BIM, GIS or Relatics was considered essential for long term use.

A final opportunity concerns digital support, including the future use of artificial intelligence. Some interviewees mentioned that AI could help extract and structure information from documents automatically. One participant described this by saying that *"AI can help us recognize and structure data automatically and translate it into usable information"* (P8). This was viewed as a promising way to reduce manual workload and improve data quality, especially for older assets with incomplete documentation.

A senior asset information advisor emphasized that "*a standardized exchange format, a shared information model and tools that make the data easy to visualize would enormously help people actually use the passport*" (P15). These technical enablers were seen as crucial for making DPP information usable across different organizational systems.

Across all interviews, opportunities were linked to conditions that keep the passport simple, reliable and connected to existing processes. Participants saw DPP as a useful tool for improving information quality, strengthening collaboration and enabling circular decision making when supported by clear roles, structured updates, shared formats and digital assistance such as AI.

3.5 Conclusion of the Interviews

The interviews provided a clear and consistent picture of how professionals across the Dutch infrastructure sector view the future of Digital Product Passports and improved traceability. Although the participants work in different roles and organizations, they expressed a shared awareness of the need for more reliable information to support reuse. Their responses showed a strong willingness to move toward better traceability, while also recognizing that successful implementation depends on simple processes, clear responsibilities and coordination across the sector. Interviewees emphasized that a DPP can contribute to the main goal of this research only if it becomes a practical tool that fits existing workflows rather than adding unnecessary complexity. The conversations also highlighted that technology alone will not solve current information issues. Participants stressed that agreements, ownership and collaboration are just as important as digital systems. The interviews suggest that the sector is ready for guidance, and that a structured strategy could help provide the direction that many organizations are currently waiting for. These insights confirm the relevance of developing a clear framework for DPP implementation, as well as improving traceability practices to support future reuse in infrastructure projects.

3.6 Synthesis of Interview Findings

The interviews highlight how professionals across the infrastructure sector interpret concepts from traceability and data governance literature within the context of their daily work. Academic and policy frameworks describe complete lifecycle information, stable identifiers and structured data processes, yet the interviews show that these ambitions often encounter practical constraints. Participants explained that traceability depends on knowing what materials contain, how they were installed and how they have changed during use. Such information is rarely complete for existing assets because documentation is missing, inconsistent or stored in separate environments. These conditions illustrate why traceability is regarded as a fundamental requirement for circular objectives and informed material related decisions.

The interviews also show a shared understanding of the value of a Digital Product Passport. Participants recognized that a passport can help prevent information loss, maintain continuity across lifecycle phases and support more consistent decision making. Although they were not highly optimistic about immediate applicability in current project environments, they agreed that a passport can influence practice significantly when implemented in a clear, simple and well integrated manner. Interviewees described that a passport becomes meaningful when it connects to existing activities such as inspections, maintenance or project handovers and supports work processes rather than increasing administrative effort.

The interviews also bring forward insights that are discussed less prominently in theoretical work. Practitioners noted that information discontinuities often originate at transitions between project phases where responsibilities, systems and data structures differ. Information may still exist but becomes inaccessible when stored in handover documentation or in formats that are not aligned with current systems. Participants described how fragmented environments, inconsistent updating and unclear ownership contribute to these gaps. Several interviewees pointed to the potential of digital tools that can extract, classify and organize information automatically, especially for assets with incomplete historical records.

The findings indicate that linking long term information ambitions to the realities of infrastructure projects requires attention to roles, routines and integration with existing systems. Participants supported the need for improved traceability and considered a passport a relevant instrument when supported by clear responsibilities, realistic updating moments and credible information structures. Their experiences show that the effectiveness of a passport depends on its fit with organizational capacities and established workflows rather than on the concept alone.

3.7 Connecting to Research Sub-Questions

SQ1: *What information gaps and missing data limit reliable traceability of materials and components in Dutch infrastructure projects?*

Interviewees described information gaps as a persistent issue across the sector. Older assets lack essential documentation, and newer assets often contain fragmented or inconsistent records. Practitioners noted that information becomes difficult to retrieve once it is stored in separate environments or only exists in handover documentation. Drawings, revision histories and metadata are frequently incomplete, and later modifications are often not registered. These gaps reduce the reliability of traceability and complicate evaluations of material condition, origin and changes over time.

SQ2: *How is material traceability currently organized in infrastructure projects, and which challenges reduce its effectiveness?*

Current traceability practices rely on several digital environments and asset management systems. These tools support project delivery, yet interviewees explained that they operate independently and are not updated consistently over the lifecycle. Information often becomes static once an asset is installed, and later interventions are not incorporated. Fragmentation across systems, unclear updating routines and inconsistent file structures contribute to data loss and reduce confidence in information that should support lifecycle decisions.

SQ3: *What are the main benefits of a Digital Product Passport, and what challenges affect its implementation across the asset lifecycle?*

Interviewees viewed the Digital Product Passport as a promising mechanism for keeping essential information connected across project phases, particularly when it provides a clear structure and supports timely updates. They considered its main benefit to be the ability to maintain continuous and reliable information on materials and components without relying on separate documents or individual practices. At the same time, participants noted challenges that could limit effective implementation, including unclear responsibilities for updates, the risk of extra administrative work and difficulties aligning the DPP with existing routines. Interviewees stressed that the passport must remain simple, integrate into current workflows and avoid becoming a parallel process, otherwise its intended benefits may not be realized.

SQ4: *What strategies can be developed to implement Digital Product Passports in infrastructure projects to enhance traceability?*

Interviewees pointed to several conditions that shape the feasibility of a passport. Clear data ownership, defined responsibilities and realistic updating practices were described as essential. Participants noted the need for shared structures to avoid parallel approaches and for alignment with current systems to prevent extra administrative work. They also mentioned that automated tools for extracting and structuring information could reduce workload during implementation, particularly for assets with incomplete documentation.

4. Findings and Analysis

4.1 Findings from Literature

The academic and policy literature on circular construction and digitalization in infrastructure emphasizes lifecycle information gaps, traceability practices and the emerging Digital Product Passport (DPP) as closely connected themes. These concepts illustrate how structured and reliable information can support circular ambitions by improving data quality, continuity and accessibility across the life cycle of infrastructure assets.

4.1.1 Information Loss Across the Asset Lifecycle

Literature on lifecycle information management shows that information loss is a persistent barrier in construction and infrastructure projects. Data generated during design and construction often does not remain linked to the asset once it enters operation, which limits later access to reliable material and component histories. (Watson et al., 2019) explain that this disconnect arises because information is stored in separate systems, transferred through unstructured handovers or not updated after commissioning. As a result, essential details such as material composition, production conditions and installation outcomes frequently become unavailable when needed for assessment.

Handover stages are identified as critical points where information gaps emerge. (Succar & Poirier, 2020) describe how milestone transitions introduce inconsistencies and omissions, since datasets are reformatted or reduced as responsibilities shift between actors. These gaps accumulate across the long service lives typical of infrastructure assets.

Fragmentation across documentation systems further contributes to information loss. (Costa & Hoolahan, 2024) highlight that data distributed across BIM files, certificates, spreadsheets and asset management tools is difficult to align and verify over time. The literature therefore positions information loss as a structural challenge that undermines lifecycle continuity and restricts reliable traceability.

4.1.2 Traceability and Life Cycle Data Continuity

Traceability is described as an essential mechanism for maintaining information about materials and components throughout their life cycle. Research on material passports demonstrates that structured documentation can improve data continuity by recording material origin, characteristics and transformation over time (Honic et al., 2021). Reviews of passport initiatives show that information consistency, verification and long term accessibility are decisive factors for ensuring that material data remains useful in later project phases (Mankata et al., 2025). Studies on construction practice further illustrate that traceability is difficult to achieve when information is dispersed across separate tools and project teams, which leads to data loss and incomplete records (Costa & Hoolahan, 2024). The literature therefore positions traceability as both a technical and organizational requirement. It depends on structured data templates, shared responsibilities and processes that ensure information is updated as assets change over time. Without such practices, the potential of reuse is limited.

4.1.3 The Digital Product Passport as an Enabler

The Digital Product Passport is presented as a harmonized information instrument intended to support transparency and circularity by organizing essential product data in a consistent and accessible format. Several studies describe the DPP as an evolution of earlier material passport concepts, designed to function across industries and to cover the full life cycle of products (Honic et al., 2024). Literature emphasizes that the DPP brings value by defining which information must be recorded, how it should be structured, and how it can be exchanged between digital systems and organizations (Jousse, 2024). Work on DPP development shows that secure identifiers, verifiable credentials and interoperable data models are required to prevent data fragmentation and to maintain continuity over long service periods (Illán García et al., 2024). Research also highlights that governance remains a central challenge. Responsibilities for updating information, verifying data quality and managing access rights must be clarified for the DPP to function as intended (Walden et al., 2021). Finally, studies on circular manufacturing and construction underline that consistent DPP data can support repair, reuse and material recovery by providing trusted and structured information about product composition, performance and environmental impacts (Saari et al., 2022; Vangelova et al., 2025; Psarommatis & May, 2024; Oteng et al., 2025). When these conditions are met, the DPP can act as a key mechanism for enabling traceability and supporting circular decision making..

4.2 Findings from Interviews

The interviews provide a practical perspective on how reuse, traceability, and DPP are perceived and implemented within the Dutch infrastructure sector. Participants largely agreed with the principles identified in the literature but described persistent organizational, cultural, and technical barriers that limit progress.

4.2.1 Information Gaps

Interviewees described reuse as technically possible but often hindered by missing or unreliable information. Participants noted that material data rarely stays complete throughout an asset's life. One interviewee explained that *"after a few years, drawings change and nobody knows which version is correct"* (P10). Others mentioned that information is scattered across systems, making it difficult to trace what a component has been through. As one respondent said, *"the data exists somewhere, but the link to the object is gone"* (P2).

Older assets were described as the most challenging, since repairs and modifications were not consistently documented. A participant observed that *"so many interventions happened that we no longer know the full history"* (P13). Because this uncertainty affects safety assessments, organizations tend to choose low-value recycling instead of high-value reuse.

Across the interviews, practitioners agreed that the main barrier is not the technical condition of materials but the lack of trusted, verifiable information needed to justify reuse.

4.2.2 Traceability and Data Fragmentation

Interviewees described traceability as inconsistent and fragile, mainly because information is distributed across separate systems, teams and project stages. Participants explained that data often exists in multiple places but lacks a single, reliable source. One interviewee noted that *"everyone keeps their own version, so there is no shared truth to rely on"* (P4). Others pointed out that BIM, Relatics, GIS and spreadsheet files are rarely aligned, resulting in duplicated or contradictory records. A respondent explained that *"you can find the information, but it is spread across so many tools that it becomes unreliable"* (P6). Several participants emphasized that traceability weakens after construction, when updates are no longer consistently recorded. As one asset manager stated, *"the moment it is delivered, the data stops moving, but the asset keeps changing"* (P8). Across the interviews, practitioners viewed fragmentation not a lack of systems as the main reason why components cannot be reliably traced for future reuse.

4.2.3 Practical Concerns and Limitations of the Digital Product Passport

Interviewees recognized the potential of the Digital Product Passport but expressed significant doubts about whether it can function in practice under current conditions. Several participants questioned whether the sector has the time or capacity to maintain another information requirement. One interviewee remarked that *"we already struggle to keep existing systems up to date, so expecting a passport to stay accurate is quite optimistic"* (P10) . Others warned that integration is often mentioned in theory but rarely achieved, noting that *"we work with BIM, Relatics, GIS and our own databases; connecting all of that is far more complex than people think"* (P1) . Participants also questioned whether suppliers would share sensitive data, with one stating that *"some producers will never put their recipes or test values in a public passport"* (P7) . Several interviewees doubted that the DPP can succeed without strict governance, summarizing that *"if nobody takes ownership after delivery, it will become outdated as fast as everything else"* (P12) . Overall, practitioners saw promise in the DPP, but only if practical limitations, sector capacity and data responsibilities are addressed realistically.

