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ERASMUS MUNDUS JOINT MASTER DEGREE

MASTER DEGREE IN SUSTAINABLE DESIGN, CONSTRUCTION AND MANAGEMENT OF THE BUILT ENVIRONMENT

MBUILD

CIRCULARITY ENABLED BY PRODUCT DATA: PRIORITISATION AND A MINIMUM VIABLE DATASET FOR DIGITAL PRODUCT PASSPORTS

KYRA MARIA VAN DEN MUYZENBERG

Supervision: Pedro Mêda FEUP, Jorge Teixeira ICS

Porto, 2026

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ABSTRACT

The construction sector is undergoing a twin transition driven by digitalisation and the shift towards a circular economy (CE), with Digital Product Passports (DPPs) emerging as a key instrument. Given the early stage of DPP implementation, gaps remain between regulatory ambition, research development, and practical application in the construction sector, as identified through the systematic literature review using the PRISMA-ScR guidelines. A consensus has yet to be established on which construction products should be prioritised for a phased EU DPP rollout, what data is required to deliver circularity, and how this data is to be structured in digital tools. By adopting a Design Science Research (DSR) approach, this dissertation addresses these gaps through a mixed-method strategy across four interlinked phases of work, grounded in two real-world construction projects of differing typologies: a residential refurbishment case and an industrial new-build.

The information environment of each project case was first analysed to understand the conditions under which product data can be identified, extracted, and structured. This revealed that developing a Bill of Materials (BoM) for an as-built project is fundamentally a retrospective reconstruction, in which forensic techniques can support the extraction and recovery of product and material details from fragmented legacy sources to inform circular interventions in construction projects.

A prioritisation method with the criteria of weight significance and circularity potential was applied to identify the construction products to prioritise for DPPs with the largest CE impact. Weight significance was assessed through a quantitative calculation and a survey evaluated the circularity potential based on the applicability of CE R-strategies. The method identified the precast concrete wall element in the new-build project, dominant on both criteria and most significantly in absolute weight. For the refurbishment project, the aluminium frame double glazed window was identified as the priority product, driven by its high circularity potential at different granularities. These differing outcomes suggest that priority products vary according to the characteristics of each project typology and are influenced by factors such as disassembly potential and material composition.

Circularity data requirements were consolidated through a top-down and bottom-up approach, drawing on regulations, standards, and existing construction processes of Level(s) assessment and pre-deconstruction audits, into a structured Circularity Minimum Viable Dataset (C_MVDataset). This provides a basis for DPP circularity data to enable multiple lifecycles and second-hand use across new-build and refurbishment projects. An evaluation of the C_MVDataset against existing industry documentation for the identified priority products revealed clear gaps in the provision of structured circularity data in current practice.

This research contributes a data maturity model for as-built construction product information environments, a prioritisation method for phased DPP implementation, and the C_MVDataset for DPPs, supporting the twin transition in the construction sector.

Keywords: circular economy, Digital Product Passport, construction products, information environments, product prioritisation, circularity data requirements

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SYMBOLS, ACRONYMS AND ABBREVIATIONS

AHI – Affordable Housing Initiative

BAMB – Buildings As Material Banks

BIM – Building Information Modelling

BoM – Bill of Materials

BoQ – Bill of Quantities

BREEAM – Building Research Establishment Environmental Assessment Method

bSDD – buildingSMART Data Dictionary

CDW – Construction and Demolition Waste

CE – Circular Economy

CE-marking – Conformité Européenne (European Conformity) marking

CEAP – Circular Economy Action Plan

CMP – Circularity Material Passport

C_MVDataset – Circularity Minimum Viable Dataset

CPR – Construction Products Regulation

DBL – Digital Building Logbook

DfD – Design for Disassembly

DoP – Declaration of Performance

DPP – Digital Product Passport

DSR – Design Science Research

DTs – Data Templates

EEA– European Economic Area

EGD – European Green Deal

EN – European Standard

EPBD – Energy Performance of Buildings Directive

EPD – Environmental Product Declaration

ESPR – Ecodesign for Sustainable Products Regulation

ETA – European Technical Assessment

ETICS – External Thermal Insulation Composite System

EU – European Union

GDPR – General Data Protection Regulation

GPP – Green Public Procurement

hEN – harmonised European Standard

ISO – International Organisation for Standardisation

LCA – Life Cycle Assessment

LEED – Leadership in Energy and Environmental Design

LOIN – Level of Information Need

MO – Macro-Objective

MP – Material Passport

MVD – Minimum Viable Dataset

NMU-DSM – Nelson Mandela University-Design Science Methodology

PCDS – Product Circularity Data Sheet

PRISMA-ScR - Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews

RIBA – Royal Institute of British Architects

RQ – Research Question

RW – Renovation Wave

SDG – Sustainable Development Goal

SDO – Standards Development Organisation

WFD – Waste Framework Directive

WoS – Web of Science

1
INTRODUCTION

1.1. THE TWIN GREEN-DIGITAL TRANSITION IN THE CONSTRUCTION SECTOR

The construction sector is undergoing a significant transformation driven by ambitions of sustainability and digitalisation. As their paths increasingly intersect, they are forming the European twin transition, where digital tools aim to accelerate the implementation of circular economy (CE) objectives and support more sustainable resource management practices in construction [1]. As one of the largest consumers of raw materials and contributors to construction and demolition waste (CDW), the construction sector faces increasing pressure to reduce waste generation and improve resource efficiency, given its one-third share of total waste generated in Europe [2]. In response to this, European initiatives, such as the new Circular Economy Action Plan (CEAP) of 2020, promote a shift from linear consumption patterns towards circular loops that prioritise reuse, lifetime extension, and recovery in accordance with the waste hierarchy in the Waste Framework Directive (WFD) [3]. These efforts are further reinforced through the revision of material recovery targets for CDW and its material-specific fractions [4], [5].

A key enabler of this transition is the availability of structured and accessible data on building projects and the products they comprise [6]. Recent European regulatory developments further reinforce the importance of digitising product data to deliver circularity. The Ecodesign for Sustainable Products Regulation (ESPR) and the revised Construction Products Regulation (CPR) are driving the development of Digital Product Passports (DPPs) for construction products placed on the EU market, which are envisioned to structure, digitise, and make product information accessible in support of circularity objectives [7], [8]. Therefore, when addressing DPP in the context of this research, it should be understood as the EU DPP, the one enabled by ESPR and CPR. Construction products and the information that accompanies them throughout their lifecycle play, therefore, a central role in facilitating the shift from waste management to resource management for a more CE. This is reflected in emerging policy ambitions that prioritise product reuse [3], [4], [8].

In the context of construction projects, characterised by varied information environments and project deliverables, DPPs are envisioned as a key digital tool to improve product traceability, transparency, and information exchange among stakeholders and across lifecycle stages [9], [10], [11]. By making product information more accessible, they offer opportunities to streamline existing construction processes with circular relevance, relying on product-level data [12], [13]. Given the scale and diversity of construction products, DPP implementation is expected to follow a phased approach, where prioritisation of products is advocated [4], [14].

1.2. PROBLEM STATEMENT

1.2.1. WHICH CONSTRUCTION PRODUCTS SHOULD BE PRIORITISED?

As DPPs are increasingly introduced in the construction sector, prioritisation efforts have emerged in both research and policy [14], [15], [16]. However, despite this advocacy for a phased, prioritised approach, clear guidance on how such prioritisation should be carried out remains limited, with a variety of approaches and criteria used. The EU has set as its main criteria the carbon footprint and energy efficiency, leading to priority products such as cement, steel and insulation [17]. However, it remains less defined which products should be targeted first to maximise circular impact at scale [4].

1.2.2. WHAT CIRCULARITY DATA IS NEEDED FOR CONSTRUCTION PRODUCTS?

Data lies at the core of circular construction, which depends on product-level information to support informed circular forecasting and decision-making throughout the product lifecycle. Yet there is still limited consensus across research and policy on what circularity-related information for construction products is needed and how it should be structured to support circular interventions and digital integration, forming the fundamental data gap illustrated in Figure 1.1. Compared with products in other sectors, construction products present greater complexity in data provision, as their circular potential and possible outlet pathways can vary widely depending on their composition, type, application, and declared use. While policy ambitions increasingly prioritise reuse and the development of secondary markets for construction products, these objectives have yet to be translated into clear and actionable product-level data requirements, prescriptions both detailed in the CPR and in the context of the WFD [3], [4], [8].

1.2.3. HOW WILL THE DPP INTERACT WITH EXISTING INFORMATION PRACTICES?

DPPs are emerging into an industry where a wide variety of information practices, tools, and digital integration solutions exist across construction projects. How the data contained in DPPs will interact with, build upon, and improve existing approaches is yet to be determined, due to their early stages of implementation [18]. At the foundational data layer of DPPs, their role in enabling circular interventions requires further clarification if such instruments are to effectively support data-driven practices and improve the circularity of construction products [19], [20], [21].

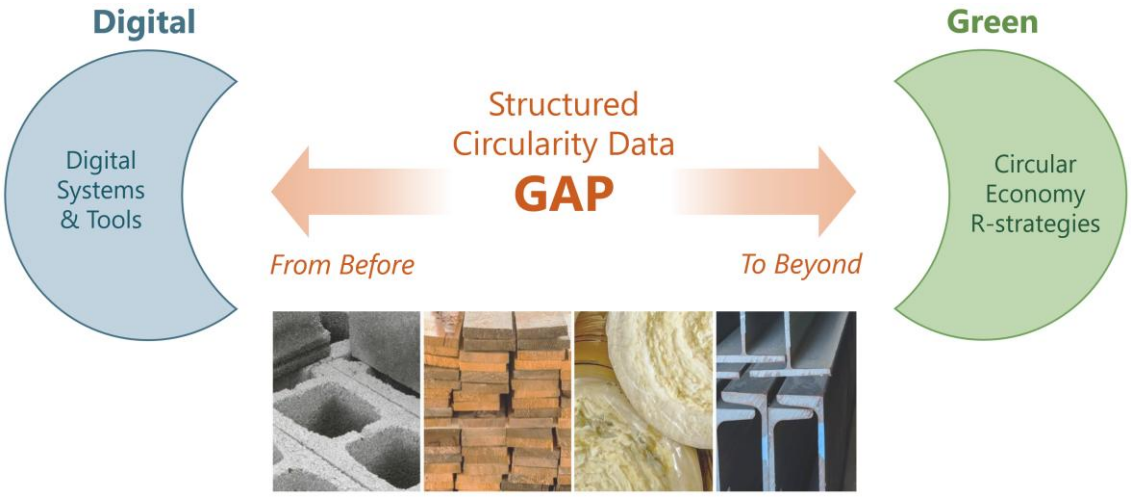


Fig. 1.1 – From before to beyond. The construction product structured data gap for circularity between the green and digital transitions

1.3. RESEARCH PURPOSE

The transition towards a circular construction sector requires a shift from linear to CE practices that prioritise reuse, lifecycle extension, and recovery. Central to this transition is the availability of structured, consistent product data throughout the product's lifespan. As DPPs emerge as a key digital instrument for carrying and exchanging this information, there is a growing need to understand which data is required to be able to perform circular interventions on construction products. This research acknowledges the varying information environments of construction projects, where product-level information availability, documentation practices, and digital maturity differ across projects, with implications for the implementation of DPPs. The purpose of this research is to bring consensus and structure product data to deliver circularity of construction products and support data-driven circular construction processes in building projects.

1.4. RESEARCH AIM

This dissertation aims to identify priority construction products and define their circularity data requirements in light of the phased implementation of DPPs to support circular construction. Grounded in real-world construction projects, the research examines existing product information environments and develops a C_MVDataset that consolidates circularity requirements into a structured dataset to support second-hand use and facilitate circular information flows across multiple product lifecycles.

1.5. RESEARCH OBJECTIVES

To achieve this aim, the dissertation is guided by the following objectives:

- **Analyse** the product information environments of real-world construction projects to establish the context for circularity data availability, collection, and application.
- **Identify and prioritise** construction products based on weight significance and circularity potential assessment to support a phased DPP implementation.
- **Determine** the data requirements needed to support existing circularity-related construction processes and enable second-hand product use, structured into a circularity dataset for construction products.
- **Evaluate** the provision of circularity data requirements against existing product documentation to examine their current availability and implications in practice.

1.6. RESEARCH QUESTIONS

1.6.1. MAIN RESEARCH QUESTION

How can circularity data requirements be structured into a C_MVDataset to support DPP implementation for priority construction products?

1.6.1.1. Subsequent Research Questions (RQs)

RQ1. What characterises the product information environments of real-world construction projects, and what opportunities do they provide for circularity data collection?

RQ2. Which construction products emerge as priorities based on their weight significance and circularity potential?

RQ3. What product data is necessary to streamline circularity-related construction processes and determine circular pathways for construction products?

RQ4. To what extent are circularity data requirements currently available and defined within existing product documentation practices?

1.7. METHODOLOGY OVERVIEW

Based on the PRISMA-ScR method guidelines, the literature review approach was developed to establish the DPP knowledge and gaps across academic, regulatory, and industry sources shaping the research objectives. To address them, a Design Science Research (DSR) paradigm was adopted, given its focus on developing a novel artefact aimed at providing a solution to a practical, real world challenge. This shaped the development of the C_MVDataset to support product circularity and DPP implementation. A mixed-methods approach was adopted, combining case study, archival research, and survey strategies. These were addressed through four interlinked phases: analysing the information environment of existing construction projects, prioritising products based on weight significance and circularity potential, consolidating data requirements into the C_MVDataset, and evaluating this dataset against existing product documentation. The full methodology is presented in Chapter 3.

1.8. SCOPE AND DELIMITATIONS

1.8.1. SCOPE

- **Building construction and product boundaries:** The research is situated in the construction sector and studies in detail the construction products used in building projects. Considering that DPPs are being developed across multiple sectors, this research examines the EU DPP in the construction sector and its role in supporting circular building practices.
- **Product circularity and information focus:** The study investigates the information needed to support the circularity of construction products. CE principles can be applied at multiple scales, from materials and products to entire buildings. This research is limited to the building element and the data required to support building-level circularity assessments. Although broader sustainability addresses carbon emissions reduction and environmental performance, which are priority policy drivers, this research focuses on the CE dimension of the built environment, aiming to reduce waste generation and increase recovery rates. Therefore, environmental impact assessment, including Life Cycle Assessment (LCA), embodied carbon, and other quantitative performance measures, is excluded. Economic and social dimensions of circularity are also out of scope, as the study concentrates on the data layer needed to enable circular pathways for construction products.
- **Circular Use Cases:** To ensure practical relevance, the research is grounded in two established construction processes that support CE practices of construction products:
    - EU Level(s) sustainability assessment framework
    - Pre-deconstruction audits
- These use cases were selected because they rely on product-level information to identify, assess, and manage construction products throughout their lifecycle. The study specifically focuses on Level(s) Macro-objective 2, which addresses resource-efficient and circular material life cycles [22].
- **Case study context:** The empirical part of the research is based on two real-world construction projects representing different project types (new-build and refurbishment) and building functions (residential and industrial), capturing the diverse contexts relevant to the implementation of DPPs. These case studies are used to examine existing product information

environments with different documentation practices, information availability and digital maturity. They provide context-specific insights into the feasibility of implementing circularity data requirements in practice.

1.8.2. DELIMITATIONS

- **Exclusions:**
  - Product information unrelated to circular interventions, except where necessary for contextual understanding or regulatory alignment.
  - Comprehensive sustainability impact assessment and environmental data related to LCA and embodied carbon calculations.
  - Other DPP components such as data architecture, user interfaces, data governance, blockchain infrastructure, and similar technical implementation aspects.
  - Infrastructure and heavy civil engineering projects, with the research limited to building's construction.
- **Regulatory and policy context:** The study is positioned within the EU policy and regulatory context as of 2025 and beginning 2026, aligned with CE objectives and the emerging regulatory framework for DPPs in construction products. It considers relevant legislation, standards, and policy initiatives that shape circularity and EU DPP development in the built environment. This provides a regulatory basis for the research and ensures alignment with existing efforts, while also recognising that these will continue to evolve and shape future DPP implementation (see Chapter 2, Background).

1.9. RESEARCH CONTRIBUTION

This research contributes to the transition towards circular construction by addressing the need for structured circularity data for construction products to support the phased implementation of DPPs. It delivers a C_MVDataset that consolidates existing circularity data requirements, a product prioritisation method, and an evaluation of current documentation practice. The contributions of this research are both academic and practical, as outlined in further detail below.

1.9.1. ACADEMIC CONTRIBUTION

This research contributes to the emerging fields of circular construction and DPPs by:

- Proposing an approach for identifying and prioritising construction products based on weight significance and circularity potential , to support a phased DPP rollout across the construction sector.
- Synthesising circularity data requirements across regulatory, technical, and practice-based sources into an initial, coherent set of circularity requirements for construction products.
- Providing empirical evidence on the current information environment of construction product data, drawn from real construction projects and industry-used documentation. This provides a clarification on the the practical conditions under which DPPs will need to be populated and implemented, which remains underexplored in current research.
- Developing a data maturity model for as-built construction product information environments, linking each maturity level to suitable forensic data collection techniques.
- Structuring the development process around the ISO 23387 data template creation activities, offering a worked example of how its preparatory activities can be applied to circularity data for construction products.

1.9.2. PRACTICAL CONTRIBUTION

This research contributes to industry practice and DPP implementation by:

- Providing practitioners with a toolbox of forensic techniques linked to differing levels of project data maturity, supporting product data extraction in as-built project contexts to construct DPPs for existing products and enable circular interventions.
- Offering an early, dataset-level indication of what second-hand market data requirements for construction products might entail, responding directly to the CPR's Recital 34 acknowledgement of this underdeveloped area.
- Establishing the C_MVDataset that streamlines existing construction processes, specifically EU Level(s) assessment and pre-deconstruction audits, to support the identification and preparation of products for deconstruction and future lifecycles.
- Providing an evidence-based account of the extent to which existing construction project documentation currently supports circularity data requirements, clarifying where practical gaps remain for future DPP implementation.
- Extending the existing CDW management decision flowchart, currently confined to reuse, recycling and recovery to include the full set of product lifetime extension strategies, supporting practicioners in circularity forecasting and pre-deconstruction audits of construction products.
- Informing policy development and industry implementation of DPPs by highlighting practical considerations at the product data layer that influence meaningful circular interventions.

1.10. SDG CONTRIBUTION

This research contributes to the United Nations Sustainable Development Goals (SDGs) by supporting the goals most relevant to a more circular and data-driven construction sector, as highlighted in Figure 1.2.



Fig. 1.2 – UN SDG goals addressed by this research (adapted from [23])

The primary contribution relates to SDG 12 (Responsible Consumption and Production) by identifying circularity information requirements that support waste reduction, resource conservation, and circular pathways for construction products. The research also contributes to SDG 9 (Industry, Innovation and Infrastructure) by developing a structured circularity dataset to support digitalisation and the implementation of DPPs for circular construction. By promoting a shared information foundation that enables collaboration across product lifecycles and stakeholders, the study further supports SDG 17 (Partnerships for the Goals). Further relevance is found in SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action) through improved management of construction resources and waste, which reduces the environmental impacts of the built environment. Addressing deconstruction planning processes and hazardous substances associated with construction products, the research also contributes to SDG 3 (Good Health and Well-Being) [23], [24].

1.11. DISSERTATION STRUCTURE

This dissertation is organised into the following chapters:

Chapter 1 - Introduction

Presents the background and context of the research, establishing the main aim and objectives. The scope, methodology overview, and contributions are also outlined.

Chapter 2 - Background

Provides the regulatory and industry context relevant to this research, addressing CE policy, circularity assessment frameworks, and the development timeline of DPPs.

Chapter 3 - Methodology

Presents the literature review approach according to PRISMA-ScR guidelines used to identify existing knowledge and gaps on DPP implementation in the built environment. This is followed by the research design based on the DSR paradigm and the use of mixed-methods strategy along four phases to address each research objective.

Chapter 4 – Literature Review

Presents the findings of the systematic literature review conducted using the method outlined in Chapter 3, identifying the key gaps in the field of DPP and circular construction that the research seeks to address.

Chapter 5 - Results

Presents the results of each phase conducted, including the case study project information environment maturity assessment, weight and circularity potential product prioritisation, the proposed Commoditised, evaluation of the dataset against industry product documentation practices, and the refinements made following focus group feedback.

Chapter 6 - Discussion

Interprets the findings in relation to the research questions and the gaps identified in the literature review, discussing their implications for circular construction practice and the phased implementation of DPPs. This chapter also addresses the limitations of the research.

Chapter 7 - Conclusion

Summarises the key findings of the dissertation, revisits the research contributions, and provides recommendations for future research and practical implementation.

Given the outlined aim, objectives, and contributions of this research, the following Chapter 2 provides the regulatory and industry background, situating this study within the broader context of the construction sector's twin transition.

2
BACKGROUND

This chapter establishes the regulatory and industry context in which DPPs are emerging for construction products, spanning CE principles, EU policy developments, and product-level regulation and standardisation.

2.1. CIRCULAR ECONOMY FOR A SUSTAINABLE BUILT ENVIRONMENT

2.1.1. SUSTAINABILITY IN THE CONSTRUCTION SECTOR

Within sustainability are environmental and CE objectives that have gained prominence across policy, research, and industry practice to address the urgent need for decarbonisation and more sustainable resource management in the built environment [23]. Although closely interconnected, environmental and CE approaches address sustainability from different perspectives, as illustrated in Figure 2.1.

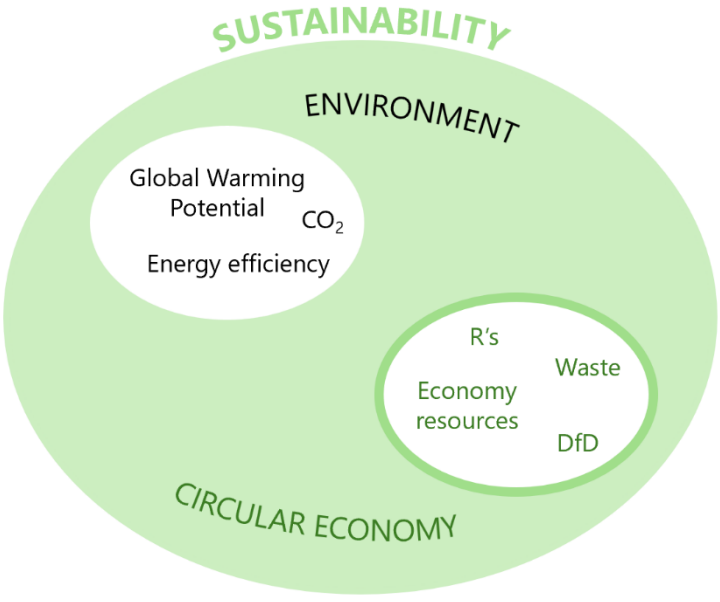


Fig. 2.1 – Two dimensions of sustainability in EU policy

Environmental aspects primarily focus on measuring and reducing impacts, such as energy consumption, carbon emissions, and environmental footprints. Whereas the CE focuses on improving the management of products and materials through waste reduction and extending the lifecycle of products and materials within the economy for as long as possible [4], [25]. CE strategies contribute to environmental objectives

by addressing the resource flows and waste generation that underpin many climatic impacts. Key principles include Design for Disassembly (DfD) and the CE framework of R-strategies [26], [27]. Recognising the significant resource consumption and waste generation of the construction sector, policy initiatives are promoting CE principles alongside climate objectives. The European Union's CEAP emphasises reducing CDW by increasing recovery rates as a key priority [4].

2.1.2. ROLE OF CONSTRUCTION AND DEMOLITION WASTE

The construction sector is responsible for significant resource consumption and waste generation, accounting for approximately 38% of total waste generation by all economic activities and households **by weight** in the EU. CDW is one of the largest waste streams generated by construction activities, mainly a result of the dominant use of "concrete, aggregates and bricks that make up to 90% (by weight)" in building construction (Figure 2.2) [2]. Within sustainability discourse, the management and disposal of CDW is of growing concern due to the pressures and risks they pose on the environment [28], [29], [30].

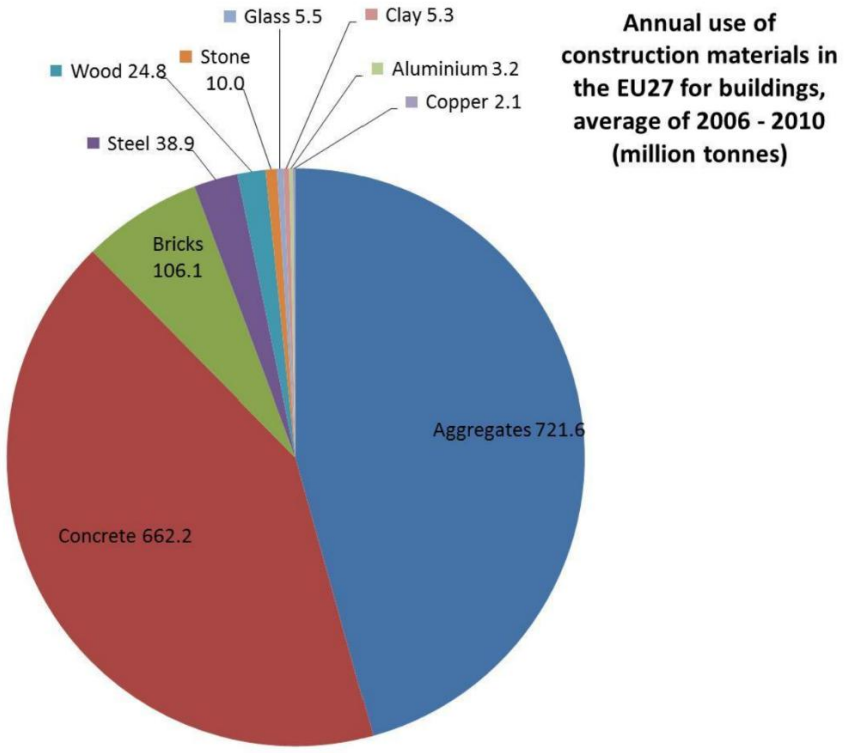


Fig. 2.2 – Annual use of construction materials in Europe for buildings, represented in weight [2]

Conventional linear practices of the "take-make-use-dispose" model continue to generate large quantities of waste and increase the demand for virgin resources [4]. Current waste management practices vary across EU countries, and mainly recycling and material recovery are being performed. However, policy attention is shifting to reuse and lifecycle extension strategies, with the "aim to ensure that this waste is managed in an environmentally sound way and contributes to the circular economy" [30].

2.1.3. LIFECYCLE THINKING AND CIRCULAR PATHWAYS

The lifecycle approach is central to circular construction and is advocated across several EU built environment frameworks, such as CEAP, the Sustainable Built Environment Agenda, and the Level(s)

methodology [4], [23], [31]. The lifecycle of construction projects is shaped by frameworks such as the RIBA Plan of Work, which structures the construction process lifecycle into detailed stages [32]. Across other lifecycle stage structures, "design, construction, use and end-of-life" are used. In this study, both structures are adapted to frame a construction project within a circular economy context. The inclusion of "**Before**" ahead of the design stage accounts for the prior project lifecycle from which resources may originate. "**Beyond**" reinterprets "end-of-life" stage as deconstruction and the extension of product lifetimes through R-strategies, entering into another building project lifecycle, as shown in Figure 2.3. The closed loop reflects that product resources recovered at the "Beyond" stage can circulate back into the "Before" stage of the same project through refurbishment.

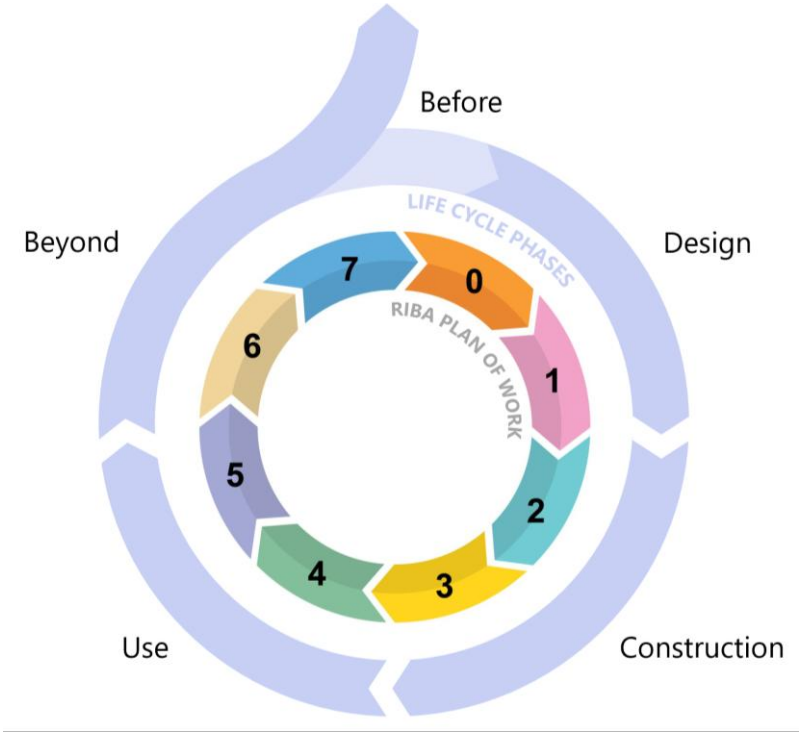


Fig. 2.3 – RIBA Plan of Work reframed into five CE-oriented life cycle phases, including "Before" and "Beyond" stages (adapted from [32])

2.1.4. FROM WASTE HIERARCHY TO CIRCULAR ECONOMY STRATEGIES

CE initiatives have gained increasing traction in the construction sector, evolving from policy discourse into practical application. The Ellen MacArthur Foundation's CE framework is widely cited for defining the core principles of eliminating waste and creating closed-loop systems that retain products in productive use and recirculate them into multiple lifecycles. Notably, in the built environment these principles have been consolidated and adapted through initiatives such as Building as Material Banks (BAMB), which emphasises lifecycle thinking, DfD, and longevity for circular construction [26], [33], [34].

Within contemporary CE discussions, circularity is positioned as a resource management strategy aimed at improving material efficiency, preventing waste, and retaining the value of products and their components and materials for as long as possible [26]. In other words, CE principles shift the perspective from waste toward resources. The waste hierarchy defines reuse, recycle, recovery, and disposal as the key waste streams used to support CDW management and activities (Figure 2.4). In accordance with WFD and CDW Protocols, pre-demolition waste audits facilitate the selective demolition of building elements [3], [35]. Within CE discourse, the term "**Deconstruction**" is used instead to emphasise the systematic, planned removal of building elements to maximise reuse, recycling, and recovery [31].

Therefore, in this study, "pre-demolition audits" or "waste audits" across the literature reviewed are reframed as "**Pre-deconstruction audits**" as understood through the CE lens of resource management.



Fig. 2.4 – Waste Hierarchy in the WFD [3]

As illustrated in Figure 2.5, the CE 10 R's framework introduces additional strategies between reuse and recycling that aim to further extend the lifetime of products and their components, including repurposing, repair, refurbishment, and remanufacturing. These frameworks are synergised in the research and underpin the analytical approach. The R0-R2 strategies are primarily design-oriented and focus on avoiding resource consumption and waste generation from the outset. The subsequent R-strategies are relevant to the use and deconstruction stages, as they support the retention, recovery, and continued use of the construction products and materials. The later is the perspective taken in the research.

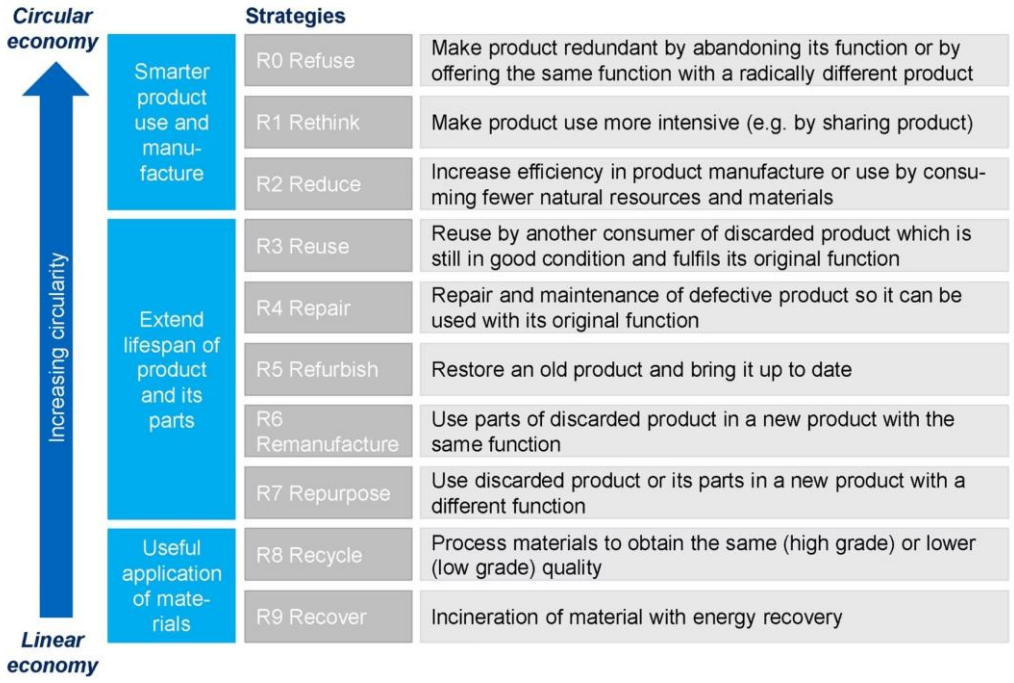


Fig. 2.5 – 10R's Framework of a Circular Economy [36]

2.1.5. LEVEL(S) AS A FRAMEWORK FOR SUSTAINABILITY ASSESSMENT

Across EU policy and action plans, alignment with Level(s), a voluntary sustainability framework, is established. Level(s) provides a common EU approach for assessing and reporting the performance of buildings and their products across their whole lifecycle [4], [31], [37]. The framework is based on six Macro-objectives, each supported by indicators, as shown in Figure 2.6. Industry sustainability assessment schemes, such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM), also evaluate building performance across predefined criteria, with certification awarded according to the level of sustainability compliance achieved [38]. For this study, Level(s) is applied, as it is fundamentally shaped by EU policy and relevant in trajectory pathways, as mentioned in the CEAP and Renovation Wave (RW) for a sustainable built environment [30], [39].

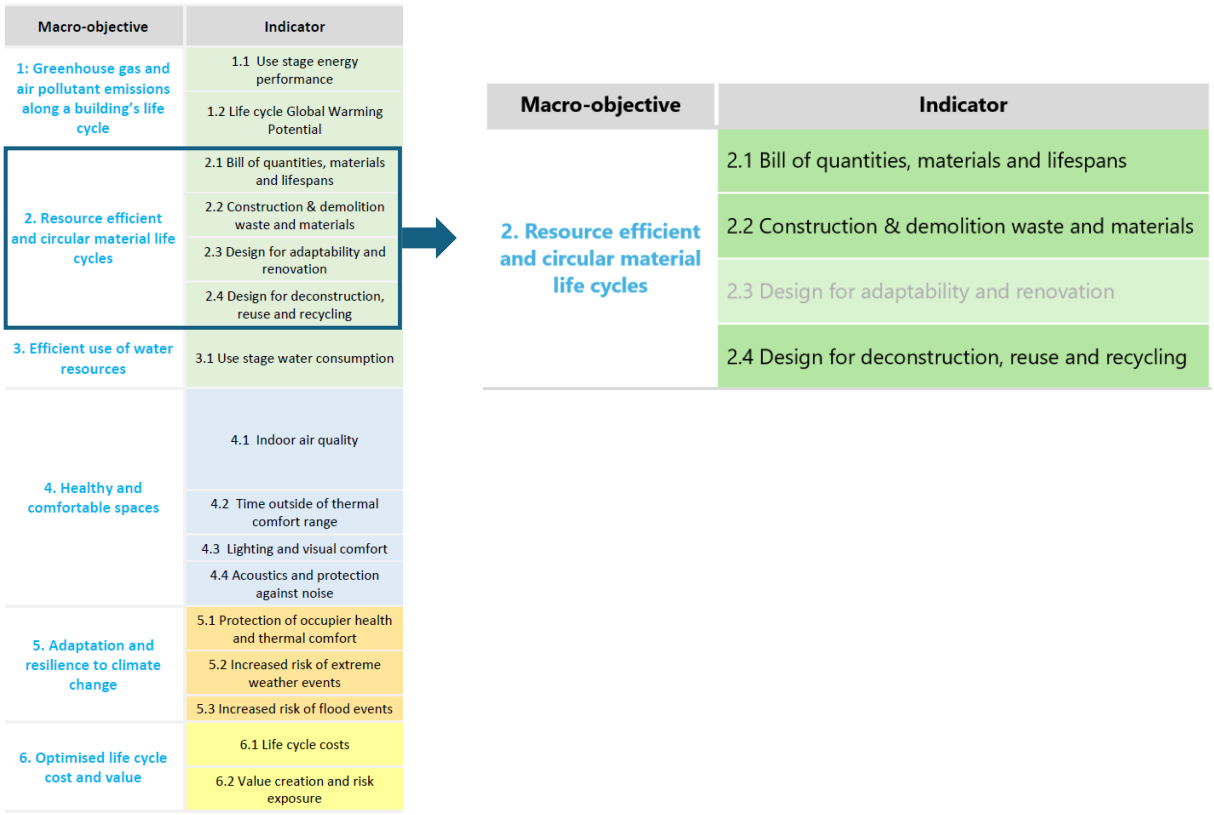


Fig. 2.6 – Level(s) Macro-objectives, highlighting the indicators that are considered for the research (adapted from [22])

Given the scope of this study in the CE dimension, the most relevant Level(s) Macro-objective is **2. Resource efficiency and circular material life cycles**, with a particular focus on indicators 2.1, 2.2 and 2.4 [37]. These indicators address material use, waste reduction, and circularity outcomes, all of which are central to this research. Indicator 2.3 is excluded because it primarily concerns design-phase considerations and spatial adaptability. This falls outside the main analytical scope of this study that focuses on the product lifespan and waste. In Chapter 4, the review of literature reinforces these indicators as relevant in the context of DPPs [13].

The Level(s) methodology is organised at three defined levels for application. Levels 1 and 2 are based on qualitative information, suitable for conceptual and design stages. Level 3 is based on quantitative

information and "as-built" data. The higher level of detail required at Level 3 enables more robust and reliable assessments, providing a closer representation of actual project performance [31]. In this study, Level 3 is applied based on the "as-built" conditions of the case study projects and the detailed product data provided in their information environments.

2.2. EUROPEAN POLICY DRIVERS AND EVOLUTION

At the EU policy agenda level, the European Green Deal (EGD) provides the overarching strategic framework for transforming the built environment in response to environmental, energy, and socioeconomic challenges [40]. Within this agenda, the RW and Affordable Housing Initiative (AHI) were introduced to prioritise the renovation of the existing building stock by improving energy efficiency, lowering lifecycle costs, and accelerating the transition towards more circular approaches in construction across EU countries. The EU Taxonomy, Green Public Procurement (GPP), and the Energy Performance of Buildings Directive (EPBD) have also shaped sustainable building policy from the perspectives of public procurement and energy performance [41], [42]. However, the later are outside the main scope of this study, which concentrates on the CE and waste-related developments.

The future-oriented agenda of the 2020's CEAP reinforces this direction aimed at accelerating the trans-formational change required by the EGD, while building on CE actions implemented since 2015. The new CEAP has marked a key shift towards a more integrated product policy agenda linking CE objectives with digitalisation [4]. For the construction sector, the plan identifies several priority actions, including:

- Digitise product information through digital passports and digital logbooks for buildings.
- Use Level(s) to support lifecycle assessment across all policy areas.
- Consider revisions to material recovery targets for CDW waste under the WFD.

These measures position construction products within broader circular and digital transition and are closely aligned with the EU's emerging vision for a transition pathway for construction, coined as the **twin transition** [1]. The timeline in Figure 2.7 captures the evolving and interlinking policy context in which EU DPPs are being shaped and continues to develop through a phased rollout.

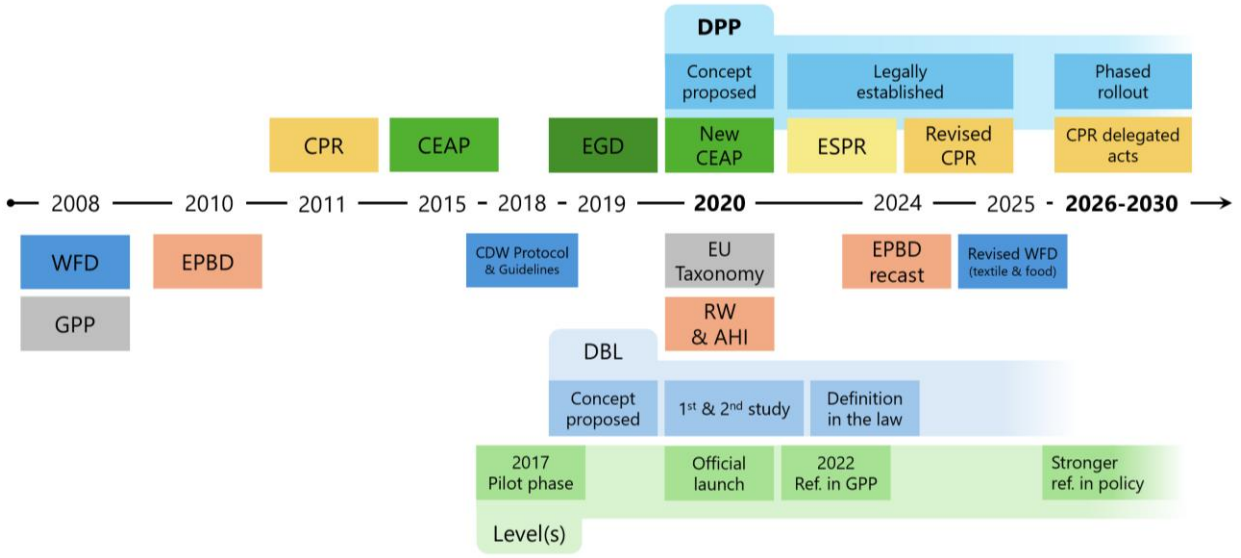


Fig. 2.7 – Timeline of EU policy developments shaping the emergence of EU DPP for construction

2.2.1. PRODUCT LEVEL REGULATION

At the product level, the ESPR delegated act establishes the legal basis for the emerging DPPs as a horizontal tool for product sustainability information. The revised CPR in 2024 translates this into the construction sector, specifically by promoting greater resource efficiency of construction products through requirements related to reuse and product lifecycle extension strategies. It also emphasises the need to facilitate the separation and recovery of products during deconstruction. Both delegated acts establish DPPs' relevance to compliance, lifecycle information management, and future circular construction practices [7], [8]. Within the broader EU digitalisation agenda, the Digital Building Logbook (DBL) is a digital system mentioned alongside DPPs for lifecycle information management at building level, supporting circular construction and enabling the EU twin transition [1].

