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Development of a Roadmap for Materials Passport Creation

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Preface

What an incredible journey it has been.

I extend my deepest gratitude to the case company and its CEO for providing me with this invaluable opportunity. I am also immensely thankful to all the stakeholders and informants who generously shared their knowledge and insights. Additionally, I express my heartfelt appreciation to all the wonderful individuals I have had the privilege to meet along this journey.

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Above all, I am most thankful to my mother, brother, and sister for their unconditional support of my dreams, and to my niece and nephew for being the source of my joy and strength. I could not have achieved this without you by my side, even though you are far away.

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Kirkkonummi

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Abstract

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This thesis explores the development of a roadmap for implementing a Materials Passport feature within a Software-as-a-Service (SaaS) company specialising in cloud software for the construction sector. The case company's platform, renowned for its automated life cycle assessment (LCA) capabilities, caters to a global clientele including architects, engineers, contractors, and sustainability consultants. However, the absence of a Materials Passport (MP) feature poses a significant challenge in aligning with circularity principles and impending EU regulations mandating Digital Product Passport (DPP).

The objective of this study is to create a strategic roadmap tailored to integrate a Materials Passport module into the company's existing offering. Through a meticulous research approach comprising review of related literature, current state analysis, stakeholder interviews, and data analysis, key strengths and critical pinch points were identified. Leveraging these insights, a comprehensive roadmap was co-created with stakeholders, adhering to specific, measurable, achievable, relevant, and time-bound goals, and comprising phases such as research, framework development, stakeholder engagement, pilot testing, implementation, and continuous improvement. The initial roadmap underwent validation, garnering positive feedback and affirming its viability in addressing the business challenge. Ultimately, this thesis provides a structured roadmap for the seamless integration of a Materials Passport within the case company's offering.

Keywords: Materials Passport, Circular Economy, Sustainability, Construction, Built-Environment, Roadmap Development, Regulatory Compliance, Data Management, Digital Record

Contents

Preface

Abstract

Table of Contents

List of Figures

List of Tables

Table of Contents

1	Introduction	1
1.1	Business Context	2
1.2	Business Challenge, Objective, and Outcome	3
1.3	Scope and Outline of the Study	3
2	Project Plan	4
2.1	Research Approach	4
2.2	Research Design	5
2.3	Data Plan and Collection	7
3	Review of Related Literature	10
3.1	Overview of Sustainability and Circular Economy in the Built Environment	10
3.1.1	Circular Economy	11
3.1.2	Circularity	13
3.2	Best Practices on Digital Record and Traceability Measures	14
3.2.1	Definition of Digital Product Passport (DPP)	14
3.2.2	Definition of Materials Passport (MP)	16
	Proposal and Recommendations for Roadmap to MP Adoption	18
3.2.3	Insights on Parameters for Materials Passport Creation	21
3.2.4	Insights on Frameworks for Materials Passport Creation	24
	Life Cycle Assessment (LCA)	24
	Environmental Product Declaration (EPD)	26
	Building Information Modelling (BIM)	27
3.2.5	Insights on Circular Construction Principles and Practices	29
	The 9R Framework	29
	Design for Disassembly and Deconstruction (DfD)	31

Design for Adaptability and Renovation (DfA)	32
Design for Longevity (DfL)	33
3.2.6 Insights on Plan for Technology Changes and Adoption Measures	34
3.3 Best Practices on Data Management Strategies	36
3.3.1 Insights on Data Requirements	37
3.3.2 Insights on Data Gap Identification and Integration	38
3.3.3 Insights on Database Creation	40
3.3.4 Insights on Physical Passporting Strategy	43
3.3.5 Insights on Data Collaboration Across Value Chain	43
3.4 Best Practices on Regulatory Landscape Initiatives	46
3.4.1 Insights on Compliance	46
3.4.2 Insights on Regulatory Shaping Initiatives	48
3.4.3 Insights on Adapting to Policy Changes	50
3.4.4 Timeline for DPP Implementation	52
3.5 Conceptual Framework	53
4 Current State Analysis	55
4.1 Overview of the Current State Analysis	55
4.2 Assessment of the Case Company's Software Offerings	56
4.2.1 Digital Record and Traceability Capabilities	59
4.2.2 Data Management Capabilities	61
4.2.3 Regulatory Landscape Capabilities	62
4.3 Summary of Key Strengths and Critical Pinch Points	63
5 Developing the Initial Roadmap	65
5.1 Introduction to Roadmap Development	65
5.2 The Roadmap Development	66
5.2.1 Digital Record and Traceability Measures	66
5.2.2 Data Management Strategies	68
5.2.3 Regulatory Landscape Initiatives	69
5.3 The Initial Roadmap	70
6 Validating the Initial Roadmap	74
6.1 Overview of the Validation Stage	74
6.2 Evaluation of the Initial Roadmap	74
6.3 Suggestions for Improvement to the Initial Roadmap	75