4.3 Comparative Analysis: Theory vs Practice

This section compares theoretical perspectives on lifecycle information loss, traceability and Digital Product Passport (DPP) implementation with the insights gathered from interviews with professionals in the Dutch infrastructure sector. The aim is to assess how far theoretical expectations correspond with practical realities and to identify the organizational and technical challenges that influence the feasibility of DPP-supported traceability in current practice.

4.3.1 Information Loss

In the literature, lifecycle information loss is described as a persistent structural limitation that undermines the reliability of asset documentation. Authors note that data generated during design and construction frequently becomes disconnected from the asset once it enters operation, largely because records are stored in isolated systems or not updated after handover

(Watson et al., 2019). Theoretical models assume that information continuity can be achieved when milestone handovers are well defined, verification procedures are embedded and responsibilities for data maintenance are clearly assigned (Succar & Poirier, 2020). Under these theoretical conditions, lifecycle information is expected to remain complete, traceable and usable for later assessment.

The interview findings show that these assumptions diverge sharply from practice. Participants consistently described information that is outdated, incomplete or inaccessible when needed. Several noted that essential documents such as installation reports or inspection records are either missing or stored in locations that are not linked to operational systems. One participant explained that "*after the project is delivered, the data more or less freezes. Ten years later, nobody knows what happened to the asset*" (P5). Others emphasized that data updates stop after commissioning and that information ownership remains unclear, which allows gaps to accumulate throughout the asset's lifetime.

This comparison reveals a gap between theory and practice. Literature treats information loss as a challenge that can be mitigated through technical alignment and structured processes, whereas practitioners experience it as an organizational problem embedded in fragmented responsibilities and inconsistent documentation practices. The feasibility of later assessments therefore depends not only on technical systems but on sustained information governance, long-term accountability and continuous updating routines, which are not yet consistently embedded in infrastructure delivery.

4.3.2 Traceability and Data Fragmentation

In the literature, traceability is described as a central requirement for circular construction. Authors emphasize that traceability enables information to follow materials across project phases when supported by interoperable systems, shared standards and stable identifiers (Honic et al., 2021; Mankata et al., 2025). Theoretical work often assumes that digital tools and semantic alignment can create continuous information flows, and that traceability will function if technical structures are in place.

The interview findings show a different picture. Practitioners recognized the importance of traceability, but most explained that information continuity is difficult to maintain in practice. Participants described that data is frequently stored in separate systems and updated inconsistently. One interviewee noted that *"the information exists, but each system keeps its own version, and it does not stay aligned over time"* (P4). Information often stops being updated after handover, and responsibilities for maintaining data are not clearly defined.

This reveals a gap between theory and practice: literature presents traceability primarily as a technical capability, while practitioners experience it as an organizational challenge shaped by fragmentation, unclear roles and limited long-term data management. Although the value of traceability is widely recognized in practice, the conditions required to sustain it are not yet consistently in place.

4.3.3 Implementation of DPP: From Concept to Practice

In the literature, the Digital Product Passport is presented as a harmonized information framework intended to support transparency, comparability and improved information flow across the life cycle of construction products. Studies emphasize that the DPP provides a structured way to store essential data on material composition, environmental performance, maintenance history and end-of-life options (Vangelova et al., 2025). Literature also describes the DPP as a tool that can reduce fragmentation by defining standard data fields and linking information across life cycle stages. Several reports note that the DPP is still under development but is expected to organize information more consistently once templates, standards and governance arrangements are established (Jousse, 2024). From a theoretical perspective, the DPP is therefore viewed as a promising mechanism that can strengthen traceability when supported by shared structures.

The interview findings show a more cautious view. Practitioners acknowledged the potential value of the DPP but questioned whether the benefits described in literature can be achieved under current sector conditions. Interviewees repeatedly stated that implementation will require a long period of development. One participant explained that *"it will take years before something like this works, not next year or the year after"* (P12) . Another remarked that *"you cannot expect that we can use this soon; it needs a lot of years before the basics are in place"* (P10) . Participants also doubted whether suppliers would provide the technical detail expected in literature and whether passport data could remain accurate without clear long-term ownership. Several interviewees added that the DPP alone cannot address deeper issues such as inconsistent updating practices and fragmented digital systems.

Across the literature and interview findings, a specific contradiction emerges regarding update responsibilities within the Digital Product Passport. While academic and policy oriented sources commonly describe the DPP as a lifecycle instrument that is updated throughout design, construction, operation and end-of-life phases, interviewees consistently reported that information entry currently concentrates on manufacturing and early project stages. Updating beyond commissioning was described as limited, ad hoc or absent, with responsibilities for maintaining passport information over time remaining unclear. This indicates that, in current practice, the DPP is more closely aligned with early-phase documentation than with the continuous lifecycle updating assumed in the literature.

5.Strategy Guide

Following the identification of challenges related to the implementation of Digital Product Passports in infrastructure projects, this chapter moves towards the development of practical strategic responses. In addition to findings from the literature review, the interviews provided concrete ideas, recommendations and practical considerations based on professional experience. These insights helped translate theoretical requirements into strategies that reflect how information is currently produced, exchanged and managed in infrastructure projects.

Based on this combined input, a strategy guide is developed to support the implementation of Digital Product Passports and, through this, enhance traceability across the asset life cycle. The guide addresses the fourth sub-question, *"What strategies can be developed to implement Digital Product Passports in infrastructure projects to enhance traceability?"*

The proposed strategies respond to challenges related to fragmented information environments, limited standardization, constrained digital and organizational capacity, unreliable data and unclear allocation of responsibilities, which collectively hinder effective DPP implementation and affect traceability throughout the lifecycle.

The strategy guide focuses on new assets, as addressing existing infrastructure would require different approaches to reconstruct missing or incomplete information that was not captured during earlier project phases. It is written from the perspective of asset owners and concentrates on governance and lifecycle information management rather than technical product design or material specification. The guide is conceptual in nature and provides strategic direction rather than detailed implementation procedures, allowing it to be applied across different project contexts.

In total, twelve strategies are presented. Each strategy is structured to outline its underlying rationale, followed by a brief indication of how the strategy could be implemented and a discussion of the expected effects and consequences for traceability. This consistent structure helps clarify the intended contribution of each strategy and highlights the implications of not addressing the identified challenges. Together, the strategies provide a structured basis for improving information continuity across project phases and supporting preparation for future Digital Product Passport requirements in infrastructure projects. An overview of the strategy guide is presented in Figure 9.

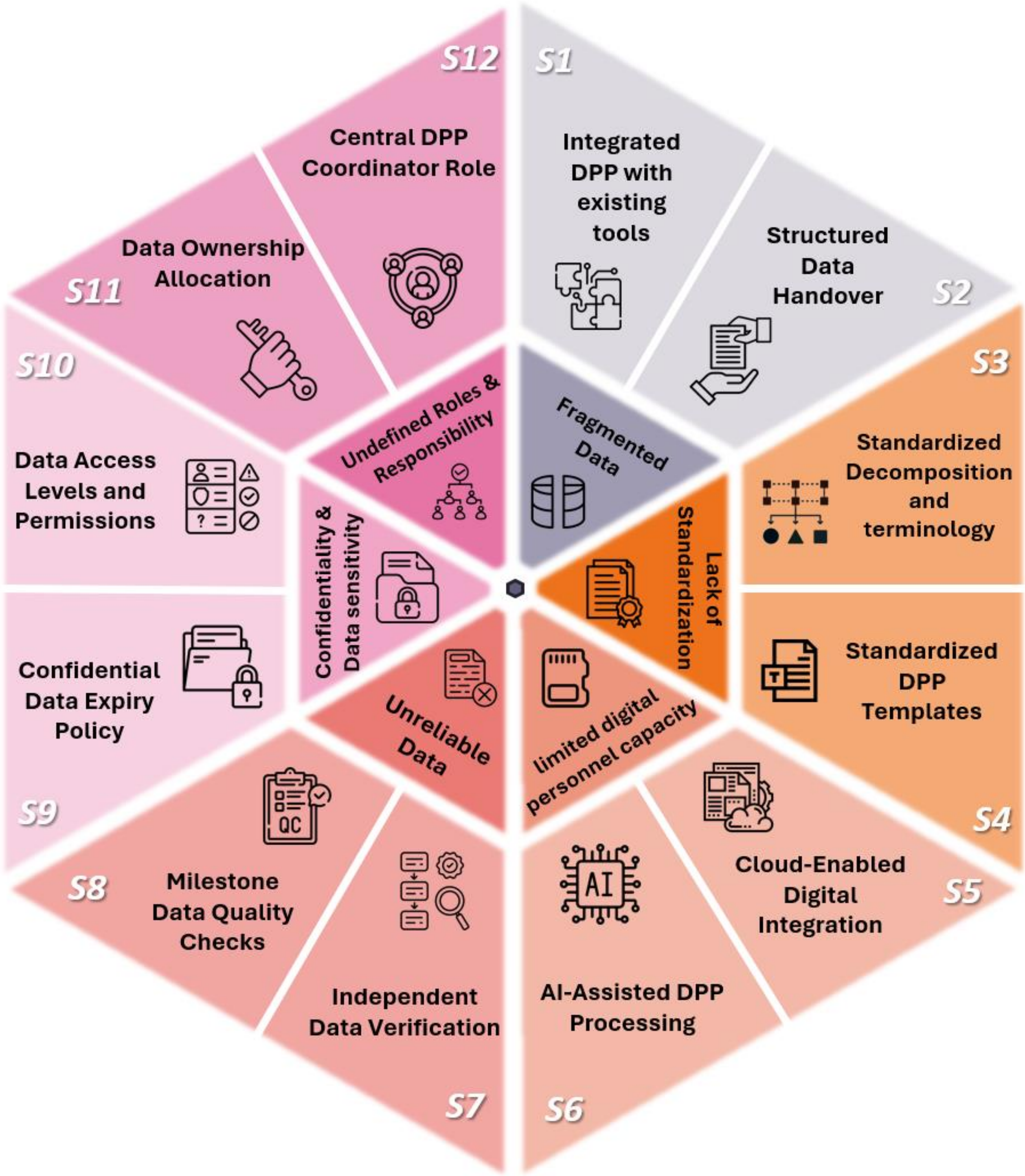

Figure 9 Strategy Guide

5.1. Fragmented Data

Fragmented information across BIM, Relatics, GIS and PDF based records limits the continuity of lifecycle data and weakens traceability. The literature and interviews show that dispersed and inconsistent datasets hinder the development of a reliable DPP structure. Strategies S1 and S2 address this challenge by improving system integration, centralizing storage and establishing structured handovers.

S1. Integration of DPP Requirements into Existing Systems

Interview and literature findings indicate that a Digital Product Passport is unlikely to function effectively when introduced as a separate platform, as project teams already work extensively with BIM, Relatics, GIS and maintenance systems such as Ultimo. Integrating DPP requirements into these existing environments therefore provides a more feasible basis for maintaining continuous lifecycle information.

Implementation
DPP requirements are embedded into systems already used by project teams by integrating mandatory DPP data fields into existing BIM, Relatics and Ultimo environments. Material properties, installation dates and component identifiers are captured within these systems during routine project activities and linked to the Digital Product Passport without repeated manual entry.