2.2.2. WASTE GOVERNANCE

The WFD, together with the EU CDW Protocol and its pre-demolition waste audit guidelines, provides the main policy basis for waste prevention and material recovery in construction. The most recent construction-relevant guidance established in the CDW Protocol aims to increase confidence in reused products and recycled materials and to maximise recovery from renovation and demolition works. The CEAP also reflects a broader policy intention to modernise EU waste law for the CE and the digital age. As indicated in the timeline, recent revisions have been published for other industry products, such as textiles and food, which reveals the direction of EU waste policy towards stronger resource efficiency and waste prevention for all industries [3], [4], [29], [35].

2.2.3. POLICY TRAJECTORY AND FUTURE DIRECTION

The timeline in Figure 2.7 provides the context for how EU policy efforts seek to improve coherence across relevant policy areas by progressively aligning CE objectives, waste governance, digital information systems, and sustainability assessment in the built environment. According to the CEAP, future revisions to current legislation and related initiatives are expected to further strengthen circularity and sustainable product to building level information through digital instruments, contributing to the EU twin transition at scale [4], [30].

2.3. CONSTRUCTION PRODUCT POLICY AND STANDARDISATION CONTEXT

2.3.1. CONSTRUCTION PRODUCTS AND DPP

At the construction product level, reliable and structured information is recognised as a prerequisite for circular construction, across policy and research. DPPs are understood as digital enablers of lifecycle decision-making and circular forecasting, aiming to facilitate product data traceability across lifecycle stages [37]. The policy trajectory of construction products demonstrates an evolution and iteration from technical compliance to environmental disclosure and the more recent economy of resources, as shown in Figure 2.8.

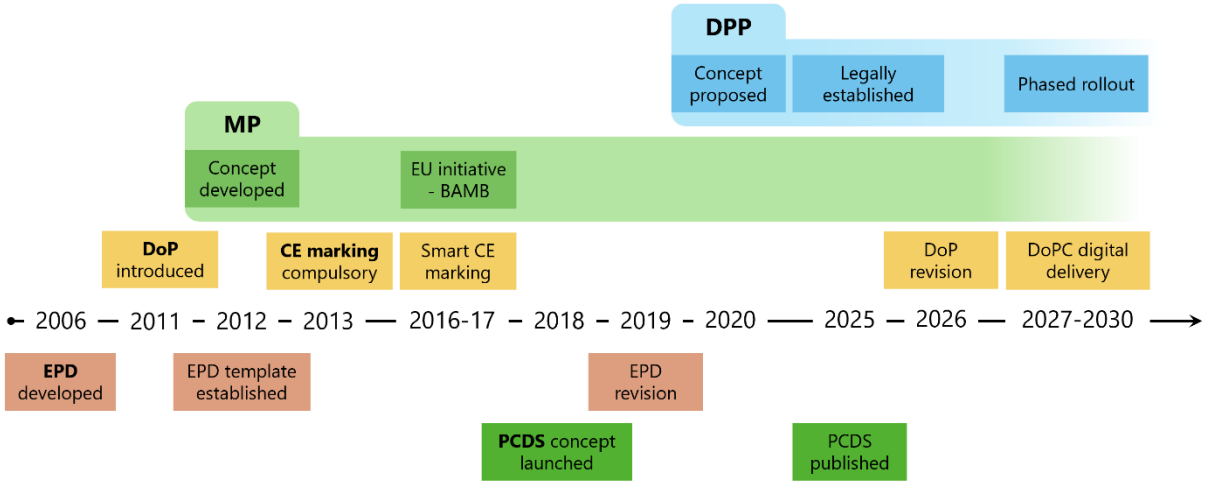


Fig. 2.8 – Evolution of construction product information standards and instruments

2.3.2. TECHNICAL FOUNDATIONS

From the beginning, the CPR established the technical basis for product conformity through the Declaration of Performance (DoP) and CE-marking. These instruments are fundamental as they provide the core framework for product performance information across Member States and ensure technical compliance of all products within the EU internal market [8], [43], [44].

2.3.3. ENVIRONMENTAL DISCLOSURE

Due to growing environmental concerns in the construction sector, the Environmental Product Declarations (EPDs) were first introduced in 2006, with standardised environmental principles [45]. In construction, product data templates were established for information on environmental impacts across the product lifecycle, later on revised in 2019 [46]. Although the primary focus is on environmental performance and emissions, EPDs also include information on end-of-life stages relevant to CE applications, as integrated in this study.

2.3.4. ECONOMY OF RESOURCES

Since the CEAP, policy has shifted more clearly towards the need for product circularity and resource efficiency in digital form. In response to this, initiatives such as the Product Circularity Data Sheets (PCDS) were conceptualised in 2018 and were recently established in 2025 to communicate circularity-related information about products specifically [47], [48].

2.3.5. DPP POLICY AND STANDARDISATION DEVELOPMENTS

The DPP can be understood as a digital tool bringing together several information dimensions based on existing construction product systems:

- **Technical dimension**: conformity and performance information through CE-marking and DoP.
- **Environmental dimension**: lifecycle environmental impacts information within EPDs.
- **Economy of resources dimension**: circularity-related information, such as disassembly, material recovery potential, reuse, recycling, reflected in a PCDS.

Recent developments in EU policy and standardisation have strengthened this information logic. Technical requirements and stronger, more sustainable product information in the ESPR and the revised CPR for construction products provide the regulatory basis for the three dimensions that shape DPP product information. In this research, the EPD and PCDS serve as references informing the circularity data requirements. These established information standards are based on product data templates informed by ISO 23387, which provides a structured machine-readable format, supporting interoperability with digital information systems, such as BIM, and underpins DPP implementation [49].

2.3.6. CONCEPTUAL MATERIAL PASSPORT AND DPP

The concept of the DPP is also closely related to earlier initiatives such as the **Material Passport** (MP), developed through the BAMB project. While voluntary and research-driven, MPs introduced the principle of documenting material composition and recovery potential to support future reuse and retain circular value. This initiative provided an important conceptual foundation for the development of DPPs that sits within a regulatory and standardised context [33], [50].

The broader progression from technical compliance to sustainability requirements reflects the evolving role of DPPs as digital tools for integrating these aspects to enable facilitate circular construction practices. This evolution is driven by an ongoing regulatory and standardisation agenda that continues to advance towards stronger alignment between digitalisation, CE objectives, and structured product information [1], [4].

With regard to how data within these passport instruments is characterised, a brief clarification on the terminology used throughout this study is given. This study uses the term "data point" to describe a discrete unit of circularity-relevant information, used interchangeably in the literature with "attribute," "property," and "parameter." For consistency and clarity, "data point" is adopted throughout this study, except in the literature review where source references use different terms.

Having established the background context, the following Chapter 3 presents the methodology adopted in this research.

3
METHODOLOGY

This chapter presents the methdology adopted in this study, which outlines the literature review approach, followed by the research design and strategy adopted.

3.1. LITERATURE REVIEW APPROACH

The PRISMA Scoping Review (PRISMA-ScR) guidelines [51] was adopted as the literature review approach to systematically identify, screen, and narrow the focus of existing knowledge, regulatory requirements, and industry context for DPPs in the built environment. A dual-stream approach of academic and grey streams was adopted to ensure methodological rigour and reproducibility. Thematic groups brought together findings from both streams to relate gaps between them. In Chapter 4, the PRISMA-ScR flow diagram and literature review findings are presented.

3.1.1. SEARCH STRATEGY AND SOURCES

The search strategy began with selecting keywords to identify relevant articles for the review. An initial search using the terms “Digital Product Passport” and “Circular economy” was conducted, informed by the crucial link between the core concepts. The outcome of this broad search yielded many out-of-scope articles from other sectors, which prompted a narrower search for “Construction products” and “Built environment”, filtering studies with greater relevance to the construction sector. The search sources used are identified in Section 3.1.1.2 (Academic Databases) and 3.1.1.3 (Grey Literature and Policy Sources) below.

3.1.1.1. Eligibility Criteria

A set of eligibility criteria was defined to ensure that all included sources were comparable in scope and quality, as shown in Table 3.1. For both academic and grey literature, the search was restricted to open-access documents written in English to ensure transparency, reproducibility, and availability for verification and future research use [51].

Table 3.1 – Eligibility criteria of literature

Academic Literature	Grey Literature
Open access only	
Published in the English language	
Building construction & DPP relevance	
Unique article without duplications between databases	EU level documents/ reports & international standards

A specific academic criterion was the removal of duplicate articles across databases to ensure unique articles. For the grey literature, delegated acts and technical reports at the European level were eligible due to the focus on DPP implementation. The eligibility criteria were applied during the screening stage of the PRISMA-ScR process to ensure a coherent and comparable body of evidence [51].

3.1.1.2. Academic Databases

For the academic stream of the literature review, the three databases: **Scopus**, **Web of Science (WoS)** and **Google Scholar,** were selected to derive publications [52], [53]. Scopus and WoS provide discipline-specific rigour in construction and sustainability research, complemented by Google Scholar for comprehensive open-access coverage. Within each database, the search results were filtered to align with the set eligibility criteria (Table 3.1). No additional filters, such as publication year range or document types, were applied to preserve the temporal breadth and maximise source coverage for the emerging DPPs. The following search string was applied across all databases and with a field limit of title, abstract, and keyword fields:

"("Construction products") AND *("Built environment")* AND *("Circular economy")* AND

("Digital product passports")"

The use of "AND" ensured that keyword overlaps were identified, as it was important to address the chain of concepts to determine potential gaps between them for this reasearch to address. The document types from the search included journal articles, conference papers/proceedings, reviews, book chapters, and reports for a variety of sources.

3.1.1.3. Grey Literature and Policy Sources

The grey part of the literature review utilised key online sources to extract policy and practice relevant findings and development areas on DPP developments, summarised in Table 3.2. Sources were identified through key databases and repositories using the same keywords and filters as in the academic review to ensure consistency. All sources were accessible via public databases and repositories. EU Commission policy databases and webpages provided the largest volume of references, while standards development organisations (SDOs) addressed standardisation at both European and international levels [54], [55], [56]. Industry pilot web pages and white papers were included through snowball sampling, which were determined mostly from EU Commision reports [51].

Table 3.2 – Grey literature sources by category

Category	Database/ Repository	Document type
Policy & guide	EUR-Lex, EU webpage	Policy documents, reports
Project	CORDIS (cordis.europa.eu)	Research/pilot project report
SDO	CEN, ISO standard	Standards

The literature review approach led to the identification of existing knowledge and gaps that informed the research objectives pursued in this study. The following Sections 3.2 and 3.3 present the research design, applying the DSR paradigm and methodological choices, to address the gaps defined and related objectives.

3.2. RESEARCH DESIGN

This study was conducted within a DSR paradigm, as its primary contribution is a novel artefact, the C_MVDataset, developed to support DPP implementation for CE applications in the construction sector [57]. DSR was suitable for this study given the activities and artefact developed to address real-world challenges [58]. As illustrated in Figure 3.1, this study applied Saunders et al.'s 'Research Onion Model' [59] to structure the research methodological and strategic decisions at each layer underpinning this DSR-oriented contribution and process overview detailed in Section 3.4.

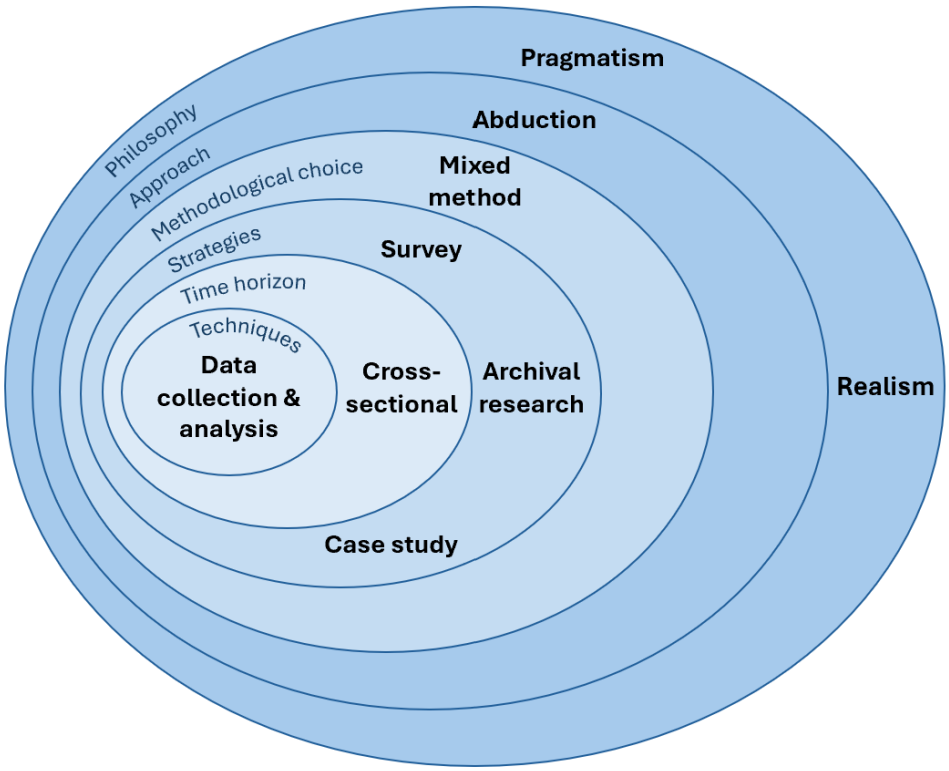


Fig. 3.1 – Research Onion Model for this study (adapted from [59])

At the outermost philosophical layer, the study adopted a pragmatic stance, prioritising practical outcomes for real-world challenges, with elements of realism reflecting the various construction project contexts and information management practices that shape product data. This combined philosophical position supports outcomes that are theoretically grounded and applicable in practice. Within the following layers, the research followed an abductive approach, enabling iteration of analysis along a cross-sectional time horizon [59].

3.3. RESEARCH STRATEGY

A mixed-methods methodological approach was adopted, using case study, archival research, and survey strategies, as each address a different evidence gap in this research [60], [61]. The case study strategy was chosen to analyse information environment context and support product weight significance assessment, as it enables detailed investigation of product data within real project contexts. The survey strategy was used to assess CE R-strategy applicability, drawing on practitioner insights in the field. Archival research strategy based on analysis of existing documents and records, including product documentation, regulatory texts, and standards, was chosen for the development of the C_MVDataset artefact and evaluation against data requirements in such documentation practices. This strategy has the focus on examining what circularity data is already recorded rather than generating new primary data. Data collection and analysis techniques were selected in line with established applied research practice. Desk-based methods were used for archival research, and case study and survey strategies also included field study approach, involving direct engagement with real-world projects and key practitioners in the field [62], [63], [64].

The DSR process followed the four-phase structure of the Nelson Mandela University Design Science Methodology (NMU-DSM), developed by Delport et al. [57] through the integration of the design-oriented IS research phases of Österle et al. [65] and the procedural guidance of design-based research from Herrington et al. [66]. This structure comprises DSR activities of **Analysis, Objectives, Design & development**, and **Evaluation**, and is suited to research requiring artefact development refined through stakeholder input. In this study, a single refinement cycle was conducted in which focus group feedback informed a revision of the C_MVDataset prior to its finalisation. The application of such a structure to this study's context is detailed in Figure 3.2.

3.4. RESEARCH PROCESS OVERVIEW

Following the four-phase DSR structure introduced in Section 3.3, the research process integrated the case study, archival research, and survey strategies into four consecutive, interlinked phases, each addressing a specific research objective in this study [57], [58]. Figure 3.2 presents the multiphase research design.

Phase 1 - Analysis

Two real-world construction case study projects (Section 3.4.1.2) were analysed to establish the practical context and information environments in which construction product data is managed. This analysis grounded the following research phases in real-world practice.

Phase 2 - Objectives

The prioritisation method based on product weight significance and circularity potential defined the scope in circular economy of construction products. Weight significance was assessed by deriving values from the two case study project information environments and the circularity potential was assessed through a survey. This method identified the priority construction products that shaped the product documentation used in Phase 4.

Phase 3 - Design & Development

Circularity data requirements were identified from the archival research and consolidated into the design of the C_MVDataset for construction products.

Phase 4 - Evaluation

The C_MVDataset consolidated in Phase 3 was evaluated by comparing the circularity data requirements against the existing product documentation of the priority products identified in Phase 2. The extent to which the artefact's circularity data requirements are reflected in current real-world product information practices was examined. In addition, a focus group discussion with key practitioners in the DPP and sustainable construction field was performed to evaluate the artefact and gain feedback. Based on this, the C_MVDataset was refined, reflecting the stakeholder-informed refinement central to design-oriented DSR [57].

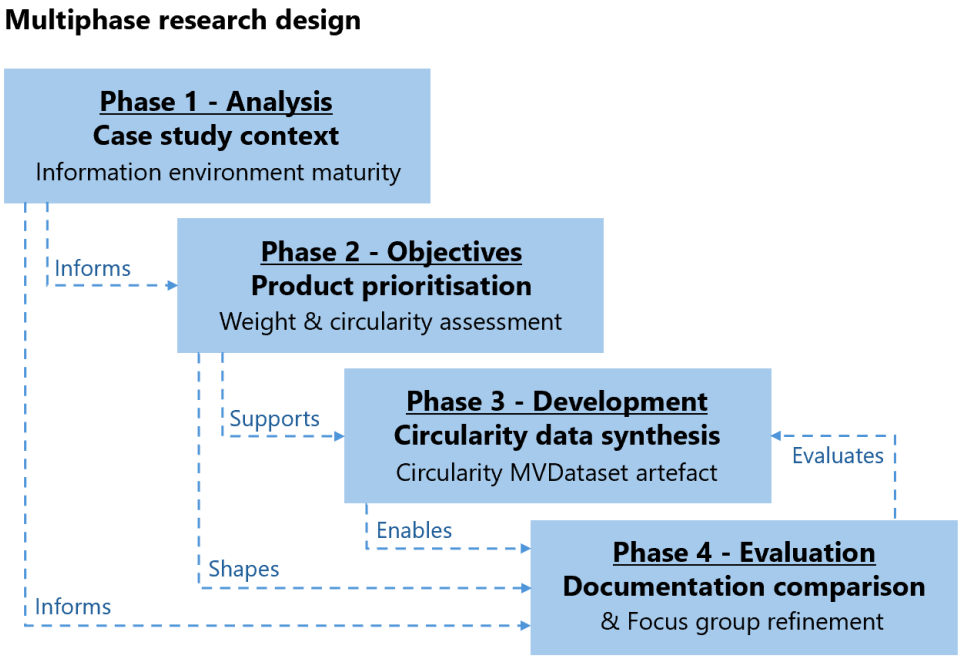


Fig. 3.2 – Multiphase research design, showing the four DSR phases and their interlinkages

The process aligned with the methodology developed for defining DPP data requirements under the ESPR framework [67], reinforcing the relevance of the DSR approach adopted. The analytical logic of the artefact development was further shaped by the ISO 23387 methodology consisting of preparatory activities in the high-level process of developing data templates. Phases 1 and 2 supported "identifying the object"; Phase 3 determined "information needs"; and Phases 1 and 4 identified "applicable sources" [49]. Altogether, these phases contributed to structuring the dataset development process undertaken in this study, providing a systematic basis for DPP implementation in the construction sector.

3.4.1. PHASE 1: CASE STUDY AND INFORMATION ENVIRONMENT ANALYSIS

3.4.1.1. Case Study Strategy

To analyse how construction product information is documented and managed in real-world construction projects, a case study strategy was employed [64]. This approach enabled detailed investigation of product information within its practical context and supported the analysis of existing information management practices relevant to DPP implementation. The analysis focused on identifying

what product information was available, where it was located, and how it could be extracted from project information sources. Forensic analysis techniques, summarised in Table 3.5, were used to investigate the case study project information environments [68]. The case study analysis provided the empirical basis for the subsequent steps of the research, supporting the information environment analysis, product identification and prioritisation, and the extraction of product-specific information for the C_MVDataset evaluation.

3.4.1.2. Case Study Selection and Description

The selected case studies represented common building typologies found in Portugal and across Europe of different project types. Initial observations of a residential refurbishment project (Project Case A) motivated the inclusion of an industrial building project (Project Case B) into the research to analyse how differences in building lifecycle context, construction approach, and project objectives influence information environments and the product scope. Both case studies provided access to a broad range of project deliverables and information sources, which gave a solid basis for the information environment analysis. A comparative overview of the case study characteristics is presented in Table 3.3.

- **Project Case A – Residential Refurbishment**
  A refurbishment project of an affordable residential housing block. The building represents a typical multi-storey residential typology and incorporates conventional construction systems and materials. The project is of small-to-medium scale with a Gross Floor Area of 154 m^2 and four floors. The refurbishment was done for the building envelope and interior spaces. As a post-construction intervention scenario, the project provides an opportunity to investigate the availability of product information within an existing building context, where information was sourced from legacy documentation and previous site-based investigations.

- **Project Case B – Industrial New-Build**
  The new-build industrial building was delivered through a Design-Build delivery model. Its large scale, with a Gross Floor Area of 16,456 m^2, incorporates prefabricated and in-situ construction systems. The full range of construction products, from structural to non-structural elements, is included. The project's high sustainability ambitions contributed to more extensive documentation and management of product information. An on-site visit was conducted during the construction phase, which informed the forensic techniques used in the information environment analysis.

Table 3.3 – Comparison between case study project characteristics

Aspect	Project Case A	Project Case B
Project type	Refurbishment	New build
Use	Residential	Industrial
Scale	Small-medium	Large-scale
Gross Floor Area (approx.)	154 m^2	16,456 m^2
Site Area (approx.)	586 m^2	41,035 m^2
Information environment	Fragmented	Comprehensive
Product scope	Non-structural, conventional system	Full range, multi-system

3.4.1.3. Data Collection and Sources

Construction product data were collected from the case study project information environments through a combination of field, desk, and digital research approaches (Table 3.4) [62], [63].

Table 3.4 – Data collection approach and sources

Approach	Data sources
Field study	Physical building asset, field notes and photographs
Desk research	Technical specifications, product datasheets, BoQ, BoM, 2D AutoCAD drawings, Revit model, EPDs, and DoPs
Digital research	BIM model and digital databases

- A **field study** was used to collect primary data directly from the physical asset through on-site investigation. This approach was relevant for investigating which construction product data can be obtained on-site, especially where documentation was incomplete.
- **Desk research** and **digital research** were used to collect secondary data from project documentation and digital information systems, which enabled the identification and extraction of product information from both unstructured and structured sources.

3.4.1.4. Information Environment Data Analysis

Following the data collection, an information environment analysis was undertaken to investigate how construction product data was generated, stored, managed and accessed within the selected project cases. The forensic techniques summarised in Table 3.5 were used to identify the available product documentation and evaluate the information environments [63], [68], [69]:

Table 3.5 – Forensic techniques applied for each research approach

Approach	Techniques
Field study	Site observation, product inspection, and photographic survey
Desk research	Document review, legacy data investigation, and cross-referencing
Digital research	Digital information retrieval, metadata extraction, common data environment

3.4.1.5. Information Environment Assessment

A data maturity assessment was conducted to evaluate and compare the product information environments within the project cases, grounded in the real project case conditions established in Section 3.4.1.2 above [64].

Assessment Framework

The assessment framework was informed by the information environment analysis and drew on data obtained through the field study, desk research, and digital research approaches described in Table 3.5. Three main factors were defined, based on the cross-referencing and observations made across both project case information environments:

- **Availability**: the extent to which product information and support documentation are available and accessible.
- **Organisation**: the degree to which information is structured and traceable across sources.
- **Completeness**: the extent that product information is sufficiently specific and free of data gaps.

Each factor was broken down into sub-criteria and were applied through an assessment matrix (Table 3.6), enabling a consistent comparison between information environments.

Table 3.6 – Assessment matrix to determine outcome: Level of data maturity of both project cases

Factor	Criteria	Yes (2 points)	Partial (1 point)	No	Points	Maturity Level
Availability	Site observation records, documentation access, digital model detailed	X			2	Level I-IV
Organization	Alignment between deliverables, classification system, data format structure		X		1	
Completeness	Product data specified, minimal assumptions, coverage of building systems			X	0	

3.4.1.6. Data Maturity Levels

Four data maturity levels were defined based on the degree of availability, organisation, and completeness of the product information across construction projects, as illustrated in Figure 3.3. The levels represent the spectrum of information environments that can be found in existing contexts, ranging from no data to fragmented, comprehensive, to future contexts with emerging digitalisation [18], [70]. At each level, the suitable data collection approaches and those used in this research are portrayed.

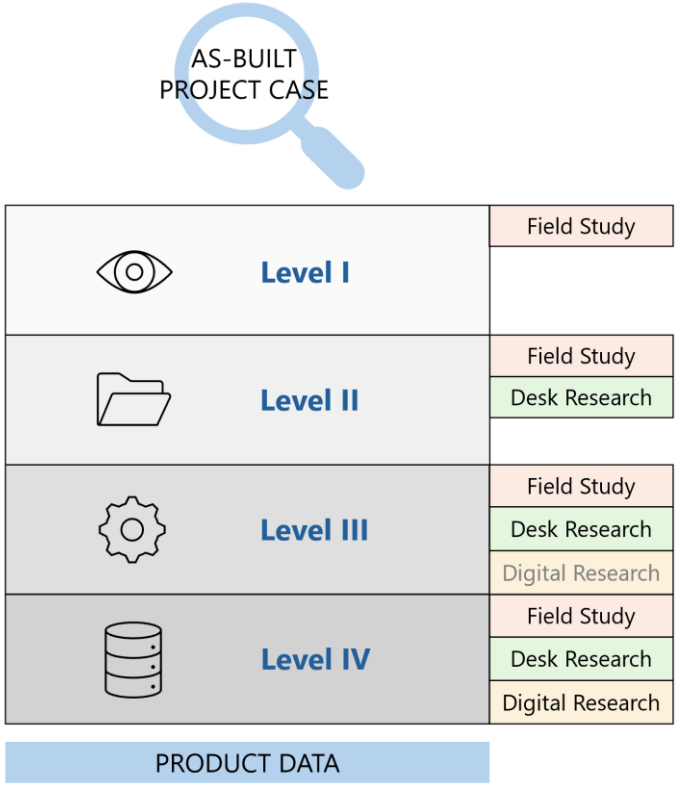


Fig. 3.3 – Data maturity levels of building projects with related research approaches

The case study and information environment analysis provided the empirical basis for the following Phase 2, in which the project deliverables and product information sources are used to identify construction products for prioritisation.

3.4.2. PHASE 2: PRODUCT PRIORITISATION

3.4.2.1. Product Identification and Classification

The inventory of construction products was identified from the Bill of Materials (BoM), providing a breakdown of all those used in the project cases. Project Case B had a complete BoM, whereas for Project Case A, one was constructed by extracting the product information from the available Bill of Quantities (BoQ) and the various project documentation sources provided. Following this identification, products were classified according to the Level(s) framework classification system for building elements [31]. Additionally, a classification of CPR Product Families and material types was conducted to establish a consistent structure for comparing both project cases and provide the basis for the product prioritisation assessment (Table 3.7) [8].

Table 3.7 – Classification of Level(s), CPR Product Families, and material types used in BoM

Level(s) Classification	**CPR Product Families** (Annex VII)		**Material Types**
1.1 Substructure/ Structure	Code	Product Family	Clay-based
1.2 Envelope	1	Precast normal/lightweight/autoclaved aerated concrete products	Concrete or cementitious
1.3 Internal Works/ Finishes	2	Door, windows, shutters, gates and related building hardware	Glass
1.4 Building Services	3	Membranes, including liquid applied and kits	Gypsum
1.5 External Works	4	Thermal insulation products, composite insulating kits/systems	Metal
1.6 Temporary Works	5	Structural bearings, pins for structural joints	Plastic, polymer, resin, paint, chemicals & bituminous
1.7 Earthworks	...		Stone or aggregate
	36	Attached ladders	Timber or timber based

3.4.2.2. Assessment of Weight Significance

Weight was selected as the priority criterion due to being a critical aspect of the CE, related to WFD, which frames CDW generation and recovery targets around the measurement of weight as a relative percentage [3], [4]. Products with the largest weight contribution represent the most significant waste streams and offer the greatest potential for CE interventions to make an impact. The assessment examined the relative weight contribution of construction products and material types within each project case. This served as an initial screening process to identify categories with the largest amount of weight, establishing a shortlist of products for the subsequent circularity potential assessment.

Data Collection and Analysis

Through desk research, the BoM of Project Case A was newly constructed to enable product weight calculation, as shown in Table 3.8 [64]. Additional product information was collected from project documentation, manufacturer sources, and online product catalogues. For Project Case B, weight quantities were readily available in the BoM provided.

Table 3.8 – Collection, reorganisation and development of BoM for both project cases

Project Case B, BoM

Level(s) 1.x Classification	CPR Product Family	Material/Product	Weight (kg)	Material Type
1.1	#	Material/Product 1	kg	Metal
1.2	#	Material/Product 2	kg	Glass

Quantity	Quantity Type	Thickness (m)	Density (kg/m^3) or Unit Weight (kg/m^2)
Value	m^2	Value	Value
Value	un	Value	Value

Project Case A, BoQ into BoM

The relative weight distribution of the product inventory in each project case was assessed using the Level(s) classification as well as material-type weight contributions. For each project case, the results were expressed as a percentage of the total building weight and visualised using pie charts and bar charts [22]. This enabled the comparison between the two project cases and the identification of a shortlist of four construction products with high weight significance.

3.4.2.3. Assessment of Circularity Potential

The circularity potential of the shortlisted construction products was assessed through a survey to identify those with the most opportunities to extend product lifetimes and reduce CDW, in line with the objectives of the CEAP [8]. The assessment evaluated the applicability of R-strategies derived from established CE frameworks, which relate to and expand on the WFD waste hierarchy (see Figure 2.4, Chapter 2) [29].

Survey Design

The survey combined multiple-choice questions assessing the applicability of CE R-strategies and factors influencing the circularity potential of products. Open-ended questions were applied to collect further observations on the topic. Annex A.4.1 presents the full questionnaire developed for this study. The structure was based on R3-R9 strategies relevant to existing products and served as a guide for respondents in selecting applicable R-strategies for each product type. The survey addressed the following topics:

- Professional background and experience
- Applicability of R-strategies to construction products
- Key factors impacting the circularity potential

Participant Selection

Participants were selected from both academia and industry backgrounds within the construction sector to capture the breadth in theoretical knowledge and practical experience. The profile and number of

participants are shown in Table 3.9. The participant group has expertise in construction and sustainability relevant to the research focus on product data and the CE.

Table 3.9 – Participant profile and related number of participants

Profile	Participants (n)
Research & Academia	8
Construction industry	10

Analysis of Survey Responses

Open-ended questions were analysed using thematic analysis to identify patterns in participant observations [71]. For the closed-ended questions, respondents indicated, for each priority product across the seven R-strategies (Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Energy recovery), whether the strategy applied to the "entire product", to "parts of the product" only, or "not possible" at all. "Entire Product" and "parts of the product" responses were treated as indicating applicability and weighted equally, while blank or skipped responses were excluded from the calculation.

For each product, an Applicability Score (%) was calculated as the proportion of respondents indicating that the R-strategy was applicable to the product entirely and parts (Equation 1):

$$\text{Applicability Scores (\%)} = \frac{\text{Entire + Parts}}{\text{Entire + Parts + Not applicable}} \quad (1)$$

A Circularity Potential (%) was then calculated for each product based on the average of the seven R-Strategy Applicability Scores (Equation 2):

$$\text{Circularity Potential (\%)} = \frac{\text{Sum of Applicability Scores}}{7} \quad (2)$$

The outcome scores were compiled into a CE R-strategy Matrix (Table 3.10) to assess which of the weight-significant shortlisted construction products rank highest in overall Circularity Potential (%).

Table 3.10 – CE R-strategy matrix of construction products

Project	Product	Re-use	Repurpose	Repair	Refurbish	Remanu-facture	Recycle	Energy recovery	Circularity Potential
A	Product 1	%	%	%	%	%	%	%	%
	Product 2	%	%	%	%	%	%	%	%
B	Product 1	%	%	%	%	%	%	%	%
	Product 2	%	%	%	%	%	%	%	%

3.4.2.4. Product Prioritisation

Product prioritisation was undertaken through a quantitative and qualitative assessment of two criteria:

1. **Weight significance**: the relative material/product weight contribution
2. **Circularity potential**: the applicability of CE R-strategies

Starting with weight significance assessment provided a screening process from the entire product inventory of both project cases to narrow down to a shortlist of products with high weights relevant to the EU recovery targets. Having these products inform the circularity potential assessment ensured that the prioritised products were resource-intensive and had the greatest potential to reduce waste through their high applicability across circular strategies. The results informed the selection of the two main priority products evaluated in Phase 4.

3.4.3. PHASE 3: CIRCULARITY DATASET DEVELOPMENT

A combined bottom-up and top-down approach was adopted to identify and consolidate the product information requirements into a general circularity dataset [67]. Through the use of archival research, the bottom-up approach captured practical information needs based on circularity-related construction processes and the top-down approach captured requirements mandated by legislation and standards. Combining both ensured the resulting C_MVDataset was grounded in practice and aligned with current EU DPP requirements. The overall approach is illustrated in Figure 3.4.

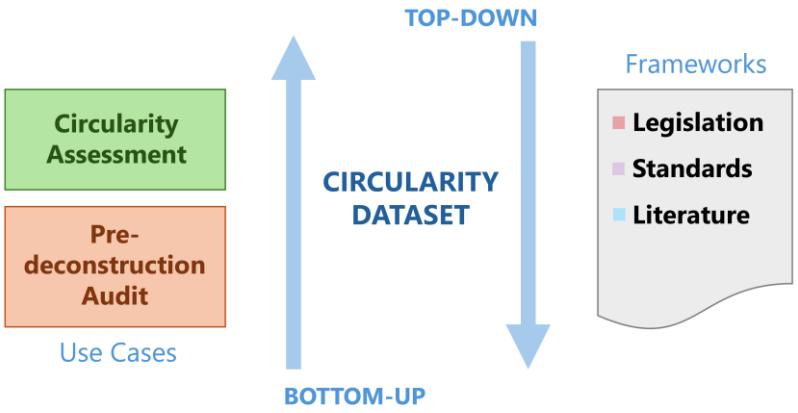


Fig. 3.4 – Circularity dataset top-down and bottom-up approach

3.4.3.1. Circularity Use Cases and Information Needs

A bottom-up, use-case-driven approach was used to identify the practical information needs arising from existing construction processes enabling circular practices [67]. The two key use cases of circularity assessment via the Level(s) framework and pre-deconstruction audit were selected as both rely on product information and directly support CEAP and WFD objectives [3], [4], [8], [29]. For each use case, the relevant actors and project stages were identified as prerequisites for the delivery of the Level of Information Need (LOIN) as shown in Figure 3.5 [72].

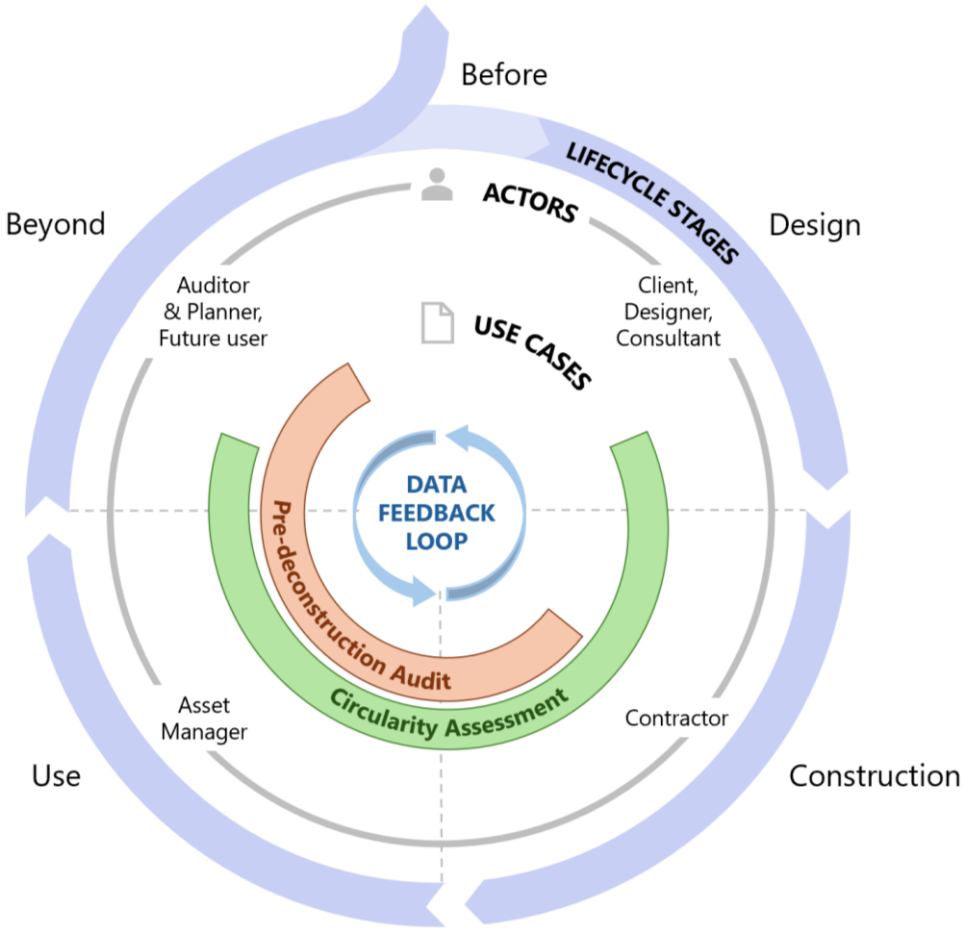


Fig. 3.5 – Use cases and LOIN delivery prerequisites (integrating stages from Figure 2.3, Chapter 2)

Both use cases span the building lifecycle. CE objectives are established at the design stage, then assessed continuously through construction and use, before informing circular decision-making at the beyond stage. For pre-deconstruction audits, data generated during the earlier construction and use stages feed into the auditing and recovery planning conducted at the beyond stage. The data feedback loop across the lifecycle stages represents the continuity from early-stage forecasting to circular potential product outlets at the beyond stage. Given this study's focus on data requirements, the LOIN framework, as defined in ISO 7817:2024 [72], was adopted to structure the definition of alphanumeric data for each use case.

The main data sources for the use cases were the EU Level(s) framework Macro-objective 2 and the CDW Management Protocol, from which indicators and deliverables were extracted and translated into data points using content analysis [22], [29], [73] (Figure 3.6). This ensured that the resulting dataset captured the information required to perform circularity-related construction processes.

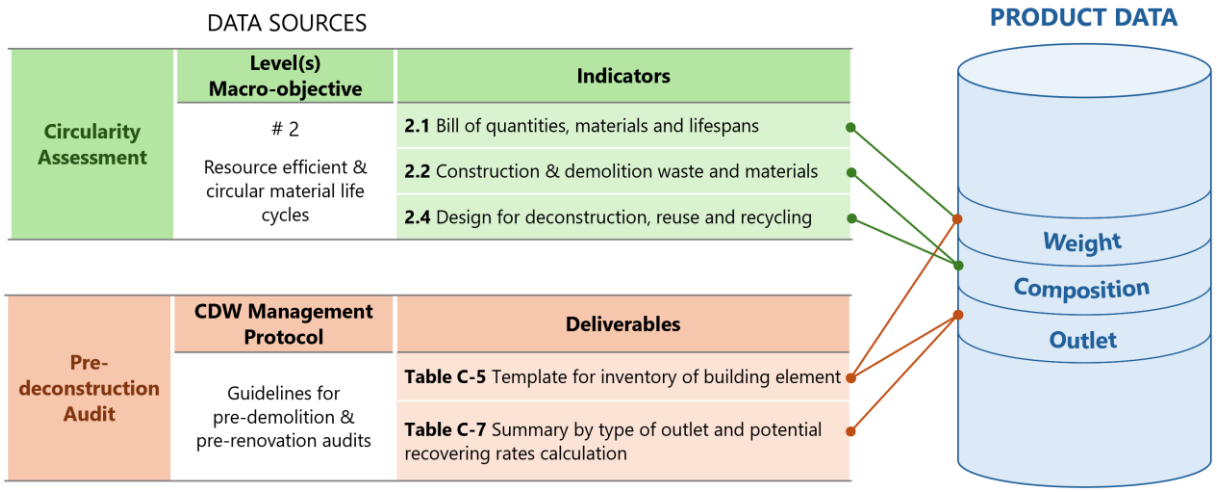


Fig. 3.6 – Bottom-up use case sources and mapping to product data requirements

3.4.3.2. Identification of Circularity Data Requirements

A top-down approach was used to identify product data requirements from legislation, standards, and the literature on CE and DPPs, establishing the theoretical and legislative foundations of the dataset (Figure 3.7). Through archival research mandatory disclosures and product information requirements set out in relevant DPP legislation were identified, that were then systematically extracted and categorised into groups of properties, following the ISO 23387 property grouping structure [49], [74]. A filtering process was performed to narrow down the requirements specifically relevant for circularity of construction products.

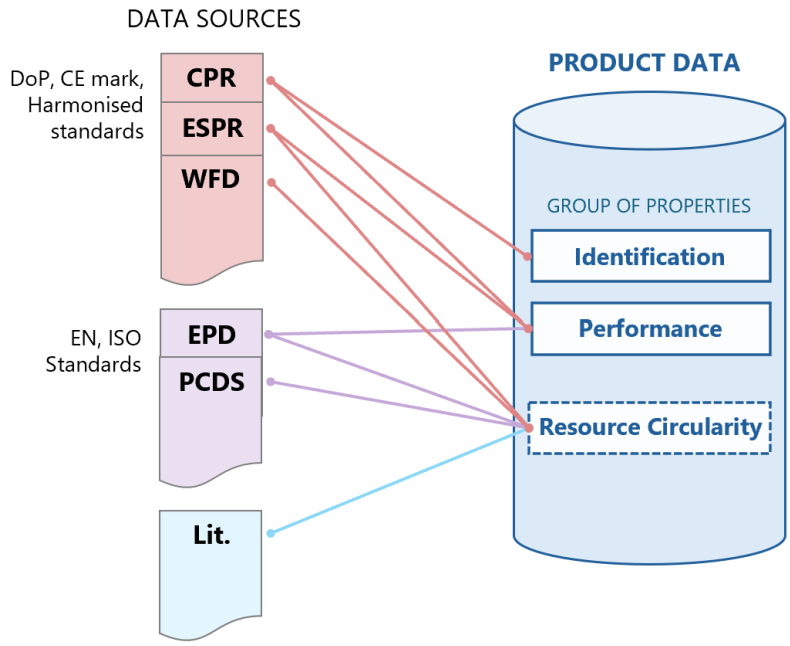


Fig. 3.7 – Top-down data sources and mapping to product groups of properties

In support of developing second-hand market requirements for construction products, the Identification and Performance property groups shaped by the CPR were included [8]. A new group, Resource Circularity, was defined to consolidate circularity-related data points that recurred across the reviewed sources but had not previously been addressed as a distinct property group. Environmental data requirements in DPP legislation were excluded from the mapping, as they fall outside the CE dimensions defined in this research (see Figure 2.1, Chapter 2).