6.4	The Final Roadmap	77
7	Conclusion	80
7.1	Executive Summary	80
7.2	Practical Next Steps Recommendations	81
7.3	Self-Evaluation of the Thesis	82
7.4	Closing Words	83
	References	83

List of Figures

	Figure 1. Research Design of this Study.	6
	Figure 2. Overview of Construction Sector's Environmental Impact. (Own Illustration)	11
	Figure 3. The Circular Economy Systems Diagram. (The Ellen MacArthur Foundation, 2019. Drawing based on Braungart and McDonough)	12
	Figure 4. Example of a Digital Product Passport for the Automotive Industry. (Circularise, 2024)	15
	Figure 5. The BAMB Materials Passport Platform Prototype. (BAMB, 2020)	17
	Figure 6. A Part Example of a Materials Passport Vision by ORMS. (ORMS, 2021)	18
	Figure 7. Costa and Hoolahan's (2024) Proposal and Recommendations for Roadmap to Materials Passport Adoption.	19
	Figure 8. BAMB Materials Passport Overview. (Heinrich and Lang, 2019a)	23
	Figure 9. Life Cycle Stages. (One Click LCA, 2023)	25
	Figure 10. BIM-Based Workflow for the Generation of a Materials Passport. (Adapted from Honic et al. 2019a)	28
	Figure 11. The 9R Framework. Adapted from Potting et al. (2017)	31
	Figure 12. Four Actions with Immediate Next Steps to Prepare for the DPP. (BCG & WBCSD, 2023)	34
	Figure 13. Building a Database Flow Chart. (Costa and Hoolahan, 2024)	42
	Figure 14. Industry Enablers and Collaboration Across Value Chain. (UKGBC, 2023)	44

Figure 15. Actions to Adapt to Policy Changes. (BCG and WBCSD, 2023)	51
Figure 16. Timeline of Actions and Initiatives Related to the Introduction of Materials Passport. (Own Illustration)	52
Figure 17. The Conceptual Framework of this Study.	53
Figure 18. Schematic Diagram of the Case Company's Platform Offering as of March 2024. (Own Illustration)	57
Figure 19. Draft Proposal Under Digital Record and Traceability.	67
Figure 20. Draft Proposal Under Data Management.	68
Figure 21. Draft Proposal Under Regulatory Landscape.	69
Figure 22. The Initial Roadmap Co-Creation Process.	71

List of Tables

Table 1. Data 1 Collection for Initial or Starting Point Analysis.	8
Table 2. Data 2 Collection for Initial Proposal Stage.	9
Table 3. Data 3 Collection for Validation Stage.	9
Table 4. Input Parameters for (Circular) Materials Passport. (Göswein et al., 2022)	22
Table 5. An Extract from an EPD Data of a Light Brick. (Wienerberger Oy Ab, 2021)	27
Table 6. Overview of Identified DPP Systems Requirements. (Jansen et al., 2023)	38
Table 7. MP Framework to Address Identified Data Gaps. (Çetin et al., 2023)	39
Table 8. Recommended Sources of Material Information for Passport Creation. (Own Illustration)	40
Table 9. Success Factors and Gaps in Policy Making. (Sharp, J. et al., 2019)	47
Table 10. A Blueprint to Enable a Circular Built Environment. (Sharp, J. et al., 2019)	48
Table 11. Summary of Key Strengths and Critical Pinch points of the Study.	64
Table 12. The Initial Roadmap for Materials Passport Creation.	73
Table 13. Changes Made to the Initial Recommendations.	76
Table 14. The Final Roadmap.	78

1 Introduction

The United Nations Brundtland Commission defines sustainability as meeting present needs without compromising the ability of future generations to meet their own. In this framework, the architecture, engineering, and construction (AEC) industry emerge as crucial product value chains, playing a pivotal role in addressing sustainability and circular economy concerns. The industry contributes 5-12% of total national GHG emissions, generates 35% of all waste in Europe (Circular Building Coalitions, 2023), and is the largest global consumer of raw materials, contributing to 25–40% of the world's carbon emissions (WEF, 2016a) and 25% of total global solid waste (Yeheyis et al., 2013). Despite circular economy principles gaining traction in various sectors, the AEC industry is lagging behind.