Effects and consequences
This supports more consistent updates, reduces parallel documentation and ensures that information generated during routine activities contributes to the long term lifecycle record. If this strategy is not applied, DPP implementation remains dependent on standalone platforms, increasing the risk of fragmented information, inconsistent updates and reduced traceability across lifecycle phases..

S2. Structured Data Handover Between Project Phases

Interview findings indicate that information loss frequently occurs during transitions between project phases, particularly when responsibilities shift from design to construction and later to asset management. Literature similarly identifies these handover moments as vulnerable, as data are often reformatted, filtered or only partly transferred.

Implementation
A structured data handover process is implemented by defining in advance which data fields must be delivered at each project transition. As built documentation, delivery batches, installation dates and inspection results are aligned and transferred in a consistent format at the moment of handover between phases.

Effects and consequences
This limits information loss during phase transitions and ensures that data generated during construction remains available for subsequent project stages. As a result, construction information can be used directly for the Digital Product Passport, reducing the need for later data reconstruction and strengthening continuity across the asset lifecycle. If this strategy is not applied, gaps in material history persist, weakening traceability and reducing the reliability of lifecycle information.

5.2. Lack of Standardization

The interviews and literature indicated that inconsistent classification and terminology make information difficult to combine across project phases. Although frameworks such as NEN 2767, ISO 19650 and CB NL exist, their use is uneven, which limits the creation of a coherent material history for the Digital Product Passport. Strategies S3 and S4 address this challenge by supporting shared standards, consistent decomposition and uniform DPP templates.

S3. Standardized Asset Decomposition and Terminology

Standardizing how assets are decomposed into components is essential for linking information across project stages. Existing frameworks such as CB NL and the structures used in NEN 2767 provide guidance for describing assets in a consistent and interpretable way, allowing information from different lifecycle phases to be associated with the same digital object.

Implementation
A standardized decomposition structure and shared terminology are applied across design, construction and maintenance phases. Components, such as precast concrete beams, are classified at a consistent level of detail and identified using the same naming conventions, enabling reinforcement drawings, delivery certificates, installation records and maintenance inspections to be linked to a single component identity.

Effects and consequences
This improves searchability, reduces misinterpretation between disciplines and ensures that material history remains attached to the same element throughout the asset lifecycle. If this strategy is not applied, records become dispersed across different decomposition structures and naming practices, making continuous traceability difficult to achieve.

S4. Unified DPP Templates

Standardized templates for Digital Product Passport content support consistent and complete data delivery across suppliers and contractors. Literature on DPP implementation highlights that templates provide a common structure and terminology, ensuring that essential information is captured in a uniform way.

Implementation
Unified DPP templates are applied across suppliers and contractors by defining mandatory fields and shared terminology for DPP-related information. Data such as production method, environmental performance, delivery batch, installation date and component location are submitted using a consistent field structure and meaning.

Effects and consequences
This reduces variation in documentation, simplifies data entry and review, and limits gaps in information, enabling easier integration into the Digital Product Passport and stronger component-level traceability. Without unified templates, documentation remains inconsistent and lifecycle information becomes fragmented.

5.3. Limited Digital and Personnel Capacity

The interviews and literature showed that many organizations lack the digital maturity and personnel capacity needed to maintain structured lifecycle information. Manual processes such as PDF based documentation and spreadsheet tracking remain common, which increases the risk of incomplete or delayed data. These constraints weaken traceability and make DPP implementation difficult. Strategies S5 and S6 address this challenge by supporting digital integration and automating data processing.

S5. Cloud Enabled Digital Integration

Cloud based environments offer a practical way to improve information management in organizations with limited digital capacity. Literature and interview findings indicate that information stored in local folders or exchanged through email often becomes outdated or fragmented, whereas shared cloud platforms support more consistent access and updates.

Implementation
Project information is integrated into a shared cloud environment that serves as a central location for storing and updating data. Installation data, delivery information and related records are uploaded directly to the cloud by project participants, allowing all contributors to work with the same dataset without additional local installations or manual data transfers.

Effects and consequences
This reduces the risk of fragmented or inconsistent records and supports real time availability of project information. As a result, data generated on site can be more easily incorporated into the Digital Product Passport, improving accessibility and strengthening traceability for asset owners. If this strategy is not applied, information remains distributed across local systems, increasing dependence on individual users and reducing the reliability of lifecycle data.

S6. AI Assisted DPP Processing

Manual data entry requires time and expertise that many organizations cannot provide. Even Rijkswaterstaat, the largest asset owner in the Netherlands, indicated in the interviews that teams are already working at full capacity and cannot maintain additional administrative tasks. Literature on Digital Product Passports highlights artificial intelligence as a useful tool for automating data extraction and validation, particularly in settings with limited digital and personnel capacity.

Implementation
AI assisted processing is used to convert unstructured information from certificates, drawings and supplier documents into structured fields suitable for the Digital Product Passport. For example, batch numbers, strength classes and production dates are extracted directly from material certificates, reducing the need for manual transcription.

Effects and consequences
This reduces the time and expertise required for data entry and lowers the risk of human error, supporting more consistent capture of essential information. Without AI assisted processing, DPP data requires more personnel, has a higher risk of errors and leads to higher administrative costs.

5.4. Unreliable Data

The interviews and literature indicated that inconsistent, incomplete or unverified information remains a major barrier to creating a reliable Digital Product Passport. Data on materials, production conditions and installation activities often arrives late or contains errors, and verification is not always carried out before storage. These issues weaken the credibility of lifecycle records and disrupt the traceability chain. Strategies S7 and S8 respond to this challenge by strengthening data verification and introducing structured quality checks at key milestones..

S7. Milestone Data Quality Checks

Milestone checks create structured points in the project where data quality is reviewed before progressing to the next phase. Literature on quality assurance indicates that validation is most effective at moments where responsibilities shift, which aligns with interview findings showing that incomplete or incorrect information is often discovered too late to correct.

Implementation
Data quality checks are performed at predefined project milestones, such as design completion, before construction, during installation and at commissioning. At each milestone, required data fields for the Digital Product Passport are reviewed to confirm completeness and accuracy before the project proceeds to the next phase.

Effects and consequences
This reduces the risk of missing or incorrect information and improves the reliability of lifecycle records. Without milestone checks, errors are detected too late to correct.

S8. Independent Data Verification

Independent verification provides an additional layer of assurance when project teams lack the time or capacity to review data in detail. Literature on data governance indicates that external or independent checks improve the credibility of information, particularly in projects involving multiple suppliers. Interview findings similarly noted that verification of certificates, environmental data or specifications is often difficult when workloads are high.

Implementation
Independent verification is applied to critical information fields that strongly influence traceability, such as material composition, batch details and installation records. These fields are reviewed by an external or independent party before being entered into the Digital Product Passport.

Effects and consequences
This prevents incorrect or incomplete information from entering the lifecycle record and improves the reliability of DPP data. In the absence of independent verification, data reliability remains uncertain, often necessitating additional testing and checks later in the lifecycle or resulting in conservative outcomes such as demolition.

5.5. Confidentiality and Data Sensitivity

Confidentiality concerns limit the sharing of detailed material and production data. Suppliers often treat this information as commercially sensitive, and project teams are unsure what can be disclosed. This results in inconsistent data sharing and weakens lifecycle records. Strategies S9 and S10 address this challenge by clarifying access, responsibilities and the handling of sensitive information..

S9. Data Access Levels and Permissions

A structured access model helps protect sensitive information while maintaining the accuracy required for the Digital Product Passport. Literature on information governance shows that defining access levels allows organizations to control who can view or modify specific data fields, which aligns with interview findings indicating that suppliers are more willing to share detailed information when access is restricted.

Implementation
Data access levels and permissions are defined for DPP related information, allowing essential data such as batch codes and performance characteristics to be shared broadly, while sensitive production details remain accessible only to authorised users.

Effects and consequences
This reduces supplier reluctance to share information and ensures that critical data remains available for traceability. When access levels are unclear or absent, suppliers may limit data sharing or provide incomplete information, weakening trust in the DPP and reducing the reliability of lifecycle records.

S10. Confidential Data Expiry Policy

Some DPP information is commercially sensitive only for a limited period. Literature and interview findings indicate that suppliers are more willing to share detailed data when confidentiality is guaranteed for a defined time rather than permanently.

Implementation
A confidentiality expiry policy defines how long sensitive DPP fields remain restricted before becoming accessible to a wider group of users. For example, material composition data remains protected during early asset use and becomes available closer to end of life.

Effects and consequences
This balances protection of commercial interests with long term traceability by releasing information when it becomes relevant for lifecycle decisions. If this is not applied, suppliers are less likely to share detailed information, resulting in gaps in critical DPP data.

5.6. Undefined Roles and Responsibility

The interviews and literature showed that unclear responsibility for creating and updating information leads to inconsistent documentation and missing data. Teams often assume that others will record material or installation details, resulting in gaps in the Digital Product Passport. Strategies S11 and S12 address this challenge by clarifying data ownership and establishing a central role for coordinating DPP processes.

S11. Data Ownership Allocation

Assigning data ownership ensures that responsibilities for accuracy and completeness are clearly understood throughout the asset lifecycle. Literature on data stewardship emphasizes that ownership should follow the lifecycle of the asset while being explicitly assigned to specific roles or teams, as undefined ownership often leads to inconsistent recording or missing information.

Implementation
Data ownership is allocated per project phase, with responsibility assigned to the party generating the information. For example, contractors are responsible for installation records and delivery information during construction, while ownership is transferred to the asset owner after commissioning.

Effects and consequences
This creates accountability for data quality, ensures that material histories remain intact and supports accurate and verifiable Digital Product Passport records. If ownership is not clearly allocated, information quality degrades over time and gaps emerge in the traceability record.

S12. Central DPP Coordinator Role

A central DPP coordinator provides oversight of information flows across design, construction and asset management. Literature and interview findings show that, without a single point of coordination, information is often recorded inconsistently or delivered too late to be verified.

Implementation
A DPP coordinator role, comparable to a BIM coordinator, is assigned to oversee the structure and timing of DPP related information. Depending on project size, this role can be carried out by one person, a small team, or allocated as a defined task within an existing project role for simpler projects.

Effects and consequences
This supports timely and consistent data delivery and prevents information gaps from being identified after commissioning. In the absence of this role, traceability is often deprioritized in favor of immediate project demands, weakening the reliability of DPP information.

6. Application of the Strategy Guide

This chapter demonstrates how the strategy guide can be applied to a specific product within the construction domain. A prefabricated concrete slab was selected because it represents a commonly used structural element in Dutch infrastructure and building projects. The slab passes through all lifecycle phases in a clear and traceable sequence, which makes it suitable for illustrating how data requirements and governance strategies can be organized in practice. The component also aligns with current industry challenges, since incomplete production records, unclear installation data and limited end-of-life documentation frequently restrict reuse potential for precast concrete elements in the Netherlands.

The purpose of this chapter is not to replicate a full digital implementation but to show how the strategies identified earlier can structure information flows throughout the lifecycle of one representative product. Each phase highlights typical information losses observed in practice and indicates which strategies from the guide could mitigate these issues. The application therefore acts as a conceptual demonstration of feasibility and illustrates how consistent data governance, structured handovers and DPP-related information fields could support traceability for the selected slab type.