3.4.3.3. Development of a C_MVDataset

The information requirements identified through the bottom-up use case analysis and top-down source review were consolidated into a single dataset, integrating practical and regulatory needs (Table 3.11). A data mapping step was then conducted across the sources, establishing data point naming conventions primarily based on existing product regulation definitions [7], [8], [75].

Table 3.11 – Circularity dataset development and data source mapping

Product data		**Data source**				
		Top-down			**Bottom-up**	
Group of property	**Data point**	**Lit.**	**CPR, ESPR, & WFD**	**Standards**	**Level(s) Indicators**	**Pre-deconstruction Audit**
Identification	Data field					

This study's approach to dataset design draws on the principle of identifying the smallest, most resource-efficient set of data required to enable a defined application, adapted from the Minimum Viable Data (MVD) concept [76], supporting the DSR paradigm's focus on producing a practical artefact [57]. Based on the consolidated mapping, a C_MVDataset was established as the study's outcome artefact, structuring the minimum set of data points needed to support the identified circularity use cases and comply with regulatory DPP and product requirements (Table 3.12) [8].

Table 3.12 – The C_MVDataset structure

C_MVDataset	
Group of property	**Data points**
Identification	Data field
	Data field
	Data field

3.4.4. PHASE 4: EVALUATION OF PRODUCT-SPECIFIC DOCUMENTATION

Combining the data collection approaches and related forensic analysis techniques established in Phase 1 with the priority products identified in Phase 2, an evaluation of the product-specific documentation compared to the C_MVDataset was conducted. The product information was collected and cross-mapped with the dataset developed to evaluate the extent to which the circularity required data was available in existing product documentation, identifying gaps and opportunities in current practice (Table 3.13).

Table 3.13 – Product information compared to the proposed C_MVDataset

	Product information							
Data collection >	**Project Case**		**Regulation & standards**			**C_MVDataset**		
Techniques & Categories >	Site observation & Photographic survey	Document review	Identification	Performance	Environment			
Data Sources >	*CE mark, labels*	*Technical sheet*	*DoP*	*Harmonised standard*	*EPD*			
	✓	✓	✓		✓	✓	Data field	Identification
							Data field	
	✓	✓	✓	✓	✓	✓	Data field	
		✓	✓		✓	✓	Data field	

3.4.4.1. Focus Group Discussion

In line with the DSR methodology, a focus group discussion was conducted to evaluate and refine the C_MVDataset based on its relevance in supporting circularity and a second-hand use of construction products [58], [77]. The discussion was conducted at the final stages of the research, through a structured workshop. Three participants were selected based on their expertise in DPPs, sustainable construction, and information management. The participant group comprised both researchers and practitioners actively engaged in DPP implementation. Structured around an open discussion format, the approaches taken and outputs developed at each research phase were presented to the participants in order to receive feedback on the dataset's development process and identify areas for refinement.

3.5. RESEARCH RIGOUR

3.5.1. VALIDITY

The validity of the research was strengthened through the triangulation of multiple sources of evidence, spanning project case documentation, archival documentation and records, survey responses, and a focus group discussion [64]. The integration of theoretical and practical perspectives enabled the evaluation of the C_MVDataset from both viewpoints. The application of the methodology across two case study projects with differing levels of information maturity and characteristics supported the robustness of the findings.

3.5.2. RELIABILITY

The systematic documentation of data collection procedures, assessment criteria, and analytical methods supported the reliability of the research [64]. Standardised classification systems, a transparent product prioritisation method, and dataset development procedures ensured the analysis followed a traceable and repeatable methodological approach.

3.6. ETHICAL CONSIDERATIONS

This research adhered to ethical principles to ensure the integrity and responsible conduct of the study. The following measures were undertaken:

- **Anonymity and confidentiality:** All participant responses and project information provided by industry partners were anonymised and treated with confidentiality. Any commercially sensitive information was excluded where necessary.

- **Voluntary participation and right to withdraw:** Participation in the survey and focus group activities was voluntary. Participants were informed of the research purpose and intended use of the collected data before participating.
- **Transparency:** Data sources, methodological procedures, and assumptions were clearly documented to ensure transparency and accountability throughout the research process.
- **Data storage and data protection**: All the research data were securely stored and managed in accordance with the General Data Protection Regulation [78]. Before data collection, the research received approval from the University of Porto Data Protection Unit (*Unidade de Proteção de Dados*) [79] under Opinion A-44/2026, ensuring compliance with institutional data protection requirements (see Annex A.4.2).

3.7. METHODOLOGICAL LIMITATIONS

The findings of this research are to be considered in light of several methodological limitations:

- **Case study scope**: Although the selected project cases represent different building typologies and levels of information maturity based in Portugal, the findings may not fully capture the diversity of construction projects and information management practices across the wider EU construction sector.
- **Stakeholder participation**: The circularity potential assessment was limited in the number of stakeholders (n=18). The findings may reflect the experiences, knowledge, and perspectives of the selected participants, which can differ when applied to a broader stakeholder group.
- **Assessment subjectivity**: Although structured prioritisation matrices and evaluation procedures were employed, the assessment of circularity potential and interpretation of stakeholder feedback involved a degree of professional judgement. This introduces a degree of subjectivity into the evaluation process.
- **Language constraints**: The multiple languages, including Spanish and Portuguese, across the case study project documentation may have introduced minor interpretation and translation inconsistencies during data extraction and analysis.
- **Evolving DPP landscape**: The regulatory, technical, and practical landscape surrounding DPPs is rapidly evolving, as indicated in Figure 2.7, Chapter 2. As legislative revisions and implementation guidance emerge, the proposed methodology and C_MVDataset may require refinement to align with future developments and industry practices [67].
- **Practical implementation**: The C_MVDataset was developed using the preparatory activities of developing a data template under ISO 23387 [49]. The outcome data template itself and its application within a live DPP environment were outside the scope of this study.

The following chapter presents the literature review, applying the approach outlined in Section 3.1.

4
LITERATURE REVIEW

This chapter presents the findings of the literature review, identifying key knowledge and gaps across academic and grey literature that are addressed by this research.

4.1. SOURCE IDENTIFICATION AND SCREENING OUTCOMES

Applying the PRISMA-ScR method outlined in Section 3.1, the dual-stream approach and screening process resulted in 97 sources across academic and grey literature streams, as illustrated in Figure 4.1 below [51].

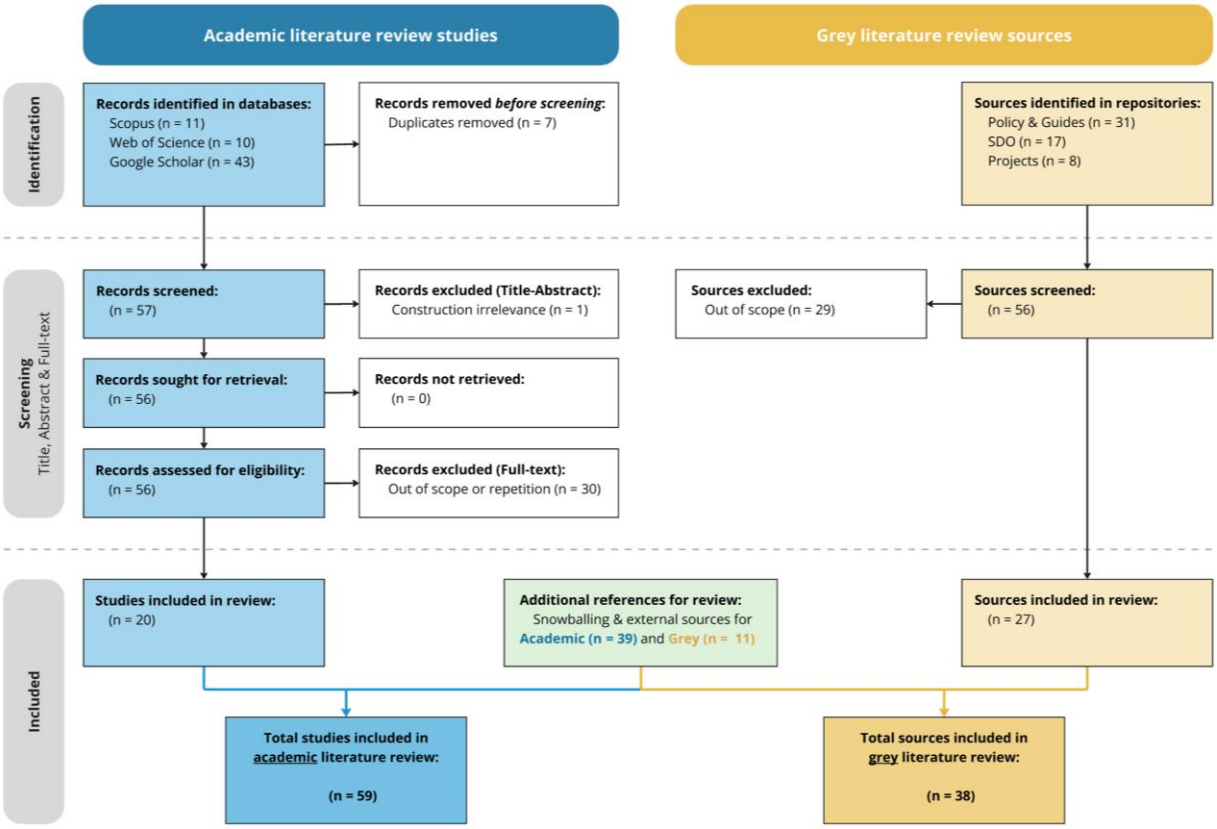


Fig. 4.1 – PRISMA-ScR flow diagram of the literature review (adapted from [51])

Further sources were identified through snowballing from the screened articles, mainly addressing MPs, which were included given their relevance to DPP development over time (Figure 4.3). The PRISMA-ScR flow diagram with convergent streams reflects the objective of systematically identifying synergies and bridging knowledge gaps among theory, policy, and industry practice, addressing the research scope of "DPPs" promoting the "circular economy" of "construction products" within the "built environment."

4.1.1. ACADEMIC PUBLICATION TRENDS VS. POLICY MILESTONES

A temporal trend analysis identified overlaps between the evolution of DPP research and the progression of relevant policy milestones. Figure 4.2 illustrates the exponential growth in DPP-related research output, with the number increasing from 2 papers in 2021 to 23 papers in 2025. As of early 2026, one article has been indexed, and future publications are anticipated given ongoing pilot initiatives, research in the field, and legislative revisions.

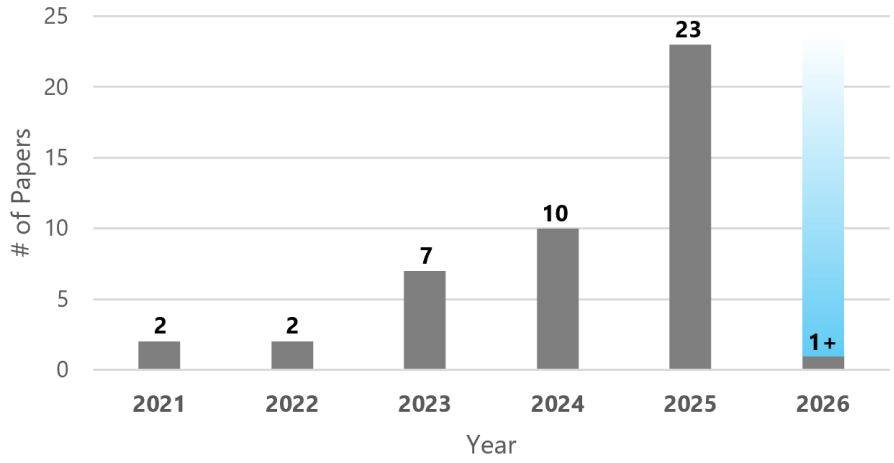


Fig. 4.2 – Temporal trend analysis of DPP academic literature publications

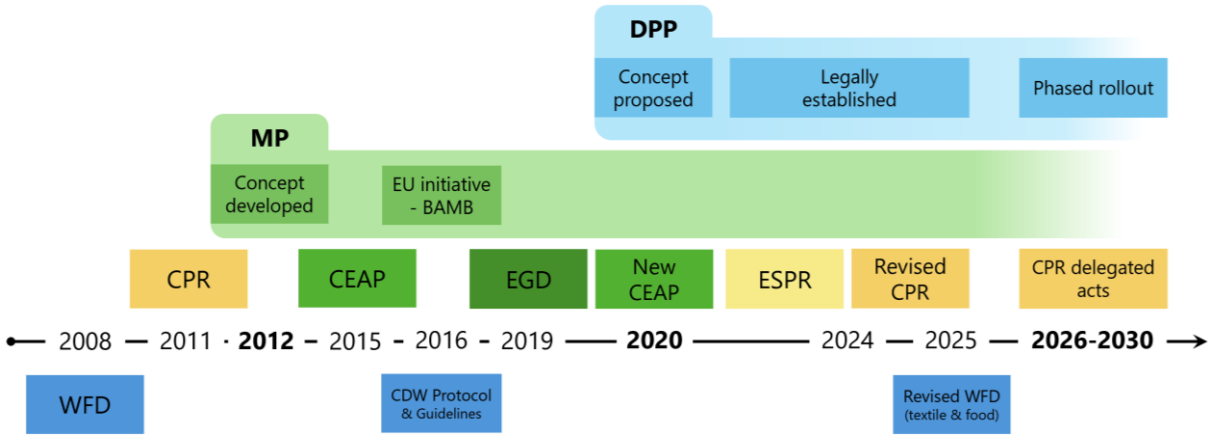


Fig. 4.3 – Timeline indicating the emergence of DPPs alongside key circular economy and product policy developments and MPs within the construction sector

Aligning this analysis with milestones related to DPP reveals several correlations:

- **2021 – Baseline**
  - Start of academic developments in 2021 (n = 2) began after the new 2020 CEAP introducing the DPP concept.
- **2023-2025 – Development phase**
  - Research acceleration and expansion from 2022 (n = 2) to 2025 (n = 23) parallels the adoption of the ESPR and revised CPR.
- **2026 – Upcoming acceleration**
  - Anticipated increase due to pilot results, conferences, and DPP rollout.

The increase in indexed publications indicates an alignment with regulatory momentum. It suggests a reciprocal relationship, where policy advancements stimulate scientific inquiry and academic developments can support policy frameworks.

The following section builds on the thematic domains in the literature review, synthesising the PRISMA-ScR validated sources [51]. The review reflects the state of DPP research as of early 2026, the point at which the search and screening process for this study concluded. Given the progress being made in the regulatory and technical landscape of DPPs, the findings and gaps identified in this review are to be interpreted within this specific point in time.

4.2. REVIEW THEMATIC DOMAINS

Recurrent topics and terms identified across the reviewed sources were grouped into broader thematic groups that structure this review, as shown in Table 4.1.

Table 4.1 – Thematic groups linked to literature review chapter sections

Chapter Section	Theme	Keywords
4.2.1	DPP Foundations and Digital ecosystem	Evolution, passport instruments, MP, CMP, digital logbooks
4.2.2	Data Structures and Standardisation	Data templates, data dictionaries, information flows, standards, EPD, PCDS, CE-marking
4.2.3	Defining Circularity Information Requirements	Passport data frameworks, circularity data, CPR & ESPR information requirements
4.2.4	Circular Economy for Construction Products	Circular economy strategies, Level(s) framework indicators, CE R-strategies, pre-deconstruction audits
4.2.5	DPP Implementation	Prioritisation approach, BAMB MPs, pilot projects, phased rollout, adoption barriers, existing building information environments

The literature review progresses from one theme to the next, beginning with DPP foundations to set the stage, followed by its data landscape, requirements and implementation progress in the context of the CE. Each thematic group section first presents an academic literature review, followed by a grey literature section. To conclude each chapter, both areas are combined to reflect the DPP development as the convergence of parallel streams, where synergies and gaps were identified.

4.2.1. DPP FOUNDATIONS AND DIGITAL ECOSYSTEM

The trajectory of passport instruments in construction traces a shift from analogue tracking tools to a regulated digital infrastructure. Early conceptions before the digital transition framed passports as devices to guide materials through their lifecycle [80], [81]. The EU Horizon 2020 BAMB project gave this idea its digital-age progression, defining MPs as "sets of data describing defined characteristics of materials and components in products and systems that give them value for present use, recovery, and reuse" [33], [82], [83]. This definition has proven durable, but its scope has since been extended. Göswein et al. [84] for instance, proposed a Circular Material Passport (CMP) model aligned with the EU Level(s) framework, extending the MP concept to support circularity-specific assessment, and current developments place this in the DPP context. Thus, a broader landscape of digital passport instruments has emerged due to increasing policy drivers in digitising material and product information in support of the twin transition [4], [80], [85]. However, the conceptual boundaries between these instruments remain under discussion due to their overlapping similarities but also differences. Table 4.2 makes this visible, where MPs and CMPs function within a non-regulatory environment and focus on the recovery of materials at the end-of-life [33], [84]. DPPs are at a pre-conceptual stage but anchored to binding regulatory acts, the ESPR and CPR, whose requirements address product market compliance, technical performance and environmental sustainability [11], [15], [42]. DBLs are positioned in EPBD mandates as overarching repositories at the building scale that orchestrate lifecycle data flows with DPPs and other information providers [42], [85], [86]. This repositioning signals a broader shift in the sector's information management logic, from single-phase records towards lifecycle-spanning infrastructure for a CE [18].

As a consequence of these developments, the DPP carries a regulatory backbone designed to store and exchange essential product information, enabling traceability, transparency, and circularity of construction products [87]. The digital tool has gained significant regulatory momentum with the revised CPR and ESPR, while its conceptual foundations are rooted in early iterations of MPs [8], [88], [89]. The literature converges on a working definition of the DPP as a product-specific and electronically accessible dataset that accompanies products throughout their lifecycle [90]. However, a universal definition and a clear consensus on how DPPs will actually drive circular interventions with the data they contain remains unresolved [91], [92].

Table 4.2 – Digital instrument ecosystem from passports to logbook

	Material Passport	**Circular Material Passport**	**Digital Product Passport**	**Digital Building Logbook**
Status	Demonstrative	Conceptual	Pre-implementation	Emerging
Industry	Built environment	Built environment	Cross-industry	Built environment
Scale	Raw Material	Raw Material	Product	Building
Life cycle stage	End-of-life focused	End-of-life focused	Whole lifecycle	Whole lifecycle
Digital system	MP platform, BIM-based	BIM-based	Undefined, BIM potential	Unknown
Information provider	Manufacturer	Manufacturer	Supplier, Manufacturer	Building owner, design team, contractor, facility manager
Policy	non-regulatory, BAMB, industry-led	non-regulatory	ESPR, CPR, CEAP, regulatory backbone	EPBD, regulatory backbone

As expressed, literature has raised uncertainties around the coherence of the digital passport landscape. Due to overlapping terminologies and data inputs between instruments, it has led to fragmented and ambiguous understandings as to which tool to use at what stage and scale [80], [93]. As the field continues to mature, recent systematic and scoping reviews have confirmed that while MPs are imperative for achieving material circularity in construction, their introduction across diverse settings has produced fragmented adoption pathways that demand conceptual consolidation [93], [94], [95]. Several scholars highlight that MPs' rigid and static nature hinders lifecycle tracking, while the dynamic interface envisioned in DPPs is expected to support emerging digital twin technology [18], [86], [96]. The literature takes the stance that the role of MPs is to supplement rather than compete with or be replaced by DPPs, as existing products without DPPs require MP "characterisation" to enable circular outcomes. In other words, MPs and DPPs share the same structure and MPs provide part of the necessary data to build DPPs for the second life of products, that can preserve their role in storing product information for future life cycles [80], [81], [88]. Therefore, DPPs are positioned as the legislative successors to voluntary MPs, by establishing a product-compliant ecosystem. At the same time, DPPs are expected to function as a structural prerequisite for DBLs, which depend on the product data that they are designed to provide [85], [86], [88]. Although literature acknowledges the layered dependency between these digital instruments, there is still limited consensus as to how they will interact, supplement, and build on one another to facilitate lifecycle information flows and improve data management for construction products.

4.2.2. DATA STRUCTURES AND STANDARDISATION

Empirical studies converge on a common aspect that the primary barriers to DPP implementation lie in the absence of standardised data requirements, unclear information hierarchies, and misaligned information needs across stakeholders [11], [15]. MPs already exhibit this barrier due to the inconsistent adoption, which stems from the absence of a shared passport structure and common schema that manufacturers and stakeholders can conform to when generating material information [18]. These obstacles have motivated recent research on data models that advocate a lean, template-based core capable of satisfying emerging DPP legal requirements while maintaining interoperability [97], [98]. Across the literature, data templates (DTs) are considered a foundational structural solution for digital passports, providing standardised, machine-readable schemas to describe and capture product characteristics [99]. These templates can enable data to circulate across lifecycle stages and be reused between digital data-driven systems, such as BIM, DBLs, and digital twins [96], [100]. Despite the benefits of common data templates, these remain contextual and persistent challenges in acquiring, managing, and standardising product information within construction project contexts [18]. These difficulties stem from the use of multiple incompatible formats, the involvement of various stakeholders, and manufacturer confidentiality constraints [96], [98]. Inconsistent terminology, hierarchies, and data structures are consistently identified as weaknesses across digital passport instruments, limiting interoperability between technologically diverse tools and the wider digital infrastructure [18], [101].

A related strand of literature links DTs at product level to circularity-specific data structures, specifically the PCDS, formally ISO 59040:2025 [48]. PCDS was developed in response to the lack of reliable and digitised circularity data at the product level. Studies advocate for aligning PCDS with DTs to enable the integration of circularity indicators as properties within the same schema used for digital passport instruments [74], [82]. From an operational perspective in construction project processes, DTs provide a data-centric foundation that can be translated into product-specific datasheets, initially populated with manufacturer data and progressively enriched during the construction and use phases [97]. Their structured and machine-readable format also positions them as a key enabler of downstream applications, including sustainability assessments and waste audits. DTs at product level have been proposed as a means of linking product information with waste audit deliverables to foster circular

information flows across the construction lifecycle. In this role, DTs can serve as structured inventories that facilitate the assessment of products during deconstruction and inform reuse and recycling decisions. However, these propositions remain conceptual and limited in empirical evidence, where their potential for DPP structures is yet to be uncovered [97].

Harmonisation efforts seek to align product information at technical and semantic levels through common data structures, dictionaries and exchange formats [102]. Within the CPR framework, DPPs are expected to integrate technical, environmental, and circularity-related information requirements [7]. Technical harmonisation efforts build on existing CPR instruments, including CE-marking and the DoP, which govern the placement of harmonised construction products on the EU market [43], [44], [103]. Standardisation activities focus on developing digital data templates based on the international standards of ISO 23386 (data dictionaries) and ISO 23387 (data templates) to enable consistent definition and exchange of product properties across life cycle stages [49], [104]. However, not all construction products have harmonised technical specifications, such as hEN or ETA, which presents a challenge to achieving fully interoperable data structures under current conditions [103], [105], [106].

Parallel harmonisation efforts have been established for environmental information and are being developed for circularity information of construction products. ISO 22057 provides a machine-readable structure for EPDs suitable for digital BIM environments, while initiatives such as the PCDS seek to standardise circularity-related product information and support digital data exchange [82], [48], [107]. Article 75 (2) (a) of the CPR formalises the expectation that ties these standardisation efforts together, where DPP systems are to remain interoperable with BIM while ensuring compatibility with existing construction product standards [36], [38], [39]. This reinforces the necessary link between regulatory product compliance and digital information management [107]. Platforms such as buildingSMART Data Dictionary (bSDD) and Define Hub provide shared vocabularies, classifications, and data structures [36], [40]. However, in practice a combination of multiple data dictionaries is used due to varying vocabulary coverage, especially for circularity requirements that are still being established. While this serves a functional interim solution, it points to the need for a common, harmonised semantic framework [103]. Therefore, current policy ambitions seek to develop a common European data dictionary based on existing harmonised standards with the intent to unify product data definitions and support interoperable DPP implementation [105], [106].

Standardisation and interoperability are widely recognised in both academic and grey literature as prerequisites for scalable DPP implementation. Across the literature, DTs and data dictionaries consistently emerge as the key mechanism for structuring and exchanging construction product information. In parallel, grey literature provides practical examples of DTs in CE-marking, DoPs, EPDs, and PCDS, which standardise technical, environmental, and circularity information, respectively. Although these are clear industry examples, the role of DTs as the foundational information structure of DPPs requires development and application in real construction project contexts to demonstrate their usability at scale and ability to support information exchange between stakeholders, lifecycle stages, and digital systems [103], [106].

Within the CPR and ESPR, DPPs are intended to consolidate technical and sustainability dimensions within a unified digital information system. DTs and data dictionaries are increasingly positioned as the underlying structure through which information related to technical performance, environmental impact, and economy of resources can be organised and exchanged [74], [80]. This is conceptually illustrated in Figure 4.4 and further explained in Section 2.3.5, Chapter 2.

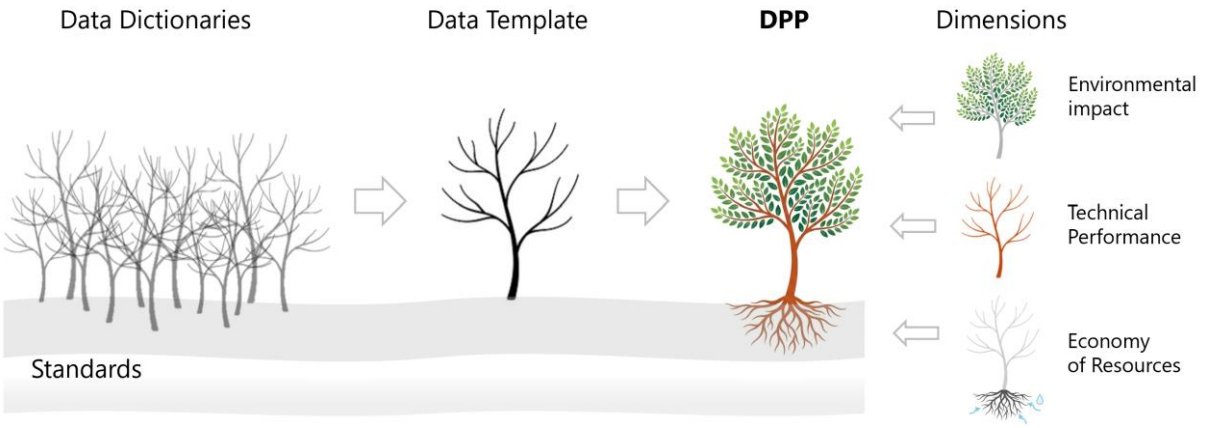


Fig. 4.4 – Conceptual data landscape shaping DPPs

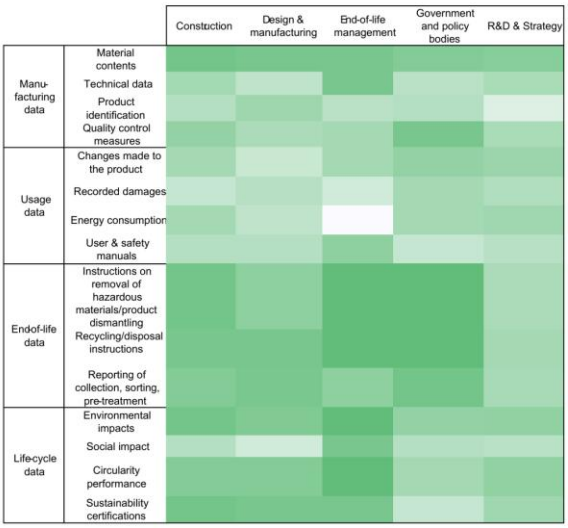
Grey literature highlights that the regulatory and technical foundations of DPPs are still evolving, with CPR-related information requirements, standardised data dictionaries, and implementation mechanisms continuing to develop in response to changing compliance needs for construction products [24], [103]. Furthermore, ongoing revisions of standards and various data models add to the complexity of achieving interoperability across the construction sector [67], [103], [106], As a result, the literature presents early progress but requires further development to shape a standardised DPP data infrastructure to be implemented as DTs that enable the circularity of construction products.

4.2.3. DEFINING CIRCULARITY INFORMATION REQUIREMENTS

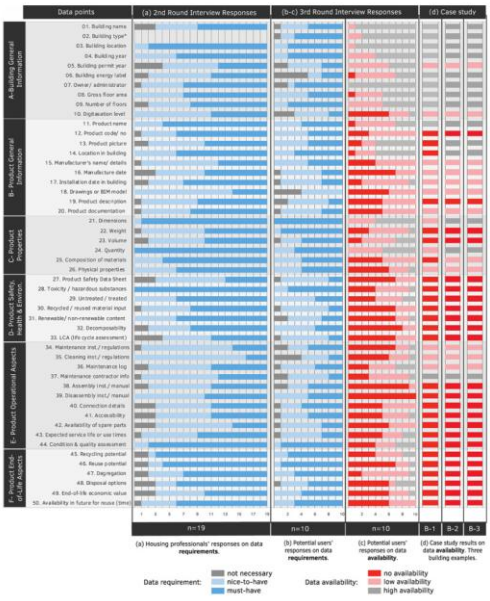
A growing body of literature has focused on defining construction product information to support MPs, CMPs, and DPPs [15], [74], [84], [108], [109], [110]. These studies propose conceptual data frameworks that identify product data for a CE. Table 4.3 consolidates the data frameworks identified across the reviewed literature, and a radar analysis was developed to compare their thematic emphasis (Figure 4.5). As represented in the radar analysis, three recurring themes appeared across the frameworks: **lifecycle, circularity,** and **deliverables**, scored on a 0-3 scale capturing the extent to which each theme is addressed and organised within the reviewed frameworks, where 3 = explicit and grouped; 2 = noticeably touches; 1 = limited mentions; 0 = absent.

Table 4.3 – Passport data frameworks across literature

Ruismäki et al. 2025



Çetin et al. 2023



Boje et al. 2021

Table 3. Attributes identified from the literature and standards.

MP Function	Attributes		
Material tracking and management	Material ID Material name/Type Batch number Brand name GTIN number Geographic origin	Manufacturer article number Manufacturer details Supplier details Weights/Quantity/Shape/Area/Length/Thickness/Volume	Manufacturing date Handling requirements Recommended usage Guidelines for storage Storage location
Circularity assessment	Physical properties Chemical Properties Mineral composition Reused/recycled/Renewable content of an inflow Renewable/non-renewable energy consumption Energy efficiency	GWP/ODP/AP/Eutrophication Potential (EP)/Photochemical Ozone Creation Potential (POCP)/Abiotic Depletion Potential (Elements) (ADPE)/Abiotic Depletion Potential (Fossil fuels) (ADPF)/Carbon footprint Health and safety	Energy/Water/Emissions Transport distances and modes Resource inflow/outflow Material productivity Transportation/handling cost Pathogens/Toxicity Unit price/Decommissioning/
Sustainability assessment	Manufacturing cost Transport distances	Renewable/Non-renewable energy consumption	
Quality assessment	Content and quality (cement, aggregate, admixtures, SCMs, and fiber) Water quality/pH Total dissolved solids	Workability (Slump) Air Content Density Bleeding Cohesion Temperature	Segregation resistance Setting time Ionic content/Solid content/Organic/Biological impurities
Material tracking and management	Material ID Date of installation	Location Service life	
Circularity assessment	Applied coatings Joining technique		
Sustainability assessment	Water/Land use Emission Levels Other environmental impact details	Renewable/Non-renewable energy consumption Designed Lifespan and durability	Warranties/Payment terms
Quality assessment	Compressive/Flexural/Tensile strength Elastic Modulus	Drying Shrinkage/Creep Deflection Freeze-thaw resistance	Permeability Abrasion resistance Load-bearing capacity

Senarathne et al. 2025

Table 2. Product and component level approaches for material passports and their data scopes across domains

Approaches from Table 1*	EPD	PEF	DPP	MP	PC DS	(Munaro & Tavares, 2021)	(Çetin et al., 2023)	(Tomczak et al., 2024)	CMP	MPF
Identity	x	x	x	x	x	x	x	x	x	x
Composition	x	x	x	x	x	x	x	x	x	x
Assembly			x	x		x	x	x	x	x
Environmental	x	x	x	x		x	x	x		x
Circularity			x	x	x	x	x	x	x	x
Energy	x	x								
Water	x	x								
Wellbeing	x									
Transport	x	x		x		x				
Usage	x	x	x	x	x	x	x	x	x	x
Economic										x
other				x		x			x	x

Goeswein et al. 2022

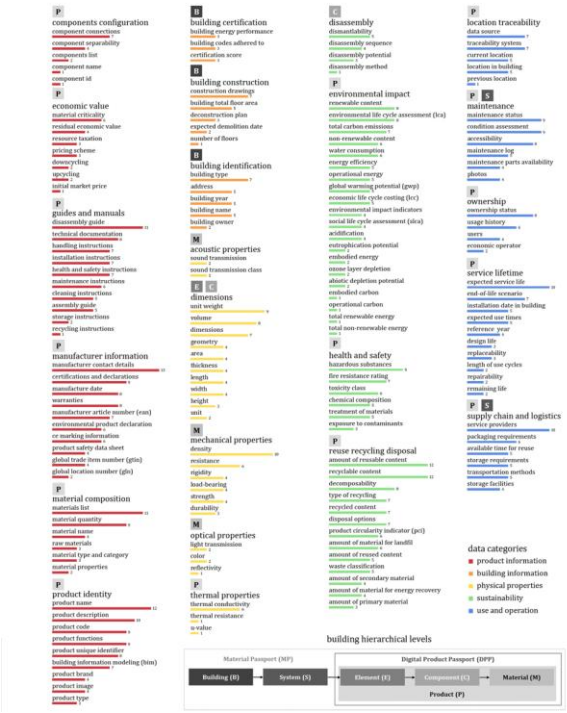
Table 3. Input parameters of the second section of the Circular Material Passport – Product Context.

Parameter	Description	Type of parameter
Building identification	Address and identification of building type in which product is installed/implemented	Open answer (text)
Installation date	Year of installation of the product	Closed answer (year)
Location	Specific location of the product within the building	Open answer (text)
Service lifespan	Expected service lifespan of the product	Option: 1.closed answer (year); 2. reference value (automatic field based on Product Categ.)
Maintenance	Information about the best maintenance to extend the product's service lifetime	Open answer (text)
End-of-life	Estimate of end-of-life occurrence	Automatic field calculated in the passport with input values through the following formula: *Expected end of life = Installation date + Expected lifespan*

Table 4. Input parameters of the third section of the Circular Material Passport – Circularity potential.

Parameter	Description	Type of parameter
Design for disassembly	Characterizes the design for disassembly of the product in terms of (1) type of connection, (2) type of connection accessibility, (3) type of crossings, and (4) type of form containment.	Closed answer (check box)
Disassembly instructions	Provides additional information for the material or product disassembly at the end-of-life for quality assurance	Open answer (text)
Quantity	Indicates the weight of the product or of its components	Closed answer (number)
Material composition	Estimates the material composition of the product or of its components in terms of (1) concrete, brick (stone), tiles and ceramics; (2) structural wood or other bio-based; (3) glass; (4) plastic; (5) bituminous mixtures; (6) metal; (7) insulation materials; (8) gypsum; or (9) mixture.	Closed answer (percentage) for a list of categories Possibility to indicate additional categories
Material input source	Estimates the percentage of the material input sources of the product or of its components in terms of (1) reused, (2) recycled, (3) biomass, or (4) virgin material.	Closed answer (percentage)
Waste scenarios	Estimates the quantities of the product or of its components sent to different waste scenarios, namely (1) reuse, (2) recycling, (3) energy recovery, (4) backfilling or other, or (5) landfill.	Closed answer (percentage)

Vangelova et al. 2025



Mêda et al. 2023

		DoP	Ecodesign	EMDG	Level(s)
1	Intended use of the product				
2	Mechanical strength				
3	Behaviour in fire				
4	Guidance/manual for installation				
5	Thermal conductivity				
6	Sound insulation properties				
7	Contents of dangerous substances				
8	Guidance/manual for maintenance or repair				
9	Contact details of manufacturer				
10	Recyclability				
11	Reusability/possibility for dismantling				
12	General EPD				
13	Emissions into indoor air				
14	Leaking into soil and water				
15	Contact details of testing facility				
16	Durability				
17	Energy use				
18	Recycled content				
19	Waste Codes				
20	Composition				
21	Global Warming Potential				
22	Aquisition cost				
23	Life-cycle cost				
24	Carbon and Environmental footprint				
25	Weight				
26	Service life				
27	GTIN				
28	Model/Brand				
29	Logistics data				

Figure 1: Data framework considering different requirements/deliverables/uses

Across the reviewed studies, a relationship is evident between circularity, lifecycle information, and construction deliverables, demonstrating that the themes collectively underpin information models for passport instruments, as illustrated in Figure 4.5.

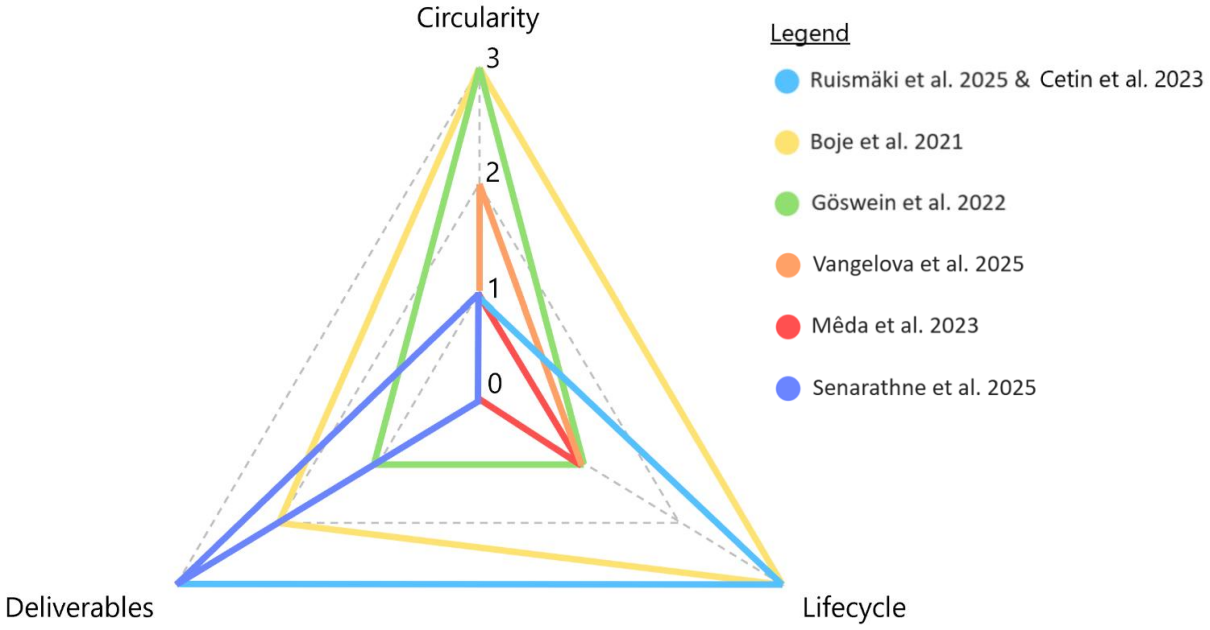


Fig. 4.5 – Radar analysis of key thematic information requirements across studies

However, the relationship is not uniformly realised across frameworks, as those with a strong focus on circularity generally provide limited consideration of construction project deliverables. In contrast, broader data frameworks attempt to integrate all three themes, often varying in degree of data completeness. Lifecycle information is addressed less consistently across these frameworks, despite the growing consensus that passports and logbooks are to capture product characteristics throughout the product lifecycle stages [111]. This inconsistency has practical consequences as early-stage design decisions require forward-looking data to support material selection for future reuse or recycling, and end-of-life planning depends on detailed as-built data describing the actual condition. However, this temporal difference is not consistently accounted for in current passport frameworks [18]. Some frameworks recognise the importance of linking product information to construction deliverables, in which attributes such as identity, geometry, and material composition serve as essential inputs for material inventories, waste quantification, and circularity assessments [95], [112]. Among the three themes, circularity receives the strongest emphasis, with most frameworks identifying material composition, product mass, hazardous substances, and reuse or recycling potential as essential data supporting circular decision-making [10], [83], [108], [111]. Despite broad agreement on which categories of information matter for circularity, comparisons at the attribute level reveal substantial inconsistencies in granularity, naming conventions, and data structures across frameworks.

Alongside academic developments, European legislation has increasingly begun to define the information requirements for construction DPPs, specifically the revised CPR, supported by the ESPR [7], [8]. Recitals 34 and 51 in the revised CPR establish the legislative intent to support reuse of construction products, strengthen secondary markets, and enable product lifecycle extension through the data provision in DPPs [8]. This direction is reflected in the environmental sustainability requirements defined in Annex III and Ecodesign requirements of Article 5 in the ESPR, which identify durability, repairability, remanufacturing, recyclability, and amounts of waste generated as key product requirements for improving the “circularity of construction products, in line with the goals of the CEAP and the waste hierarchy” [3], [4], [7]. Notably, these requirements are framed at the product level and defined at an overarching policy level, wherein a structured data schema and the specific circularity data attributes that a DPP should contain remain undefined.