The chapter begins with a short explanation of why the prefabricated slab is an appropriate example. It then outlines the method used to translate the strategies into lifecycle requirements. The five lifecycle phases are subsequently described, with each phase indicating (1) the information relevant for traceability, (2) common gaps identified in interviews and literature, and (3) the strategies that could reduce these gaps by improving data consistency, visibility and responsibility allocation. The overall aim is to clarify how the strategy guide can be used to structure information within a real product context and to provide a practical reference for discussing its applicability with industry stakeholders.

6.1 Rationale for Selecting a Prefabricated Concrete Slab

A prefabricated concrete slab was selected because it is used extensively in both building and infrastructure projects in the Netherlands. The element can serve multiple structural functions, such as floor components, bridge deck units or temporary support slabs. This flexibility makes it a suitable example for illustrating how traceability must be managed across different project types and functional contexts.

The slab also represents a component with realistic potential for second-life use. Prefabricated elements often retain sufficient structural capacity for repurposing, provided that reliable information is available about their geometry, reinforcement, material quality and exposure history. These characteristics allow the slab to be considered in several reuse scenarios, ranging from direct replacement in similar structures to application in lower-load situations.

This range of possibilities highlights the dependence of circular strategies on consistent and verifiable lifecycle data.

Although precast slabs are perceived as robust, their performance over time depends strongly on installation conditions, joint behavior, environmental exposure and the maintenance activities carried out during operation. These aspects are rarely documented in a structured way, which makes future assessment more complex than commonly assumed. The slab therefore reflects a product type for which improved traceability could have a direct impact on long-term usability and reuse decisions.

In addition, prefabricated concrete elements are receiving increasing attention in Dutch construction practice as potential circular building blocks. Their standardization, controlled production environment and repeatable dimensions make them suitable candidates for future reuse markets, provided that complete and reliable information can accompany them through the lifecycle. This development further strengthens the relevance of using a prefabricated slab as a demonstration case for applying the strategy guide.

Figure 10 Prefab Slab Elements Prepared for Digital Traceability

6.2 Method for Applying the Strategy Guide

The strategy guide was applied by analyzing how its strategies operate within the five lifecycle phases of a prefabricated slab. The same phase structure was used to maintain consistency with the strategy development process and to reflect the typical progression of a precast concrete element.

For each phase, the required information was identified. This concerns the data that must be available at that stage and the updates expected, including design parameters, production records, installation conditions, operational observations and end of life assessments.

Update and verification moments were mapped to determine when the slab is scanned, when information is added to the passport and how new entries are checked against the dataset carried over from earlier phases. These points ensure that information is validated before the slab progresses to the next stage.

Inputs and outputs were specified for each phase. Inputs include the dataset received from the previous stage together with the technical and organizational requirements of the current phase. Outputs consist of the expanded dataset generated through the activities performed in that phase.

Stakeholders active in each phase were identified, and their responsibilities were linked to relevant strategies. Designers, manufacturers, contractors, asset owners and deconstruction teams contribute different forms of information, and their actions are connected to strategies concerning dataset structure, terminology alignment, milestone checks, responsibility allocation, information control and verification.

This method provides a structured way to examine how the strategies function across the lifecycle and how they support traceability for a prefabricated slab.

Phase 1: Project Setup, Design and Information Structuring

Phase 1 establishes the organizational and technical foundations for implementing a Digital Product Passport at the level of an individual hollow core slab. The phase is guided by project inputs including contract requirements, information needs, the BIM object library, factory data formats, available digital tools, identification and naming rules, slab geometry and load data, and available data carrier options. These inputs define how slab related information is structured and managed during design and production.

The phase begins with defining roles and responsibilities for slab information. The designer, contractor, IT specialist, asset owner, asset manager, DPP coordinator and precast manufacturer agree on who creates, updates and verifies information for each hollow core slab across design modelling, factory production records and installation related data. This allocation ensures traceability of slab information from its source (S11).

The required dataset for the Digital Product Passport is then set at slab level. This specifies which information must be available for each slab to support verification, operational use and potential second life assessment. The dataset structure follows the information categories defined in Table 5, including slab identification, geometry and physical properties, material composition, reinforcement configuration, production and quality control data, logistics and handling information, and environmental and circularity attributes.

Terminology, classification levels and slab identifiers are aligned across the BIM model, factory systems and delivery documentation to ensure consistent referencing of each slab and to reduce mismatches between design and production records (S3). Design parameters are completed and verified, with the designer confirming geometry, spans, loads and exposure classes, and the precast manufacturer verifying compatibility with production constraints (S11).

Following verification, the technical structure of the Digital Product Passport is linked within the BIM environment. Each hollow core slab is assigned a unique identifier, and the dataset categories defined in Table 5 are linked directly to the corresponding BIM object, enabling structured access to slab information through the model (S4).

Digital Product Passport requirements are embedded within the digital tools already used by the project team. Design information remains within the BIM environment, while production and quality data are recorded within factory systems and linked to the slab identifier, avoiding parallel documentation (S1). A suitable digital platform is selected based on project scale and complexity to ensure continuity and accessibility of slab information throughout the project (S5).

A decision is made regarding the physical data carrier for each slab, such as QR, NFC or RFID, based on handling conditions, durability and accessibility during storage and installation (Dervishaj et al., 2023). The carrier location is defined in the digital model. Verification checks confirm identifier consistency, alignment between design information and the dataset categories, and correct structuring of the Digital Product Passport, while information intended for later lifecycle stages remains defined but unfilled.

The outputs of Phase 1 are an approved slab specific DPP dataset, unique slab identifiers, aligned terminology, a structured Digital Product Passport linked within BIM, verified slab design data, and defined verification and data control rules. These outputs provide a stable information baseline for each hollow core slab and support continuation in subsequent phases.

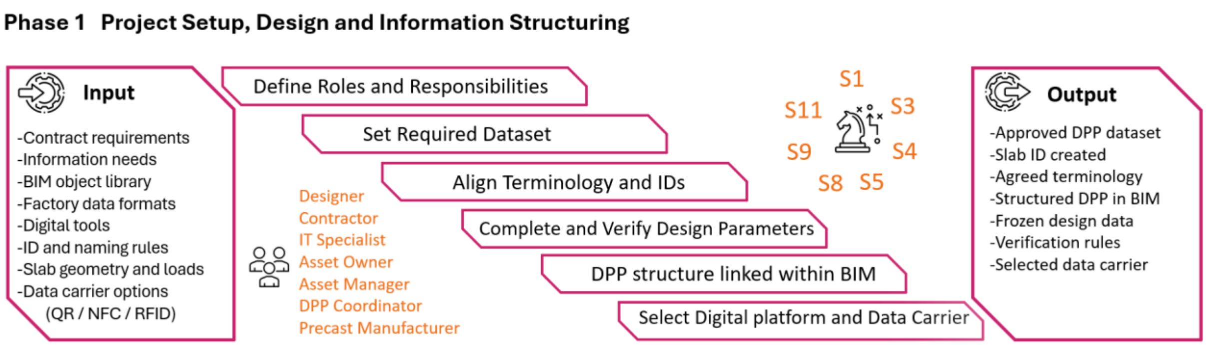

Figure 11 Phase 1 : Project Setup, Design and Information Structuring (Process Mapping Diagram)

Identification	Geometry & Physical Properties	Material Composition	Reinforcement & Inserts	Production & Quality Control	Logistics & Handling	Environmental & Circularity Data
Unique element ID	Length, width, thickness	Concrete mix designation	Reinforcement diameters & grades	Curing method	Factory storage location	Product-specific EPD reference
Production order	Weight / density	Strength class (e.g., C30/37)	As-built reinforcement layout	Curing duration & temp. profile	Storage duration	CO_2 footprint per slab (MKI/LCA)
Casting date & time	Camber / flatness	Batch number	Total reinforcement weight	Dimensional checks	Dispatch date	Material composition for LCA
Formwork / mould ID	Void pattern (HCS slabs)	Cement type, aggregate type, admixtures	Embedded items (anchors, sockets)	Visual inspection (surface defects)	Loading reference	Disassembly feasibility
Production line	Bearing width requirement	Water–cement ratio	Prestressing info (if relevant)	Strength test results (1/7/28 days)	Internal handling notes	Remaining service-life indicators
Operator reference (optional)	Tolerances	Aggregate grading (if available)	Lifting points & lifting limitations	Compliance with spec & deviations	Site storage conditions	Reuse potential classification
Digital tag / QR location	Installability features	Chemical admixture class	Risk zones (cutting, weak planes)	Verification checkpoints	Transport conditions	Link to Madaster / reuse platforms

Table 5 Prefabricated Slab Data Requirements

Phase 2 : Manufacturing and Data Capture

Phase 2 documents the technical information generated during the manufacturing of each hollow core slab and connects this information to the slab's established digital identity. The inputs for this phase consist of the frozen design dataset, the slab identifier, approved reinforcement drawings, concrete mix specifications, quality control procedures, environmental reporting requirements and production equipment settings. These inputs define the conditions under which slab production is executed and documented.

The phase begins by integrating the slab identity into the existing factory production systems. The slab identifier is embedded in the systems used for reinforcement placement, concrete batching, curing control and quality monitoring. This ensures that all production related data is captured directly within the systems already used by the precast manufacturer and consistently linked to the correct hollow core slab within the Digital Product Passport (S1).

Reinforcement data is then captured in the Digital Product Passport. This includes reinforcement diameters, spacing, prestressing layout and the as executed reinforcement configuration. The transfer of reinforcement information from approved drawings to manufacturing records follows a structured handover process, ensuring that design intent is preserved and traceable during production (S2).

Concrete batch and mix information is subsequently recorded. The precast manufacturer documents batch numbers, mix composition, water cement ratio, admixture dosages and fresh concrete properties such as temperature and workability. Access to detailed mix parameters is controlled through defined permissions, allowing sensitive production information to be recorded while limiting visibility to authorized parties (S10).

Curing conditions and dimensional outcomes are then documented. The factory records curing temperature, humidity, curing duration and early age strength development. Dimensional checks are performed to verify slab length, width, camber and tolerances at voids and bearing zones. These values are recorded using predefined data fields to ensure consistency across slabs and production cycles (S3).

Verification of production data against the frozen design dataset is carried out before factory release. Reinforcement execution, batch records, curing data and dimensional results are reviewed by the quality engineer. This review functions as a milestone data quality check, ensuring that required information is complete and consistent before the slab is released from the factory (S7).

In addition, critical data fields such as reinforcement execution, batch identification and strength test outcomes are subject to independent verification. This verification provides an additional level of assurance that key information entered into the Digital Product Passport is accurate and reliable before it becomes part of the long term lifecycle record (S8).

Once verification is complete, release information is updated and confirmed in the Digital Product Passport. This includes strength test results, confirmation of compliance with production requirements and the slab's storage location and condition within the factory yard. At this point, the manufacturing record for the slab is considered complete and ready for transfer to the next project phase.

The outputs of Phase 2 consist of reinforcement as executed, concrete batch and mix information, fresh concrete properties, environmental indicators derived from mix data, casting and curing records, dimensional verification results, strength test outcomes and documented factory storage conditions. Together, these outputs form a validated manufacturing record that supports subsequent transport, installation and lifecycle phases.