Both academic and grey literature developments indicate an early, unclear definition of the information required in passport instruments to support circularity. As a result, the translation of data frameworks and regulatory requirements into a harmonised, implementable circularity dataset remains underdeveloped, leaving both streams operating in parallel. The PCDS represents a partial bridge between these efforts by developing a circularity-specific, product-level dataset informed by the ISO 59000 Series on the CE, which provides an early indication of what a DPP-ready structure may look like. Yet, its potential connection is overlooked [48]. A fundamental inconsistency across frameworks concerns how granular information is defined within passport instruments, of MPs, CMPs, and DPPs, despite their shared purpose of providing data to support CE objectives in the construction sector [80], [85]. Early MP initiatives developed through the BAMB project establish extensive lists of material data for the CE, describing physical properties, disassembly, and recovery potential [33], [113]. Emerging DPP frameworks and regulatory requirements, by contrast, define information at the product level. Given the coexistence of MPs and DPPs in the literature, and the overlap in the data attributes they capture, it remains unclear how information at these two levels of granularity can be aggregated, translated, or mutually informed to support circularity [81]. A product, according to the CPR, ranges along a granularity spectrum, for example, aggregates and cement at the elementary end, window units at an intermediate level, to complete kits or systems such as prefabricated curtain walling assemblies. While these levels of granularity are present under the CPR's single legal category of "construction product," the relationship between them is rarely made explicit, offering limited guidance on how data granularity should be structured or integrated within emerging DPPs to deliver circularity of construction products.

Empirical evidence on whether these proposed circularity attributes can be obtained from real project documentation is similarly limited. To date, this has been examined in a single study [108], which compared what professionals find necessary with data available in the project information practice. Differences between them were identified, with the availability of attributes related to end-of-life information consistently low despite being deemed necessary by practitioners. As this finding comes from a single case, the extent to which it is representative across construction projects remains unexplored. A related and frequently overlooked limitation concerns the scope of existing manufacturer-provided data. The data supplied by manufacturers tends to be oriented toward regulatory compliance and commercial validation rather than circularity-specific attributes such as disassembly potential and recovery strategies [18].

Overall, these findings point to three layers of work, that are conceptual data frameworks, regulatory requirements, and practical considerations, that currently exist in isolation from one another. While each contributes to the development of DPPs, efforts to consolidate all areas into a single and structured circularity dataset remain limited. Such integration can offer insight into the practical feasibility of implementing circularity information within real construction project environments and support effective DPP implementation at scale for the CE in the construction sector, but this avenue has yet to be explored [111].

4.2.4. CIRCULAR ECONOMY FOR CONSTRUCTION PRODUCTS

4.2.4.1. Digital Passports as Key Enablers of Circular Construction

The findings in the previous section on circularity-related information closely align with the main goals of digital passport instruments identified in the academic literature. A cumulative review, illustrated in Figure 4.6, indicates that the majority of studies (40 papers) position "identification of product reuse value" as the primary goal of digital passports, followed by their role to "stimulate reuse and recycling", and "support CE decision making of products". Although this review is based on a 2023 study, excluding papers published since, it gives an indication of how academia frames digital passports as key enablers that link product-level information with circular strategies and evaluation methods for construction products [5].

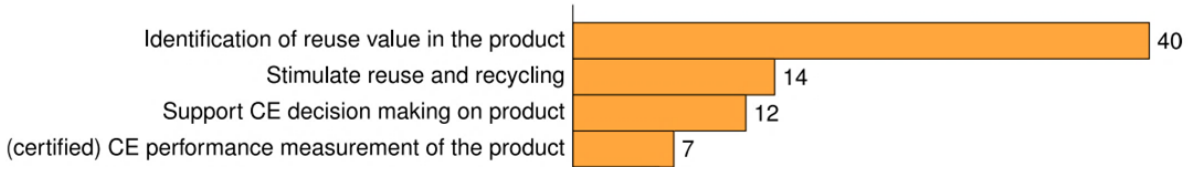


Fig. 4.6 – Main goals of digital passport instruments based on number of papers (adapted from [5])

Further studies suggest that DPPs can provide "insight into sustainability characteristics, circular value estimation, and circular opportunities" by facilitating the evaluation of product reusability, recyclability, deconstructability, recovery potentials and lifecycle information flows [92], [114], [115]. A shared stakeholder agreement defines the role of MPs and DPPs in enabling circularity, particularly in supporting reuse, recycling, and lifecycle extension strategies (R3-R7; reuse, repair, refurbish, remanufacture, repurpose) out of the 10R's circular strategies framework, as presented in Figure 2.5, Chapter 2 [15], [108]. High relevance is attributed to reuse, recycling, and supporting maintenance and retrofit, while upstream (R0-R2; refuse, rethink, and reduce) receive less emphasis. This suggests that DPPs are perceived primarily as traceability and operational tools that facilitate product lifespan extension, rather than as drivers of design-stage prevention.

The EU Level(s) framework is frequently referenced across research, policy documents, and certification systems sharing a common aim to advance CE concepts in the built environment [38]. The complete framework is represented in Figure 2.6, Chapter 2. Level(s) complements the most widely used LEED and BREEAM building certification schemes with over 60% topic and indicator overlap. Studies highlight that MPs can meaningfully support sustainability reporting across certification schemes, due to the provision of structured product data [11], [116]. However, such data is often "simply estimated globally in projects" due to inconsistent product data collection and aggregation, which "limits the chances of waste prevention and recovery" [117]. This underscores that the potential identified throughout the literature has not yet translated into consistent practice. This gap has prompted growing scholarly attention focusing on the EU Level(s) framework as a methodology for standardising lifecycle data and integrating digital passports to improve sustainability assessments of construction projects [13], [84], [101]. Table 4.4 consolidates findings from studies that examined the link between passport instruments and specific Level(s) indicators.

Table 4.4 – Passport relation with Level(s) Framework objectives

Macro-objective	Aim	Addressed in literature	Passport & digital instrument relevance
1. Greenhouse gas and air pollutant emissions along a building's lifecycle	Minimise total GHG emissions from cradle to grave	(Markou et al. 2025) (Mêda et al. 2021)	MP, DPP (1.2 Indicator)
2. Resource efficient and circular material life cycles	Optimise circular flows, extend long-term material use, and reduce environmental impacts	(Markou et al. 2025) (Göswein et al. 2022) (Mêda et al. 2021)	MP, CMP, DPP (All Indicators)
3. Efficient use of water resources	Use water resources efficiently to reduce long-term water	(Markou et al. 2025)	MP
4. Healthy and comfortable spaces	Create buildings that protect human health by being comfortable and productive to be in	N/A	N/A
5. Adaptation and resilience to climate change	Futureproof building performance against projected climate changes	N/A	N/A
6. Optimised life cycle cost and value	Optimise costs and value across life cycle stages for long-term performance improvement potential	(Mêda et al. 2021)	DPP (6.1 Indicator)

Across the reviewed studies, links between DPPs, MPs, and Level(s) macro-objectives vary considerably, ranging from high-level mentions to clearly mapped out and explicit connections. Among the Level(s) six macro-objectives, digital passport instruments are most frequently associated with Macro-objective 2 (MO2), "Resource efficient and circular material life cycles."

This objective is quantified through the following four indicators [22]:

- 2.1 Bill of Quantities (BoQ), Bill of Materials (BoM), and lifespans
- 2.2 Construction and demolition waste (CDW)
- 2.3 Design for adaptability and renovation
- 2.4 Design for deconstruction

Scholars suggest that aligning the structure of passports with the Level(s) framework provides a standardised, policy-driven digital tool focused on circularity [84]. Construction products are detailed as the primary source for Level(s) circularity indicators, based on their product identity and disassembly data. Complementing this, Mêda et al. [13] demonstrated specifically for DPPs how they can streamline Level(s) circularity and cost indicators through standardised data integration. Defined product data, such as composition, life span, and disassembly coefficient, are able to feed directly into the indicator deliverables of BoQM (2.1) waste generation forecasts (2.2) and deconstruction circularity coefficients (2.4), that support an MO2 assessment of building projects. In this approach, DPPs serve as a "collection hub" for existing inputs and outputs, enabling a streamlined Level(s)-aligned workflow [13].

The relevance of macro-objectives 1 (MO1, GHG emissions) and 6 (MO 6, Life cycle cost and value) towards DPPs receives acknowledgement but remains premature. MO1's global warming potential indicator, now reframed as climate change, is noted due to CO_2 emissions reduction goals stated within EPBD, though this link is currently supported by limited literature [42]. MO6 addressing life cycle costs, such as labour, utilities, and residuals, is similarly driven by policy drivers of Affordable Housing and Renovation Wave strategy [39]. Research suggests that not all indicators required for MO1 and MO6 can be derived from DPP data alone, as they often depend on broader system-level information beyond product-level, such as those provided by DBLs [88]. As a result, both objectives are understood as complementary to DPPs rather than fully integrated within their data landscape. The absence of links to macro-Objectives 4 and 5 points to a further area for exploration as to whether DPP data intersects with their indicators, given the presence of building certifications, such as the WELL Building Standard, that evaluate comfortable and healthy interior environments in buildings [118].

Within grey literature, including the CEAP, EU technical reports, and industry projects, the Level(s) methodology is consistently identified as a key approach for promoting CE principles throughout the lifecycle of buildings [1], [22], [31]. The methodology is also placed in the context of the ESPR and CPR by providing sustainability assessment of products [119]. Findings from the EEA Grants-funded GrowingCircle project highlight the importance of integrating Level(s) assessments with digital information environments to enable the aggregation of product-level information into building-level sustainability indicators [22], [31]. A significant gap is identified where the "EU waste audit guidelines omit digitalisation" [120]. At the policy level, the role of digitising waste-related information is largely overlooked, although the potential benefits and opportunities of digital integration in building waste auditing and management are highlighted throughout the literature. Using material/product traceability tools and BIM systems, more proactive waste prevention and accurate deconstruction planning can be enabled [5], [120]. Within the CDW Management Protocol are pre-demolition waste audits and detailed waste stream assessments based on data templates. However, their translation into digitised formats through the DPP is yet to be established [5], [29], [35]. Therefore, the extent to which DPPs capture and provide the data needed to streamline waste-auditing processes in construction projects remains unclear [120].

In a broad setting, the role of pre-deconstruction audits and integration in earlier stages of a project is increasingly recognised in the literature to facilitate ease of circular practices due to the identification, quantification, and handling recommendations they provide [29]. However, as illustrated empirically in end-of-life decision-making contexts, challenges are faced in determining product recovery pathways as they depend on detailed historical records that are frequently undocumented and outdated, leaving stakeholders to make recovery decisions with limited or unreliable information [18]. This finding

reinforces the case for embedding waste audit and material recovery data within digital tools to streamline information flows throughout the product lifecycle and be able to forecast recovery strategies better [96], [97], [98].

Bringing together academic and grey literature, DPPs are positioned as a "single point of information" that can meaningfully contribute to building-level assessment frameworks and circular construction processes [13], [121]. Yet what specific information is required, how it should be structured in DPPs, and how it can simultaneously support Level(s) reporting and waste auditing remain largely conceptual and underexplored in real-project information contexts, which limits the practical potential of DPPs to fulfil this role. The CEAP positioned the waste audit guideline and Level(s) as parallel outputs of the same ambition, calling for the integration of Level(s) assessments with digital information environments on one hand, and for closing the documented absence of digitalisation in EU waste audit guidance on the other [4], [29], [35]. Grey literature has long identified this lack of digital integration as a gap to be closed, pointing to digital passport instruments and BIM as solutions without specifying yet how they would function in practice [5]. Academic literature reinforces this direction, lending conceptual substance to the idea that DPPs could feed both Level(s) indicators and waste audit records from a single dataset [13], [97]. However, this claim rests on a small number of studies, and the ways in which such integration could be structured within the DPP data landscape require further clarification to support industry ambitions.

4.2.4.2. Circularity Potential of Construction Products

Academic literature on CE in the construction sector focuses on the circular potential of construction products and the factors that influence their recovery pathways. Reuse and recycling consistently emerge as the two principal circular strategies, with reuse generally recognised as the preferred pathway due to its preservation of product value and material resources [83]. However, the literature demonstrates that circular potential varies considerably across construction products, shaped by factors such as material composition, technical performance, expected lifespan, and the ability to be disassembled into reusable components. Bellini et al. [122] identify internal walls, doors, timber frames, and bricks as products with high reuse potential, largely due to their ease of disassembly and relatively lower performance constraints. In contrast, structural components often present greater challenges due to their integration within building systems, the difficulty of disassembly, and stringent technical performance requirements. Nevertheless, recent research suggests that prefabrication and demountable systems may improve future reuse and recycling opportunities of structural components by facilitating disassembly and material recovery [75]. Variations in circular potential are also reflected in stakeholder perceptions of reuse potential across different component types, as shown in Figure 4.7. Although reuse is a targeted circular strategy, its perceived potential for façade systems is represented as low.

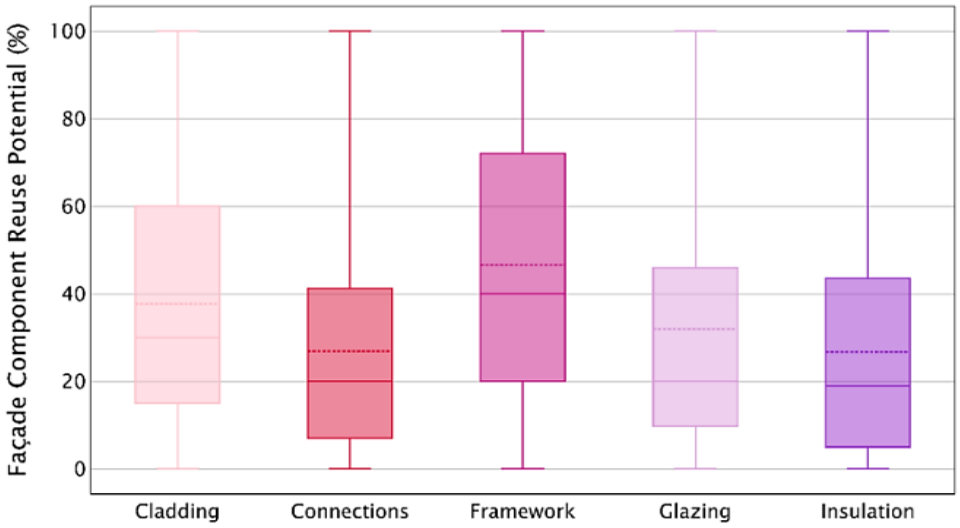


Fig. 4.7– Stakeholder-perceived reuse potential across façade component types [124]

Frameworks made of steel and aluminium are perceived as having higher reuse potential among the façade components due to their technical durability and retained end-of-life value [124]. On the other hand, insulation, glazing, and connection systems are commonly perceived as less suitable for reuse, with median values concentrated toward the lower end of the range. The factors underlying these stakeholder perspectives are not defined in detail in the study, limiting understanding of which product characteristics could have led to these different conclusions. In addition, the results are based on a relatively small sample of respondents from a single national context and were collected several years ago, which may limit their wider applicability. Therefore, further stakeholder understanding is necessary to clarify what product characteristics influence perceived reuse potential and how perceptions may vary across construction products, geographical contexts, and circular strategies in order to fully capture product circularity.

Further studies suggest that circularity potential is highly product-specific and context-dependent. Products that maintain quality and functionality throughout their lifecycle are more likely to be reused, refurbished, or recovered rather than becoming demolition waste [34], [125]. However, a limited understanding of the existing building stock and insufficient quantitative information on product composition and condition continue to constrain the assessment and implementation of circular interventions in practice [123]. These challenges are also influenced by socio-cultural barriers, such as a lack of widespread knowledge and trust among stakeholders, which hinder the adoption of reuse, recycling, and DfD, despite the growing body of research demonstrating their technical viability and benefits [126], [127].

Grey literature consistently positions reuse as the preferred circular strategy for construction products, owing to its ability to preserve product functionality and reduce resource use. This is reflected in the waste hierarchy established under the WFD and the broader objectives of the CEAP, promoting reuse over recycling and disposal. Consequently, current policy and industry initiatives are encouraging DfD, selective deconstruction, and circular strategies that extend product service life [96]. Despite these ambitions, current industry practice remains largely concentrated on lower levels of the waste hierarchy, where recycling dominates in CDW management due to more established markets and existing processing infrastructures [3], [29].

Wider adoption of reuse continues to face several barriers due to technical performance verification and uncertainty about how to assess product quality, both of which stem from the limited availability of

reliable product information throughout the construction product lifecycle [28]. Notably, current reuse of products within the same building project falls outside of CPR regulatory compliance, as such products are not placed on the EU market, according to Recital 34 [8]. Barriers to reuse arise primarily when products are intended for reuse across projects or for placement on secondary markets. The revised CPR recognises the need to facilitate the trade and wider reuse of construction products to support CE objectives at scale. Anyhow, as stated in Recital 34, it remains challenging due to differing EU Member State requirements, the need for the harmonisation of technical specifications for reused products, and the limited market confidence [8]. Despite growing policy recognition and support for reuse, its practical implementation remains constrained.

Both academic and grey literature converge on reuse as the main circular strategy for construction products but diverge in how they frame its scope and feasibility. Academic literature emphasises that a product's reusability depends not only on its physical characteristics but also on the available technical product information, the possibility of disassembly, stakeholder perceptions of value, and supporting market and regulatory capacity [122]. Policy and standards primarily address circular strategies at a broader, sector-wide level, whereas academic research shows that circularity potential varies considerably across construction products due to their distinctive characteristics. Another notable distinction is that academic studies narrow the focus to product reuse and recycling. In contrast, grey literature promotes further lifecycle extension strategies, such as repurposing, repair, refurbishment, and remanufacturing, reflected in CE frameworks of the Ellen MacArthur Foundation, ISO 59020:2024 for measuring and assessing circularity performance, and Ecodesign requirements for products in the ESPR [7], [26], [128]. However, under the WFD, the waste hierarchy and CDW management guidelines are limited to reuse, recycling, and recovery, without considering repurpose and the full set of R-strategies for CE [3], [29]. This narrower focus overlooks that a single construction product can follow multiple recovery pathways depending on its material composition, condition, application type, and its ability to be disassembled into components [91], [129]. Altogether, these findings suggest that the evaluation of circularity potential of construction products extends beyond reuse and recycling alone, and that capturing the full range of viable recovery pathways requires product-specific and context-dependent analysis.

4.2.5. DPP IMPLEMENTATION

4.2.5.1. Prioritisation of Construction Products

Several studies have developed product prioritisation frameworks to identify construction products that offer the greatest environmental, economic, and circularity impact. Due to the diversity of construction products used in the built environment, prioritisation has emerged as a necessary strategy for targeting those products contributing most significantly to CE objectives and supporting phased implementation of DPPs [14], [15], [89]. Current literature addresses this through a range of approaches drawing on existing project data analysis, stakeholder surveys, and empirical testing, as summarised in Table 4.5.

Table 4.5 – Product prioritisation frameworks across academic literature

Study	Approach	Priority Criteria	Key Findings
Mêda et al. (2024)	Project data	Portion of environmental, economic, and material impact	~11 priority DPPs (structural, façade, and technical) for incremental DPP rollout
Ruismäki (2023)	Stakeholder survey	Circularity potential and handling ease	Concrete > plastic > insulation > steel; with quick wins and implementation
Devos et al. (2025)	Empirical testing	Reuse potential, environmental and economic value	Bricks and tiles: 12.3% mass and 18.8% CO_2 savings
Riuttala et al. (2024)	Value assessment	Environmental and economic value	Precast concrete systems yields highest BCR value

Mêda et al. [14] developed a multi-criteria prioritisation method specifically for DPP implementation and applied it to a renovation case study. By combining BoQ data with criteria spanning economic ratio, waste management, hazards, energy performance, and facility management, the analysis identified approximately 11 priority product categories for DPPs. These range from structural elements and facade systems to technical installations, that are considered most suitable for early DPP implementation due to their high impact across criteria [14]. Devos et al. [123] identify façade bricks and tiles as having high circular reuse potential in a social housing case study in Belgium, achieving savings equivalent to 12.3% of building mass and reducing emissions by 18.8%. Similarly, Riuttala et al. [16] further demonstrated that reusing precast concrete components can generate both environmental and economic benefits. Despite methodological differences, most studies converge on structural systems and concrete products as priorities, reinforcing the relevance of products with high material quantities, significant embodied impacts, and strong circular potential for prioritisation. However, these approaches also reveal that product prioritisation outcomes are highly dependent and sensitive to the criteria applied and to the specific products used within a given building project, meaning that different studies can reach distinct priority outcomes [9], [15], [121].

A stakeholder-based prioritisation study arrives at similar priorities by identifying which products stakeholders perceive as benefiting most from DPP implementation, rather than by measuring impact criteria. As illustrated in Figure 4.8, concrete products, plastic products, and insulation are perceived as the product groups that would most benefit from a DPP in supporting circularity gains. Although a minority view within the survey, some respondents advocated prioritising product groups with short lifespans or frequently undergoing maintenance, with the reasoning that they would more rapidly demonstrate practical benefits of DPP use and in turn encourage wider stakeholder adoption [15]. The high ranking given to insulation is notable, as it contrasts with studies that prioritise products based on mass. What criteria informed the rankings are not clearly defined, limiting the transparency of the findings and their usefulness in supporting prioritisation decisions.

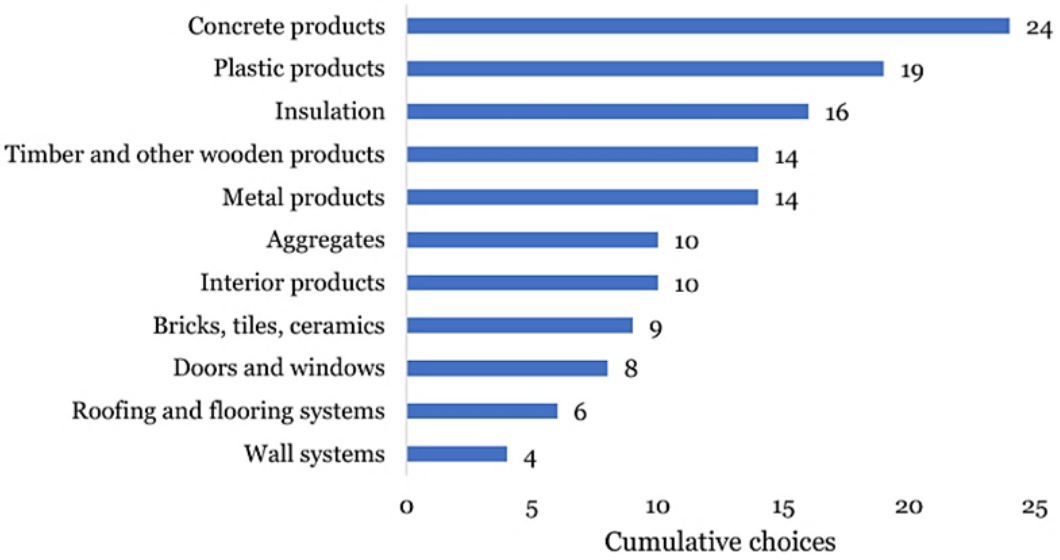


Fig. 4.8 – Prioritised products based on stakeholder survey [15]

A recurring challenge across the literature concerns the granularity used to define construction product groups, which varies considerably. Product categories in the survey range from material, component, product, and system definitions, with some overlapping. This reflects how they are also represented in the CPR product families list [15]. From a circularity perspective, granularity matters, as circularity potential varies not only between construction products but also within a single product, including its individual components and materials [123]. Given that circularity potential is itself one criterion used for prioritisation and is relevant to DPP implementation, the variations and inconsistencies in product granularity can obscure how it is evaluated and perceived. As the survey is one of its kind, clarification and broader stakeholder engagement are necessary to reinforce its findings.

The importance of prioritisation is also reflected in policy initiatives, where CEAP singles out insulation as a growing waste stream of particular concern [4]. A further list of priority CPR product families has been defined by the EU Commission, with "Precast normal/ lightweight/ autoclaved aerated concrete products" (Family 1) as the highest ranked product, based on eight criteria, including environmental, economic, and safety factors [17]. This indicates that depending on the policy context and criteria used, different priority products emerge.

Altogether, the different approaches employed, ranging from project-based to stakeholder-driven assessment, reveal that prioritisation outcomes depend on the specific products present within a building project and on stakeholder perceptions of those products. However, these two factors are rarely considered together across studies, despite both playing crucial roles in prioritisation within practical contexts. Across these studies, environmental and economic value are the most recurring criteria that also confirm the broader EU carbon emission and affordable housing targets and align with criteria used in the CPR product family priority list [17], [39], [41]. However, the view in enhancing the circularity of construction products, reinforced in CPR, is not reflected in the prioritisation criteria. Recital 51 of the CPR relates circularity specifically to resource efficiency, waste prevention, and the waste hierarchy, in line with the CEAP, suggesting that criteria such as mass and circularity potential of construction products, used less frequently across the studies reviewed, present more direct relevance to these specific waste- and resource-oriented objectives [1], [4], [8]. In addition, current literature provides limited guidance on the appropriate level of granularity across different product types, which has a direct bearing on how the circularity potential of construction products is evaluated [121]. More fundamentally, how circularity potential is defined and measured remains unclear across the studies reviewed, making

it difficult to benchmark products on this basis. Given various prioritisation methods, the extent to which conclusions can be drawn at scale remains limited. Therefore, to support gradual DPP implementation in construction to contribute to a CE, a strategic direction on what products to prioritise requires clarification. This points to the need for a consistent prioritisation approach, reconciling top-down EU CE and CDW recovery targets with bottom-up practice needs, to benchmark products by circular and waste impact, informing transition pathway actions [1], [4].

4.2.5.2. Progress and Challenges Faced in the Construction Sector

The transition from linear to circular approaches in the construction sector relies on the integration of digital tools [96], [114], [116]. DPPs are positioned as digital solutions providing structured and accessible product data for stakeholders to make informed lifecycle decisions and supporting long-term data storage benefits, especially for structural elements with longer service lifespans [11], [15], [98], [130]. Although the construction sector is often labelled as "resistant to change", targeted efforts and increased awareness can unlock productivity gains and circularity opportunities of construction products through DPP integration [11]. These expected benefits, however, come with trade-offs between information completeness and practical usability. On the one hand, detailed product information can improve decision-making and assessment processes. Still, if it is too extensive or overly specific, it can increase complexity and impose burdens on stakeholders, especially manufacturers. Therefore, an "optimal level of detail" is considered necessary to ensure practical applicability and support the circularity of products [15].

This balance is closely tied to the condition of the existing product information DPPs are expected to draw upon. A case study of a building retrofit illustrates that at the level of product information itself, archiving practices present a structural constraint on circularity. Documentation is typically created during the design phase and archived in static, unstructured formats such as paper drawings and PDFs, producing legacy data gaps and limited access further along the lifecycle stages [18]. This positions structured data templates for DPPs as a direct response to the absence of retrieval-oriented design in current product-information practice.

Existing buildings face a different DPP implementation challenge from new-build construction [18]. New-build projects can generate and embed passport data from the outset. In contrast, retrofit and renovation projects must contend with legacy data gaps that often require investigation and reconstruction, sometimes at high practical cost when historical infrastructure is undocumented. The case study project highlighted that, without digital tools, the project team reverted to manual documentation, illustrating how far passport aspirations currently are from the implementation capacity within the existing building stock, compared with new-build potential. These findings raise important practical considerations for DPP implementation in as-built information environments, but the evidence is drawn from a single case, which the authors themselves note "restricts the depth and diversity of practical insights" and call for more case analysis to strengthen transferability [18].

Early developments such as the EU-funded BAMB project introduced MPs as a foundational step toward structured material data [33], [131]. Since then, a broader ecosystem of industry platforms and pilot projects has emerged, some of which are DigiPass, CIRPASS-2, and CRediBIE [132], [133], [134]. Across these initiatives, a clear sectoral shift from "what materials are in the building?" to "how can product data be standardised, exchanged, and reused across the lifecycle?" is evident through DPPs. The progression illustrates the iterative nature of DPP development, in which implementation approaches continue to evolve in response to practical lessons, standardisation efforts, and technological advancement [67]. Academic and grey literature address this evolving landscape from complementary perspectives. Research primarily focuses on the technical potential of DPPs to advance circularity, whereas grey literature emphasises implementation feasibility and regulatory compliance [10], [122]. As DPPs depend on the comprehensive integration of existing legislation due to its regulatory backbone, they are

continuously adapting to ongoing revisions and evolving policy direction. Their combined perspectives position DPPs within a broader policy and data ecosystem, where circular ambitions require balancing with what is practical, standardisable and scalable under current industry conditions [124], [135].

4.3. SYNTHESIS AND RESEARCH GAPS

DPP is emerging as a key data-driven instrument supporting the construction sector's twin transition towards a CE [4]. Considering the early stages of development, a consistent finding across the current body of knowledge is that several foundational aspects require further development and clarification to facilitate DPP implementation in support of a CE transition [8], [106]. The review identifies a lack of stabilisation in the roles of MPs and DPPs. Although both passports are considered key digital tools to advance CE objectives in construction, it remains unclear how they will interoperate and complement each other [33], [81], [87], [114]. Product granularity is fundamental to understanding the implications of circularity, yet it is rarely made explicit in the literature, as reinforced by the CPR itself, spanning a granularity spectrum from elementary materials to complete systems under a single legal category of "construction product" [8].

Existing studies focus primarily on which circularity practices to implement, such as material efficiency, waste reduction strategies, and digital innovation, while a clear consensus on the underlying information requirements for circularity of construction products is yet to be established. Circularity requirements, as framed in legislation, defined academic data frameworks, and needed in practice, follow parallel streams with minimal convergence, limiting the potential of DPPs to deliver on the circularity of construction products. The CPR recognises, under Recital 34, the need for long-term harmonisation to support the reuse and trade of used construction products. However, the definition of the information requirements needed to enable this is undefined [8]. DPPs are positioned as capable of consolidating this information [13], [121], although their specific circularity data points and structure remain unestablished. PCDS content and DTs' structure offer early indications of what this might resemble but are yet to be realised in the implementation of DPPs [82].

A related gap concerns the scope of circularity strategies considered across both literature and practice. Current CE frameworks and Ecodesign product requirements promote the full range of R-strategies beyond reuse and recycling, such as repurposing, repair, refurbishment, and remanufacture [7], [26]. However, throughout the academic literature and under the WFD, these product-extension pathways remain largely unexplored for construction products, and the waste hierarchy and CDW Protocol management guidelines remain confined to reuse, recycling, and recovery [3], [29]. This overlooks that a single construction product can follow multiple recovery pathways depending on its material composition, condition, application type, declared use and disassembly potential. In addition, regulatory requirements continue to pose challenges to reuse at scale, where the rules governing the placement of reused products on secondary markets are yet to be established.

Prioritisation outcomes depend on both the specific products present in a project and stakeholder perceptions of those products, yet these two factors are rarely considered together across studies. Most prioritisation approaches focus on environmental and economic criteria aligned with significant EU carbon and affordable housing targets. An an approach targeted towards EU CE objectives and CDW recovery targets goes undefined across the literature [14], [16], [17], [123]. This limits the ability to benchmark products consistently or draw conclusions at scale to support the phased rollout of DPPs for circularity [1], [3].

A consistent finding across the literature is the gap between the theoretical potential of DPPs and their practical implementation within construction projects and processes [122]. Data gaps in existing building contexts are the main barriers to using digital tools effectively to support construction processes and inform product recovery decisions. The literature highlights the potential for DPPs to streamline

circularity-oriented construction processes, specifically as pre-deconstruction audits and Level(s) assessment indicators to facilitate the identification of reuse and recycling potential and quantify value [97], [121]. Still, it treats these as separate considerations despite their shared CEAP origin. The CDW Management Protocol and Level(s) framework have so far been digitalised independently, leaving the potential for DPP data to serve as a convergence point across these tools largely unexplored [13], [22], [97]. How DPPs can be populated from existing project information and streamline these circular construction processes remains limited [34], [108].

Beyond the definition of circularity data that DPPs are expected to capture, the literature raises a further, underexplored area on the information conditions of the building projects DPPs are expected to serve. As highlighted by one study, building information environments pose structural barriers to DPP implementation, particularly when documentation is archived in static, unstructured formats and when legacy data gaps in existing buildings cannot be readily resolved [18]. However, how variation plays out across real-world construction projects, and what it means for DPP readiness, remain open questions [108]. Both findings point to a broader gap, where the empirical study of circularity-related information requirements across varied, real-world building projects remains under-evidenced in the literature. This leaves a minimal understanding of DPP implementation capability across the range of information environments it will encounter and operate in. Overall, the conceptual circularity data frameworks, regulatory requirements, practical implementation, and real-world information conditions all remain partially developed and follow parallel paths due to the emerging DPP context. The research gaps are summarised in Table 4.6 and form the basis of the research objectives.

Table 4.6 – Synthesis of literature gaps identified and addressed through research objectives

Literature theme	Identified gap	Research contribution
DPP Foundations & Digital Ecosystem	Limited understanding of how existing passports and digital systems will interact as DPPs emerge.	Objective 1
Data structures & standardisation	Unstructured data structure and inconsistent semantic definitions for circular economy properties, necessary to develop a DT for DPP implementation.	Objective 3
Defining Circularity Information Requirements	Unclear consensus on DPP data requirements for product circularity and second-hand placement, and how this data can be streamlined into processes like pre-deconstruction audits and Level(s) assessments to support digitalisation.	Objective 3
Circular Economy for Construction Products	Academic literature and WFD focus on reuse and recycling overlooks lifetime extension strategies enabling full circularity potential of construction products.	Objective 2 & 3
DPP Implementation	Product prioritisation methods use inconsistent criteria, without a circularity-focused approach to support phased DPP rollout.	Objective 2
	Variations in project information environments and product documentation remain underexplored, leaving empirical evidence limited.	Objective 1 & 4

4.4. POSITIONING OF THE PRESENT RESEARCH

The gaps identified above point to a field in which consensus on how DPP can deliver on circularity remains unclear across regulatory, academic, and practical streams. This is compounded by limited empirical grounding in real construction projects [1], [4]. Therefore, the research is positioned to respond to these gaps.

In response to the underexplored empirical studies on information environments, a new-build and a renovation project, representing differing typologies, are examined from a post-intervention perspective. This provides an understanding of how product data can be derived, captured, and extracted from current documentation practices in construction projects, posing opportunities and challenges to DPP implementation to deliver circularity of construction products **(Objective 1 & 4)** [18], [67].

The literature presents early progress in how DPP can be implemented in a machine-readable format through DTs, however, a standardised data structure is yet to be established. The research addresses this by proposing a structured circularity dataset that consolidates circularity requirements that are currently distributed across sources **(Objective 3)** [33], [81], [108], [114]. This responds to the CPR's own recognition of undefined requirements for used construction products to be placed on a second-hand market, in support of lifetime extension, waste reduction, and resource efficiency objectives (Recital 34) [8].

To address the absence of a prioritisation method targeted to CE objectives and CDW recovery targets under WFD, this research develops a prioritisation approach that combines two complementary sources of evidence, that are weight significance derived from project cases and circularity potential from a stakeholder survey. Bringing these together allows weight significance and circularity potential to be assessed, reconciling top-down regulatory targets with bottom-up practice-based insight to determine which products should be prioritised for a phased DPP rollout supporting the twin transition **(Objective 2)** [14], [17], [123].

The review further reveals that current WFD and CDW Management Protocol guidelines remain confined to reuse, recycling, and recovery, despite the broader set of product lifetime extension R-strategies already recognised within CE frameworks, the ESPR and CPR requirements [7], [8], [26]. This research responds to this gap by assessing the circularity potential of different products across the CE R-strategies, their applicability at different granularities, and integrating them in the dataset development **(Objectives 2 & 3).** The use cases of Level(s) reporting and pre-deconstruction auditing are generally treated as separate and unrelated, despite both originating from the same CEAP construction sector ambitions. Their digitalisation has so far been pursued on separate tracks, and only one study has identified their potential convergence, positioning DPPs conceptually as the instrument capable of streamlining both from a single dataset [4], [13]. By integrating both bottom-up use cases in the C_MVDataset development, this research makes an empirical contribution supporting the digitalisation of these circular construction processes **(Objective 3).**

The research addresses these objectives collectively, as they form the preparatory activities required to move DPP implementation from concept to practice in support of circularity.

5
RESULTS

This chapter presents the research findings following the methodology described in Chapter 3. The results are organised according to the four phases, covering the analysis of construction product information environments, product prioritisation method, development of the C_MVDataset, and evaluation of existing product documentation practices.

5.1. CASE STUDY INFORMATION ENVIRONMENT FINDINGS (PHASE 1)

5.1.1. INFORMATION ENVIRONMENT MATURITY ASSESSMENT

The maturity assessment evaluated the information environment of both case study projects according to the availability, organisation, and completeness of construction product information. The detailed assessment of each criterion's results is provided in Annex A.1. As illustrated in Figure 5.1 below, Project Case B has higher points than Project Case A across all three assessment factors.

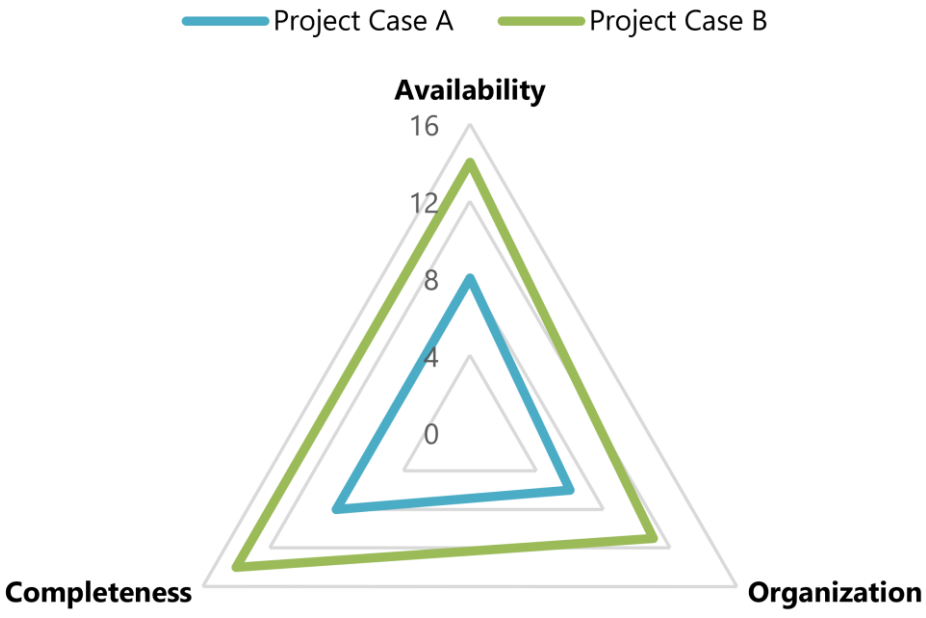


Fig. 5.1 – Multi-factor radar map analysis of project information environments

- **Completeness** recorded the highest overall score, with Project Case B acquiring the maximum of 14 points. This indicated that both projects provided substantial identification and performance product information. However, completeness also showed the largest disparity between the two project cases.
- **Organisation** was the lowest scoring factor for Project Case A, indicating that product information was distributed across multiple sources and formats without a consistent structure.
- **Availability** was the lowest scoring factor for Project Case B at 11 points. Still, it exceeded the result of Project Case A, with the available BoM, environmental product documentation, and site observation records.

To support comparisons between projects, the total assessment points were mapped to maturity levels, with Level I corresponding to 0-5 points, Level II to 6-9 points, and Level III to 10-14 points. The outcome maturity levels are presented in Table 5.1 and correspond to the previous results shown in Figure 5.1.

Table 5.1 – Assessment results of each project case maturity level across factors

	Factor		
Project	Availability	Organization	Completeness
A	II	II	II
B	III	III	III

Project Case B achieved Level III maturity consistently across all factors, indicating a more comprehensive and structured information environment. In contrast, Project Case A achieved Level II maturity, reflecting its fragmented project documentation and lower availability of product information. Overall, these findings demonstrate a clear difference in the data maturity of the two project information environments.

Different approaches and techniques used in the research to extract product information from both case study projects are illustrated in Figure 5.2. For Project Case A, product information was derived through a desk research of legacy data from multiple independent sources, such as BoQ, technical sheets, 2D AutoCAD plan drawings, Revit model, and archived photographs. Forensic techniques of document review and cross-referencing were used to fill in gaps and inconsistencies between sources. In addition, an external search of catalogues was required to supplement some missing product data. Due to the digital maturity of Project Case B, product data was entirely obtained through digital research of product documentation, where product data was extracted from a common data environment and the structured BoM. The field study activities conducted during the site visit served as supporting records rather than the primary information source, and also provided an indication of the techniques necessary for a project scenario when no data is documented or available.

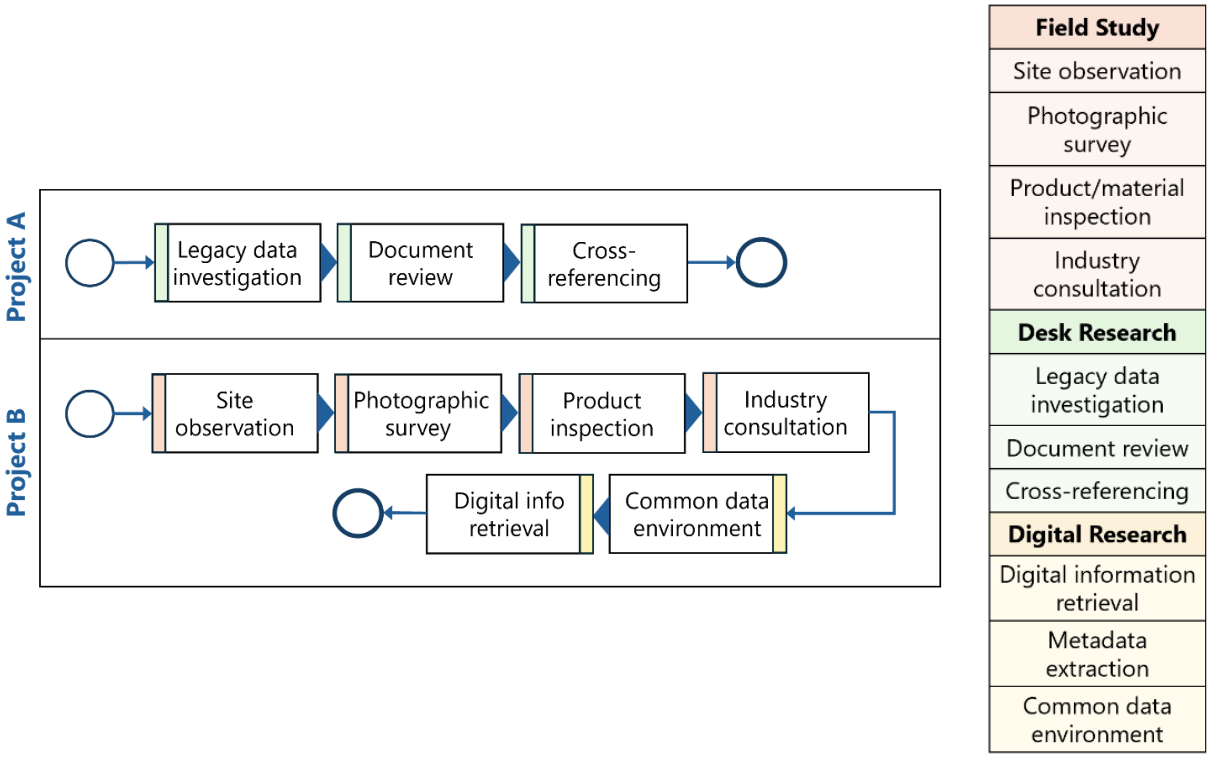


Fig. 5.2 – Techniques and process applied to extract product information from the project cases

The product data derived from the project information environments, using these forensic techniques and processes, informed the weight significance assessment and the evaluation of product documentation practices in the following results sections.

5.2. PRODUCT PRIORITISATION (PHASE 2)

5.2.1. WEIGHT SIGNIFICANCE ASSESSMENT

To derive weight values of the product inventory of both project cases for the weight significance assessment, a BoM for Project Case A was constructed, and the one already provided by Project Case B was used. In Annex A.2, the BoM development process with product classifications can be found, indicating the method used, as well as the time taken to develop the BoM and notes taken on limitations during the process.

With a focus on the building level, the weight significance of product inventory for both project cases indicated clear differences in Figure 5.3:

- **Project Case A** is mainly characterised by internal works and finishes, followed closely by envelope-related products.
- **Project Case B** is dominated by substructure and structural elements, and the envelope represents the second most significant weight contributor.
- Building services contribute a minor proportion of total building weight in both projects.

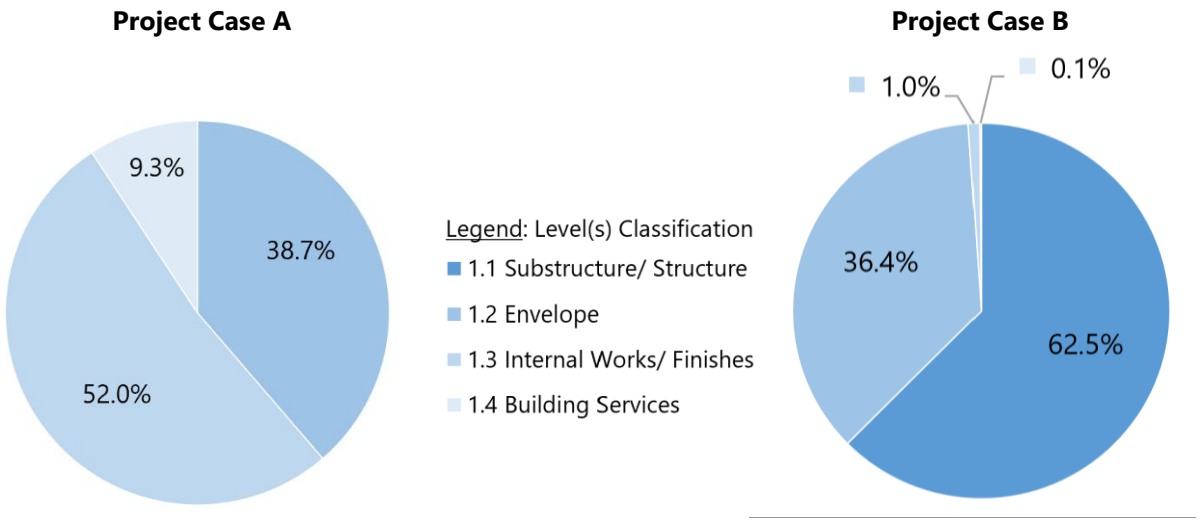


Fig. 5.3 – Weight distribution by building element for Project Case A and B

The results demonstrate that weight distribution is mainly influenced by project typology and construction approach. Despite these differences, the envelope accounts for a substantial proportion of the total building weight in both projects, underscoring its significance in overall building element inventories. For the entire project-level weight significance results, including external works, temporary works, and earthworks, refer to Annex A.3.

5.2.1.1. Building Element Material Type and Relative Weight

Figures 5.4 and 5.5 present the relative weight distribution of material types across both case study projects and along the Level(s) building element classifications.

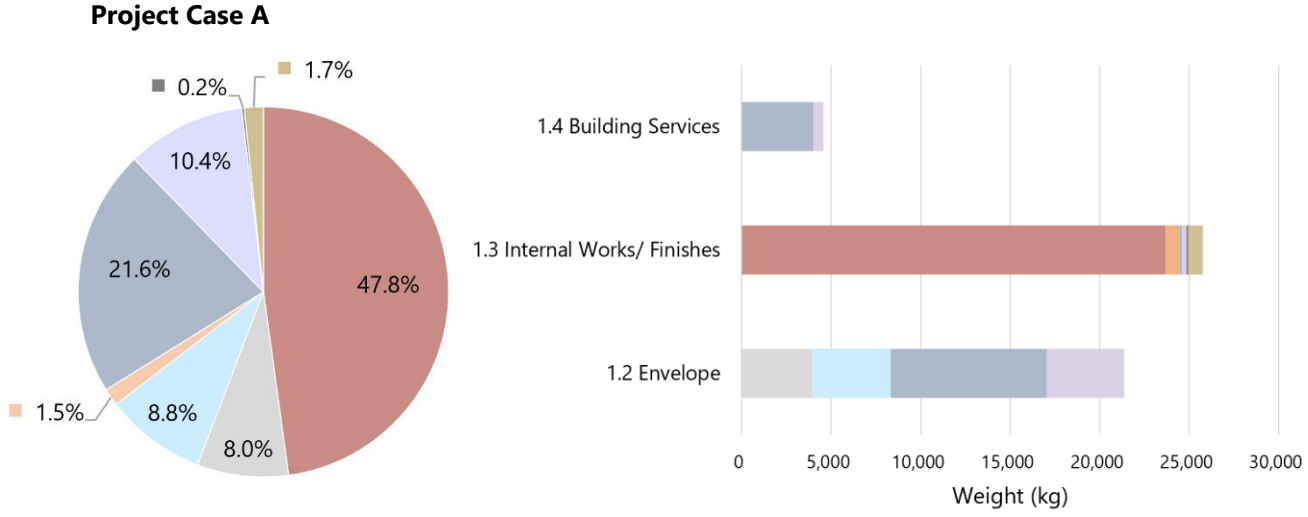


Fig. 5.4 – Relative weight of material types and mass in kg across building Level(s) classification of Project Case A

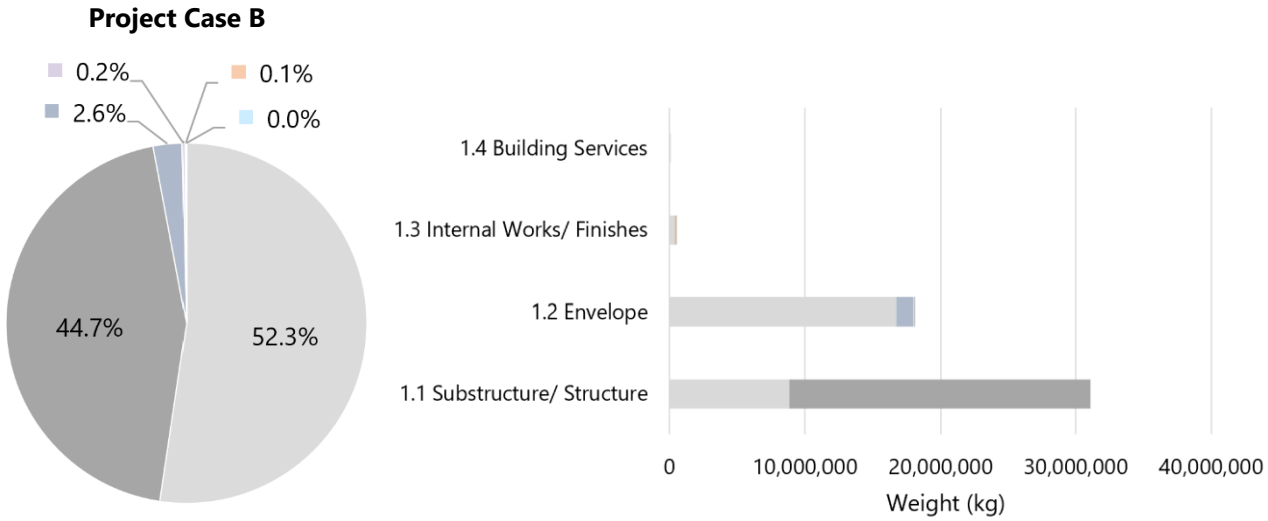


Fig. 5.5 – Relative weight of material types and mass in kg across building Level(s) classification of Project Case B

The results reveal significant differences between the project cases in the magnitude of weight and material stocks distributed along the Level(s) classification, where:

- **Project Case A** has a diverse material composition distributed across the envelope and internal works categories. Internal works and finishes are largely comprised of clay-based materials from ceramic products, and the envelope contains a broader range of materials, including aluminium, glass, and plastics.
- **Project Case B** has a highly concentrated material stock of concrete and aggregate materials. Most of the material weight is from the substructure and structure elements.

These findings highlight the difference in the types of materials used between the projects. The refurbishment housing project (Project Case A) demonstrates greater material diversity across product categories, with clay-based and metal materials accounting for the largest share of the weight. In contrast, the industrial new-build project (Project Case B) has more concentrated material stocks and larger overall quantities due to the heavier weight and the greater use of concrete, cementitious materials, and aggregates.

5.2.1.2. Weight Contribution across CPR Product Families

The classification according to CPR Product Families presents the relative weight contribution and distribution of products observed in the previous findings (Figure 5.6).

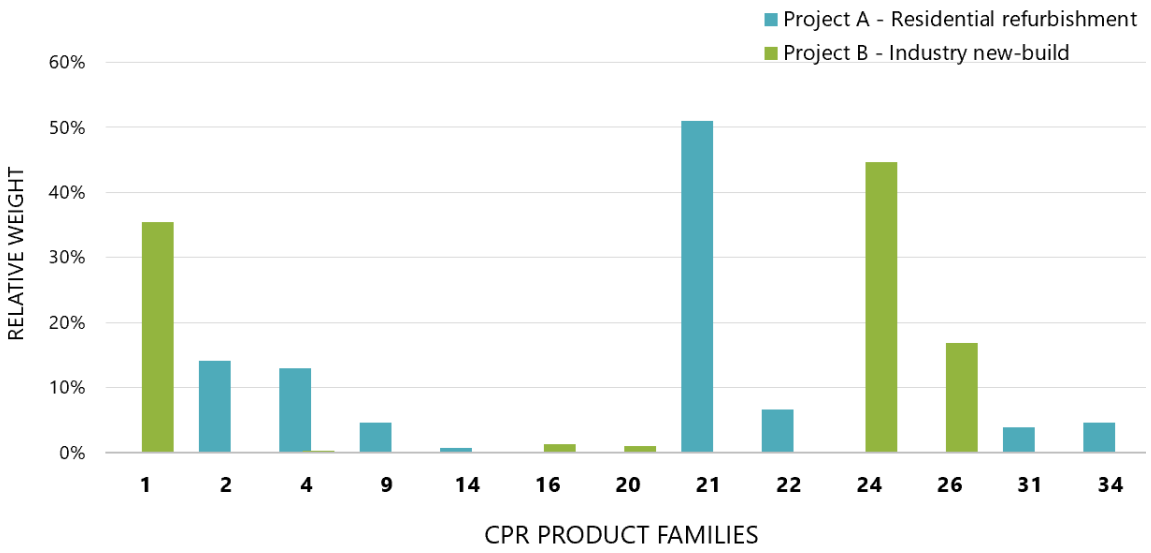


Fig. 5.6 – Project A and B relative weight distribution classified across CPR Product Families

A key finding from Figure 5.6 is the limited overlap in CPR Product Families for each project case.

- **Project Case A** dominates in Product Family 21 (Internal & External wall and ceiling finishes, Internal partition kits), which reflects the significant contribution of finishing products within the refurbishment project. Additional weight contributions at a much lower percentage are façade-related product families.
- **Project Case B** is primarily of Product Families 24 (Aggregates), 1 (Precast Normal/lightweight/autoclaved aerated concrete products), and 26 (Products related to concrete, mortar and grout) that account for the majority of the project's total product stock in the industrial development.

Notably, the two projects share almost no common high-weight products and materials, indicating that the two construction typologies draw largely on distinct sets of product families. When replotted using a logarithmic vertical axis (Figure 5.7), the CPR Product Families with low relative weights become visible.

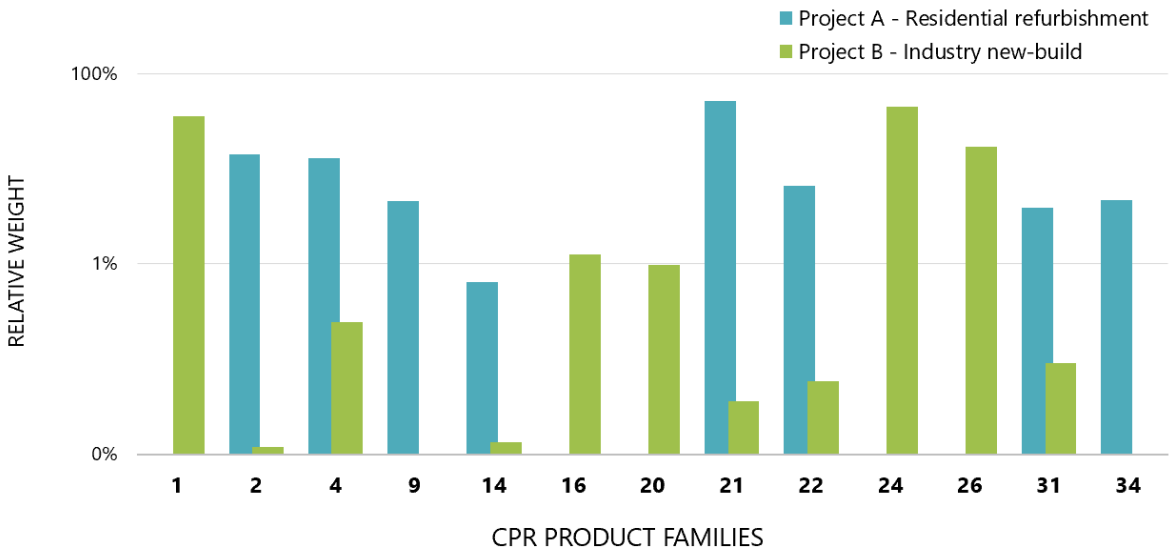


Fig. 5.7 – Project relative weight distribution across CPR Product Families (logarithmic scale at 10)

These overlaps in weight contribution that were not previously seen due to the graph scale in Figure 5.6. For example, the highest shared Product Family between both project cases is 4 (Thermal insulation products, composite insulating kits/systems). Therefore, the two figures provide a complete picture of the Product Family weight distribution. Figure 5.6 emphasises the magnitude of the dominant families, while Figure 5.7 reveals the overlaps among the minor contributors.

When comparing CPR Product Family weight in kilograms, concrete-based products (Families 1, 24, and 26) are substantially greater than those of all other product types, with this weight entirely attributable to Project Case B. By contrast, product weights in Project Case A are negligible, as shown in Figure 5.8.

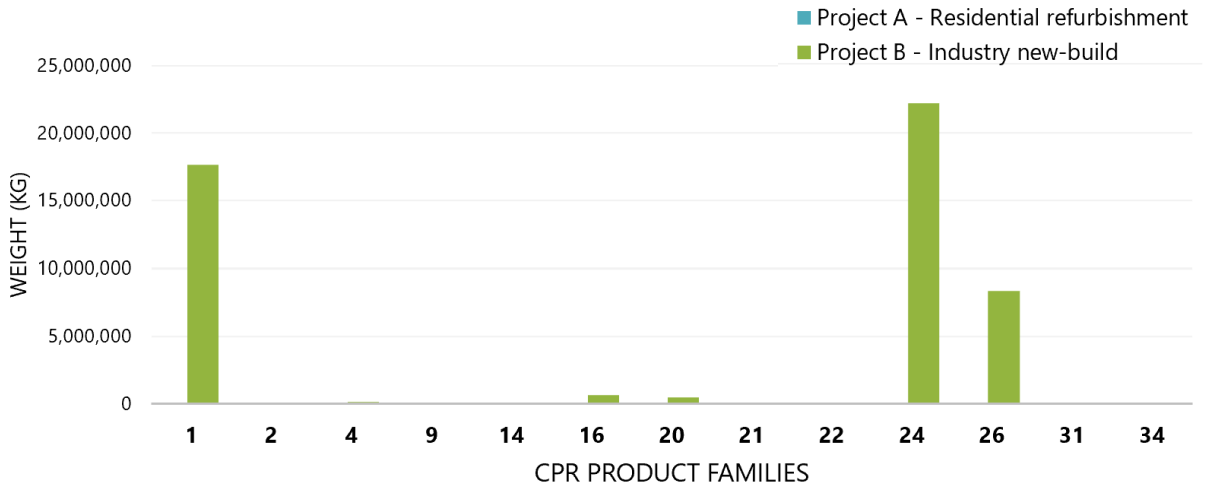


Fig. 5.8 – Total weight quantities of CPR Product Families in Project Case A and B

5.2.1.3. Priority Products based on Highest Weight Contributions

The assessment of individual product weights identified those that contributed the largest share in each project case (Figure 5.9).

- **Project Case A** was characterised by the highest weights in interior finishing and envelope products, with ceramic tiles and aluminium-framed glazed windows together accounting for approximately two-thirds of the total project weight.
- **Project Case B** exhibited a high concentration of weight in concrete-related products, namely aggregates and precast concrete wall elements, which collectively accounted for approximately 80% of the total project weight.

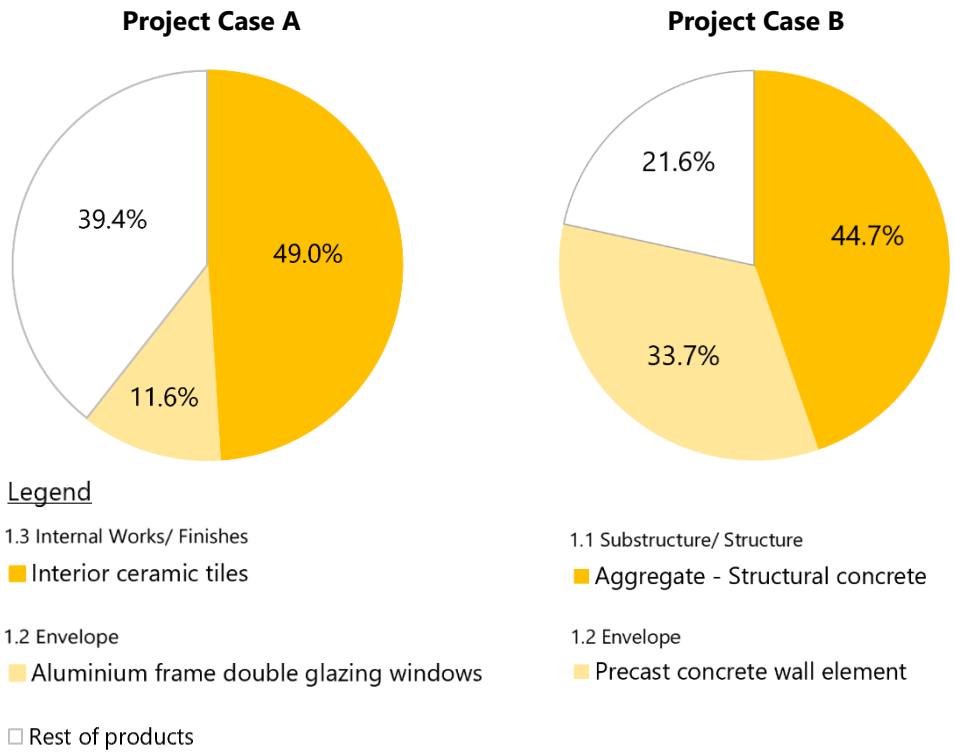


Fig. 5.9 – Main construction products with highest-weight constructions in both project cases

The types of high-weight products differed between the two project cases, that can be attributed to their specific construction approaches and building typologies, each consisting of different product inventories. While Project Case A exhibited a distribution of weight across interior finishes and envelope building elements, Project Case B was dominated by structural concrete-based elements. Both project cases shared the envelope building element as one of the most significant weight contributors. The four high-weight products identified in Figure 5.9 were shortlisted for the circularity potential assessment in the following results section.

5.2.2. CIRCULARITY POTENTIAL ASSESSMENT

Based on the circularity potential questionnaire in Annex A.4, Figure 5.10 presents the results of respondent perceptions of CE R-strategies' applicability for the four high-weight products, considering whether they are feasible at the "entire product", "parts of the product", or "not possible". Reuse and Repurpose were rated as the most applicable strategies to the entire product for most, except for interior ceramic tiles. The two concrete-based products assessed were considered applicable at the entire-product level for the majority of R-strategies. In contrast, the aluminium frame double-glazed window presented the highest applicability of R-strategies as parts of the product.

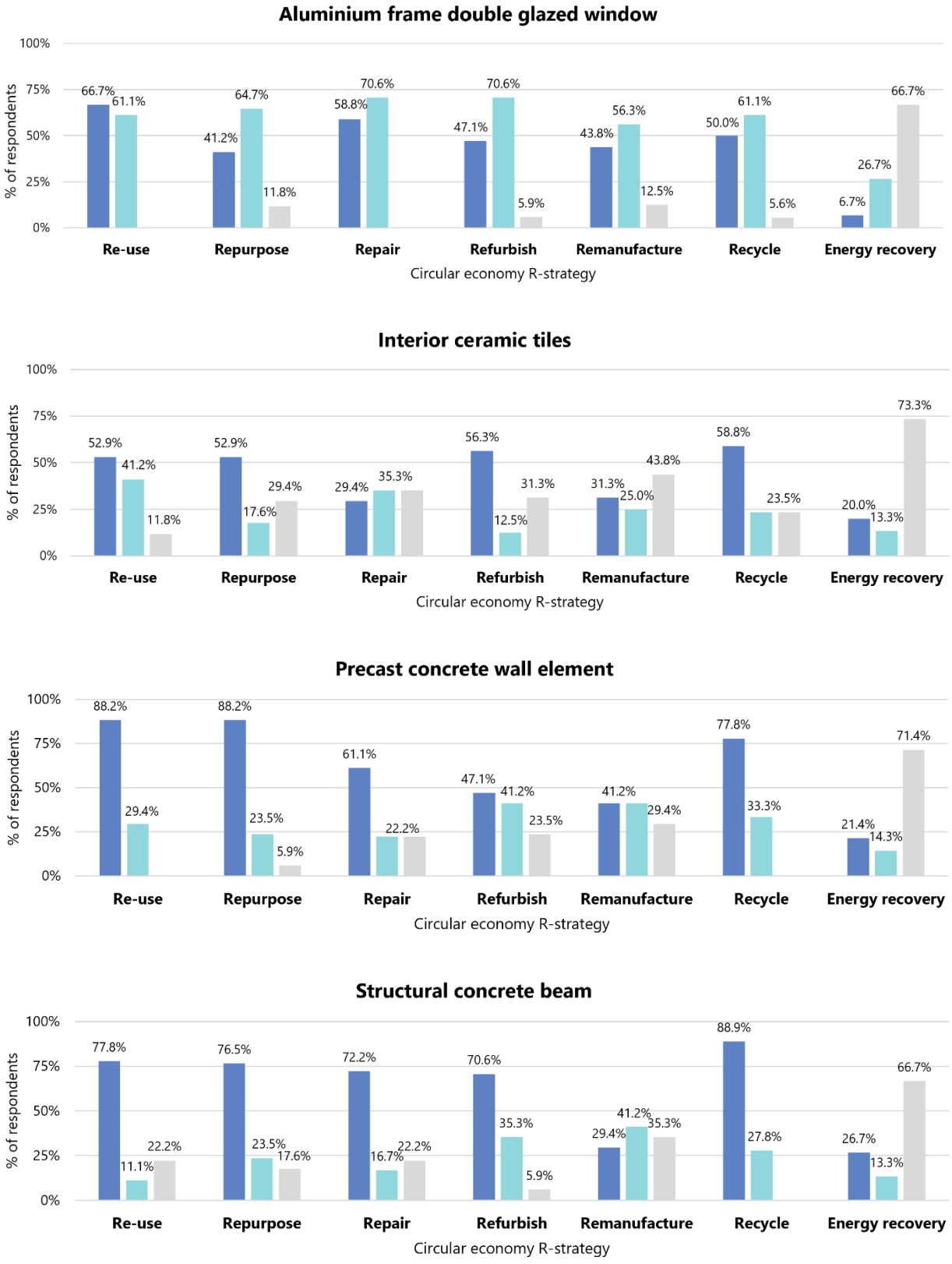


Fig. 5.10 – Circular economy R-strategies applicability of weight-significant products

The circularity assessment results for the shortlisted products are presented in Table 5.2. When combining the "entire product" and "parts of product" applicability, it is evident that certain construction products exhibit higher applicability across all R-strategies. The aluminium frame window ranks highest in circularity potential (85.4%) and across most R-strategies. Interior ceramic tiles rank lowest circularity potential at 64.5%, with none of the strategies reaching full percentage applicability, unlike the three other products. Notably, the Reuse strategy is rated highly at 100% for the aluminium frame double-glazed window and precast concrete wall element. Whereas Energy recovery is the lowest for the interior ceramic tiles at 26.7%, meaning that its applicability is recognised as least feasible. Recycle generally scores highest among the seven R-strategies, followed by Reuse, whereas Remanufacture and Energy recovery score the lowest across all products.

Table 5.2 – Circularity potential assessment results for shortlisted products across CE R-strategies

Project	Product	Reuse	Repurpose	Repair	Refurbish	Remanu-facture	Recycle	Energy recovery	Circularity Potential
A	Aluminium frame win-dow	100.0%	88.2%	100.0%	94.1%	87.5%	94.4%	33.3%	**85.4%**
	Interior ce-ramic tiles	88.2%	70.6%	64.7%	68.8%	56.3%	76.5%	26.7%	**64.5%**
B	Precast concrete element	100.0%	94.1%	77.8%	76.5%	70.6%	100.0%	28.6%	**78.2%**
	Structural concrete beam	77.8%	82.4%	77.8%	94.1%	64.7%	100.0%	33.3%	**75.7%**

5.2.2.1. Outcome Priority Products

The shortlisted products, based on their high weight significance and assessed on their circularity potential, identified the two priority products: aluminium frame double-glazed window and precast concrete wall element (Table 5.3).

Table 5.3 – Circularity potential scores and resulting two priority products from project cases

Project	Product	Circularity Po-tential	Priority Product
A	Aluminium frame window	85%	✓
	Interior ceramic tiles	65%	
B	Precast concrete wall element	78%	✓
	Structural concrete beam	76%	

5.2.2.2. Factors Influencing Circularity Potential

Across the two highest-scoring products, "Material composition" and "Ease of disassembly" were the most frequently cited factors by survey respondents, as shown in Figure 5.11. "Spare parts availability" received fewer votes, specifically for the precast concrete element, reflecting its structural role, whereas for windows it is more common for components to be maintained or replaced during their lifecycle.

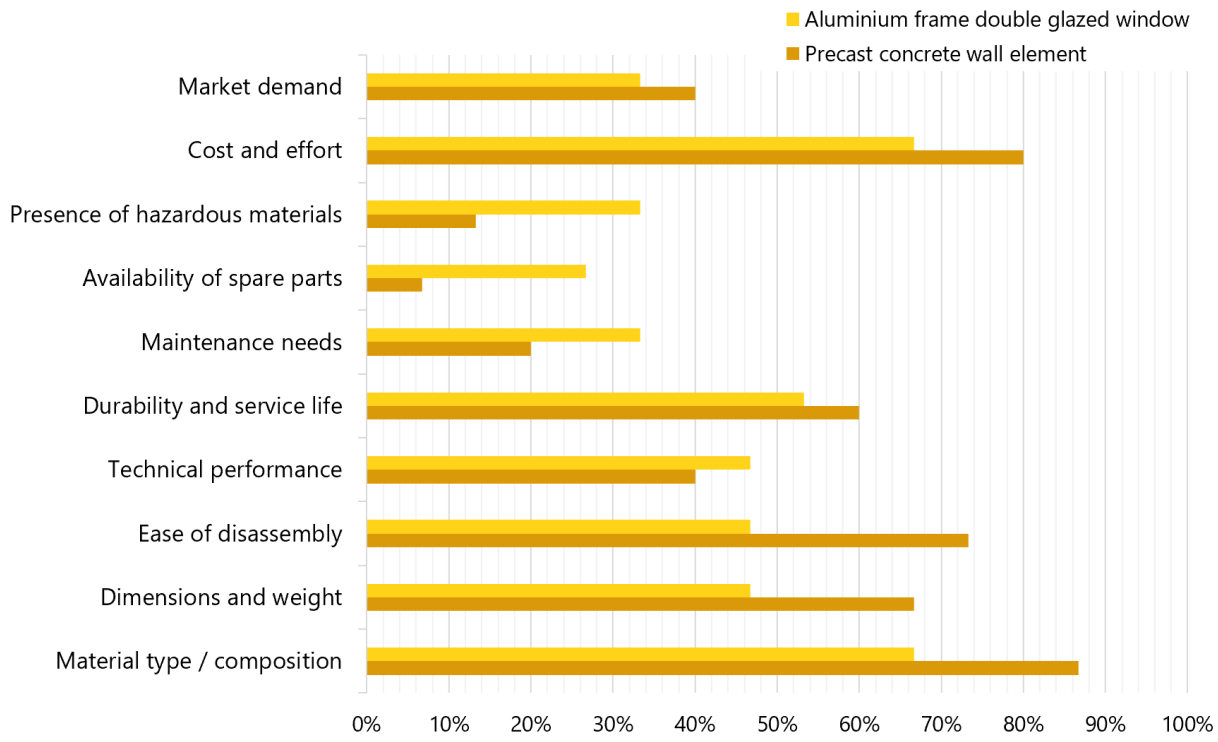


Fig. 5.11 – Survey results on factors influencing circularity potential of priority products

Beyond these rated factors provided by the survey, respondents also gave further insights into the circularity potential of each product in the open-ended questions, summarised thematically below.

1. Aluminium frame double-glazed window:

- **Standardisation** of opening dimensions was identified as a means of reducing waste during profile assembly and facilitating ease of disassembly.
- **Reuse** in a secondary market was considered feasible, in cases where there are less stringent thermal insulation requirements. However, this was noted to be dependent on the economic viability of dismantling and transport. Where reuse was not considered viable, recycling was identified as the primary alternative.
- **Frame and glass coatings** were identified as a factor influencing the ease of implementing circular strategies, both for the entire product and its parts.

2. Concrete-based products (Precast concrete wall element and Structural concrete beam):

- **Recycling** was consistently identified as a viable pathway for both concrete products, through the crushing of concrete into recycled aggregate and the reprocessing of rebar at steel plants.
- **Market demand** for recycled aggregate was described as requiring policy support, such as mandated minimum quotas in construction projects.
- **Reuse and repair** were identified as the preferred strategies where feasible, with recycling into aggregate considered a final option for material of insufficient quality.
- **Structural challenge** for both products due to difficulty of separating concrete from steel reinforcement, which typically requires energy-intensive processes such as sawing to facilitate removal.
- **Economic and operational viability** of circular strategies was described as dependent on the available specialised labour and machinery. Cost and effort were also considered significant, interdependent barriers to CE implementation.

5.3. CIRCULARITY DATASET DEVELOPMENT (PHASE 3)

Following product prioritisation, the CE information requirements were consolidated into a C_MVDataset for DPPs, with a focus on delivering circularity product data. Annex A.5 presents the complete data-mapping process, and the various information sources used to develop the C_MVDataset.

5.3.1. CIRCULARITY DATASET REQUIREMENTS

The C_MVDataset was developed by integrating top-down and bottom-up product data requirements, reflecting the Chapter 3 Methodology approach. The dataset comprises 29 data points, organised into three main property groups of Identification, Performance, and Resource Circularity, as presented in Table 5.4. Identification and Performance were defined by CPR and Ecodesign requirements for placing a product on the market [7], [8], whereas Resource Circularity is a newly formed group that consolidates data points on product life extension and recovery pathways.

The source mapping revealed distinct patterns in the origin of information requirements. Identification and Performance were mainly derived from top-down sources, specifically the CPR and Ecodesign delegated acts product requirements. The mandatory product information in Annex IV of the CPR was included as data points in the Identification property group of the C_MVDataset to ensure compliance. Performance-related and *Durability/expected life span* data points in the dataset correspond to the CPR horizontal essential characteristics applicable across all CPR Product Families. The Resource Circularity data points were drawn from a broader set of sources, specifically top-down literature, regulatory frameworks and circularity-related standards (EPD, PCDS) to bottom-up Level(s) indicators and pre-deconstruction audit deliverables, as mapped out in Table 5.4.

CPR and Ecodesign naming conventions provided the primary semantic reference for the C_MVDataset, as shaded lightly and written in red (Table 5.4). Where equivalent terminology was unavailable, naming conventions from standards and use cases were adopted, including *Repurpose* from PCDS (purple), *Possible outlets* and *Recommended outlets* from the pre-deconstruction audit deliverables (orange). This enabled the harmonisation of requirements from both legislative and practical contexts into a collective dataset.

Several data requirements are consistently mentioned across multiple information sources. Within the Performance category, *Materials used/composition* and *Weight* were the most frequently recurring in top-down and bottom-up sources. Similarly, for Resource Circularity, the repeating data points were *Reusability, Recyclability, Energy recovery, Waste code, Substances of concern,* and *Possible outlets*. Their repetition indicates alignment between compliance-driven requirements and the data needs of construction project processes. However, differences were observed in the representation of the CE strategies within the Resource Circularity property group. Data requirements associated with *Reuse, Recycling*, and *Energy recovery* were widely represented across sources, whereas those related to the extended R-strategies of *Repurpose*, *Repair, Refurbishment*, and *Remanufacturing* appeared less frequently. *Repurpose* is especially underrepresented, with only PCDS and its related ISO 59000 Series vocabulary defining this circularity requirement [47]. Although most R-strategies are recognised within CPR and Ecodesign environmental sustainability product requirements, some absences remained across the literature and industry use cases.

Table 5.4 – Development of C_MVDataset for construction products through data source mapping

C_MVDataset		Data source				
		Top-down			Bottom-up	
Group of property	Data point	Lit.	CPR, ESPR, & WFD	Standards	Level(s) Indicators	Pre-deconstruction Audit
Identification	Manufacturer details					
	Manufacture date					
	Product type					
	Declared use					
	Conditions of use					
	Durability / expected life span		Horizon.		2.1	
	Materials used / composition				2.1, 2.2	
	Weight				2.1, 2.2, 2.4	
	Dimensions					
	Volume					
	Thickness					
Performance	Essential characteristics					
	Reaction / resistance to fire		Horizon.			
	Noise absorption		Horizon.			
Resource Circularity	Availabilty of spare parts					
	Maintanence					
	Upgradability					
	Disassembly					
	Reusability				2.2	
	Repurpose					
	Repairability					
	Refurbishment					
	Remanufacturing					
	Recyclability				2.2	
	Energy recovery				2.2	
	Waste code (EWC)				2.2	
	Substances of concern (SoC)					
	Possible outlets				2.2	
	Recommended outlet				2.2, 2.4	

The outcome research artefact of the C_MVDataset for DPPs of construction products is illustrated in Table 5.5, that consolidates all sources into a structured and concise circularity-focused dataset.

Table 5.5 – The C_MVDataset artefact

C_MVDataset	
Group of property	**Data point**
Identification	Manufacturer details
	Manufacture date
	Product type
	Declared use
	Conditions of use
	Durability / expected life span
	Materials used / composition
	Weight
	Dimensions
	Volume
	Thickness
Performance	Essential characteristics
	Reaction / resistance to fire
	Noise absorption
Resource Circularity	Availabilty of spare parts
	Maintanence
	Upgradability
	Disassembly
	Reusability
	Repurpose
	Repairability
	Refurbishment
	Remanufacturing
	Recyclability
	Energy recovery
	Waste code (EWC)
	Substances of concern (SoC)
	Possible outlets
	Recommended outlet

5.4. EVALUATION OF PRODUCT-SPECIFIC DOCUMENTATION (PHASE 4)

The mapping of existing product information in industry documentation practices of the two priority products, precast concrete wall element and aluminium frame window, compared with the data points in the C_MVDataset revealed overlaps and gaps, as presented in Table 5.6 (Precast element) and Table 5.7 (Window).

Based on the information environment analysis of the case study projects, product-specific data was identified from the photographic record of CE-marks and labels, as well as document review of technical sheets. For both project cases, regulations and standards information sources were integrated, defining key identification and performance requirements for both construction products. EPD data requirements were derived from a representative example in the International EPD System [136].

Table 5.6 – Precast concrete wall element information compared to C_MVDataset

Precast concrete wall element information								
Project Case B		Regulation & standards			C_MVDataset		
Site observation & Photographic record	Document review	Identification (CPR Annex V)	Performance (EN 14992: Load-bearing)	Environment (EPD-IES-0029404:001)			
CE mark, labels	*Technical sheet*	*DoP*	*Harmonised standard*	*EPD*			
✓	✓	✓		✓	•	Manufacturer details	Identification
✓					•	Manufacture date	
✓	✓	✓	✓	✓	•	Product type	
✓	✓	✓			•	Declared use	
	✓				•	Conditions of use	
	✓	✓		✓	•	Durability / expected life span	
✓	✓	✓		✓	•	Materials used / composition	
✓				✓	•	Weight	
✓	✓	✓		✓	•	Dimensions	
✓	✓				•	Volume	
✓	✓			✓	•	Thickness	
	✓	✓	✓	✓	•	Essential characteristics	Performance
	✓	✓	✓	✓	•	Reaction / resistance to fire	
	✓	✓	✓	✓	•	Noise absorption	
						Availabilty of spare parts	Resource Circularity
						Maintanence	
						Upgradability	
						Disassembly	
						Reusability	
						Repurpose	
						Repairability	
						Refurbishment	
						Remanufacturing	
				✓	•	Recyclability	
						Energy recovery	
						Waste code (EWC)	
	✓	✓	✓	✓	•	Substances of concern (SoC)	
						Possible outlets	
						Recommended outlet	

Table 5.7 – Aluminium-frame window information compared to C_MVDataset

Aluminium frame doubled glazed window information									
Project Case A		Regulation & standards					C_MVDataset		
Photographic record	Document review	Identification (CPR Annex V)	Performance			Environment (EPD-IES-0002163:001)			
			Windows (EN 14351-1)	Insulating glass unit (EN 1279-1)	Aluminium frame profile (EN 12020-1&-2)				
CE mark, labels	*Technical sheet*	*DoP*	*Harmonised standard*			*EPD*			
✓	✓	✓		✓	✓	✓	•	Manufacturer details	Identification
✓							•	Manufacture date	
	✓	✓	✓	✓	✓	✓	•	Product type	
✓	✓	✓					•	Declared use	
	✓						•	Conditions of use	
		✓				✓	•	Durability / expected life span	
	✓	✓		✓	✓	✓	•	Materials used / composition	
✓					✓	✓	•	Weight	
✓		✓		✓	✓	✓	•	Dimensions	
								Volume	
				✓	✓	✓	•	Thickness	
	✓	✓	✓	✓	✓	✓	•	Essential characteristics	Performance
	✓	✓	✓	✓	✓	✓	•	Reaction / resistance to fire	
	✓	✓	✓	✓	✓	✓	•	Noise absorption	
								Availabilty of spare parts	Resource Circularity
								Maintanence	
								Upgradability	
								Disassembly	
			✓				•	Reusability	
								Repurpose	
								Repairability	
								Refurbishment	
								Remanufacturing	
						✓	•	Recyclability	
						✓	•	Energy recovery	
								Waste code (EWC)	
	✓	✓	✓		✓	✓	•	Substances of concern (SoC)	
								Possible outlets	
								Recommended outlet	

Differences were observed in the information sources and product-specific requirements for each product:

- **Precast concrete wall element** information was primarily supported by EN 14992 for load-bearing precast concrete elements (harmonised standard) [137], with *Volume* identified as a product-specific requirement derived from CE-mark and technical documentation. Recycle was the only R-strategy represented in the EPD.
- **Aluminium-framed window** information drew upon multiple harmonised standards covering the overall window product (EN 14351-1) [138], insulating glass units (EN 1279-1) [139], and aluminium frame profiles (EN 12020-1 and -2) (all harmonised standards) [140]. The two R-strategy data points of *Reusability* and *Energy recovery* were identified within the overall window product harmonised standard and in the EPD for aluminium-frame windows but were absent for the precast concrete wall element [141], [142].

Across both products, Identification and Performance information came from the combination of case study project sources and industry-used documentation, such as DoPs, harmonised standards, and EPDs. By contrast, Resource Circularity data was largely absent. Within this property group, only *Recyclability* and *Substances of concern* were consistent for both products. Data supporting product lifetime extension, such as *Disassembly*, and extended R-strategies, was absent from all product information sources reviewed. Overall, these findings indicate that circularity data requirements remain substantially underrepresented in current product documentation practice.

5.4.1. FOCUS GROUP DISCUSSION FINDINGS

The focus group discussion provided feedback on the refinement of the C_MVDataset, focusing on the clarification of data points within the Identification property group. Participants noted that *Intended use* and *Declared use* are both necessary data points, as they establish a complete and traceable conformity record for the product. *Intended use* refers to the general purpose and scope of essential characteristics that apply to the product category as a whole, whereas *Declared use* is the specific application of the product as intended by the manufacturer, within the broader scope. Participants mentioned that further clarification of how these points apply form a circularity persective to support second-hand market placement will be necessary in product documentation practice. Based on this feedback, both data points were included within the C_MVDataset, as represented in the refined artefact in Table 5.5 above.

The following chapter discusses the significance and implications of these findings from each phase in dialogue with the literature reviewed.

6
DISCUSSION

This chapter follows the four phases of this research, expanding on their broader significance and implications for DPP implementation for circular construction and concluding with the limitations of this study.