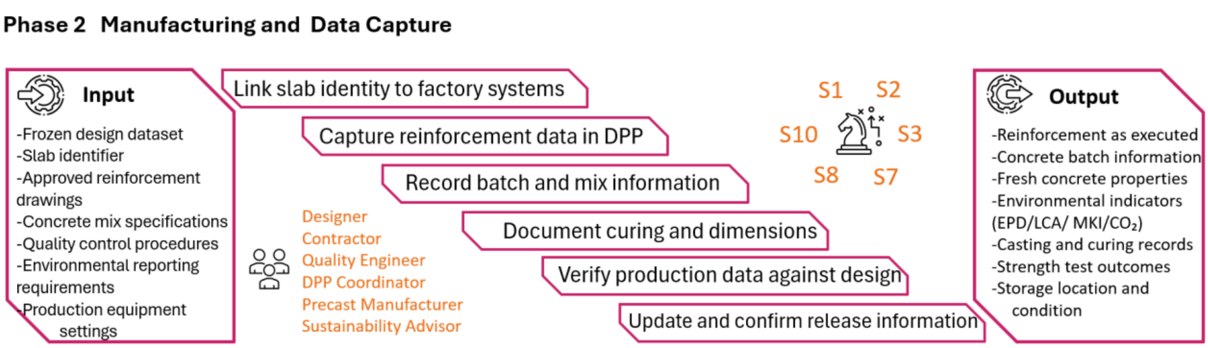

Figure 12 Phase 2 : Manufacturing and Data Capture (Process Mapping Diagram)

Phase 3 : Transport, Site Handling and Installation

Phase 3 transfers responsibility for the hollow core slab from the factory to the contractor and documents the conditions under which the slab is transported, handled and installed on site. The inputs for this phase consist of the verified design data, transport documentation, installation requirements, the lifting plan, storage specifications, environmental and handling notes, and the factory release record. These inputs define the technical requirements governing the slab's movement from production to final placement.

The phase begins at factory release, where the slab identifier is scanned and registered to confirm that the correct slab is being transferred from manufacturing to transport. This scan initiates a structured handover between the manufacturing and logistics phases, ensuring that verified production data is formally transferred and remains linked to the slab throughout transport and installation (S2).

Before transport, storage and lifting configurations are documented. The contractor or logistics provider records the storage orientation, lifting method and protection measures applied at the point of release. This information is captured using predefined Digital Product Passport fields to ensure consistent documentation of handling conditions prior to transport (S4).

During transport and upon arrival on site, the slab identifier is scanned again and the contractor records the transport condition of the slab. Observations such as chipped edges, abrasion or visible cracking are documented so that transport related effects can be distinguished from installation related effects. Responsibility for recording this information is clearly assigned to the contractor during this phase, ensuring accountability for data accuracy after factory release (S11).

Before installation, verification checks are performed to confirm that the scanned slab identifier corresponds to the slab scheduled for placement. The lifting configuration and lifting points are checked against the approved lifting plan to avoid eccentric loading or unintended stress concentrations. These checks function as milestone data quality controls before the slab is installed (S7).

During installation, installation parameters are recorded. The contractor documents achieved bearing length, alignment, support conditions and any local adjustments required for fit. Critical installation data and tolerance checks are subject to independent verification to ensure that recorded values accurately reflect site conditions and comply with design assumptions (S8).

The outputs of Phase 3 consist of transport condition records, site storage information, identity verification checks, lifting and handling records, installation parameters, and bearing and alignment results. Together, these outputs form a verified site handling and installation record that supports subsequent operational and lifecycle phases.

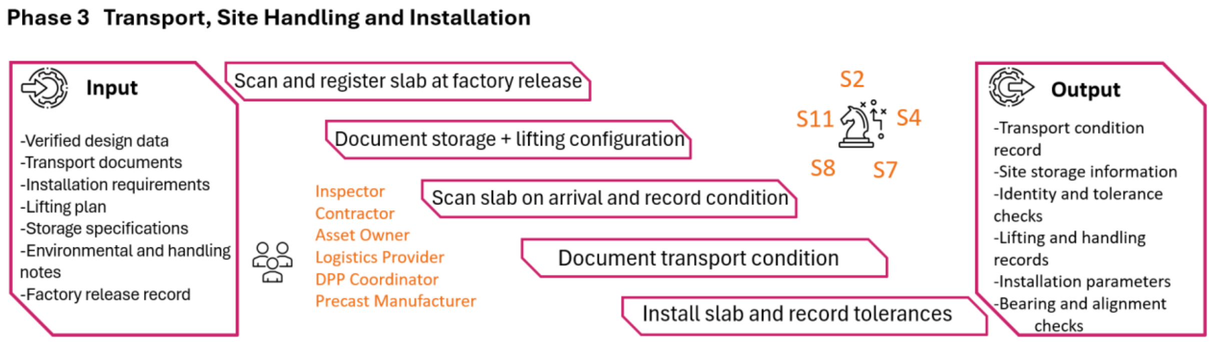

Figure 13 Phase 3 : Transport, Site Handling and Installation (Process Mapping Diagram)

Phase 4 : Operation and Maintenance

Phase 4 covers the operational life of the hollow core slab and focuses on keeping the Digital Product Passport up to date as the slab is inspected, maintained and exposed to changing conditions over time. The dataset established in earlier phases provides the technical baseline against which new observations are interpreted and assessed. The inputs for this phase consist of the verified Digital Product Passport dataset, inspection reports, maintenance history, environmental observations, operational requirements, installation verification data and condition assessment standards.

The phase begins with reviewing existing operational and performance data. The asset owner, supported by the asset manager and the DPP coordinator, reviews the current passport content to understand the slab's baseline condition and previous interventions. This review ensures that new information is interpreted in relation to verified manufacturing and installation data and prevents isolated updates that lack context (S12).

Inspection findings are then recorded and updated in the Digital Product Passport. The slab is accessed on site through its physical identifier, such as a QR code or NFC tag, to retrieve the correct passport entry and confirm the slab's identity. Observations including cracks, surface wear, local damage, moisture presence and visible changes in texture or color are entered using the predefined DPP fields. By integrating inspection updates directly into the existing digital systems used for asset management, inspection data contributes continuously to the lifecycle record rather than being stored in separate reports (S1).

Maintenance actions are documented when they occur and used to update the slab's operational history. Interventions such as local repairs, bearing adjustments, cleaning or reapplication of protective measures are recorded together with the reason for the intervention and the method applied. Where maintenance documentation is generated in different formats, structured handover rules ensure that relevant information is transferred into the Digital Product Passport in a consistent way, preserving continuity between inspection findings and maintenance actions (S2).

Environmental changes affecting the slab are captured and updated when conditions evolve. Prolonged exposure to moisture, changes in temperature regimes or altered usage conditions are recorded because they influence deterioration mechanisms and long term performance. When environmental observations are derived from sensor data or unstructured reports, AI assisted processing can be used to extract relevant parameters and update the corresponding DPP fields efficiently (S6).

Operational performance data is updated as new measurements or observations become available. This may include changes in alignment, joint behavior, vibration response or other performance indicators observed during routine operation. Updates follow standardized terminology and classification to ensure that new entries remain comparable with earlier data and interpretable across asset management systems (S3).

Before updates are confirmed, data quality checks are performed. At predefined moments, such as after major inspections or maintenance activities, the completeness and consistency of updated fields are reviewed to ensure that critical information has been correctly entered and linked to the correct slab record (S7). Access to sensitive operational and maintenance information is managed through defined data access levels, allowing detailed records to be protected while maintaining transparency for authorized users (S10).

The outputs of Phase 4 consist of updated condition assessments, documented maintenance actions, revised operational performance data and a verified continuation of the Digital Product Passport throughout the operational phase. Together, these outputs ensure lifecycle continuity and prepare the dataset for future reuse assessment or end of life decision making.

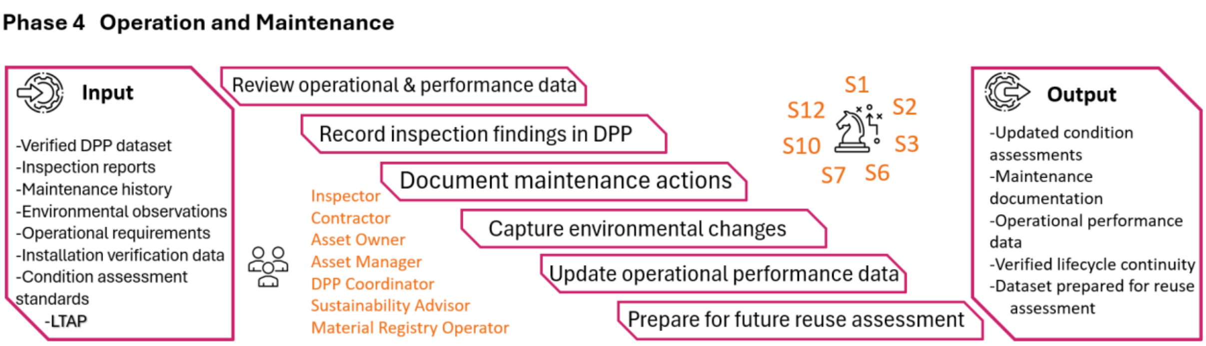

Figure 14 Phase 4 : Operation and Maintenance (Process Mapping Diagram)

Phase 5: End-of-Life Assessment, Deconstruction and Next Lifecycle Decision

In the final stage of the lifecycle, the Digital Product Passport becomes the primary reference for determining the next lifecycle pathway of the slab once it is removed from the existing structure. This phase represents a critical decision point, as no new design information is generated and decisions rely entirely on the availability, reliability and accessibility of existing data. The inputs for this phase include the complete passport dataset, operational condition data, pre-deconstruction inspection results and any structural assessments required to plan dismantling. Responsibility shifts towards the deconstruction contractor, the structural engineer and the asset owner, with data ownership remaining clearly allocated to ensure accountability for the passport content (S11).

The process begins with a pre-deconstruction survey. The slab is identified by scanning its QR code or NFC tag, providing immediate access to its full technical history and confirming that the correct element is being assessed. Because information has been handed over in a structured and consistent manner across earlier project phases, the passport can be accessed without reformatting or reconstruction of data (S2). The engineer records the current condition of the slab, including visible cracking, surface degradation, local damage at supports and deterioration observed during service. These observations are added to the passport using the existing information structure, maintaining continuity between production, installation, operation and end-of-life records.

Before lifecycle decisions are made, the completeness and reliability of the passport data are confirmed. Milestone data quality checks performed earlier in the lifecycle ensure that key fields required for end-of-life assessment are present and accurate, reducing uncertainty at this stage (S8). Where decisions depend on critical information such as material composition, reinforcement configuration or strength development, independently verified data provides additional confidence, limiting the need for extensive re-testing and enabling timely decision making (S7).

Based on this verified information, the next lifecycle pathway is selected. The technical condition of the slab is evaluated against reinforcement configuration, concrete composition, strength development and dimensional data stored in the passport. At this stage, the Digital Product Passport enables rapid comparison between observed condition and original design and production parameters. This significantly reduces the time required for assessment and avoids conservative assumptions that often result in unnecessary demolition.

When the slab is found to be structurally sound and suitable for direct reuse, it enters a controlled dismantling process. In this scenario, no redesign is required and the slab re-enters the lifecycle at Phase 3 (Transport, Site Handling and Installation). The deconstruction contractor prepares a controlled dismantling plan, and the identifier is scanned before lifting operations to ensure correct handling. Handling conditions and any new observations are documented, while additional testing is only carried out when required by the receiving project, rather than as a default precaution.

If the slab requires adjustment, refurbishment, repurposing or partial recovery, the element remains identifiable but its design parameters change. In this case, the slab re-enters the lifecycle at Phase 2 (Manufacturing and Data Capture). The passport supports this transition by providing reliable information on geometry, material composition and reinforcement, allowing redesign or strengthening activities to be carried out without reconstructing information from fragmented sources.

If the slab does not meet reuse or recovery thresholds, it proceeds to controlled recycling. The removal process is documented, and the passport provides recyclers with information on concrete composition, aggregate type and reinforcement content, supporting efficient material separation and improved recycling outcomes. After recycling, the component-level passport is archived with a complete record of the selected pathway.