6.1. INFORMATION ENVIRONMENT MATURITY AS THE CONTEXT OF PRODUCT DATA FOR CIRCULARITY

Both case study project information environments share the same characteristic, where product information is distributed across multiple sources with different structures, granularity, and purpose. Given this existing condition, the extent to which product information is available, organised, and complete differs significantly between projects, as indicated by the findings in Section 5.1. Project Case A presented a fragmented information environment with product data spread across several formats and gaps in granularity. This is owing to its nature as a refurbishment project, constrained by the legacy data available from multiple sources and structured around a traditional linear workflow centred on a BoQ for cost and procurement purposes [18]. In contrast, Project Case B presented more comprehensive product information, structured around a BoM that provided extensive product and material data organised within a classification system. This reflects the modern context of the new-build project, in which sustainability and digitalisation ambitions shaped the structured information environment from the outset. Importantly, their differences in the data maturity level of the information environments suggest what kind of deliverable is conventionally produced for each project type, rather than a deficiency in either project's documentation practices. For Project Case B, it was intended to produce a BoM at inception, whereas for Project Case A, it was not the case. The high completeness of Project Case B was largely the result of a prior manual extraction from a common database and its structuring into a BoM. In response to the limited empirical evidence on real-world information environments across the literature [18], this study's findings reveal that product documentation maturity can vary based on the project type, depending on whether it is a new-build or a refurbishment project of an existing building.

Both cases had a low score for "information linked between sources," suggesting that regardless of how mature or complete the project documentation is, the cross-alignment between documents is a consistent gap in existing information environments. Studies raise that document linkage lags due to continued reliance on static formats and low digital maturity [18], [143]. This shared limitation reveals the kind of challenge that emerging digital solutions are positioned to address. The growing body of knowledge on the digitalisation of information environments in construction projects indicates that product data capture and storage are expected to improve with the emergence of DPPs and digital common data environments [85], [86]. Looking ahead, an even higher level of data maturity is expected to emerge within circular construction practices, which require more granular and structured data. It is

within this ideal future scenario that construction product data would be centrally managed within a common database, facilitating more efficient data extraction and integration into digital instruments, such as the DPP [12], [96], [114]. In the context of the Renovation Wave, to support large-scale retrofit activity across the existing building stock, there is a need for efficient, building-level mechanisms, such as DBLs, to capture and structure product data at scale [98].

Based on the analysis of the case study project information environments and emerging digital instruments, a product data maturity model is proposed, as shown in Figure 6.1 below, which builds on Figure 3.3, Chapter 3. Its progressive levels of data maturity aim to capture the variety of information environments encountered in as-built projects today and what they are expected to become in the near digitised future. The first level represents contexts where older existing buildings may have no product data at all; the intermediate levels correspond to the real-world information environments identified in the case study projects, and the fourth level illustrates the emerging digital product information practices in the construction sector. In this respect, the proposed model defines Levels I to III grounded in empirical case studies, whereas Level IV represents a prospective state derived from the reviewed literature findings [25], [70], [85], [86], [96]. Each maturity level is linked to the forensic techniques explored and applied in the methodology of this study, outlining which are most suited to derive and extract product data from that specific condition [18], [68]. The case study projects in this research are positioned according to the information environment analysis results in Section 5.1.

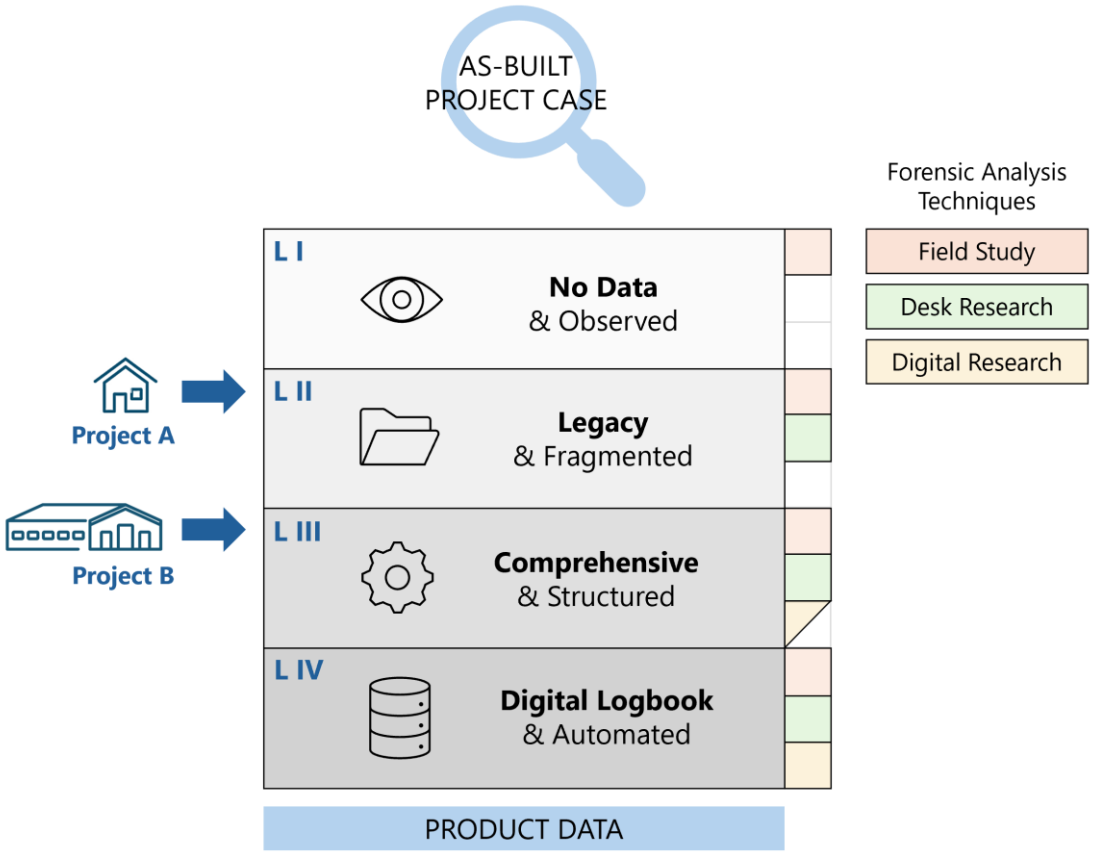


Fig. 6.1 – Data maturity model defining characteristics and forensic techniques of information environments where the case study projects of this study are positioned

- **No data (Level I)**: Undocumented information within a construction project, requiring visual inspection of the physical asset to derive all possible product characteristics.
- **Legacy data (Level II)**: Product information exists across various legacy sources in a fragmented form with information gaps, where legacy documentation review supplemented by field observation addresses data gaps.
- **Comprehensive data (Level III):** Documented and structured product data exists across multiple sources, requiring a systematic document review and metadata extraction from a common database.
- **Digital Logbook data (Level IV)**: Product data is managed, structured and automated within live and digital common data environments, representing the future-state of information ecosystems.

From a post-intervention perspective, new-builds like Project Case B provide a comprehensive information environment better positioned to support future CE interventions. Its structure around the BoM provides the granularity in a building's product and material inventory required for circular construction processes, such as Level(s) circularity assessment and pre-deconstruction audits. In fact, the creation of a BoM aligns with the Level(s) macro-objective 2 indicator activities at Level 3 application, revealing the importance of as-built detailed data structured in this format to support circular forecasts and reporting [31].

Transforming the available BoQ for Project Case A into an approximate BoM with a detailed breakdown of the products and materials used in the refurbishment project enabled the recovery of the granularity, comparable to that in Project Case B. This process surfaced specific gaps in product-level information, namely, lack of detailed material composition, density, and unit weight values. Product data had to be reconstructed from fragmented legacy sources using a combination of forensic techniques under field study, desk research, and digital research, which illustrates what a Level II information environment demands in practice [62], [68], [69]. Critically, these techniques were shown to be complementary, as one helped identify information that the other was missing, thereby filling data gaps that may arise. The suitability of the techniques being used ultimately depends on how complete and available product data is, as well as the digital maturity of the project's information environment.

The on-site field study of Project Case B provided insights as to how sufficient product data in as-built condition can essentially be derived from site observation and photographic records. In cases where documentation is unavailable, these are valuable strategies to fall back on, as it is possible to derive an approximation of dimensions and weight from the physical object and any labels it may have. For Project Case A, where an on-site visit was not conducted, access to photographic records of products as installed and their CE-marks was useful in confirming as-built dimensions that were otherwise inconsistent across product information sources and estimated in design-phase sources. However, detailed material composition and density, also required to calculate product weight, could not be derived from the field study alone; therefore, desk research was necessary. Where gaps persisted even after cross-comparison of documentation sources, an online search for the closest-matching product was used to approximate the missing information. This confirms that piecing together all available sources through forensic analysis plays a significant role in reconstructing fragmented information environments of existing buildings. However, it does so with an inherent margin of error due to discrepancies in product information and approximations made. The forensic reconstruction in Level II environments suggests that circular interventions in the existing building of Project Case A remain a significant challenge, as reliable and available as-built data is often difficult to access and derive.

Constructing the BoM by consolidating all product sources from the fragmented information environment of Project Case A brought to light the substantial amount of resources and effort required. Approximately 41 hours of manual work were required to search for and extract the relevant product data from various sources. The greatest effort was in determining the material composition breakdown

of building elements a part of the envelope, such as windows, curtain walls, and the External Thermal Insulation System (ETICS), to calculate their weight more accurately. Annex A.2 indicates the hours spent per day to build the BoM. This quantifies, in a way not previously reported in the literature, the practical effort of the legacy data reconstruction burden identified more generally as a structural barrier to DPP implementation [18]. Project Case B, by contrast, required minimal additional time, largely because others had already invested manual effort in compiling its BoM before this study. From this outcome, the current effort required to extract product data and structure it into a BoM that supports CE interventions can be regarded as substantial for existing buildings. This reflects current practices more broadly, where construction processes are mostly unautomated and unstandardised, a condition that introduces human error and consumes considerable resources [18]. The effort to bring existing conditions up to Level IV therefore remains a significant undertaking with a degree of inaccuracies, though not unattainable. As widely discussed in the literature, the introduction of structured DPPs can help consolidate product information into a single source and streamline data extraction, thereby reducing the challenges faced [9], [15], [121].

Existing building stock is largely characterised by Level I and Level II information environments, which are paper-based, marked by fragmented legacy data or, in some cases, lack product information altogether [18], [69]. In as-built contexts, with buildings that will remain standing for decades to come, refurbishment projects are largely constrained by pre-existing, often outdated product information. Therefore, field study remains a fundamental technique across all information environments, enabling the derivation of product characteristics and filling gaps left by incomplete legacy records. As shown in Figure 6.1, the forensic approaches derived from the study's methodology can serve as a toolbox for extracting as much product information as possible at each level of data maturity, thereby supporting the creation of DPPs for existing products [68], [106]. For the future scenario represented by Level IV, the full range of forensic techniques share complementary roles in linking the physical object with digital information environments. This contributes to the development of digital twins of existing buildings and can support circular information flows [96], [97]. However, this future state remains theoretically grounded and tested in pilot projects, where its realisation in industry practice at scale is yet to be established.

All these levels of data maturity in as-built construction project information environments, along with associated product extraction techniques, shape the existing context in which emerging digital solutions will be developed and implemented. This confronts the more general position in the literature that DPPs will simply consolidate existing product data into a structured format [90], [121]. Critically, the adoption of DPPs to improve the provision of product data depends on first identifying the maturity level of an as-built building project case, followed by applying the forensic approach suited to that context to collect all available product information and reconstruct what already exists [9], [68]. This underscores that digital readiness is not uniform across the sector, but instead counts on the manual, investigatory effort required to bridge the gap between fragmented as-built reality and structured digital data provision.

6.2. PRODUCT PRIORITISATION FOR DPP PHASED IMPLEMENTATION

6.2.1. WEIGHT SIGNIFICANCE

Based on the weight significance assessment results in Section 5.2.1, the distinct relative weight distribution between the two project cases indicates how outcome-priority products vary by building typology and project type. Envelope and interior finishes accounted for the largest share of weight in Project Case A, whereas concrete structural elements dominated in Project Case B. This reflects the inherent characteristics of both project cases, where residential refurbishment projects typically focus on internal finishes and envelope interventions, as the existing structure is retained and upgraded mainly when damaged or user-driven modifications occur during the use stage. In addition, refurbishment-specific

products and materials vary depending on factors such as regional context, material availability, and inhabitant preferences. New-build industrial projects, on the other hand, tend to adopt a more standardised construction approach and often use concrete products, due to their large scale and the functions they are designed for. Therefore, structural concrete building elements are where weight concentrates most at high values. On this basis, prioritising products according to project type (new-build or refurbishment) and building typology (industrial or residential) could be a relevant approach to take into account their differing weight significance outcomes.

However, when narrowing down to the product weight in absolute terms of kilograms rather than as a relative proportion of each project individually, a different picture emerges. The CPR Product Families contributing the largest weight in kilograms by far are Families 1, 24, and 26, all of which are concrete-based and are highly concentrated in the industrial new-build project (Project Case B). By comparison, the weights of the residential refurbishment project (Project Case A) products used are negligible. This reveals an important distinction in the weight significance approach, where the relative weight distribution within a single project suggests that product prioritisation outcomes are typology-dependent and vary with the nature of the project. However, the findings comparing projects based on absolute weight magnitude reveal that concrete-based products are by far the product with the highest weight significance, due to the magnitude of its use in Project Case B (see Figure 5.8, Chapter 5). Existing literature assessing construction product stocks of case studies, along with EU Commission prioritisation efforts, comes to the same conclusion, though typically based on multiple criteria, such as environmental, safety and economic impact rather than weight-based [17]. Although weight is not commonly used as a direct prioritisation criterion, it already underpins EU CDW share and recovery target calculations, suggesting it holds practical relevance that existing prioritisation methods have yet to draw on if aiming to target high CE impact products [3]. Given its relative ease of estimation compared to the more complex criteria typically used, weight may offer an accessible prioritisation criterion, one that this study's findings suggest is capable of supporting prioritisation decisions for construction products in line with CE objectives of waste reduction and resource efficiency. This has implications for DPP rollout, as prioritising concrete-based products offers the potential for greater sector-wide impact given the scale of their use. Critically, the outcome of windows as high-weight contributors in the refurbishment Project Case A are equally worthwhile to consider prioritising, due to the scale of window replacement of existing building stock expected under the Renovation Wave and their common use across all project types, offering scalable impact across the sector [41].

A notable point of friction emerges when these weight-based findings from the project cases are compared with EU CEAP product prioritisation. The CEAP flags insulation products as a priority waste stream to reduce, despite their less significant weight contribution to CDW compared to concrete-based products. The absence of insulation in the top weight-contributing products from this study’s weight significance assessment reinforces this [15], [87]. This raises an important consideration in the proposed prioritisation approach in this study. With weight significance as a prioritisation criterion, insulation products become excluded, which contradicts their identification as a priority product under the CEAP as well as the high ranking they have in a stakeholder survey reported in the literature review (Figure 4.8, Chapter 4) [15]. Together, these findings suggest that weight-based prioritisation alone does not capture targeted circularity of lower-weight products, pointing to the need for additional criteria that reconcile CE top-down regulatory priorities with bottom-up empirical evidence in order to identify and prioritise products like insulation.

6.2.2. CIRCULARITY POTENTIAL

The circularity potential results in Section 5.2.2, show that concrete-based products, dominant in Project Case B, show considerable applicability across R-strategies. Thus, there is the potential to reduce CO_2 emissions associated with virgin-material extraction and to enhance resource efficiency. However, R-

strategies alone are insufficient to fully divert concrete from landfill in practice, as feasibility depends on specialised labour and machinery for deconstruction, with cost and effort as significant barriers [144], [145]. This points to an important distinction between potential and realised circularity, where a product that demonstrates high technical circularity potential, as identified in this study's assessment, does not guarantee its actual diversion from landfill in practice. Given the significant weight of concrete-based products in the wider building stock, closing this gap between potential and practice requires measures beyond R-strategies assessment alone, such as incentives or restrictions on manufacturing and transportation to drive reuse at scale [146], [147].

A primary finding is that a holistic circularity assessment depends on the granularity at which a product is evaluated. Assessing a product as an entire product risks overlooking circular pathways that can apply to parts of the product or its materials, and vice versa. Survey findings show that circularity potential, as measured by the applicability of R-strategies, differs significantly among products. In the case of windows, "parts of the product" received higher applicability across the R-strategies than "entire product." For example, survey results of aluminimumframe doubld glazed window in Figure 5.10 indicated 70.6% "parts of product" versus 47.1% "entire product" for Refurbish and 64.7% versus 41.2% for Repurpose. In contrast, for the precast concrete wall element, "entire product" received considerably greater applicability, especially for Reuse, Repurpose, and Recycling, each rated at 88.2%, 88.2%, and 77.8%, respectively. This suggests that evaluating the applicable R-strategies of a construction product requires a granular approach, as each can have multiple viable circular pathways.

This granularity lens explains why material composition and ease of disassembly emerge as the most critical factors of circularity potential from the survey findings. Windows, prioritised in Project Case A, provide a clear illustration of this. While a window may be reused as a whole unit, its composition of glass and aluminium frame can follow different circular pathways once carefully disassembled [148]. Both components may be recycled separately, or the aluminium frame reused and the glass recycled, as shown in Figure 6.4 in Section 6.4 below. However, the realised outcome depends mainly on the dismantling process, the condition of each component, and the product data available at the time of intervention. According to findings in this study, current product documentation practice does not consistently reflect this granularity. For example, the aluminium window EPD, identified in the evaluation, defines Reuse only at the level of the entire product, without addressing the reuse potential of individual components, such as the frame and glazing unit [142]. As a result, linking circularity potential assessment outcomes with the provision of product information could facilitate the application in current circularity reporting practice.

On the other hand, the precast concrete wall element, identified in Project Case B, presents a more complex picture. Although its mechanical connections offer greater potential for whole-panel disassembly than conventional in-situ concrete, this is still limited by the mortar joints between panels, that require breakage rather than clean unfastening. Therefore, the findings from the current documentation and observations made by the respondents in the survey reinforce why industry practice sticks to recycling, in which the concrete wall system is crushed to recover metal and aggregates at the material level [123]. Despite this, the reuse potential of precast concrete wall elements as a complete product was highly favoured from this study's circularity potential assessment with an applicability score of 100%. This supports the emphasis placed on reuse as the primary strategy in both policy ambitions and research, where pilot projects are exploring new methods to deconstruct structural concrete for other uses [123]. The overall Reuse strategy was closely followed by Repurpose, scoring a high 94.1% for the precast concrete element and 88.2% for the aluminium window, according to Table 5.2. However, when compared to the established CE R's framework, Repurpose is positioned as a lower-tier lifetime extension strategy relative to Reuse, since the product is applied to a different purpose rather than retaining its original one (see Figure 2.5, Chapter 2) [26]. Considering that this framework was developed with other product sectors in mind, such as electronic products, the Repair strategy presents a higher priority and more feasible extension strategy, whereas Repurpose is less so, since these types of products

are typically restored to their original function rather than reassigned to another one. Construction products, on the other hand, present a different situation, as evidenced by the circularity potential assessment of this study, the literature reviewed, and their presence in the PCDS. Both Reuse and Repurpose yielded preferable and more feasible circular outcomes across multiple construction products, as these strategies can retain a product's embodied value with minimal alterations and reduce the need for energy-intensive processing to break it down into raw materials [123], [147]. These findings on the greater applicability and advantages of Repurpose suggest that the generic CE hierarchy of R-strategies with Repair holding a higher priority than Repurpose warrants reconsideration for construction products.

At the broader level of R-strategies, the waste hierarchy and CDW Management Protocol guidelines confine potential outlets for construction products to Reuse, Recycle, and Recovery, with the full set of R-strategies absent despite high relevance to construction products, as evidenced by this study and environmental sustainability requirements set out in delegated acts [29]. Thus, anticipated regulatory revisions of the WFD are expected to address this gap to better align with CE objectives.

This study proposes a synergy between the waste hierarchy and the CE framework R-strategies, wherein the "Preparing for re-use" level of the waste hierarchy is expanded to incorporate the R-strategies supporting lifetime extension of construction products [3]. Given the findings above, Repurpose can be repositioned directly below Reuse to reflect its practical relevance for construction products, as illustrated in Figure 6.2. While preliminary, this adaptation suggests the necessary shift toward managing and perceiving existing construction products as valuable resources rather than waste, in support of a CE in the construction sector.

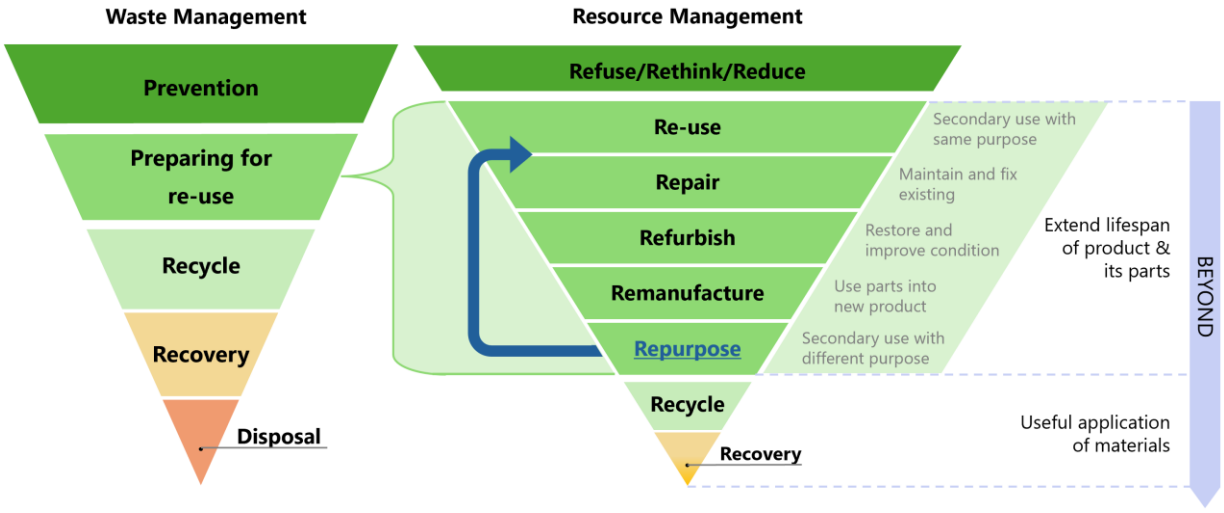


Fig. 6.2 – Shift from waste to resource management for construction products by implementing CE R-strategies and repositioning Repurpose (adapted and expanded from [3], [4])

Overall, these findings demonstrate that circularity potential is a valuable prioritisation criterion, but varies considerably between construction products, depending on material composition, disassembly method, and practical conditions [91], [129]. Beyond this, a product's circularity potential is to be understood in the context of broader factors, such as logistics (transportation and storage), infrastructure, skills, and regulatory approval processes, which were highlighted in survey observations and reviewed literature [20], [123], [135], [149]. Consequently, this study's assessment provides an initial, technically grounded basis for prioritisation. However, translating circularity potential into a holistic prioritisation criterion supporting DPP phased rollout requires clarification of how the practical and contextual factors

raised are to be systematically incorporated alongside technical circularity assessment. From a data requirement perspective, these findings suggest that sufficient granularity and integration of material composition, disassembly, and all R-strategies are essential to deliver circularity for construction products.

6.3. BUILDING THE MINIMUM VIABLE DATASET FOR CIRCULARITY OF CONSTRUCTION PRODUCTS

Among different information sources, namely regulations (CPR, ESPR, and WFD), product standards (EPD, PCDS), BAMB's existing MP, and circular use cases of Level(s) and pre-deconstruction audits, circularity-relevant information was scattered, in explicit or implicit ways, with differing formats and terminology used [3], [7], [8], [33]. Presented with this existing condition, raises a significant finding that the challenge to circularity data implementation is not necessarily the lack of underlying knowledge or information, but the absence of clear consensus and a structure that synthesises circularity data for construction products, which the development of the C_MVDataset aimed to address.

A key challenge in defining the circularity data points within the C_MVDataset based on CPR and ESPR delegated act semantics was that they often stated product requirements as broader descriptive phrases framed around environmental sustainability rather than articulating standalone circularity data points. To address this, discrete data points were interpreted and extracted from the regulatory product requirements by cross-referencing them with literature sources and PCDS that provided circularity data more explicitly. For example, the Ecodesign requirements state "the possibility of remanufacturing", whereas the proposed C_MVDataset operationalises this into the discrete data point of *Remanufacturing* [7]. Across multiple instances, this translation occurred, suggesting that a standardised data dictionary would provide more consistency and support practical integration in the DPP data landscape [143]. Some data points within the Resource Circularity group of properties are confined to regulatory and standards aspiration. This is most evident in the lower frequency with which information sources address the full range of R-strategies. *Reuse, Recycling*, and *Energy recovery* are consistently represented across sources. However, product life extension strategies such as *Repurpose, Repair, Refurbishment*, and *Remanufacturing* are largely absent from practice and inconsistent across the literature. The development of the C_MVDataset exposes this gap between regulatory ambition and practical operationalisation, and at the same time attempts to bridge it through its structured consolidation.

Bringing together the existing regulatory market-placement requirements in the Identification and Performance property group with the consolidated Resource Circularity group responds to the CPR's Recital 34, that acknowledges the underdeveloped second-hand market and the wide variation in requirements for used products across Member States [8]. This gap in current market placement requirements for circularity is reflected at the level of individual data points, as evidenced by the evaluation of product-specific data and the focus group discussion in Section 5.4. Current regulatory semantics are suited for original market placement but have yet to be extended to address a product's subsequent circular application. Therefore, the C_MVDataset can be understood as an early step toward what formalised second-hand DPP requirements might look like, with its proposed structure offering a possible basis for such requirements to develop, grounded in current mandates.

In the context of digitalisation, the developed dataset can be systematised as an LOIN for circularity, specifying what information is required, who needs it when, and at what granularity to support product life-extension scenarios such as Level(s) assessments and pre-deconstruction audits (see Figure 3.5, Chapter 3) [72]. In this sense, the C_MVDataset represents a worked example of such a LOIN, delivering the information structure needed to facilitate circularity of construction products across the project lifecycle stages.

6.4. OPERATIONALISING THE C_MVDATASET

Across construction project deliverables used in the circular use cases, a small subset of data points is required, with several recurring across them, as illustrated in Figure 6.3. This finding suggests that consolidating them into a single C_MVDataset can effectively streamline the product data required for building-level circular assessments and pre-deconstruction audits, thereby better facilitating circular interventions in construction projects [13], [97], [150].

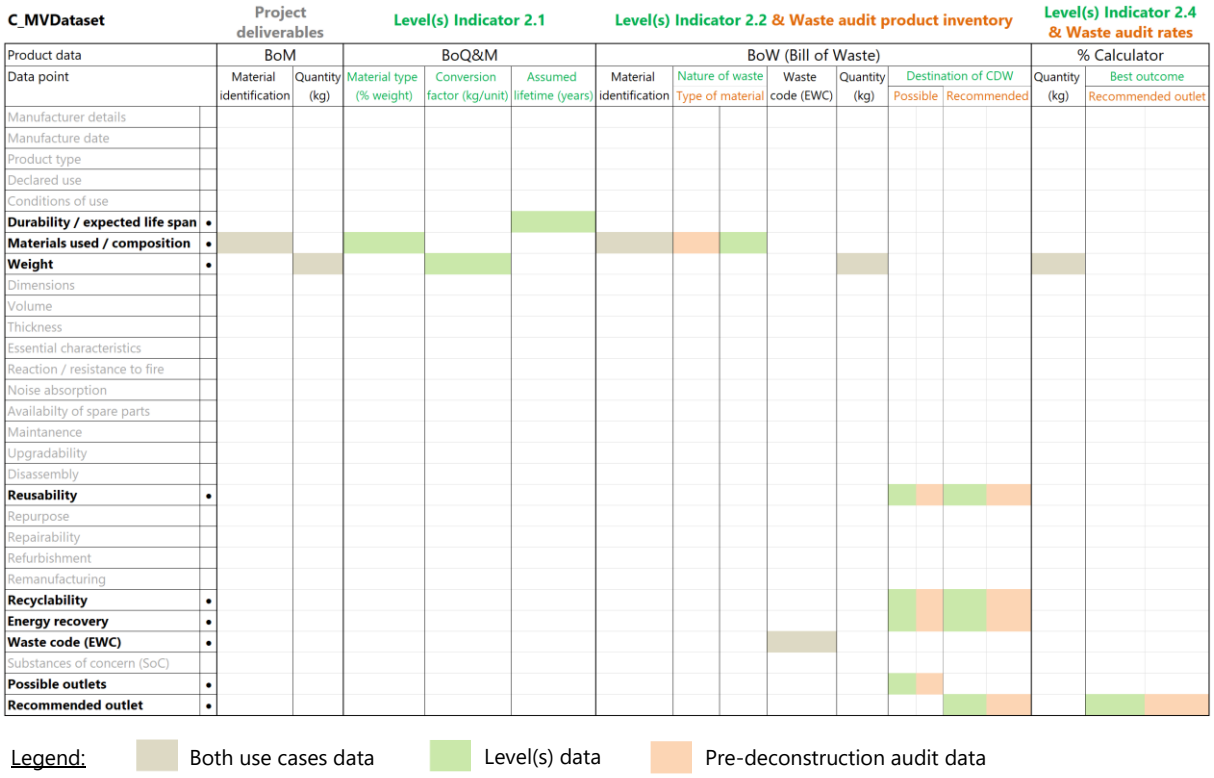


Fig. 6.3 – Mapping of the C_MVDataset to Level(s) and pre-deconstruction audit deliverables requiring product data

As these construction processes gain traction in circular construction projects, it is important to address the product data they require to reduce the data-collection burden and speed up the process for practitioners developing the deliverables. A practical efficiency gain is facilitated that would otherwise be overlooked when these use cases are considered in isolation. This has largely been the case as Level(s) and pre-deconstruction audits have developed independently of one another despite sharing a common origin in the EU's CEAP and CDW policy agenda [4], [22], [29]. Against this backdrop, the data overlap identified across both use cases in this study points to a shared foundation neither has yet drawn on, one that the proposed C_MVDataset provides.

Linking the two also addresses a temporal disconnect between recovery scenarios at deconstruction, which depend heavily on design-stage information maintained throughout the lifecycle [96], [114]. By consolidating circular assessment data with pre-deconstruction audit information into a single dataset, a direct link between them is realised, supporting the circular information feedback loops needed for informed decision-making across a product's lifecycle [13], [97], [151]. Higher accuracy and up-to-date product data are needed for these use cases at the moment of intervention and deconstruction, as specific dimensions and specifications are required to determine a product's suitability for circular pathways and be reintroduced in new project construction deliverables. However, this is often complicated by

changes in units and quantities throughout the product's lifecycle. In this respect and as part of complementary work under this master's dissertation, Kyra van den Muyzenberg and Pedro Mêda explored these variations for construction products across the building project phases and their implications for CE forecasting (Figure 6.4) [148].

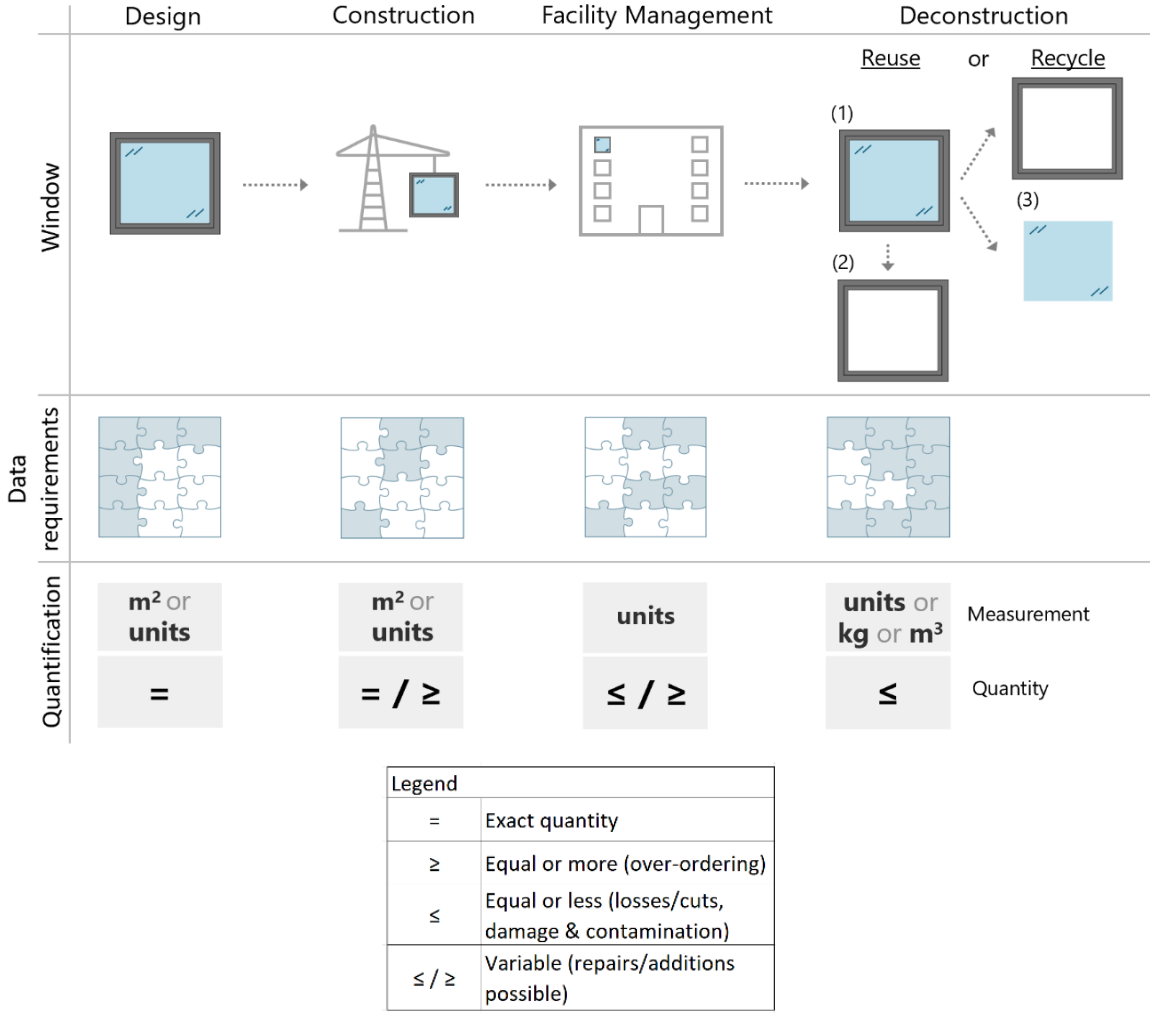


Fig. 6.4 – Data requirements and quantification across lifecycle stages for a window leading to reuse and recycle pathways at deconstruction

The study found that by the time quantities reach deconstruction, they inevitably diverge from those originally estimated at design, due to over-ordering, installation waste, in-use repairs, and losses from damage or contamination throughout the lifecycle. This matters for circularity, since forecasts can risk over- or underestimating the actual recovery potential of construction products. Therefore, it is advocated that implementing DfD for products can reduce such inaccuracies, and linking DPPs to BIM can enable tracking of conditions throughout the lifecycle [12]. This can support the delivery of reliable CE forecasts and speed up the evaluation of pre-deconstruction audits for assigning suitable circular pathways for construction products.

From comparing the developed C_MVDataset with current product documentation of the priority products side by side, it became evident that standardised information relevant to Resource Circularity is largely underrepresented. This reflects a broader pattern in how these two categories are treated in

current practice. Identification and Performance information is consistently required across conventional product documentation, whereas circularity-related requirements tend to be framed as optional or standard-dependent rather than compulsory under the CPR. This finding is consistent with prior research on the availability of data requirements for MPs based on case study project information practices [18], [108]. Despite this, the consistency of *Recyclability* and *Substances of concern* data point in information sources for both products may be explained by existing WFD mandates and hazardous-substance concerns that predate current CE policy [3]. In addition, an adequate number of data points within the Identification and Performance group of properties are readily established to support circular use cases, which may not have been recognised before. These information requirements have been embedded in existing documentation routines, unlike the newer circularity-related requirements. This gap can be attributed to the fact that policy drivers such as the ESPR, CPR and the EU CEAP are increasingly placing circularity at the centre of product regulation [4], [7], [8]. Whereas documentation practices have yet to capture data points currently unavailable in the Resource Circularity property group to promote circular practices of construction products at scale.

In the meantime, as product documentation is expected to catch up and align with CE legislative direction, the results show that an adequate amount of data points can still be derived through on-site inspection. This positions pre-deconstruction auditing and related potential outlet analysis as key on-site assessment activities that can narrow this documentation gap. This is especially relevant in the case of an existing building, where documented data on the products used may be entirely unavailable due to previous practice approaches. Characteristics of the physical object can be derived through these activities, for instance, volume can be derived from dimensions, and weight can be approximated from surface area and known material density. Capturing this data into a digital passport instrument would support the digitalisation and streamlining of what is currently a manual, one-time assessment under the CDW Management Protocol guidelines [29], [120], [152]. This would support more reliable potential outlet analysis and circularity decision-making for the product's future lifecycles [13]. However, realising this at scale depends on the future development of standardised DTs for DPPs, a direction already suggested in the literature but not yet fully realised [81], [97]. Such templates would be capable of operationalising the dataset developed in this study into a machine-readable format for DPPs that can be updated and reused across projects.

6.5. CONVERGENCE OF THE MP AND DPP

Throughout this study, "product" and "material" have been in constant dialogue, which warrants clarification. The findings show that, depending on the context, a material can be assumed as a product, and a product can have a wide range from materials to a complete system, as evidenced by CPR's product family classification [8]. Whether a construction element is classified as a material or a product varies depending on the regulatory context, given that the WFD treats elements mainly as materials for recycling and recovery [3], while the CPR classifies them as products to be placed on the EU market. Aggregates, for instance, are labelled as "products" to exist within the DPP ecosystem, despite intuitively reading as a raw material [8]. This uncertainty is compounded by the CE R's framework, where R-strategies apply to an entire product, parts of the product, or its materials. Therefore, there remains a broader lack of stabilisation identified in the literature regarding the relationship between MPs and DPPs, as they share a common purpose in capturing data to enable circularity of construction elements, but are characterised by different levels of granularity and regulatory standing [15], [88], [108].

The literature frames the MP's role, in this respect, as one of "characterisation" that establishes a product's characteristics to enable circular outcomes for existing products that predate DPP requirements [34], [153]. For existing buildings, such as Project Case A, the complementary use of MPs and DPPs becomes paramount. Throughout the lifecycle of a building, renovation or deconstruction triggers a moment when the circular assessment and pre-deconstruction audit processes are performed

on existing products. This is precisely where the forensic analysis and techniques used in this study can become relevant, facilitating the collection and extraction of all available legacy data from which an MP can be built [95]. With this characterisation established, the formal preparation for the product's entry into the second-hand market can realistically take place, a role fulfilled by transforming the MP into a DPP, which provides the regulatory compliance required for market entry. In new-build projects, such as Project Case B, a DPP is associated with the product from its entry into the market and building project, to be updated throughout the product's lifecycle [154]. Once an intervention or deconstruction occurs, a new version of the DPP supports the product's future use, extending its life in the same or a different form to promote the CE [9], [87], [155]. As a result, the practical relationship between MPs and DPPs depends on whether a product originates in a new-build or an existing-building context, as illustrated in Fig. 6.5.

This positions MPs as a foundational source that can supply the granular data from which a regulatory-compliant DPP can be developed when a used product is to be placed on a second market. Regardless of whether a product's circular journey began at installation or was reconstructed later, at the point of intervention, it is the DPP's compliance and data-carrying capabilities that enable the product's continuous reintroduction across multiple lifecycles, closing the loop between building projects and promoting a CE. As a result, in response to the lack of stabilisation identified in the literature between the role of MPs and DPPs, the study findings suggest that both are understood as complementary instruments, enabling the circularity of existing and new construction products in the built environment [81], [84].

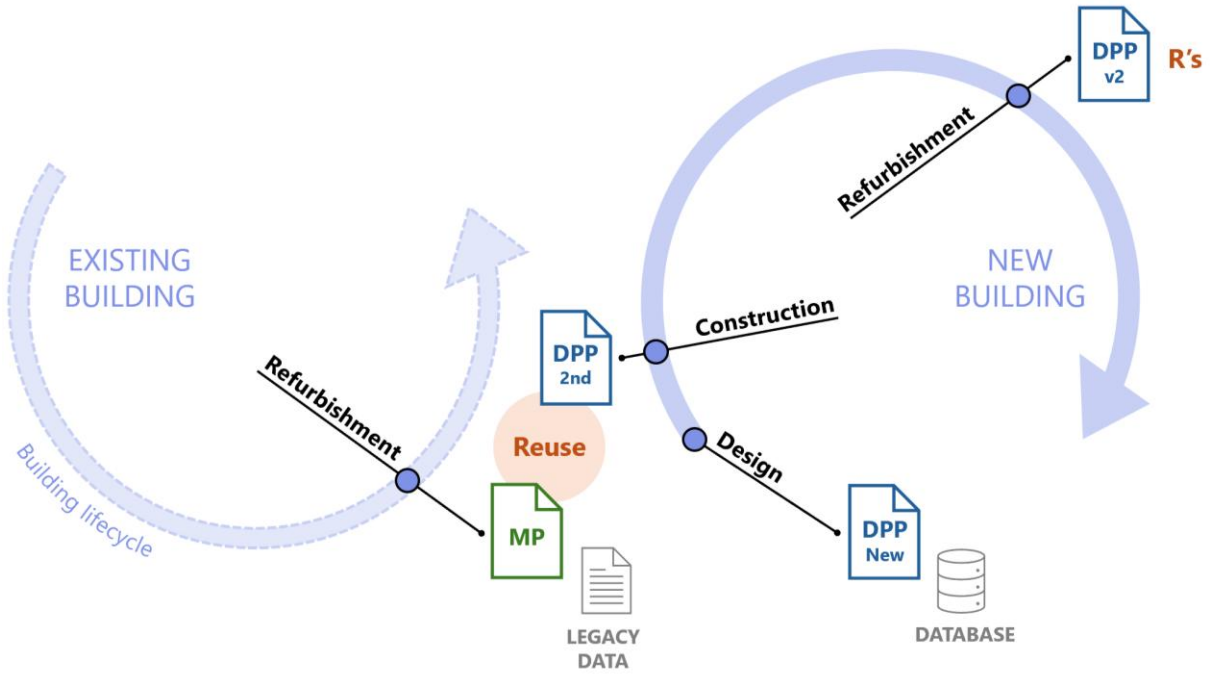


Fig. 6.5 – Conversion of MP into DPP at a moment of intervention in existing building lifecycle compared to DPP introduction and versioning in new building construction project

The literature proposes an underlying structure for passports, based on ISO 23387 DT creation, that can facilitate a more standardised, streamlined MP-to-DPP transformation process and support circular information flows in the context of existing building projects [74], [81], [97]. As identified across literature and findings, such alignment in structure can help reduce the manual reconstruction and interpretation of data for circularity estimation and evaluation [15], [18]. In addressing this, the C_MVDataset developed

in this study offers a structural bridge and conversion from MPs extensive list of circularity information into a compliant DPP-ready data structure, to support the second-hand product market entry, an area the CPR itself identifies as requiring further definition

6.6. CRITICAL REFLECTION AND LIMITATIONS

6.6.1. DATA ACCURACY AND RELIABILITY

- **Weight data accuracy and approximation:** The weight values used in the significance assessment were derived in different ways with a degree of approximation across the two project cases. For Project Case B, weight values were derived from design deliverables, with product information extracted from a common database. During the development of the BoM for Project Case A, weight values were calculated by estimating dimensions and quantities from design drawings, the BoQ, and product specs and material densities were identified from external references. As both rely on design-stage estimates rather than on-site as-built measurements, the weight-based prioritisation should be read as a directional indicator of which products matter most, not an exact quantification. The extent to which such an indication is sufficient for making prioritisation decisions in practice requires further evaluation. Another source of approximation came from excluding certain auxiliary materials from the weight calculations, such as the cement used for ceramic tiles in the refurbishment of Project Case A. This may have led to an underestimation of the products' true weight significance, compared to other products where all constituent materials were included in the calculation.