Once dismantling is completed and the selected lifecycle pathway has been executed, the passport is updated to reflect changes in ownership or status. Clear data ownership allocation ensures that responsibility for updating or archiving the passport remains defined throughout this phase, preventing traceability from being deprioritized under demolition time pressures (S11).

The outputs of this phase include updated condition assessments, dismantling documentation, any additional test results where applicable, and an updated or archived Digital Product Passport. Together, these outputs ensure that end-of-life decisions are based on reliable and verified information, demonstrate the value of structured data handover, quality control and ownership clarity, and support efficient and traceable transitions to subsequent lifecycle phases.

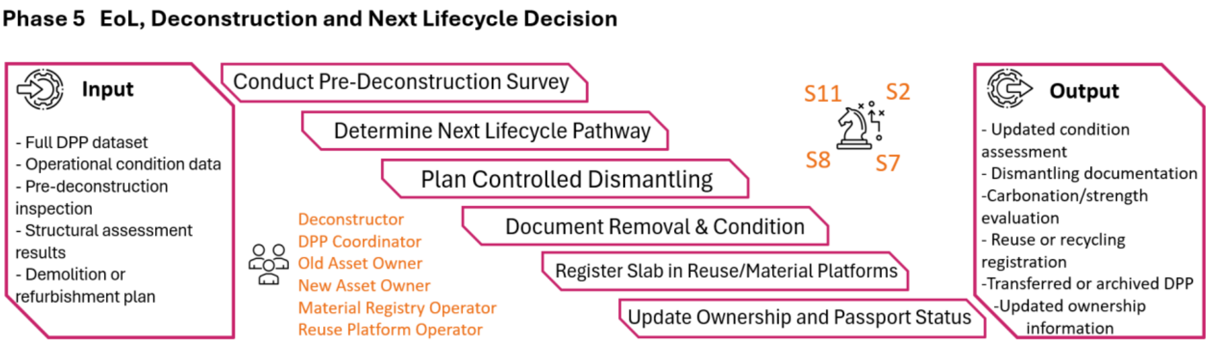

Figure 15 Phase 5: EoL , Deconstruction and Next Lifecycle Decision (Process Mapping Diagram)

7. Discussion

This chapter reflects on the findings of this research in relation to the main research question, which examined how Digital Product Passports can address information gaps and strengthen traceability in Dutch infrastructure projects.

7.1 Reflections on the Strategy Guide

The strategy guide developed in this thesis is a conceptual framework that translates the study's insights into a structured set of measures for improving information continuity. It illustrates how activities related to Digital Product Passports can be organized across lifecycle stages and how responsibilities, data requirements and update moments may be aligned in practice. The guide shows how individual strategies can be positioned within project processes to address recurring points of information loss. However, it remains a theoretical construct rather than a validated model, since none of the strategies have been tested in real project environments.

The implications of this conceptual status are important. The guide is based on interviews with organizations that already possess relatively advanced digital and information management capabilities. Its applicability in contexts with lower digital maturity, more fragmented supply chains or different contracting arrangements is therefore uncertain. It also does not fully reflect the organizational dynamics involved in implementing Digital Product Passports, including negotiations about responsibilities, resource limitations and differences in documentation cultures.

Despite these limitations, the strategy guide offers a useful foundation for reflection and early experimentation. It helps organizations identify where information responsibilities weaken and provides an initial structure for piloting and refinement. Although it cannot yet be generalized, it offers a starting point for understanding how strategies might be operationalized and where further empirical research is required.

7.2 Limitations

Several limitations affect how the findings of this research should be interpreted. The strategy guide developed in this thesis focuses on new assets, since the study did not examine how Digital Product Passports could be introduced in existing infrastructure where historical data is often incomplete. This restricts the applicability of the guide to projects involving renovation and renewal. The interview sample did not include manufacturers or contractors, which limits understanding of production processes and on-site documentation practices. This reduces insight into practical implementation conditions. The influence of different contracting forms was also not explored, even though contracts strongly shape information responsibilities. This limits understanding of how procurement choices affect data governance.

Both the strategy guide and its implications remain conceptual and cannot be validated at this stage. Infrastructure assets often have lifecycles of fifty years or more, which means that the long-term functioning of a Digital Product Passport cannot yet be assessed in practice. This means the long term effectiveness of the proposed approach cannot be confirmed.

Limitations also arise from the literature. Research on Digital Product Passports in the construction and infrastructure sector is still sparse, and the few available studies rarely focus on a specific country or material type. Very little literature examines the Dutch context in detail, and no studies offer long term evidence of how DPP systems perform in real infrastructure projects

7.3 Contribution

This research contributes to the growing body of work on digitalization and information governance in infrastructure by offering one of the first detailed examinations of the Digital Product Passport within the Dutch context. It brings empirical depth through a substantial number of interviews, which provide insight into current information practices and the organizational conditions that shape traceability. The study clarifies how fragmented documentation routines, unclear responsibilities and inconsistent use of digital systems disrupt lifecycle information flows, and it demonstrates that Digital Product Passports have the potential to create a more coherent information structure when supported by appropriate organizational processes. The research also advances the conceptual understanding of DPP implementation by translating empirical findings into a strategy guide that outlines practical measures for improving data continuity. Although not yet validated in real projects, the guide offers a structured basis that practitioners can use to reflect on their internal workflows and prepare for emerging European requirements related to product information. By identifying where information gaps arise and showing how strategic measures can strengthen lifecycle documentation, the research provides a valuable foundation for future studies and contributes to the wider transition toward more transparent, coordinated and reliable digital asset management in the Dutch infrastructure sector.

8. Conclusion

This chapter presents the main conclusions derived from the research. The findings are based on the literature review, interviews and analysis. It begins with the conclusions for each sub-question, followed by the conclusion that addresses the main research question. The chapter then outlines recommendations for practice and suggestions for future research.

8.1 Research conclusion

SQ1: *What information gaps and missing data limit reliable traceability of materials and components in Dutch infrastructure projects?*

The research shows that reliable traceability is limited because essential information does not remain connected across the lifecycle of infrastructure assets. Data produced in early phases is often not transferred in a structured manner, and documentation of material characteristics, design choices and construction outcomes varies between actors. During operation, updates from maintenance and inspections are not consistently integrated with earlier records, creating further fragmentation. These discontinuities make it difficult to reconstruct component histories. The issue arises less from missing data itself than from the absence of stable processes, shared conventions and clear responsibilities for maintaining information over time.

SQ2: *How is material traceability currently organized in infrastructure projects, and which challenges reduce its effectiveness?*

Traceability in infrastructure projects is shaped by project documentation routines rather than by a continuous lifecycle perspective. Information created during design, construction and handover serves immediate project needs, yet these records rarely evolve into a coherent long-term history of individual components. Documentation practices differ across organizations, and once the asset moves into operation, updates become irregular and are seldom aligned with earlier information. Responsibilities for sustaining accurate records remain diffuse, and coordination between actors decreases after project delivery. These conditions interrupt information continuity and limit the effectiveness of traceability, even when considerable documentation is produced during earlier phases.

SQ3*: What are the main benefits of a Digital Product Passport, and what challenges affect its implementation across the asset lifecycle?*

The research shows that a Digital Product Passport can strengthen lifecycle traceability by providing a consistent structure for recording essential information and linking it to identifiable materials and components. This shared framework reduces fragmentation, supports clearer interpretation of component histories and enhances transparency between actors. At the same time, effective use of the passport depends on organizational conditions rather than its technical design alone. Challenges arise when responsibilities for updating information are unclear, when documentation practices differ across organizations or when digital capacity is limited. Without coordinated routines and long-term commitment, the expected benefits of the DPP cannot be fully realized.

SQ4: *What strategies can be developed to implement Digital Product Passports in infrastructure projects to enhance traceability?*

Strengthening traceability through Digital Product Passports requires strategies that establish coherent, reliable information practices across the asset lifecycle. The strategy guide developed in this thesis outlines measures that support this aim, beginning with clearly assigned responsibilities for recording, updating and verifying information. A defined dataset, shared terminology and stable identifiers help maintain consistency between project actors and phases. Aligning update moments with existing workflows ensures that information remains current rather than fragmented. Verification routines and quality-control measures reinforce accuracy over time. When combined, these strategies create the organizational conditions needed for a DPP to function as an effective traceability mechanism.

Main research question:

How can Digital Product Passports address information gaps and strengthen traceability in Dutch infrastructure projects?

A Digital Product Passport can address information gaps in Dutch infrastructure projects by providing a consistent structure for recording essential lifecycle data and linking it to specific materials and components. This organization reduces fragmentation and supports a clearer reconstruction of asset histories, reinforcing the basis for reliable traceability.

Its effectiveness, however, depends on integration into existing project and asset management practices. Traceability improves only when responsibilities are defined, documentation routines are aligned and information is verified as the asset moves between phases.

The strategy guide developed in this thesis sets out measures that enable such integration, including structured data requirements, ownership roles and coordinated update moments. With these organizational foundations, a Digital Product Passport can function as a practical mechanism for strengthening traceability.

8.2 Recommendations for practice

Strengthening the practical use of Digital Product Passports in infrastructure projects requires coordinated action across the supply chain, beginning with the organizations that manage assets over the long term. Asset owners should integrate DPP requirements into procurement procedures as early as possible so that information expectations are clear from the outset. When information responsibilities are communicated during tendering, contractors and manufacturers can structure their processes accordingly, which reduces uncertainty and prevents the need for retrospective data reconstruction. Procurement can also be used to encourage adoption by recognizing suppliers who demonstrate strong information management and by rewarding consistent delivery of complete and verifiable data.

Collaboration between project actors emerged repeatedly during interviews as an essential condition for improving information continuity. Initiatives such as shared terminology, common decomposition structures and early data coordination meetings can reduce interpretive inconsistencies and support smoother information transfer between disciplines. Pilot projects offer an opportunity to test these forms of collaboration while exploring how DPP procedures fit within existing workflows. The insights gained from such pilots can guide internal standardization and inform sector-wide practices.
Contractors and manufacturers each carry distinct but interconnected responsibilities. Contractors should embed DPP-related work within established construction and commissioning activities instead of creating parallel documentation processes. Manufacturers should ensure that product information is verified, consistent and provided in a format that supports long-term traceability.

Asset management teams require strengthened information management capability because they ultimately inherit the responsibility for maintaining the accuracy and relevance of DPP information. Regular reviews, quality checks and clear ownership structures will help preserve continuity throughout the operational phase. Organizations should also remain attentive to developments in information technology. Advances in artificial intelligence, automated data extraction and digital collaboration platforms offer opportunities to improve accuracy, reduce manual workload and sustain information reliability as project environments evolve.

8.3 Recommendations for future research

Future research should examine how Digital Product Passports are applied in real project settings and evaluate how the strategy guide performs across different organizational and project contexts. Validation studies would help determine which strategies are most effective, which require refinement and how they interact with established workflows. Extending this research to other material groups, such as steel, asphalt, or composite components, would provide insight into whether DPP structures function differently depending on material characteristics or supply chain complexity.

There is also value in investigating how DPP approaches can be adapted for existing assets, where information is often incomplete and where lifecycle documentation practices differ significantly from new construction. Understanding how DPP principles function in such environments would clarify the practical challenges of retroactive data collection and long-term asset information recovery. Studies focusing on sectors outside civil infrastructure, such as telecommunications or energy networks, could further illustrate how DPP concepts transfer to other asset-intensive systems.