- **Manual data extraction:** The forensic investigation of product data in Level II environments inherently involved a degree of approximation that depended on the completeness of the product documentation. Much of the data extraction and handling in this study was done manually, that naturally carries some risk of inaccuracy and required several rounds of refinement to reconcile values. The reconstruction of the BoM for Project Case A took approximately 41 hours, which indicates the substantial manual effort currently required to derive product data when a structured BoM is not available (reference Annex A.2). This raises questions about the scalability of this approach when applied across larger scale projects and suggests the potential value of more automated methods.

- **Representativeness of case study information environments and product prioritisation:** The product prioritisation based on weight significance outcomes is specific to the two case studies examined, where products can vary significantly across national contexts, building typologies, and intervention types. As prioritising products on this weight-based approach is itself an initial attempt, the extent to which these findings can be generalised for phased DPP implementation remains to be established. Given the limited existing research on the construction project information environment, these two project cases represent only one example, and differences in product data availability, documentation practices, and levels of detail across other project contexts should be accounted for.

- **Scope of circularity potential:** The circularity potential assessment focused on the general and technical suitability of products for R-strategies, without integrating broader operational factors, which arose as a limitation noted by survey feedback. Incorporating factors such as logistics, economic viability, and regulatory conditions may yield construction product prioritisation outcomes that differ from those based solely on applicability potential.

- **Subjectivity and sample size in circularity potential assessment:** The stakeholder-based circularity potential assessment is inherently subjective, as the applicability of R-strategies for construction products can vary depending on the respondent's experience, disciplinary background, and assumptions made. In addition, the outcomes represent an assessed potential based on subjective judgement rather than actual measurement of realised circularity outcomes, that have yet to be empirically evidenced in practice. Although the survey sample of 18 respondents spanned professional backgrounds from research and academia to the construction industry, the relatively small sample size may not fully capture the diversity of perspectives across the sector. For example, certain roles like contractors and policymakers could enrich insights. This limitation, combined with the subjectivity of the assessment, further limits the generalisability of the findings, calling for a larger and more diverse sample of respondents.

6.6.2. STANDARDISATION AND MEASURABILITY CHALLENGES

- **Interpretation of information requirements:** The process of interpreting data requirements from regulatory text into discrete data points introduces a degree of subjectivity and inconsistency. An example of this is the Ecodesign requirement for "the possibility of maintenance and refurbishment," translated into the singular data points *Maintenance* and *Refurbishment* due to their different purpose. Another challenge arose in defining *Disassembly* data point, as across the sources analysed, the terms disassembly, demounting, dismantling, and deconstruction are often used interchangeably, although they refer to different processes of component recovery and removal. Therefore, a clearer specification of the exact data points expected in a DPP to enable circular construction is necessary for practical implementation and standardisation of semantics.

- **Data point interdependence:** Some data points are less independent than they appear to be, such as *Volume* can often be derived from *Dimensions* and *Reusability* and *Repurposing* conceptually overlap. This raises the question of how concise the C_MVDataset can be and suggests that future refinement could link these interdependencies to reduce the need to measure each property separately.

- **Evolving policy, research, and industry context:** Ongoing revisions to delegated acts and evolving ESPR and CPR requirements suggest that the proposed C_MVDataset may require refinement as regulatory consensus and industry practice on CE and product information requirements mature.

Having discussed these implications and the limitations of this research, the final chapter draws together the key findings and contributions of this study, along with recommendations for future work.

7
CONCLUSION

The construction sector is experiencing a twin transition driven by data-centred digitalisation and a shift to a CE. At the intersection is the emerging DPP for construction products, a digital instrument established to support resource efficiency, waste prevention, and facilitate the evaluation of product lifecycle extension strategies [8], [92]. Although progress is being made in early stages of adoption, gaps remain between regulatory ambitions, research developments, and practical application, with each advancing at their own pace on parallel tracks, as evidenced in the literature review (Chapter 4). Given this context, the study set out to converge these dimensions and their unstructured circularity data requirements to support DPP implementation towards delivering circularity for construction products. This was addressed through four interlinked phases methodology (Chapter 3): analysing the information environment of existing construction projects (Phase 1); developing a prioritisation method to determine which products within these projects matter most for the CE (Phase 2); consolidating product requirements from multiple sources into a structured C_MVDataset (Phase 3); and evaluating this dataset against existing product documentation for the resulting priority products (Phase 4). Altogether, these four phases brought to the surface the following key contributions.

7.1. CONTRIBUTIONS

Survey Design As-built Construction Project Information Environments

Considering the large share of existing building stock with product documentation designed for traditional, linear workflows, the findings indicate that developing a BoM for an as-built project is fundamentally a retrospective reconstruction and requires all available sources. Whether product data is collected on-site, extracted from documentation, or recovered through other forensic techniques applied in this study, this process facilitates the extraction and approximation of the product and material detail that CE forecasting and decision-making require. As the majority of the existing building stock is expected to undergo refurbishment under the Renovation Wave, this structural condition is likely to reccur across as-built interventions more broadly, underscoring the practical relevance of this reconstruction process for DPP implementation [41]. This study's analysis of two distinct information environments, one from a new-build project and the other a refurbishment, provided the contextual basis for understanding the challenges and opportunities of implementing DPPs under differing project data conditions where the extent that product data can be identified, extracted and structured can vary significantly.

Product Prioritisation for Phased DPP Implementation

The prioritisation method, based on weight significance and circularity potential, showed that the priority product outcome depends on the combination of both criteria and project typology. For Project Case B (new-build), the precast concrete wall element dominated both criteria, which positions it as the highest priority for phased DPP implementation, given the circular impact it can have at scale. In Project Case A (refurbishment), the aluminium frame window was identified as a priority due to its high circularity potential, despite not carrying the highest weight within that project. Weight significance, although not often used as a prioritisation criterion in the literature, provides a practical, quantitative basis for identifying priority products, given its relevance to revision of legislative recovery targets and its ease of estimation from available product data. Combined with circularity potential criteria, this positions both products as priority targets for phased DPP rollout in the construction sector, directing attention to construction products that are not only significant waste generators, but also capable of following multiple circular pathways, supporting transition pathways actions and CE objectives.

Consolidated Circularity Data Requirements

Data requirements that already exist across regulatory, standard, and practice-based sources were integrated into a concise, structured dataset for a construction product, fulfilling two functions of compliance with market-placement requirements through Identification and Performance data points, and consolidating CE requirements in a newly defined Resource Circularity property group. Across construction project deliverables and circular use cases, a recurring subset of data points was identified, suggesting that a single C_MVDataset can deliver the LOIN required to streamline data for building-level circular assessments and pre-deconstruction audits. By facilitating the digitalisation of these use cases through a DPP, products can be more easily evaluated and prepared for reintroduction into a second-hand market, reducing the data-collection burden for stakeholders involved.

Existing Product Documentation and Practical Feasibility

The evaluation of existing product documentation, compared with the consolidated circularity data requirements, found that current information supports Identification and Performance data, whereas Resource Circularity data is largely absent. This gap reflects a deficiency of structured provision rather than a missing underlying data, as much of this information is already known, defined in regulation, or derivable, but is not currently recorded in a standardised format to support its consistent capture in practice. Guided by the dataset developed in this study, DPP implementation offers a starting point for establishing Resource Circularity data as a standard part of construction product documentation. This has the potential to close the existing information gap between regulatory CE ambitions and current documentation practices, which are yet to develop in a coordinated way.

Further Contributions

As an additional contribution, this study extends the existing decision flowchart provided in CDW management guidelines, currently confined to reuse, recycling, and recovery, with the full set of product lifetime extension strategies, addressing this incompleteness (see Annex A.6) [29]. The resulting tool can help practitioners performing pre-deconstruction audits and circularity assessments to make more informed decisions and determine appropriate circular pathways at the product, component, and material level, to maximise the opportunities available for a given product.

In response to the literature's suggestion of DTs as a direction for structuring DPP data, this study's phases were structured around the ISO 23387 (data templates) methodology, anchored in three

preparatory activity layers: Object (Product Prioritisation), Information (Circularity Data Requirements), and Source (Existing Product Documentation), as illustrated in Fig. 7.1 below. All three layers draw on the contextual analysis of the case study project information environments, grounding each in the practical realities of as-built construction projects. Together, they provide the ingredients of the C_MVDataset developed in this research, marking the furthest point to which data dictionary activities could be conducted, given the current low maturity of a common CE data dictionary. This boundary reflects where the field currently stands. As CE data dictionary maturity develops, future research can build on this study's foundation to complete ISO 23387's "Create Data Template" activity, translating the C_MVDataset into an industry-ready, machine-readable format capable of supporting DPP implementation at scale across the construction sector [8], [49].

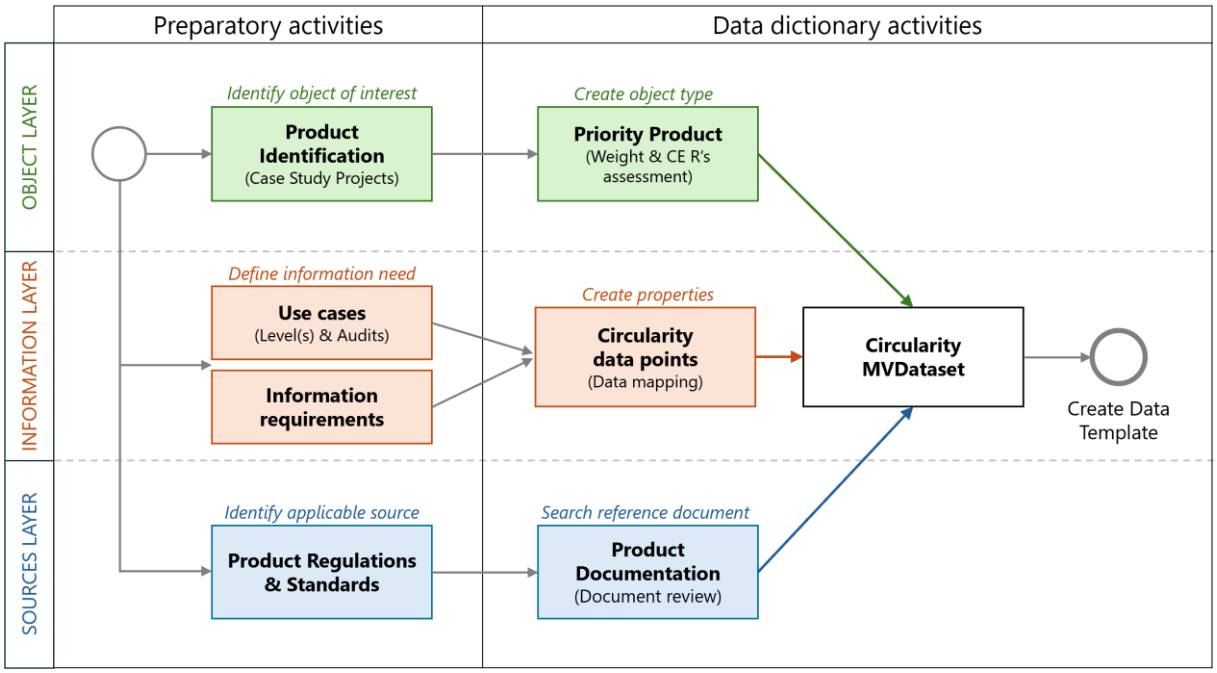


Fig. 7.1 – High-level methodology process in creating the C_MVDataset (adapted from ISO 23387 Figure B.1 [49])

7.2. RECOMMENDATIONS FOR FUTURE RESEARCH

Several directions for future research follow from this study, in which gaps were bridged, and others were revealed.

- Broader empirical studies across a wider range of projects would clarify patterns in existing information environments and maturity levels across construction contexts and further assess the potential of the forensic analysis applied in this study to support the reconstruction of as-built information environments more broadly, facilitating circular interventions in practice.
- Extending this study's circularity potential assessment framework to incorporate broader CE-related criteria, such as related logistics and economic impact, could take into consideration products whose circular impact is not fully captured by weight significance and R-strategy applicability alone. Applying this method across a wider range of project contexts would clarify whether other high-impact products emerge for DPP prioritisation.
- Given the high weight and circularity potential identified for concrete-based products, there may also be value in exploring how reuse of these elements and their components can be technically improved through DfD to address current limitations around material composition

and ease of disassembly [123]. This in turn could help inform the circularity requirements necessary to be captured in product documentation and standards.

- Data point semantics have yet to be specified in Ecodesign regulations and in the ISO 59004 vocabulary properties for the CE, which a shared data dictionary could help resolve [27]. Emerging standardisation efforts towards semantic interoperability within the DPP system point in this direction [17], [67].
- The interchangeable use of the terms "material," "product," "component," and "system" across existing frameworks and passport instruments call for clarification, in order to establish the level of granularity necessary for circularity of construction elements.
- The practical transition from MPs to DPPs warrants further investigation, particularly how both instruments will interact and can be structured through DTs to support circular information flows.
- In anticipation of translating the proposed C_MVDataset into implementable product DTs, a clear methodology and product-specific data guidelines are necessary to facilitate this and address how data will populate, be measured, and interpreted across the value chain.

The research suggests that delivering circularity for construction products can be realised by structuring data that already exists, rather than reinventing the wheel. This structure is what can give a product its circular identity, where data is consolidated into a single record that a product carries beyond, from one building's deconstruction to another's construction. Thereby, the shift from waste to being a resource throughout multiple lifecycles can be realised. The proposed C_MVDataset offers this structure by integrating circularity requirements and product regulatory compliance, with the potential to support the second-hand use of products across construction projects in the built environment [8].

This positions the DPP as a central enabler of circularity, a role reinforced by complementary instruments. MP, as a transitional instrument that bridges legacy as-built information into a structured market-ready DPP, offers a practical pathway through which regulatory ambition can be operationalised in existing building contexts to support the development of a second-hand market for construction products. Foreseen integration with building-level DBLs and BIM can further facilitate the automated exchange and long-term management of product data across a building's lifecycle [24]. Altogether, these instruments help close the gap between the digital and green transitions, turning largely fragmented, manual data environments of existing buildings into ones where structured, accessible, and reusable product data can circulate across projects from before to beyond, as demonstrated in Figure 7.2.

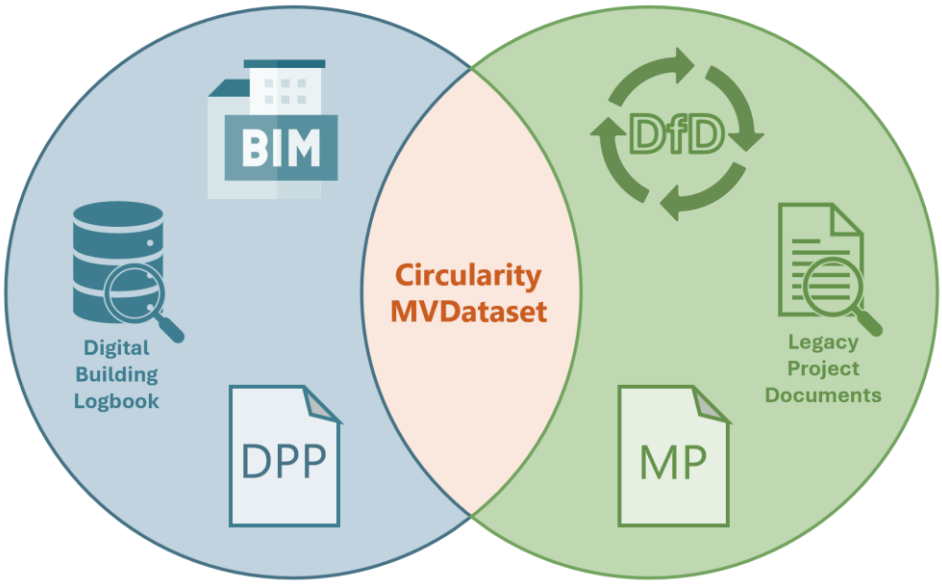


Fig. 7.2 – The C_MVDataset enabling the twin transition in the construction sector

To conclude, as DPPs continue to emerge in the construction sector, closer and continuous alignment among policy, research, and industry practice will be essential to realising its potential at scale for a CE in the construction sector. In navigating the twin transition, this study mapped a path from fragmented, as-built information toward structured data enabling measurable circularity for construction products.

8
REFERENCES

[1] I. Papadaki, P. Moseley, P. Staelens, R. Horvath, O. Gutierrez Velayos, and H. Vaananen, "Transition pathway for Construction," Mar. 2023.

[2] M. Herczeg, D. McKinnon, I. Bakas, E. Klaassens, K. Svatikova, and O. Widerberg, "Resource efficiency in the building sector Final report Client: DG Environment," Rotterdam, May 2014. [Online]. Available: www.ecorys.nl

[3] Office of the European Union, "Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives," Oct. 16, 2025, *European Comission, Luxembourg*.

[4] "A new Circular Economy Action Plan For a cleaner and more competitive Europe," Mar. 11, 2020, *European Commission, Brussels*.

[5] M. Wahlström, J. Bergmans, T. Teittinen, J. Bacher, A. Smeets, and A. Paduart, "Construction and Demolition Waste: challenges and opportunities in a circular economy," Jan. 2020. [Online]. Available: http://europa.eu

[6] I. Atta, E. S. Bakhoum, and M. M. Marzouk, "Digitizing material passport for sustainable construction projects using BIM," *Journal of Building Engineering*, vol. 43, Nov. 2021, doi: 10.1016/j.jobe.2021.103233.

[7] Office of the European Union, "Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC," Luxembourg, 2024. [Online]. Available: http://data.europa.eu/eli/reg/2024/1781/oj

[8] P. Office of the European Union L- and L. Luxembourg, "Regulation (EU) 2024/3110 of the European Parliament and of the Council of 27 November 2024 laying down harmonised rules for the marketing of construction products and repealing Regulation (EU) No 305/2011." [Online]. Available: http://data.europa.eu/eli/reg/2024/3110/oj

[9] W. Ruismäki, "Digital product passports for construction products," Sep. 2023. Accessed: Mar. 15, 2026. [Online]. Available: https://aaltodoc.aalto.fi/items/25e233f6-ab5d-4302-989d-a1f08c9cac4a/full

[10] S. F. Jensen, J. H. Kristensen, S. Adamsen, A. Christensen, and B. V. Waehrens, "Digital product passports for a circular economy: Data needs for product life cycle decision-making," *Sustain. Prod. Consum.*, vol. 37, pp. 242–255, May 2023, doi: 10.1016/j.spc.2023.02.021.

[11] P. Mêda, D. Calvetti, E. Hjelseth, and H. Sousa, "Digital Product Passports in Construction–Barriers and Opportunities at People, Process and Technology Dimensions," in *EC3 Conference 2024*, European Council on Computing in Construction, 2024, p. 0.

[12] S. Hamidkhaniha, A. G. Martínez, and M. Sedaghat, "Integrating Digital Product Passports and BIM for Circular Construction: A Review of Challenges and Opportunities for Data-Driven Material Reuse and Sustainability Assessment," in *IOP Conference Series: Earth and Environmental Science*, 2025. doi: 10.1088/1755-1315/1568/1/012026.

[13] P. Mêda, D. Calvetti, R. Quiñones, and H. Sousa, "Streamlining Level(s) circularity and cost indicators estimation using Digital Product Passports," in *Proceedings of the 41st International Conference of CIB W78*, Marrakesh, Oct. 2024, pp. 1–10. Accessed: Apr. 24, 2026. [Online]. Available: https://eres.scix.net/pdfs/w78-2024-paper_137.pdf

[14] P. Mêda, E. Hjelseth, D. Calvetti, and H. Sousa, "Exploring the significance and priority of digital product passports implementation in building renovation projects targeting circular economy," *Scopus*, 2024.

[15] W. Ruismäki, M. zu Castell-Rüdenhausen, E. Pohjalainen, and M. Wahlström, "Stakeholder perspectives on digital product passports for construction products," *Cleaner Logistics and Supply Chain*, vol. 17, 2025, doi: 10.1016/j.clscn.2025.100275.

[16] M. Riuttala, L. Harala, L. Aarikka-Stenroos, and S. Huuhka, "How building component reuse creates economic value – Identifying value capture determinants from a case study," *J. Clean. Prod.*, vol. 443, Mar. 2024, doi: 10.1016/j.jclepro.2024.141112.

[17] "(First) CPR Working Plan for 2026-2029," Brussels, 2025. Accessed: Apr. 14, 2026. [Online]. Available: https://webgate.ec.europa.eu/circabc-ewpp/d/d/workspace/SpacesStore/1e989b50-3020-406b-9add-f847fc26de49/download

[18] Y. Sun, R. Rameezdeen, C. W. K. Chow, and J. Gao, "Information Sharing Barriers of Construction Projects Toward Circular Economy: Review and Framework Development," *Buildings*, vol. 15, no. 15, Aug. 2025, doi: 10.3390/buildings15152744.

[19] R. van den Brink *et al.*, "New Needs in Construction for Circular Transitions," Oct. 2024. Accessed: Mar. 10, 2026. [Online]. Available: https://cris.vtt.fi/en/publications/new-needs-in-construction-for-circular-transitions-task-report/

[20] P. A. Rao, M. M. Rahman, and S. B. Duraman, "Adopting circular economy in construction: a review," 2025, *Frontiers Media SA*. doi: 10.3389/fbuil.2025.1519219.

[21] M. Jansen, T. Meisen, C. Plociennik, H. Berg, A. Pomp, and W. Windholz, "Stop Guessing in the Dark: Identified Requirements for Digital Product Passport Systems," *Systems*, vol. 11, no. 3, Mar. 2023, doi: 10.3390/systems11030123.

[22] EU Commision, "Level(s) common framework," Joint Research Centre. Accessed: Feb. 26, 2026. [Online]. Available: https://susproc.jrc.ec.europa.eu/product-bureau/product-groups/412/documents

[23] United Nations Development Programme, "Sustainable Development Goals." Accessed: Mar. 12, 2026. [Online]. Available: https://www.undp.org/sustainable-development-goals

[24] D. Oteng, R. Asante, H. Omrany, and B. T. B. Eshun, "Achieving the UN Sustainability Goals: The Role of Digital Product Passports in the Architecture, Engineering and Construction Industry," *CIB Conferences*, vol. 1, no. 1, Jun. 2025, doi: 10.7771/3067-4883.1916.

[25] C. De Wolf, S. Çetin, and N. Bocken, *Circular Economy and Sustainability A Circular Built Environment in the Digital Age*. Springer, 2024. doi: https://doi.org/10.1007/978-3-031-39675-5.

[26] "Ellen MacArthur Foundation," The Ellen MacArthur Foundation. Accessed: Apr. 18, 2026. [Online]. Available: https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview#:~:text=The%20circular%20economy,of%20finite%20resources

[27] Iso, *Circular economy-Vocabulary, principles and guidance for implementation International Standard ISO 59004*. 2024.

[28] EU Commission, "Environmental statistics and accounts; sustainable development Reporting on material recovery of C&D waste," eurostat. Accessed: Mar. 10, 2026. [Online]. Available: https://ec.europa.eu/eurostat/web/main/data/database

[29] M. Camboni, F. Chiabrando, M. Hayleck, and R. Akelytė, "EU Construction & Demolition Waste Management Protocol including guidelines for pre-demolition and pre-renovation audits of construction works," Luxembourg, Sep. 2024. doi: doi:10.2873/77980.

[30] European Comission, "Construction and Demolition Waste." Accessed: Apr. 14, 2026. [Online]. Available: https://environment.ec.europa.eu/topics/waste-and-recycling/construction-and-demolition-waste_en

[31] "Level(s): Putting circularity into practice," 2021. Accessed: Mar. 11, 2026. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/ea438090-cf14-11eb-ac72-01aa75ed71a1

[32] "RIBA Plan of Work 2020 Overview," 2020. Accessed: Feb. 22, 2026. [Online]. Available: www.ribaplanofwork.com

[33] BAMB, "Buildings as Material Banks: Integrating Materials Passports with Reversible Building Design to Optimise Circular Industrial Value Chains," Horizon 2020 - European Commission. Accessed: Mar. 12, 2026. [Online]. Available: https://cordis.europa.eu/project/id/642384

[34] A. Rute Costa, "A Roadmap to Accelerate Material Reuse in Construction and Use Materials Passports," Lancaster. Accessed: Feb. 15, 2026. [Online]. Available: https://www.scmt-conferences.com/proceedings

[35] "Guidelines for the waste audits before demolition and renovation works of buildings EU Construction and Demolition Waste Management," 2018. [Online]. Available: http://ec.europa.eu/environment/circular-economy/index_en.htm

[36] J. Kirchherr, D. Reike, and M. Hekkert, "Conceptualizing the circular economy: An analysis of 114 definitions," 2017, *Elsevier B.V.* doi: 10.1016/j.resconrec.2017.09.005.

[37] "Circular Economy Principles for Buildings Design." Accessed: Feb. 02, 2026. [Online]. Available: https://environment.ec.europa.eu/strategy/circular-economy_en

[38] R. T. Lima, P. Couto, and T. F. Bastos, "Buildings Sustainability Certifications and the Common European Framework Level(s)," in *Lecture Notes in Civil Engineering*, Springer Science and Business Media Deutschland GmbH, 2024, pp. 496–507. doi: 10.1007/978-3-031-48461-2_43.

[39] *The European Green Deal*. Belgium, 2019. Accessed: Apr. 03, 2026. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640

[40] EU Commission, "The Green Deal." Accessed: Mar. 12, 2026. [Online]. Available: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[41] Office of the European Union, "Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency," Luzembourg, 2018.

[42] O. Nieto, "Smart CE marking," Brussels, Dec. 2017. Accessed: Feb. 08, 2026. [Online]. Available: https://www.construction-products.eu/application/files/3215/2475/6977/20171211154333-05_presentation_of_the_draf_cen_workshop_agreement_document.pdf

[43] "European Commission CE Marking of Construction Products Step By Step." Accessed: Mar. 15, 2026. [Online]. Available: https://thehea.org.uk/hea-content/uploads/2019/10/European-Comission-CE-Marking-Step-by-Step.pdf

[44] *ISO 14025:2006 Environmental labels and declarations — Type III environmental declarations — Principles and procedures*. Switzerland, 2006.

[45] Iso, *Sustainability in buildings and civil engineering works-Data templates for the use of EPDs for construction products in BIM ISO/CEN*. 2021.

[46] *ISO 59040:2025 Circular economy — Product circularity data sheet*. 2025.

[47] "The Product Circularity Data Sheet," TerraMatters. Accessed: Mar. 12, 2026. [Online]. Available: https://terramatters.net/en/pcds_21

[48] Iso, *Building information modelling (BIM)-Data templates for objects used in the life cycle of assets ISO/CEN Parallel Processing ii ISO/FDIS 23387:2025(en)*. 2025.

[49] C. Henrotay, "BAMB Building As Material Banks," BAMB. Accessed: Jan. 27, 2026. [Online]. Available: https://www.bamb2020.eu/topics/circular-built-environement/

[50] P. M. J. Delport, R. Von Solms, and M. Gerber, "Methodological Guidelines for Design Science Research," in *Procedia Computer Science*, Elsevier B.V., 2024, pp. 195–203. doi: 10.1016/j.procs.2024.05.096.

[51] W. Kuechler and V. Vaishnavi, "A framework for theory development in design science research: Multiple perspectives," *J. Assoc. Inf. Syst.*, vol. 13, no. 6, pp. 395–423, 2012, doi: 10.17705/1jais.00300.

[52] M. Saunders, P. Lewis, and A. Thornhill, *Research Methods for Business Students*, 4th Edition. Harlow: Pearson Education Limited, 2023. Accessed: Jun. 15, 2026. [Online]. Available: https://www.researchgate.net/publication/240218229_Research_Methods_for_Business_Students#fullTextFileContent

[53] J. Creswell and V. Plano Clark, *Designing and Conducting Mixed Methods Research*, Third Edition. Sage Publications, 2017.

[54] S. McLeod, "Mixed Methods Research," Simply Psychology. Accessed: Jun. 15, 2026. [Online]. Available: https://www.simplypsychology.org/mixed-methods-research.html

[55] P. Verhoeven, *Doing Research: the Hows and Whys of Applied Research*, 3rd ed. Eleven International Publishing, 2011.

[56] C. Robson and K. McCarten, *Real World Research*, 4th Edition. Chichester, 2016.

[57] R. Yin, *Case Study Research and Applications: Design and Methods*. SAGE Publications, 2017.

[58] H. Österle *et al.*, "Memorandum on design-oriented information systems research," 2011, *Palgrave Macmillan Ltd.* doi: 10.1057/ejis.2010.55.

[59] J. Herrington, S. Mckenney, T. C. Reeves, and R. Oliver, "Design-based research and doctoral students: Guidelines for preparing a dissertation proposal." Accessed: Jun. 20, 2026. [Online]. Available: https://researchportal.murdoch.edu.au/esploro/outputs/conferencePaper/Design-based-research-and-doctoral-students-Guidelines/991005539978007891/filesAndLinks?index=0

[60] "PRISMA-Scoping Reviews," PRISMA Executive. Accessed: Mar. 20, 2026. [Online]. Available: https://www.prisma-statement.org/scoping

[61] "Web of Science," Clarivate. Accessed: Jan. 26, 2026. [Online]. Available: https://mjl.clarivate.com/home

[62] "Scopus," Elsevier B.V. Accessed: Jan. 26, 2026. [Online]. Available: https://www.scopus.com/pages/home

[63] "International Standards," International Organisation Standards. Accessed: Jan. 26, 2026. [Online]. Available: https://www.iso.org/standards.html

[64] "CORDIS," Publications Office of the European Union. Accessed: Jan. 26, 2026. [Online]. Available: https://cordis.europa.eu/

[65] "EUR-Lex," Publications Office of the European Union. Accessed: Jan. 26, 2026. [Online]. Available: https://eur-lex.europa.eu/homepage.html

[66] T. Chirvasuta *et al.*, "Methodology for defining data requirements for the Digital Product Passport under the ESPR framework," Luxembourg, 2026. doi: 10.2760/4511279.

[67] E. R. Sophie, "Forensic Analysis of Construction Defects: Techniques for Conducting Forensic Analysis of Construction Defects and Determining Root Causes," Jun. 2025. Accessed: May 08, 2026. [Online]. Available: https://www.researchgate.net/publication/393005218_Forensic_Analysis_of_Construction_Defects_Techniques_for_Conducting_Forensic_Analysis_of_Construction_Defects_and_Determining_Root_Causes

[68] P. Allison, "Dealing with Legacy Data - an introduction," *Internet Archaeology* , 2008, doi: https://doi.org/10.11141/ia.24.8.

[69] S. Çetin, "Towards a circular building industry through digitalisation: Exploring how digital technologies can help narrow, slow, close, and regenerate the loops in social housing practice," *A+BE Architecture and the Built Environment*, vol. 22, pp. 1–236, 2023, doi: 10.7480/abe.2023.22.

[70] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qual. Res. Psychol.*, pp. 77–101, 2006, doi: hhttp://dx.doi.org/10.1191/1478088706qp063oa.

[71] *ISO 7817-1:2024 Building information modelling — Level of information need Part 1: Concepts and principles*. 2024.

[72] K. Krippendorff, *Content Analysis: An Introduction to Its Methodology*. SAGE Publications, 2018.

[73] S. Vangelova, K. Forth, and C. De Wolf, "Towards a Compatible Digital Product Passport Data Template in Construction," in *IOP Conference Series: Earth and Environmental Science*, 2025. doi: 10.1088/1755-1315/1554/1/012053.

[74] "What is a Data Template (DT)? ," Cobuilder. Accessed: Apr. 19, 2026. [Online]. Available: https://cobuilder.com/en/international-construction/what-is-a-data-template-dt/

[75] T. Ahmed and J. Siegel, "Pareto Data Framework: Steps Towards Resource-Efficient Decision Making Using Minimum Viable Data (MVD)," Sep. 2024, [Online]. Available: http://arxiv.org/abs/2409.12112

[76] R. Krueger and M. Casey, *Focus Groups: A Practical Guide for Applied Research*, 5th Edition. SAGE Publications, 2014.

[77] "General Data Protection Regulation (GDPR)," European Union. Accessed: Jun. 14, 2026. [Online]. Available: https://eur-lex.europa.eu/EN/legal-content/summary/general-data-protection-regulation-gdpr.html

[78] "Política de Proteção de Dados Pessoais da U.Porto," Universidade do Porto. Accessed: Jun. 14, 2026. [Online]. Available: https://sigarra.up.pt/up/pt/web_base.gera_pagina?p_pagina=pol%c3%adtica%20de%20prote%c3%a7%c3%a3o%20de%20dados%20pessoais

[79] B. Weber and M. Achenbach, "A new legal framework for digital building passports in a sustainable building life cycle," in *ECPPM 2024, 15th European Conference on Product & Process Modelling*, 2024. Accessed: Apr. 23, 2026. [Online]. Available: https://www.researchgate.net/publication/385249173_A_new_legal_framework_for_digital_building_passports_in_a_sustainable_building_life_cycle

[80] M. Honic, P. Mêda, and P. Van den Bosch, "From data templates to material passports and digital product passports," in *A circular built environment in the digital age*, Springer, 2024, pp. 79–94. doi: 10.1007/978-3-031-39675-5_5.

[81] D. Mulhall, A. C. Ayed, J. Schroeder, K. Hansen, and T. Wautelet, "The Product Circularity Data Sheet—A Standardized Digital Fingerprint for Circular Economy Data about Products," *Energies (Basel).*, vol. 15, no. 9, May 2022, doi: 10.3390/en15093397.

[82] M. Honic, I. Kovacic, and H. Rechberger, "Improving the recycling potential of buildings through Material Passports (MP): An Austrian case study," *J. Clean. Prod.*, vol. 217, pp. 787–797, Apr. 2019, doi: 10.1016/j.jclepro.2019.01.212.

[83] V. Göswein, S. Carvalho, C. Cerqueira, and A. Lorena, "Circular material passports for buildings - Providing a robust methodology for promoting circular buildings," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics, 2022. doi: 10.1088/1755-1315/1122/1/012049.

[84] P. Mêda and J. Fauth, "Building Research & Information Bridging Digital Concepts in Construction: An Exploratory Review of Logbooks, Permits, and Renovation Passports Bridging Digital Concepts in Construction: An Exploratory Review of Logbooks, Permits, and Renovation Passports," 2025. Accessed: Apr. 25, 2026. [Online]. Available: https://mc.manuscriptcentral.com/rbri

[85] S. Çetin, P. Mêda, K. Farghaly, and S.-A. Hwang, "Linking digital product passports and digital building logbooks: Socio-Technical challenges and a pathways for integration," *Developments in the Built Environment*, vol. 25, p. 100877, Mar. 2026, doi: 10.1016/j.dibe.2026.100877.

[86] T. Götz *et al.*, "Digital Product Passport: the ticket to achieving a climate neutral and circular European economy?," University of Cambridge Institute for Sustainability Leadership, Cambridge, 2022. Accessed: Apr. 23, 2026. [Online]. Available: https://epub.wupperinst.org/frontdoor/index/index/docId/8049

[87] J. A. M. Bosma, "From Material Passports to Digital Product Passports," 2024.

[88] "Digital Product Passport (DPP) in the construction industry - everything you need to know about the new EU regulation," bimobject. Accessed: Feb. 26, 2026. [Online]. Available: https://business.bimobject.com/blog/digital-product-passport-dpp-in-construction/

[89] C. Plociennik *et al.*, "Requirements for a Digital Product Passport to Boost the Circular Economy," in *Lecture Notes in Informatics (LNI), Proceedings - Series of the Gesellschaft fur Informatik (GI)*, Gesellschaft fur Informatik (GI), 2022, pp. 1485–1494. doi: 10.18420/inf2022_127.

[90] M. R. N. King, P. D. Timms, and S. Mountney, "A proposed universal definition of a Digital Product Passport Ecosystem (DPPE): Worldviews, discrete capabilities, stakeholder requirements and concerns," *J. Clean. Prod.*, vol. 384, Jan. 2023, doi: 10.1016/j.jclepro.2022.135538.

[91] G. van Capelleveen, D. Vegter, M. Olthaar, and J. van Hillegersberg, "The anatomy of a passport for the circular economy: a conceptual definition, vision and structured literature review," May 01, 2023, *Elsevier Inc.* doi: 10.1016/j.rcradv.2023.200131.

[92] A. Veliz-Reyes, D. Olmez, J. Grout, and A. Carr, "Digital material passports in the AEC industry: a scoping review and conceptualisation of future research challenges," *Architectural Engineering and Design Management*, 2025, doi: 10.1080/17452007.2025.2579731.

[93] A. KC, S. Senaratne, S. Perera, and S. Nanayakkara, "Review of Material Passports and Their Application in Industrialised Construction: Enhancing Material Circularity in Construction," *Sustainability (Switzerland)*, vol. 17, no. 12, 2025, doi: 10.3390/su17125661.

[94] L. M. Mankata, P. Antwi-Afari, S. Y. Frimpong, and S. T. Ng, "Material Passports in Construction Waste Management: A Systematic Review of Contexts, Stakeholders, Requirements, and Challenges," *Buildings*, vol. 15, no. 11, 2025, doi: 10.3390/buildings15111825.

[95] P. Mêda, D. Calvetti, E. Hjelseth, and H. Sousa, "Incremental digital twin conceptualisations targeting data-driven circular construction," Nov. 01, 2021, *MDPI*. doi: 10.3390/buildings11110554.

[96] P. Mêda, E. Hjelseth, D. Calvetti, and H. Sousa, "Enabling Circular Construction Information Flows Using Data Templates - Conceptual Frameworks Based on Waste Audit Action," in *2021 European Conference on Computing in Construction*, Jul. 2021. Accessed: Apr. 23, 2026. [Online]. Available: https://ec-3.org/wp-content/uploads/2025/10/EC32021_208.pdf

[97] P. Mêda, H. Sousa, and E. Hjelseth, "Data Templates—Product Information Management Across Project Life-Cycle," 2020, pp. 117–133. doi: 10.1007/978-3-030-46800-2_5.

[98] G. Bernardo, D. Dall'Arche, and A. Manicone, "Circular Data Flowchart for Sustainable Ecodesign," in *Lecture Notes in Civil Engineering*, Springer Science and Business Media Deutschland GmbH, 2025, pp. 104–125. doi: 10.1007/978-3-032-06993-1_7.

[99] M. Honic, I. Kovacic, and H. Rechberger, "Concept for a BIM-based Material Passport for buildings," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics Publishing, Feb. 2019. doi: 10.1088/1755-1315/225/1/012073.

[100] I. Markou, D. Sinnott, and K. Thomas, "Current methodologies of creating material passports: A systematic literature review," *Case Studies in Construction Materials*, vol. 22, Jul. 2025, doi: 10.1016/j.cscm.2025.e04267.

[101] J. Gayko and B. Helfritz, "Landscape of Digital Product Passport Standards," 2026. doi: 10.5281/zenodo.7728381.

[102] "Whitepaper Linked construction product data for the circular economy requirements and solutions," Zurich, Sep. 2024. [Online]. Available: www.bauen-digital.ch

[103] Iso, "Building information modelling and other digital processes used in construction-Methodology to describe, author and maintain properties in interconnected data dictionaries COPYRIGHT PROTECTED DOCUMENT," 2019.

[104] "Whitepaper Digital product passport (DPP) for construction products," Zurich, Sep. 2024. [Online]. Available: www.bauen-digital.ch

[105] technalia, cobuilder, and UNE, "Feasibility study on the establishment of the Construction Products Regulation (CPR) Digital Product Passport (DPP) system," Mar. 2025, doi: 10.2873/7605332.

[106] E. Schulze, "Espen Schulze," Mar. 2021.

[107] S. Cetin, D. Raghu, M. Honic, A. D. Straub, and V. H. Gruis, "Data requirements and availabilities for material passports: A digitally enabled framework for improving the circularity of existing buildings," *Sustain. Prod. Consum.*, vol. 40, pp. 422–437, 2023, doi: 10.1016/j.spc.2023.07.011.

[108] H. N. Y. Senarathne, N. P. Weerasinghe, and G. Zhang, "Developing a standardized materials passport framework to unlock the full circular potential in the construction industry," *Sustainability (Switzerland)*, vol. 17, no. 14, p. 6337, Jul. 2025, doi: 10.3390/su17146337.

[109] C. Boje *et al.*, "Ranking domain data sources which influence building circularity passports," in *CIB W78 Conference 2024*, Marrakesh, Oct. 2024. Accessed: Apr. 23, 2026. [Online]. Available: https://itc.scix.net/pdfs/w78-2024-paper_95.pdf

[110] A. Bellini, A. Tadayon, B. Andersen, and N. J. Klungseth, "The role of data when implementing circular strategies in the built environment: A literature review," Jun. 01, 2024, *Elsevier Ltd*. doi: 10.1016/j.cesys.2024.100183.

[111] S. Giorgi, "Assessment methods and digital tools to support circular building strategies," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics, 2024. doi: 10.1088/1755-1315/1402/1/012047.

[112] M. Heinrich and W. Lang, "Materials Passports - Best Practice," 2019. Accessed: Apr. 24, 2026. [Online]. Available: https://www.bamb2020.eu/news/publication-materials-passports/

[113] E. Bayazidi, M. Jelodar, W. Shahzad, V. Kumar, and S. Shooshtarian, "Integrating Circular Economy Principles in Construction: Comparing Product Data Templates, Material Passports, and Other Digital Tools," *CIB Conferences*, vol. 1, no. 1, Jun. 2025, doi: 10.7771/3067-4883.2139.