As European regulatory frameworks evolve, research should also consider how new data requirements shape organizational processes and information governance. Finally, deeper exploration of digital tools, including artificial intelligence and automated data extraction, may provide pathways to reduce capacity constraints and support more reliable and scalable DPP implementation.

9. Reflection

This graduation project, developed within the CME track, examines how Digital Product Passports can help address information gaps and strengthen traceability in Dutch infrastructure projects. The topic aligns with the program's focus on process management, digitalization and improving information flows in complex construction environments. It also contributes to ongoing efforts in the Netherlands to prepare for upcoming European regulations and support more transparent asset management practices.

At the start of the project, defining the scope was challenging. The initial research direction covered both reuse and traceability, but it became clear that the topic was too broad for the time available. Focusing the study on DPP and information gaps provided more clarity and created a better connection between literature findings and the practical insights from interviews. This shift strengthened the coherence of the research, but it also meant that less time was available for exploring the technical or regulatory aspects of DPP in detail.

Throughout the process, interpreting large amounts of interview data and shaping the strategy guide required careful judgement. Translating interview insights into structured strategies was more difficult than expected. The interviews highlighted many issues related to responsibilities, data quality and system alignment, but turning these insights into practical measures required multiple iterations and discussions with supervisors. These moments of uncertainty helped refine the structure of the thesis and shaped the eventual focus of the strategy guide.

Working on a topic that is still developing, both in policy and practice, was another challenge. The lack of established standards for DPP adoption meant that the research needed to balance theoretical expectations with the daily realities described by practitioners. This helped me understand the importance of grounding conceptual ideas in practical constraints and not assuming that digital tools alone can solve information problems. The process strengthened my ability to connect abstract concepts to specific conditions in real projects.

The chosen methodology, combining literature review, interviews and comparative analysis, worked well for generating insight into the current state of traceability. Although the sample size was limited, the qualitative data provided valuable perspectives on how information flows are managed in practice and what organizations need to improve. Earlier clarity on the intended output of the strategy guide would have helped streamline the process, but the iterative approach provided space to refine the research direction in a meaningful way.

Overall, this thesis has strengthened my understanding of digital information management and the organizational conditions needed for tools like the Digital Product Passport to succeed. It has also helped me develop skills in conducting qualitative research, structuring complex material and translating theoretical ideas into practical guidance. These lessons will remain valuable as I continue working in the field of construction management and digital innovation.

References

Akanbi, L. A., Oyedele, L. O., Omoteso, K., Bilal, M., Akinade, O. O., Ajayi, A. O., Davila Delgado, J. M., & Owolabi, H. A. (2019). Disassembly and deconstruction analytics system (D-DAS) for construction in a circular economy. *Journal of Cleaner Production, 223*, 386–396. https://doi.org/10.1016/j.jclepro.2019.03.172

AlJaber, A., Martinez-Vazquez, P., & Baniotopoulos, C. (2024). Towards Circular Building Key Performance Indicators. In *4th International Conference "Coordinating Engineering for Sustainability and Resilience" & Midterm Conference of CircularB "Implementation of Circular Economy in the Built Environment," Lecture Notes in Civil Engineering* (Vol. 489, pp. 414–423). https://doi.org/10.1007/978-3-031-57800-7_38

Amarasinghe, I., Stewart, R. A., Sahin, O., & Liu, T. (2025). Drivers and barriers for material circularity in construction: A systems perspective. *Sustainable Production and Consumption, 57*, 106–120. https://doi.org/10.1016/j.spc.2025.05.012

Anastasiades, K., Goffin, J., Rinke, M., Buyle, M., Audenaert, A., & Blom, J. (2021). Standardisation: An essential enabler for the circular reuse of construction components? A trajectory for a cleaner European construction industry. *Journal of Cleaner Production, 298*, 126864. https://doi.org/10.1016/j.jclepro.2021.126864

Assefa, G., & Ambler, C. (2017). To demolish or not to demolish: Life cycle consideration of repurposing buildings. *Sustainable Cities and Society, 28*, 146–153. https://doi.org/10.1016/j.scs.2016.09.011

Chu, X., Wang, Y., & Wang, R. (2023). Facilitating Digital Product Passport in construction supply chains. Preprint submitted to *International Journal of Production Economics*. https://ssrn.com/abstract=4598796

Coenen, T. B. J., Visscher, K., & Volker, L. (2023). A systemic perspective on transition barriers to a circular infrastructure sector. *Construction Management and Economics, 41*(1), 22–43. https://doi.org/10.1080/01446193.2022.2151024

Costa, A. R., & Hoolahan, R. (2024). *Materials Passports: Accelerating Material Reuse in Construction*. Orms Designers & Architects Ltd. https://doi.org/10.5281/zenodo.10472214

Dams, B., Maskell, D., Shea, A., Allen, S., Driesser, M., Kretschmann, T., Walker, P., & Emmitt, S. (2021). A circular construction evaluation framework to promote designing for disassembly and adaptability. *Journal of Cleaner Production, 316*, 128122. https://doi.org/10.1016/j.jclepro.2021.128122

Davari, S., Jaberi, M., Yousfi, A., & Poirier, E. (2023). A traceability framework to enable circularity in the built environment. *Sustainability, 15*(10), 8278. https://doi.org/10.3390/su15108278

Dervishaj, A., Hernández Vargas, J., & Gudmundsson, K. (2023). Enabling reuse of prefabricated concrete components through multiple tracking technologies and digital twins. *Proceedings of the 2023 European Conference on Computing in Construction and the 40th International CIB W78 Conference*, Heraklion, Crete, Greece, July 10-12, 2023. https://doi.org/10.35490/EC3.2023.220

Ducuing, C., & Reich, R. H. (2023). *Data governance: Digital product passports as a case study*. Journal of Industrial Information Integration, 24. https://doi.org/10.1177/17835917231152799

European Commission. (2024). *Ecodesign for Sustainable Products Regulation and Digital Product Passport*. https://cirpassproject.eu/wp-content/uploads/2024/03/A2-EC-Michele-Galatola.pdf

Giovanardi, M., Konstantinou, T., Pollo, R., & Klein, T. (2023). Internet of Things for building façade traceability: A theoretical framework to enable circular economy through life-cycle information flows. *Journal of Cleaner Production, 382*, 135261. https://doi.org/10.1016/j.jclepro.2022.135261

Government of the Netherlands. (2016). *A Circular Economy in the Netherlands by 2050: Government-wide programme for a circular economy*. The Hague.

Government of the Netherlands. (n.d.). Circular Dutch economy by 2050. Retrieved from https://www.government.nl/topics/circular-economy/circular-dutch-economy-by-2050

Hart, J., Adams, K., Giesekam, J., Densley Tingley, D., & Pomponi, F. (2019). Barriers and drivers in a circular economy: The case of the built environment. *Procedia CIRP, 80*, 619–624. https://doi.org/10.1016/j.procir.2018.12.015

Honic, M., Kovacic, I., Aschenbrenner, P., & Ragossnig, A. (2021). Material passports for the end-of-life stage of buildings: Challenges and potentials. *Journal of Cleaner Production, 319*, 128702. https://doi.org/10.1016/j.jclepro.2021.128702

Honic, M., Meda Magalhães, P., & Van den Bosch, P. (2024). From data templates to material passports and digital product passports. In C. De Wolf, S. Çetin, & N. Bocken (Eds.), *A circular built environment in the digital age* (pp. 79–94). Springer. https://doi.org/10.1007/978-3-031-39675-5_5

Illán García, I., Muñoz-Escoí, F. D., Arjona Aroca, J., & Fernández-Bravo Peñuela, F. J. (2024). Digital product passport management with decentralised identifiers and verifiable credentials: Extended version. *arXiv preprint arXiv:2410.15758*. https://arxiv.org/abs/2410.15758

INCOSE. (2023). *INCOSE Systems Engineering Handbook: A guide for system life cycle processes and activities* (5th ed.). Wiley. https://www.incose.org/products-and-publications/se-handbook

International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), & Institute of Electrical and Electronics Engineers (IEEE). (2023). *ISO/IEC/IEEE 15288:2023—Systems and software engineering—System life cycle processes* (2nd ed.). https://www.iso.org/standard/63711.html

Jousse, A. (Ed.). (2024). *DPP System Roadmap* (Version 2.0). CIRPASS Consortium. https://doi.org/10.5281/zenodo.11096973

Karaca, F., Tleuken, A., Awan, H. H., et al. (2024). Stakeholder perspectives on the costs and benefits of circular construction. *Scientific Reports, 14*, 30039. https://doi.org/10.1038/s41598-024-81741-z

Katenbayeva, A., Glass, J., Anvuur, A., & Ghumra, S. (2016). Developing a theoretical framework of traceability for sustainability in the construction sector. Loughborough University. Conference contribution. https://hdl.handle.net/2134/23842

Kühn, M., Baumann, M., Volz, F., & Stojanovic, L. (2025). Digital Product Passport design supporting the circular economy based on the Asset Administration Shell. *Sustainability, 17*(3), 969. https://doi.org/10.3390/su17030969

Lei, B., Yang, W., Yan, Y., Tang, Z., & Dong, W. (2023). Carbon emission reduction evaluation of end-of-life buildings based on multiple recycling strategies. *Sustainability, 15*(22), 15711. https://doi.org/10.3390/su152215711

Lei, B., Yang, W., Yan, Y., Zaland, S., Tang, Z., & Dong, W. (2023). Carbon-saving benefits of various end-of-life strategies for different types of building structures. *Developments in the Built Environment, 16*, 100264. https://doi.org/10.1016/j.dibe.2023.100264

Mankata, L. M., Antwi-Afari, P., Frimpong, S., & Ng, S. T. (2025). Material passports in construction waste management: A systematic review of contexts, stakeholders, requirements, and challenges. *Buildings, 15*(11), 1825. https://doi.org/10.3390/buildings15111825

Michelini, E., Bernardi, P., Cerioni, R., & Belletti, B. (2020). Experimental and Numerical Assessment of Flexural and Shear Behavior of Precast Prestressed Deep Hollow-Core Slabs. *International Journal of Concrete Structures and Materials, 14*, Article 7. https://doi.org/10.1186/s40069-020-00407-y

Oteng, D., Asante, R., Omrany, H, & Eshun, B. T. B. (2025). Achieving the UN sustainability goals: The role of digital product passports in the architecture, engineering and construction industry. *CIB Conferences, 1*, Article 163. https://doi.org/10.7771/3067-4883.1916

Platform CB'23. (2022). *Guide to Passports for the Construction Sector: Parts 1 and 2 – Working agreements and substantiation for passports in a circular construction sector*. Platform CB'23.

Protokol. (2024). *Digital Product Passport (DPP): The complete guide*. https://protokol.com

Psarommatis, F., & May, G. (2024). Digital Product Passport: A pathway to circularity and sustainability in modern manufacturing. *Sustainability, 16*(1), 396. https://doi.org/10.3390/su16010396

Ranasinghe, N., Domingo, N., & Kahandawa, R. (2024). Enhancing building material circularity: A systematic review on prerequisites, obstacles and the critical role of data traceability. *Journal of Building Engineering, 98*, 111136. https://doi.org/10.1016/j.jobe.2024.111136

Ranasinghe, N., Domingo, N., & Kahandawa, R. (2025). Advancing circularity: A review of technologies for material data traceability in the built environment. In *Proceedings of the 23rd CIB World Building Congress* (pp. 1–17). Purdue University. https://doi.org/10.7771/3067-4883.1775

Rijkswaterstaat. (n.d.). Systems engineering. https://www.rijkswaterstaat.nl/zakelijk/zakendoen-met-rijkswaterstaat/werkwijzen/werkwijze-in-gww/systems-engineering

Rijkswaterstaat. (2023). WP2 Circular Procurement: Construction/demolition procurement guidelines with case study examples (CityLoops Deliverable 2.4, Version 3.0). https://cityloops.eu/fileadmin/user_upload/D2.4_CityLoops_CDW_Procurement_Consolidated_Guidelines_RW_June_2023.pdf

Roxas, C. L. C., Bautista, C. R., Dela Cruz, O. G., Dela Cruz, R. L. C., De Pedro, J. P. Q., Dungca, J. R., Lejano, B. A., & Ongpeng, J. M. C. (2023). Design for manufacturing and assembly (DfMA) and design for deconstruction (DfD) in the construction industry: Challenges, trends and developments. *Buildings, 13*(5), 1164. https://doi.org/10.3390/buildings13051164

Ruismäki, W., zu Castell-Rüdenhausen, M., Pohjalainen, E., & Wahlström, M. (2025). Stakeholder perspectives on digital product passports for construction products. *Cleaner Logistics and Supply Chain*. Advance online publication. https://doi.org/10.1016/j.clscn.2025.100275

Saari, L., Heilala, J., Heikkilä, T., Kääriäinen, J., Pulkkinen, A., & Rantala, T. (2022). Digital product passport promotes sustainable manufacturing: Whitepaper (VTT White Paper Vol. 2022). VTT Technical Research Centre of Finland. https://cris.vtt.fi/en/publications/7ed70481-85d8-4e26-822b-97cdb1fa917e

Santana, S., & Ribeiro, A. (2022). Traceability models and traceability systems to accelerate the transition to a circular economy: A systematic review. *Sustainability, 14*(9), 5469. https://doi.org/10.3390/su14095469

Succar, B., & Poirier, E. (2020). Lifecycle information transformation and exchange for delivering and managing digital and physical assets. *Automation in Construction, 112*, 103090. https://doi.org/10.1016/j.autcon.2020.103090

Tleuken, A., Karaca, F., Askar, R., Leindecker, G., Kahraman, I., Giarma, C., ... & Bragança, L. (2025). Circularity criteria and indicators at the building component and system level. In L. Bragança et al. (Eds.), *Circular economy design and management in the built environment* (pp. 335–369). Springer. https://doi.org/10.1007/978-3-031-73490-8_13

Tsoka, S., & Tsikaloudaki, K. (2024). Design for circularity, design for adaptability, design for disassembly. In D. Iatridis & E. Psomopoulos (Eds.), *Circular economy design and management in the built environment* (pp. 257–272). Springer. https://doi.org/10.1007/978-3-031-73490-8_9

van den Berg, M., Voordijk, H., & Adriaanse, A. (2020). Recovering building elements for reuse (or not): Ethnographic insights into selective demolition practices. *Journal of Cleaner Production, 256*, 120332. https://doi.org/10.1016/j.jclepro.2020.120332

Vangelova, S., Forth, K., & De Wolf, C. (2025). Towards a compatible digital product passport data template in construction. ETH Zurich Research Collection. https://doi.org/10.3929/ethz-b-000739400

Walden, J., Steinbrecher, A., & Marinkovic, M. (2021). Digital product passports as enabler of the circular economy. *Chemie Ingenieur Technik, 93*(11), 1717–1727. https://doi.org/10.1002/cite.202100121

Watson, R., Kassem, M., & Li, J. (2019). Traceability for built assets: Proposed framework for a Digital Record. In *Proceedings of the Creative Construction Conference 2019*. Diamond Congress Ltd. https://researchportal.northumbria.ac.uk/files/65374122/Traceability_for_built_assets_proposed_framework_for_a_Digital_Record_Watson_Kassem_Li_2019.pdf

Wautelet, T., & Ayed, A.-C. (2024). Exploring possible Digital Product Passport (DPP) use cases in battery, electronics and textile value chains (Version 2.0). CIRPASS Consortium. https://doi.org/10.5281/zenodo.10974901

Appendix A (Interview guide)

1. Introductievragen

a) Kunt u uzelf kort voorstellen uw functie, rol en aantal jaren ervaring binnen de infrasector?

b) Voor welk type organisatie werkt u, en bij wat voor soort infrastructuurprojecten bent u voornamelijk betrokken?

c) Hoe bekend bent u met circulair bouwen of met het concept van Digitale Productpaspoort (DPP)?

2. Circulariteit en hergebruik in infrastructuur

a) Maakt circulariteit of hergebruik van materialen deel uit van de huidige strategie of projectdoelen van uw organisatie?

b)Hoe wordt hergebruik in uw projecten toegepast of gestimuleerd?

c) Wat zijn de belangrijkste uitdagingen of belemmeringen die het hergebruik in infrastructuurprojecten moeilijk maken?

d)Worden er binnen uw projecten specifieke digitale systemen gebruikt om traceerbaarheid te verbeteren en hergebruik van materialen in een latere fase te ondersteunen?

3. Data en traceerbaarheid voor hergebruik

a) Op welke manier wordt informatie over materialen en componenten momenteel vastgelegd en beheerd binnen bestaande kunstwerken of assets?

b) Wie is verantwoordelijk voor het actueel houden van deze informatie gedurende de levenscyclus van een asset? En hoe vaak wordt deze informatie gecontroleerd of geverifieerd?

c) Wordt binnen uw werk ervaren dat de mate van traceerbaarheid verschilt per materiaalsoort, projectfase of objecttype ?

d) Welke typen informatie zijn volgens u nog onvolledig of ontbreken om materialen over de levenscyclus herleidbaar te houden en hergebruik in de toekomst te ondersteunen?

e) Wat zou er volgens u moeten worden aangepast aan de huidige asset en informatiesystemen om materiaalinformatie beter te koppelen en toegankelijk te maken voor alle partijen in het project?

4. Voordelen en toekomstig gebruik van Digitale Productpaspoorten (DPP's)

a) Denkt u dat Digitale Productpaspoorten (DPP's) de komende jaren binnen uw organisatie/ projecten zullen worden ingevoerd?
Indien **ja**: wat zijn de belangrijkste redenen, en is er al sprake van voorbereiding of pilotprojecten?
Indien **nee**: wat is volgens u de reden dat dit onderwerp nog weinig aandacht krijgt?

b) Voor welke materiaalstromen of bouwdelen binnen infrastructuurprojecten verwacht u dat (DPP) de meeste meerwaarde kan bieden?
en op welke manier zou een DPP het proces of de informatiestroom kunnen verbeteren?

c) Denkt u dat het gebruik van een DPP op de lange termijn zal leiden tot tijds-, kosten- of grondstofbesparing?

d) Hoe zou DPP kunnen bijdragen aan betere samenwerking en gegevensuitwisseling tussen verschillende ketenpartners, zoals opdrachtgevers, aannemers, ontwerpers en leveranciers?

5. Inhoud van het Digitaal Productpaspoort (DPP)

a) Op basis van uw ervaring: welke soorten informatie (zie tabel 5) zijn volgens u het meest waardevol om op te nemen in een Digitaal Productpaspoort (DPP) om traceerbaarheid en hergebruik binnen infrastructuurprojecten te ondersteunen?

Datacategorie	**Toelichting en relevantie**
1. Herkomst- en leveringsinformatie	Toont de herkomst van materialen en versterkt transparantie en controle op duurzaamheid.
2. Milieuprestatiegegevens (EPD, LCA, MKI, CO_2-footprint)	Bevat milieugegevens zoals CO_2-uitstoot en levenscyclusimpact, gebruikt voor MKI- en aanbestedingsbeoordelingen.
3. Inspectie- en onderhoudsgegevens	Legt inspecties en onderhoud vast om de conditie en levensduur van objecten te volgen.
4. Reparatie- en aanpassingsgeschiedenis	Registreert uitgevoerde reparaties en aanpassingen om betrouwbaarheid en hergebruik te beoordelen.
5. Verwachte restlevensduur	Geeft een inschatting van de resterende levensduur ter ondersteuning van hergebruik of vervanging.
6. Verbindingen en bevestigingsdetails	Beschrijft het type verbindingen, bouten, lassen of lijmen dat is toegepast. Essentieel voor demontage of selectieve sloop, maar vaak niet volledig vastgelegd.
7. Demontage- of hergebruikinstructies	Bevat richtlijnen voor veilige demontage en hergebruik van onderdelen..
8. Conditiebeoordeling voor hergebruik of sloop	Bevat inspectieresultaten om hergebruikspotentieel en kwaliteit van onderdelen te bepalen..
9. Eigendom en verantwoordelijkheid per projectfase	Geeft aan wie eigenaar is van zowel het object als de bijbehorende data in elke fase (ontwerp, bouw, beheer).
10. Gevaarlijke stoffen en veiligheidsbeperkingen	Geeft aan welke gevaarlijke stoffen aanwezig zijn en welke beperkingen gelden voor veilig hergebruik
11. Transport en logistieke gegevens	Volgt hoe, waar en wanneer herwonnen elementen worden opgeslagen, vervoerd of opnieuw toegepast. Verbetert transparantie van materiaalstromen.
12. Restwaarde- of circulaire waardedata	Geeft een inschatting van de resterende waarde van onderdelen voor hergebruik en LCA-afwegingen.
13. Verificatie- en datakwaliteitsgegevens	Geeft weer wie data heeft ingevoerd en gecontroleerd om betrouwbaarheid te waarborgen.
14. Koppeling met bestaande datasystemen (BIM, Relatics, GIS, Madaster)	Toont hoe het DPP aansluit op bestaande systemen voor betere integratie en datacontinuïteit.

Table 6 Important information for DPP

b) Op welke momenten zou DPP-informatie moeten worden gecontroleerd of geactualiseerd om actueel te blijven?

c) Welke eigenschappen maken DPP-informatie betrouwbaar en bruikbaar voor langetermijn-assetmanagement ?

d) Hoe gedetailleerd moeten materiaal- en productgegevens zijn om hergebruik mogelijk te maken, zonder onnodige administratieve belasting te veroorzaken?

e) Welke milieu- of circulariteitsindicatoren zouden volgens u in een DPP moeten worden opgenomen om het hergebruik- of recyclingpotentieel zichtbaar te maken?

f) Denkt u dat het nuttig of haalbaar is om onderdelen in projecten te voorzien van een digitale identificatie, zoals een QR- of RFID-tag, die direct toegang geeft tot het Digital Product Passport? Waarom wel of niet?

6. barrières bij de implementatie van Digitale Productpaspoorten (DPP's)

a) Vanuit uw ervaring: wat zijn de belangrijkste uitdagingen bij het invoeren van Digitale Productpaspoorten (DPP's) om traceerbaarheid en hergebruik te verbeteren?

b) Hoe beïnvloeden de volgende aspecten de implementatie van DPP's?

- **Gegevensdeling en vertrouwelijkheid**:
- **Procesintegratie:** In welke projectfasen
- **Digitale capaciteit**:
- **Rollen en werkbelasting**:
- **Beleid en standaarden**:

c) Wat zouden volgens u de belangrijkste risico's zijn als deze belemmeringen niet worden aangepakt Bij: dataverlies, onduidelijke verantwoordelijkheden of lage datakwaliteit?

d) Wat zou de implementatie van DPP's eenvoudiger en effectiever kunnen maken ?
Bijv: duidelijke rolverdelingen, gestandaardiseerde dataformaten of betere samenwerking tussen stakeholders?

7. Slotvraag

Is er nog iets wat u verder zou willen toevoegen, of kent u iemand anders die volgens u waardevolle inzichten kan bieden voor dit onderzoek?