[114] N. Trubina *et al.*, "Digital Technologies and Material Passports for Circularity in Buildings: An In-Depth Analysis of Current Practices and Emerging Trends," in *Lecture Notes in Civil Engineering*, Springer Science and Business Media Deutschland GmbH, 2024, pp. 690–699. doi: 10.1007/978-3-031-57800-7_64.

[115] G. Yilmaz *et al.*, "Material Passport for Modular Construction," *IET Conference Proceedings*, vol. 2024, no. 11, pp. 159–164, 2024, doi: 10.1049/icp.2024.3501.

[116] C. Llatas, "A model for quantifying construction waste in projects according to the European waste list," *Waste Management*, vol. 31, no. 6, pp. 1261–1276, Jun. 2011, doi: 10.1016/j.wasman.2011.01.023.

[117] "A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives," Brussels, Oct. 2020. Accessed: Mar. 17, 2026. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0662

[118] "The WELL Building Standard." Accessed: Apr. 05, 2026. [Online]. Available: https://standard.wellcertified.com/v8/

[119] "New Construction Products Regulation (CPR) and Ecodesign for Sustainable Products Regulation (ESPR)," 2024.

[120] "GrowingCircle," EEA Grants Portugal. Accessed: Feb. 26, 2026. [Online]. Available: https://growingcircle.netlify.app/cases/

[121] T. Adisorn, L. Tholen, and T. Götz, "Towards a digital product passport fit for contributing to a circular economy," *Energies (Basel).*, vol. 14, no. 8, Apr. 2021, doi: 10.3390/en14082289.

[122] A. Bellini, B. Andersen, N. J. Klungseth, and A. Tadayon, "Achieving a circular economy through the effective reuse of construction products: A case study of a residential building," *J. Clean. Prod.*, vol. 450, Apr. 2024, doi: 10.1016/j.jclepro.2024.141753.

[123] K. Devos, M. Steeman, and L. Devlieger, "Material use in the building envelope of 23 social housing neighborhoods with reuse insights from a case study," *Discov. Mater.*, vol. 5, no. 1, Dec. 2025, doi: 10.1007/s43939-025-00224-8.

[124] R. Hartwell, S. Macmillan, and M. Overend, "Circular economy of façades: Real-world challenges and opportunities," *Resour. Conserv. Recycl.*, vol. 175, Dec. 2021, doi: 10.1016/j.resconrec.2021.105827.

[125] A. R. Costa, R. Hoolahan, and R. Charef, "Eight recommendations to adopt materials passports and accelerate material reuse in construction: insights from academia and practice," *npj Materials Sustainability*, vol. 3, no. 1, p. 33, Oct. 2025, doi: 10.1038/s44296-025-00079-3.

[126] S. Shooshtarian, S. Caldera, T. Maqsood, and T. Ryley, "Using recycled construction and demolition waste products: A review of stakeholders' perceptions, decisions, and motivations," Dec. 01, 2020, *MDPI AG*. doi: 10.3390/recycling5040031.

[127] M. Ramos, A. Paiva, and G. Martinho, "Understanding the perceptions of stakeholders on selective demolition," *Journal of Building Engineering*, vol. 82, Apr. 2024, doi: 10.1016/j.jobe.2023.108353.

[128] Iso, *Circular economy-Measuring and assessing circularity performance*. 2024.

[129] A. T. Lima *et al.*, "Mapping circular economy practices for steel, cement, glass, brick, insulation, and wood – A review for climate mitigation modeling," Jun. 29, 2024, *Elsevier Ltd*. doi: 10.1016/j.rser.2024.114697.

[130] D. Calvetti, P. Mêda, H. de Sousa, M. C. Gonçalves, J. M. A. Faria, and J. M. da Costa, "Experiencing Education 5.0 for Civil Engineering," in *Procedia Computer Science*, Elsevier B.V., 2024, pp. 2416–2425. doi: 10.1016/j.procs.2024.02.060.

[131] R. Charef and S. Emmitt, "Uses of building information modelling for overcoming barriers to a circular economy," *J. Clean. Prod.*, vol. 285, Feb. 2021, doi: 10.1016/j.jclepro.2020.124854.

[132] DigiPass, "Harmonization of Advanced Materials Ecosystems serving strategic Innovation Markets to pave the way to a Digital Materials & Product Passport," HORIZON EUROPE. Accessed: Mar. 12, 2026. [Online]. Available: https://cordis.europa.eu/project/id/101138510

[133] "CIRPASS Digital Product Passport." Accessed: Mar. 05, 2026. [Online]. Available: https://cirpassproject.eu/

[134] CRedIBlE, "Circular REDesign for a Resource-efficient, Innovative, and Transformative Built Environment," HORIZON EUROPE. Accessed: Mar. 12, 2026. [Online]. Available: https://cordis.europa.eu/project/id/101235056

[135] H. Martin, D. Chebrolu, A. Chadee, and T. Brooks, "Too good to waste: Examining circular economy opportunities, barriers, and indicators for sustainable construction and demolition waste management," *Sustain. Prod. Consum.*, vol. 48, pp. 460–480, Jul. 2024, doi: 10.1016/j.spc.2024.05.026.

[136] "International EPD System," EPD International AB. Accessed: Apr. 10, 2026. [Online]. Available: https://www.environdec.com/library

[137] *Precast concrete products - Wall elements EN 14992:2007*. 2007.

[138] *Windows and doors - Product standard, performance characteristics EN 14351-1*. 2006.

[139] *Glass in Building - Insulating glass units EN 1279-1*. 2018.

[140] *Aluminium and aluminium alloys. Extruded precision profiles in alloys EN AW-6060 and EN AW-6063*. 2022, p. 14.

[141] "Environmental Product Declaration Precast Concrete Wall," Apr. 2026. Accessed: Jul. 20, 2026. [Online]. Available: www.environdec.com/contact.

[142] "Environmental Product Declaration Aluminium Windows," Jul. 2020. Accessed: Jul. 20, 2026. [Online]. Available: www.environdec.com

[143] M. D. O. Gondak, C. Hluszko, V. Moretti, G. L. F. Zeni, and A. C. De Francisco, "Guide to digital technologies for circularity in the project lifecycle: perspective of the EN 15643-3:2012 standard," *Construction Innovation*, 2025, doi: 10.1108/CI-01-2025-0021.

[144] A. M. Walker *et al.*, "Environmental and Socio-Economic Impacts of the Circular Economy Transition in the EU Cement and Concrete Sector," 2025, *Publications Office of the European Union*. doi: 10.2760/6579506.

[145] "Cost-Effective Recycling of CDW in High Added Value Energy Efficient Prefabricated Concrete Components for Massive Retrofitting of our Built Environment," Jun. 01, 2016, *Rina Consulting Spa*. Accessed: Mar. 13, 2026. [Online]. Available: https://cordis.europa.eu/project/id/723582

[146] A. Antunes, J. Silvestre, H. Costa, R. D. Carmo, and E. Júlio, "Reducing the environmental impact of the end-of-life of buildings depending on interrelated demolition strategies, transport distances and disposal scenarios," *Journal of Building Engineering*, vol. 82, 2024, doi: 10.1016/j.jobe.2023.108197.

[147] P. Hagedorn, A. Hafner, N. Krautgartner, M. Thewes, and M. König, "Prozessgesteuerte Nachhaltigkeitsbewertung der Wiederverwendung von Betonbauteilen im digitalen ökosystem," *Bautechnik*, vol. 102, no. 8, pp. 449–457, Aug. 2025, doi: 10.1002/bate.202500021.

[148] K. van den Muyzenberg and P. Mêda, "Navigating the Twin Transition: Data Requirements and Accuracy in Construction Products for Sustainable Building Practices," in *6º Congresso Português de Building Information Modelling*, Porto, Jun. 2026.

[149] P. Ghisellini, M. Ripa, and S. Ulgiati, "Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review," *J. Clean. Prod.*, vol. 178, pp. 618–643, Mar. 2018, doi: 10.1016/j.jclepro.2017.11.207.

[150] N. Dodd and S. Donatello, "Level(s) indicator 2.2: Construction and Demolition waste and materials User manual: overview, guidance and instructions (Publication version 1.0)," 2020. [Online]. Available: https://ec.europa.eu/jrc

[151] F. Kedir, D. M. Hall, S. Brantvall, J. Lessing, A. Hollberg, and R. K. Soman, "Circular information flows in industrialized housing construction: the case of a multi-family housing product platform in Sweden," *Construction Innovation*, vol. 24, no. 5, pp. 1354–1379, 2024, doi: 10.1108/CI-08-2022-0199.

[152] "Automated solutions for sustainable and circular construction and demolition waste management," Horizon Europe - European Commission. Accessed: Apr. 25, 2026. [Online]. Available: https://www.reconmatic.eu/

[153] M. Honic, I. Kovacic, P. Aschenbrenner, and A. Ragossnig, "Material Passports for the end-of-life stage of buildings: Challenges and potentials," *J. Clean. Prod.*, vol. 319, Oct. 2021, doi: 10.1016/j.jclepro.2021.128702.

[154] C. Stretton and Z. Buzeti, "Digital product passports (DPP): what, how, and why?," Circularise. Accessed: Mar. 12, 2026. [Online]. Available: https://www.circularise.com/blogs/digital-product-passports-dpp-what-how-and-why

[155] P. K. Wan and S. Jiang, "Enabling a dynamic information flow in digital product passports during product use phase: A literature review and proposed framework," *Sustain. Prod. Consum.*, vol. 54, pp. 362–374, 2025, doi: 10.1016/j.spc.2025.01.014.

A
ANNEXES

A.1. INFORMATION ENVIRONMENT ANALYSIS OF PROJECT CASES

Project Case A

Factor	Criteria	Yes (2 points)	Partial (1 point)	No (0 points)	Points	Total Points	Maturity Level
Availability	Drawings available (plans, sections, details)	X			2		
	Bill of Quantities (BoQ)	X			2		
	Bill of Materials (BoM)			X	0		
	Revit/ BIM model (detailed)		X		1		
	Technical specifications	X			2		
	Site observation records (photos, notes)		X		1		
	Environmental/ sustainability documentation			X	0	8	II
Organization	Consistent breakdown structure		X		1		
	Cross-document consistency		X		1		
	Consistent naming conventions	X			2		
	Classification system			X	0		
	Information linked between sources			X	0		
	Structured data formats		X		1		
	Standardised metadata structure		X		1	6	II
Completeness	Product quantities provided	X			2		
	Material information specified		X		1		
	Technical performance data specified	X			2		
	Coverage across all building systems		X		1		
	Product composition defined		X		1		
	Minimal assumptions required		X		1		
	Weight value directly provided			X	0	8	II

Project Case B

Factor	Criteria	Yes (2 points)	Partial (1 point)	No (0 points)	Points	Total Points	Maturity Level
Availability	Drawings available (plans, sections, details)	X			2		
	Bill of Quantities (BoQ)	X			2		
	Bill of Materials (BoM)	X			2		
	Revit/ BIM model (detailed)	X			2		
	Technical specifications	X			2		
	Site observation records (photos, notes)	X			2		
	Environmental/ sustainability documentation	X			2	14	III
Organization	Consistent breakdown structure		X		1		
	Cross-document consistency	X			2		
	Consistent naming conventions	X			2		
	Classification system	X			2		
	Information linked between sources			X	0		
	Structured data formats	X			2		
	Standardised metadata structure	X			2	11	III
Completeness	Product quantities provided	X			2		
	Material information specified	X			2		
	Technical performance data specified	X			2		
	Coverage across all building systems	X			2		
	Product composition defined	X			2		
	Minimal assumptions required	X			2		
	Weight value directly provided	X			2	14	III

A.2. BILL OF MATERIALS RECONSTRUCTION FOR PROJECT CASE A AND PROJECT CASE B

- Project Case A: Reconstruction of BoQ into BoM with a record of the sources used to derive information and process limitations.
- Project Case B: Included Level(s) and CPR Product Families classification system.

Project Case B

Classification	BoM

Project Case A

Classification		BoQ			BoM Extension						Data sources			
Level(s) 1.x Classification	CPR Product Family	Material/Product	Quantity	Quantity Type	Thickness (m)	Density (kg/m3) or Unit Weight (kg/m2)	Unit	Weight (kg)	Unit	Material Type	Specification	Drawings	Photos	External source
1.2 Envelope	22	Sandwhich panel, metal panels with 5cm rockwool insulation	182	m2		11.1	kg/m2	2020.20	KG	Metal	X			
1.2 Envelope	4	Extruded polystrene thermal insulation 12cm (XPS)	182	m2	0.12	33	kg/m3	720.72	KG	Plastic, polymer, resin, paint, chemicals & bituminous	X			
1.2 Envelope	22	Flashings No.14 Zinc and double sealed	182	m2	0.0008	7135	kg/m3	1038.86	KG	Metal	X			
1.2 Envelope	28	Overflow outlets No.14 galvanzied steel, 90mm diameter	4	un				7.40	KG	Metal				X
1.2 Envelope	22	Flashings No.14 Zinc sheet	67.5	m	0.000104	7135	kg/m3	50.09	KG	Metal	X			
1.3 Internal Works/ Finishes	21	Red stoneware mosaic tiles, including setting mortar, grouting of joints	37.8	m2	0.009	2300	kg/m3	782.46	KG	Clay-based	X			X
1.3 Internal Works/ Finishes	21	Interior paint, high-gloss enamel, based on polyurethane resins and pigments with rutile titanium dioxide	131.5	m2	0.0001	1250	kg/m3	16.44	KG	Plastic, polymer, resin, paint, chemicals & bituminous				X
1.3 Internal Works/ Finishes	21	Finishing paint based on an aqueous dispersion of a special synthetic resin, vinyl acetate copolymer, pigmented with rutile titanium dioxide, alkali-resistant pigments, and inert fillers	51	m2	0.0001	1550	kg/m3	7.91	KG	Plastic, polymer, resin, paint, chemicals & bituminous				X
1.3 Internal Works/ Finishes	21	Glazed stoneware tiles, measuring 33x33 cm, frost-resistant	392	m2	0.02	2300	kg/m3	18032.0	KG	Clay-based	X			

Log of hours to develop BoM for Project Case A:

	MON	TUES	WED	THURS	FRI	Total
Week 1	7hr	6hr	5hr	6hr	5hr	29
Week 2	6hr	4hr	2hr	-	-	12
						41

Notes taken during the process:

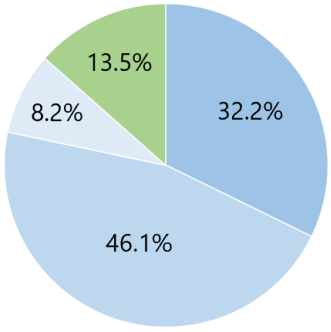
Notes taken on process and limitations
· Measurement unit variations and conversions.
· Thin membranes are not included.
· Estimation of dimensions.
· Started with specifications where lack of information led to the use of drawings and then to photos for further clarification.
· Used drawings for a more detailed understanding of the composition.
· Discrepancies between drawings and product specifications and accuracy considerations of drawings.
· Using the model to verify the type by looking at the measurements.
· Some of the references to specifications were not available.
· External references were used where no information was found in the project documentation.
· An identical or similar product was identitified, leading to assumptions being made.
· Cross comparison between specifications and drawings led to different dimensions, such as the case for windows.
· Cement used between layers is not considered and specified; it could contribute a significant value if all added together.

A.3. ENTIRE PROJECT RELATIVE WEIGHT SIGNIFICANCE ANALYSIS

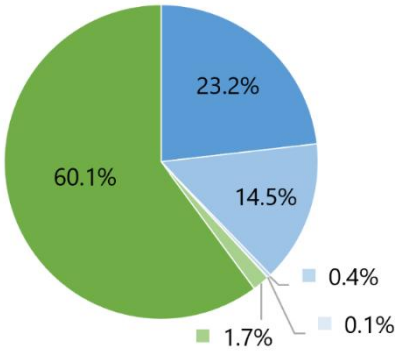
The analysis below includes all the weight constribution of all site works for both project cases.

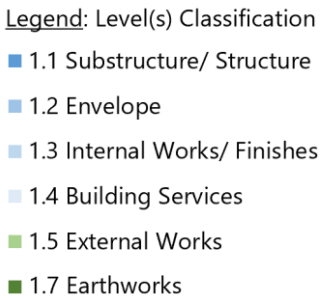
- Project Case A: 1.5 External Works weight contribution entirely from stone threshold products.
- Project Case B: 1.7 Earthworks, comprised of clay soil, dominates weight contribution. For 1.5 External Works, road asphalt and concrete-based products (road pavers and manholes for wastewater networks) are the highest contributors.

Project Case A



Project Case B





A.4. CIRCULARITY POTENTIAL QUESTIONNAIRE

A.4.1. QUESTIONNAIRE DETAILS

Circularity of Construction Products

Thank you for taking part in this survey that will support my Master Dissertation development.

Your contribution will help identify and prioritise circular strategies for construction products and support the development of circularity-focused Digital Product Passport (DPP) dataset.

This survey explores the circular potential of construction products and the factors that support circular strategies across the product lifecycle.

Participants will be asked to assess different construction products and identify:

- possible circular strategies (e.g. reuse, repair, and recycling) that can be applied for the entire product and/or parts of it.
- the factors that are most relevant and have the largest impact on its circular potential.

Your participation is essential to gaining an insight into the sector and better guiding our efforts in awareness-raising and training initiatives. Thank you very much!

Google account covered by the University of Porto's institutional licence

The data collected will be processed exclusively for scientific research purposes, within the scope of the Master's thesis entitled "Circularity Data for Construction Products: Prioritisation and Dataset Development for Digital Product Passports", carried out at the Faculty of Engineering of the University of Porto (FEUP), under the MBUILD Erasmus Mundus Joint Master Programme.

This survey is addressed to stakeholders in the construction sector (including professionals, researchers, academics, educators, and students). The data collected may include information relating to participants' field of involvement, professional background, and their responses regarding the applicability of circular economy strategies to selected construction products, as well as factors influencing the circular potential of such products. Participants may also provide optional comments or observations in open-ended questions.

The questionnaire has been structured so as not to request information that directly identifies participants.

Respondents are also explicitly instructed not to include any personal or identifying information in their answers.

However, as some questions include open-ended fields, there is a possibility that personal data may be inadvertently provided by participants. In such cases, any identifying elements will be removed during a data cleaning process prior to analysis. Only data that has been reviewed and cleared of identifying elements will be used for research purposes.

The University of Porto, through FEUP, acts as the controller of the data processing carried out within this research context. The data will be accessed only by the researcher and the academic supervisor(s) directly involved in the project and will not be shared with third parties.

The questionnaire is hosted using Google Forms within the University of Porto's institutional Google Workspace environment.

The data will be analysed exclusively in aggregate form, ensuring that individual responses cannot be associated with specific participants.

The data collected will be retained only for the period strictly necessary to complete and assess the Master's dissertation project, and will be securely deleted no later than September 2027. Deletion will include removal from Google Forms, Google Drive, and any local storage devices used in the context of the research.

Participants may withdraw from the survey at any time before submitting their responses by closing their browser, without any consequences.

For any questions regarding the research project, you may contact: Kyra Maria van den Muyzenberg, FEUP student – up202400708@g.uporto.pt Pedro Mêda, FEUP – pmeda@fe.up.pt

1. Which field are you involved in? (Please note that there is an open-ended option. Please do not include any information and/or data that could identify you).

   Select all that apply.

   Tick all that apply.

   - [ ] Construction industry
   - [ ] Research and academia
   - [ ] Education
   - [ ] Policy
   - [ ] Other: _____

2. What is your professional background?

Select all that apply.

Tick all that apply.

- [ ] Researcher
- [ ] Professor
- [ ] Student
- [ ] Engineer
- [ ] Architect
- [ ] Consultant
- [ ] Contractor
- [ ] Project Manager

Circular Potential and Strategies of Construction Products

For the following construction products, please identify all circular strategies that are possible from your perspective.

For each strategy, indicate whether it applies to:

- **Entire product**
- **Parts of the product**: its components and materials
- **or not at all possible**

Recommended approach

For each construction product and circular strategy, consider the following:

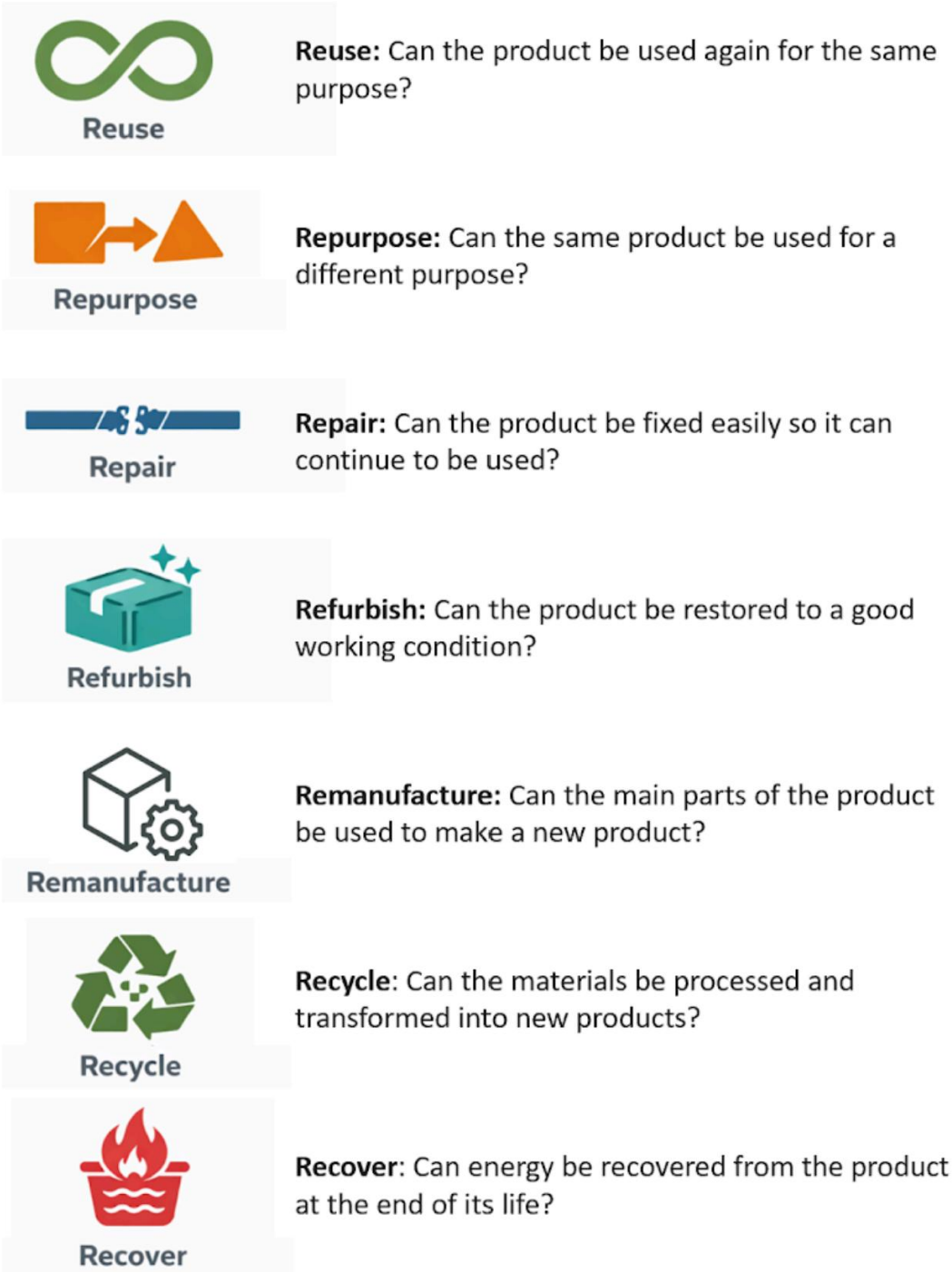
1. Based on the product description provided, is the strategy technically possible for this product?

2. If the strategy is feasible, does it apply to the "Entire product", "Parts of the product" or both?
Tick the relevant checkbox(es) where it applies.

3. If the strategy is not feasible, select “Not possible”.

Circular R-strategies

The diagram below provides decision-support questions for reference when selecting applicable circularity R-strategies for specific construction products.



Product 1: **Aluminium frame window with double glazing**

Exterior window along a building façade composed of an aluminium frame and double-glazed glass, including seals and fittings.

3. Which circularity R-strategies are applicable for the **aluminium frame window**?

Select all the strategies that apply, considering the entire product and its components and materials.
Refer to Section 2 for the recommended response approach and the Circularity R-strategies diagram with the strategy definitions.



Tick all that apply.

	Entire product	Parts of the product	Not possible
Reuse	☐	☐	☐
Repurpose	☐	☐	☐
Repair	☐	☐	☐
Refurbish	☐	☐	☐
Remanufacture	☐	☐	☐
Recycle	☐	☐	☐
Energy recovery	☐	☐	☐

4. Which factors are most relevant and have the largest impact on the circular potential of the **aluminium frame window**?

   Select all that apply to the product.

   Tick all that apply.

   - [ ] Material type / composition
   - [ ] Dimensions and weight
   - [ ] Ease of disassembly
   - [ ] Technical performance
   - [ ] Durability and service life
   - [ ] Maintenance needs
   - [ ] Availability of spare parts
   - [ ] Presence of hazardous materials
   - [ ] Cost and effort
   - [ ] Market demand

5. Any comments or observations on the circular potential of **aluminium frame windows** are welcome here (Please note that this is an open-ended question. Please do not include any information and/or data that could identify you).

Product 2: **Interior ceramic tile**

The tiles are made of ceramic material and installed with adhesive and grout. These are used for interior wall and floor finishes in kitchens, bathrooms, and living areas.

6. Which circularity R-strategies are applicable for **interior ceramic tiles**?

   Select all the strategies that apply, considering the entire product and its components and materials.
   Refer to Section 2 for the recommended response approach and the Circularity R-strategies diagram with the strategy definitions.



Tick all that apply.

	Entire product	Parts of the product	Not possible
Reuse	☐	☐	☐
Repurpose	☐	☐	☐
Repair	☐	☐	☐
Refurbish	☐	☐	☐
Remanufacture	☐	☐	☐
Recycle	☐	☐	☐
Energy recovery	☐	☐	☐

7. Which factors are most relevant and have the largest impact on the circular potential of **interior ceramic tiles**?

   Select all that apply to the product.

   Tick all that apply.

   - [ ] Material type / composition
   - [ ] Dimensions and weight
   - [ ] Ease of disassembly
   - [ ] Technical performance
   - [ ] Durability and service life
   - [ ] Maintenance needs
   - [ ] Availability of spare parts
   - [ ] Presence of hazardous materials
   - [ ] Cost and effort
   - [ ] Market demand

8. Any comments or observations on the circular potential of **interior ceramic tiles** are welcome here (Please note that this is an open-ended question. Please do not include any information and/or data that could identify you).

Product 3: **Precast concrete wall element**

Exterior precast concrete wall element manufactured off-site and installed on-site, consisting of reinforced concrete and a metal connection system. These elements provide structural support and building enclosure.

9. Which circularity R-strategies are applicable for a **precast concrete wall element**?

   Select all the strategies that apply, considering the entire product and its components and materials.
   Refer to Section 2 for the recommended response approach and the Circularity R-strategies diagram with the strategy definitions.



Tick all that apply.

	Entire product	Parts of the product	Not possible
Reuse	☐	☐	☐
Repurpose	☐	☐	☐
Repair	☐	☐	☐
Refurbish	☐	☐	☐
Remanufacture	☐	☐	☐
Recycle	☐	☐	☐
Energy recovery	☐	☐	☐

10. Which factors are most relevant and have the largest impact on the circular potential of the **precast concrete wall element**?

Select all that apply to the product.

Tick all that apply.

- [ ] Material type / composition
- [ ] Dimensions and weight
- [ ] Ease of disassembly
- [ ] Technical performance
- [ ] Durability and service life
- [ ] Maintenance needs
- [ ] Availability of spare parts
- [ ] Presence of hazardous materials
- [ ] Cost and effort
- [ ] Market demand

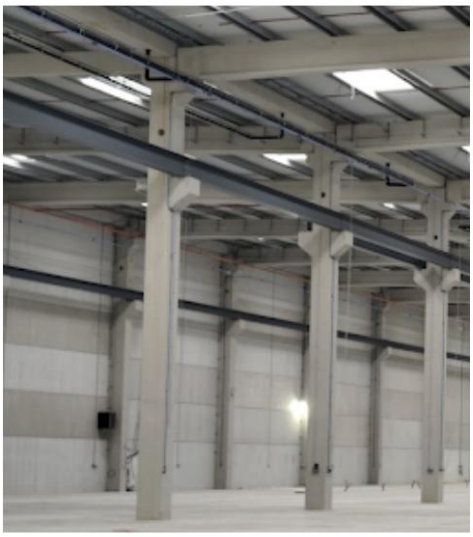
11. Any comments or observations on the circular potential of **precast concrete wall elements** are welcome here (Please note that this is an open-ended question. Please do not include any information and/or data that could identify you).

Product 4: **Structural concrete beam**

The structural beam consists of concrete with reinforcing steel rebars that are designed to provide structural stability and transfer building loads.

12. Which circularity R-strategies are applicable for a **structural concrete beam**?

    Select all the strategies that apply, considering the entire product and its components and materials.
    Refer to Section 2 for the recommended response approach and the Circularity R-strategies diagram with the strategy definitions.



Tick all that apply.

	Entire product	Parts of the product	Not possible
Reuse	☐	☐	☐
Repurpose	☐	☐	☐
Repair	☐	☐	☐
Refurbish	☐	☐	☐
Remanufacture	☐	☐	☐
Recycle	☐	☐	☐
Energy recovery	☐	☐	☐

13. Which factors are most relevant and have the largest impact on the circular potential of a **structural concrete beam**?

Select all that apply to the product.

Tick all that apply.

- [ ] Material type / composition
- [ ] Dimensions and weight
- [ ] Ease of disassembly
- [ ] Technical performance
- [ ] Durability and service life
- [ ] Maintenance needs
- [ ] Availability of spare parts
- [ ] Presence of hazardous materials
- [ ] Cost and effort
- [ ] Market demand

14. Any comments or observations on the circular potential of **structural concrete beams** are welcome here (Please note that this is an open-ended question. Please do not include any information and/or data that could identify you).

15. Please share any additional thoughts, reflections, or suggestions related to circularity in construction products or this survey (Please note that this is an open-ended question. Please do not include any information and/or data that could identify you).

Thank you for your contribution!

MBUILD
U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO
UC UNIVERSIDAD DE CANTABRIA
THM TECHNISCHE HOCHSCHULE MITTELHESSEN
Co-funded by the European Union
With support from:
ics Instituto para a Construção Sustentável
DPP4SBE

A.4.2. QUESTIONNARIE DATA COMPLIANCE

U.PORTO	Unidade de Proteção de Dados	DATA: 11/06/2026

PARECER A-44/2026

Nome	Kyra Maria van den Muyzenberg
Nº. Mecanográfico	202400708
Entidade Constitutiva	FEUP
Título	Circularity Data for Construction Products: Prioritisation and Dataset Development for Digital Product Passports

Sumário do Pedido

Foi solicitado à Unidade de Proteção de Dados da Universidade do Porto que se pronunciasse sobre um projeto de investigação que se encontra a ser desenvolvido pela requerente, mais concretamente a apreciação jurídico-institucional do questionário intitulado *Circularity of Construction Products*, a aplicar no âmbito da dissertação de Mestrado designada *"Circularity Data for Construction Products: Prioritisation and Dataset Development for Digital Product Passports"*, desenvolvida na Faculdade de Engenharia da Universidade do Porto, no quadro do programa MBUILD Erasmus Mundus Joint Master Programme.

De acordo com a versão do formulário submetida para análise, o instrumento em causa destina-se à recolha de contributos de intervenientes do setor da construção, incluindo profissionais, investigadores, académicos, docentes e estudantes, sendo-lhes solicitada a indicação da respetiva área de envolvimento, enquadramento profissional e respostas relativas à aplicabilidade de estratégias de circularidade a determinados produtos de construção, bem como aos fatores suscetíveis de influenciar o respetivo potencial de circularidade.

Conclusões

Da análise do conteúdo do questionário resulta, porém, que o mesmo foi estruturado de forma a não solicitar nomes, contactos, afiliações organizacionais ou quaisquer outros elementos direta ou imediatamente identificativos dos participantes, sendo adicionalmente dada indicação expressa para que não seja introduzida informação suscetível de identificar o próprio respondente ou terceiros.

Resulta igualmente da informação constante do formulário que os dados recolhidos se destinam exclusivamente a fins de investigação científica, sendo tratados no âmbito da dissertação em causa e analisados em forma agregada e estatística, com acesso limitado à estudante investigadora e ao respetivo orientador académico.

Neste enquadramento, e tendo presente a natureza das perguntas formuladas, entende-se que o instrumento submetido não se orienta à recolha de dados pessoais, mas antes à obtenção de perceções técnicas e profissionais sobre produtos e estratégias de circularidade no setor da construção, considerando ainda que os elementos solicitados incidem sobre domínios funcionais e apreciações temáticas, sem exigirem a identificação civil, profissional ou institucional dos respondentes, nem permitindo, nos termos em que o questionário se encontra desenhado, a individualização dos respetivos participantes.

Acresce que o propósito do estudo, tal como delimitado, se reconduz à produção de resultados agregados e não à análise de perfis individuais, o que reforça a conclusão de que, para efeitos da presente apreciação, a informação recolhida deve ser qualificada como anónima e, nessa medida, não reconduzível a titulares identificados ou identificáveis e esta conclusão mostra-se particularmente sustentada pela própria arquitetura do questionário, pela ausência de campos nominativos e pela indicação expressa de que a informação será trabalhada em termos agregados.

Nessa conformidade, não se afigura que o procedimento em apreço envolva, em termos materialmente relevantes, um tratamento de dados pessoais sujeito ao regime geral do Regulamento (UE) 2016/679, na medida em que a informação recolhida, considerada no seu desenho, finalidade e modo de exploração, não permite a associação das respostas a pessoas concretas.

U.PORTO	Unidade de Proteção de Dados	DATA: 11/06/2026

Em consequência, entende-se que o presente caso deve ser enquadrado, para efeitos internos de apreciação, na tipologia correspondente a tratamento sem dados pessoais, não se justificando a realização de Avaliação de Impacto sobre a Proteção de Dados. Tal entendimento não prejudica, naturalmente, a necessidade de manutenção das cautelas operacionais já refletidas no formulário, designadamente quanto à instrução dada aos participantes para não inserirem elementos identificativos e quanto à utilização da informação exclusivamente para os fins académicos declarados.

Assim, a solução adotada evidencia, em termos institucionais, um nível de prudência adequado, desde logo por se prever que o questionário seja alojado em ambiente abrangido pela licença institucional da Universidade do Porto e por se consignar que os resultados serão tratados e apresentados de forma agregada, pois a finalidade do estudo encontra-se claramente delimitada, os destinatários do questionário apresentam-se definidos de forma objetiva e o horizonte temporal do projeto académico mostra-se igualmente circunscrito, sendo referido no próprio formulário que os dados serão conservados até à conclusão do curso, expectável em setembro de 2027, e eliminados subsequentemente de forma segura.

Face ao exposto e considerando os elementos submetidos para apreciação, é nosso entendimento que o questionário em causa, tal como se encontra configurado, pode ser considerado, para efeitos da presente análise, um instrumento de recolha de informação anónima, não se identificando, por isso, impedimento de natureza jus-protetiva à sua utilização no contexto da dissertação em apreço. Em consequência, emite-se parecer favorável à prossecução do procedimento, sem prejuízo de dever ser mantida, na versão final do formulário e na respetiva operacionalização, a estrutura que afasta a recolha de elementos identificativos e que assegura a utilização da informação exclusivamente para as finalidades científicas e académicas comunicadas.

A Encarregada da Proteção de Dados
da Universidade do Porto

Raquel Mendes da Rocha

Digitally signed by Raquel Mendes da Rocha
Date: 2026.06.11 16:07:14 +01'00'

Dra. Raquel Mendes da Rocha

A.5. C_MVDATASET DEVELOPMENT

A.5.1. DATA MAPPING ACROSS ACADEMIC, LEGISLATION, STANDARDS, AND USE CASES SOURCES

	Academic Literature									
	Ruismaki et al. 2025	Vangelova et al.2025	Meda et al.2023		Goeswein et al. 2022	Boje et al. 2021	Çetin et al. 2023			
	Category	Data point	DoP	Ecodesign	Product Context & Circularity	Circularity assessment	Data point			
1		Manufacturer contact details	Contact details of manufacturer	Contact details of manufacturer		Manufacturer details	Manufacturers name/details			
2		Manufacture date								
3		Product name								
4										
5										
6		Durability / Expected service life		Durability	Service life span	Durability / Service life	Expected service life			
7	Manufacturing data	Materials list		Composition	Material composition		Composition of materials			
8		Weight				Weight	Weight			
9		Volume				Volume	Volume			
10		Dimensions				Dimensions	Dimensions			
11		Thickness				Thickness				
12						Physical properties	Physical properties			
13		Sound transmission	Sound insulation properties							
14		Fire resistance rating	Behaviour in fire							
15	Usage data	Maintanence status		Maintanence	Maintanence		Maintanence instru.			
16		Maintanence parts availability					Availability of parts			
17				Possibility of dismantling						
18										
19		Reusable content		Reuseability			Reuse potential			
20										
21		Repairability		Repair						
22										
23	Lifecycle/ end-of-life data	Recyclable content		Recyclability			Recycling potential			
24										
25		Material for energy recovery								
26		Waste classification		Waste codes						
27		Hazardous substances		Contents of dangerous substance		Hazardous waste	Hazardous substances			
28		End-of-life scenario			Waste scenarios %		Disposal options			
29										

	Legislation				Standards			
	CPR		ESPR	WFD - Directive 2008/98/EC	ISO 59040 - PCDS & Series		ISO 22057 - EPD	
	Category	Requirements	Requirements	Requirements	Category	Data point	Group of properties	Data point
1	Identification	Manufacturers name/details	Manufacturers name/details		Company and product information & Material inputs	Supplier identification		Manufacturer
2		Manufacturer date						
3		Product identification	Product			Product identification		Product name
4		Declared use	Declared use					
5		Conditions of use	Conditions of use					
6		Durability / Expected life span	Durability / Expected lifetime					
7		Materials used	Materials / Composition	Material		Product composition		Product content
8			Weight	Weight				
9			Volume					
10		Dimensions						
11								Thickness
12	Performance	Essential characteristics	Functional performance					
13		Noise absorption						
14		Reaction / resistance to fire						Reaction to fire
15	Environmental Sustainability	Ease of maintanence	Maintanence		Durability and extended lifetime & Circularity at end of product use period	Maintanence		
16		Availability of spare parts	Spare parts					
17		Seperation possibility	Diassembly	Diassembly		Disassembly		
18		Upgradability	Upgradability					
19		Reusability	Reusability	Re-use		Reuse	Output flows & waste categories	Components for re-use
20						Repurpose		
21		Repairability	Repairability	Repair		Repair		
22		Refurbishment	Refurbishment			Refurbishing		
23		Recyclability	Recyclability	Recycling		Recycling		Materials for recycling
24		Remanufacturing	Remanufacturing			Remanufacturing		
25			Material recovery	Recovery				Materials for energy recovery
26				Waste code (EWC)				
27		Substances of concern	Substances of concern	Hazardous/ non-hazardous waste		Hazardous substances		Hazardous, non-hazardous waste
28			Possibilities for reuse, recycling, recovery	Waste streams				End-of-life route (mass & %)
29								

	Level(s) Indicators			Pre-deconstruction Audit
	MO2 - In.2.1 - BoM/Q	MO2 - In.2.2 - BoW	MO2 - In.2.4 - Circularity score	Product inventory & recovery rates
	Input	Input	Input	Input
1				
2				
3				
4				
5				
6	Assumed lifetime			
7	Material type	Material identification		Material identification & type
8	Quantity (kg)	Estimated quantity (kg)	Quantity (kg)	Quantity (kg)
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19		On-site / off-site reuse		Reusable, some re-use
20				
21				
22				
23		Onsite / off-site recycling		Recycling
24				
25		On-site / off-site recovery		Energy recovery / backfilling
26		Waste code		Waste code
27				
28		Destination of CDW		Possible outlet
29		Destination of CDW	Best outcome	Recommended outlet

A.5.2. CONSOLIDATION OF SOURCES INTO A SET OF CONCISE DATA POINTS

	Data point	Academic Literature					Legislation				Standards			Use cases	
		Vangelova et al.2025	Meda et al.2023	Goeswein et al. 2022	Boje et al. 2021	Cetin et al. 2023	Literature	CPR	ESPR	WFD	CPR, ESPR & WFD	PCDS & ISO series	EPD	Standards	Level(s) Indicators	Pre-deconstr. Audit
1	Manufacturer details	X	X		X	X		X	X			X	X			
2	Manufacture date	X						X	X							
3	Product type	X						X	X			X	X			
4	Declared use							X	X							
5	Conditions of use							X	X							
6	Durability / expected life span	X	X	X	X	X		X	X	X	Horizon.				2.1	
7	Materials used / composition	X		X		X		X	X	X			X		2.1, 2.2	
8	Weight	X			X	X		X	X				X		2.1, 2.2, 2.4	
9	Dimensions	X			X	X		X	X				X			
10	Volume	X			X	X		X	X				X			
11	Thickness	X			X			X	X				X			
12	Essential characteristics	X			X	X		X	X				X			
13	Reaction / resistance to fire	X			X	X		X	X		Horizon.					
14	Noise absorption	X	X		X	X		X	X		Horizon.					
15	Availabilty of spare parts	X						X	X							
16	Maintanence	X	X	X		X		X	X			X				
17	Upgradability							X	X			X				
18	Disassembly	X	X					X	X			X				
19	Reusability	X	X			X		X	X	X		X	X		2.2	
20	Repurpose											X				
21	Repairability	X	X					X	X	X		X				
22	Refurbishment							X	X							
23	Remanufacturing							X	X			X				
24	Recyclability	X	X			X		X	X	X		X	X		2.2	
25	Energy recovery	X						X	X	X		X	X		2.2	
26	Waste code (EWC)	X	X							X					2.2	
27	Substances of concern (SoC)	X	X		X	X		X	X	X		X	X			
28	Possible outlets	X		X		X				X		X	X		2.2	
29	Recommended outlet														2.2, 2.4	

A.6. CONTRIBUTION TO EU CDW MANAGEMENT PROTOCOL GUIDELINES

An extension of CE R-strategies in the decision-making process on the formulation of the inventory and management recommendations in EU CDW Management Protocol [29]