The imperative of sustainable development has led to a pressing need for integrating circular economy principles in the AEC industry. Industries globally, including construction, grapple with the challenge of enhancing resource efficiency and minimising environmental impact.

The urgency for a circular economy in the construction industry is underscored by initiatives such as the 2018 Nordic Council of Ministers project, aiming to accelerate the transition toward circularity in the Nordic countries. Their report highlighted key instruments for this transition, and one of them is Materials Passport and/or Building Passport. From a lifecycle perspective, the construction sector's impact on global resources and landfill waste production is substantial (Badi and Murtagh, 2019). Efforts to address these challenges involve the adoption of practices such as Life Cycle Assessment (LCA) (Akanbi et al., 2018), and Materials Passport (MP) (Honic et al., 2019), among others. The European Commission (EC) leads the way, aiming for the mandatory implementation of Digital Product Passport (DPP) across diverse products and industries. The EC targets the final approval of the Ecodesign for Sustainable Products Regulation (ESPR), inclusive of the DPP, by 2024. This initiative signals a transformative

shift toward sustainability within product lifecycles, setting the stage for digital passports as integral components of future regulatory frameworks.

The Materials Passport (MP), focusing on the construction sector, emerges as a transformative tool guiding the AEC industry toward a more sustainable future. Beyond enabling resource traceability, it assumes a crucial role in fostering circularity — an increasingly pivotal concept embraced by businesses, policymakers, and the construction industry. As the AEC industry adapts to the demands of a circular economy, the creation and implementation of Materials Passport emerge as vital tools.

This thesis proposes a roadmap for the creation of Materials Passport, incorporating key sustainability and circularity concepts. Its aim is to address the practicalities of integrating Materials Passport into the case company's current offering.

1.1 Business Context

The subject of this thesis is a Finnish Software-as-a-Service (SaaS) company that specialises in the development of cloud software for the construction sector. This innovative platform is designed to be user-friendly and features automated life cycle assessment (LCA) capabilities. The software serves a diverse range of professionals, including architects, engineers, designers, contractors, manufacturers, investors, and sustainability consultants. Its primary function is to assist users in calculating and mitigating the environmental impacts associated with various projects, such as building construction, infrastructure development, and manufacturing. Moreover, it facilitates the creation of Environmental Product Declarations (EPD) for building materials.

This sophisticated software enables users to perform Whole Building Life Cycle Assessments efficiently and rapidly, thanks to its seamlessly automated processes. Since its establishment in 2001, the company has expanded its reach to over 130 countries. It is crucial to note that the incorporation of a Materials Passport (MP) feature is fundamental for a company of this nature, specialising

in life cycle assessment. This addition enhances the platform's capacity to provide a more comprehensive analysis, aligning with the company's commitment to sustainability and circularity in the construction industry. At the time of writing, the author does not work for the case company.

1.2 Business Challenge, Objective, and Outcome

The case company currently provides a comprehensive offering of sustainability and circularity assessment tools, accessible to a global subscriber base. However, a notable business challenge has emerged due to the absence of an inclusive Materials Passport (MP) feature. This absence impedes circular alignment and resource traceability, a concern accentuated by the impending European Union (EU) regulations mandating Digital Product Passport (DPP) for a wide array of products. To overcome this challenge, the case company aims to integrate a Materials Passport module into its circularity offering. However, the necessary process has not yet been established. This addition has the potential to retain existing clients and attract new ones, ultimately leading to potential revenue addition.

The objective of this thesis is to develop a roadmap specifically tailored for the creation of a Materials Passport. In the following chapters, the thesis explores foundational principles and look into data management aspects of Materials Passport, while dissecting the regulatory landscapes that underscore their relevance in the construction sector. In the thesis' conclusion, a strategic roadmap is presented for creating a Materials Passport tool, enabling its integration into the company's existing offering.

1.3 Scope and Outline of the Study

The study is focused on analysing the current state of the case company's existing tools and platform and ultimately proposing a roadmap. This study does not include the software prototyping, pilot testing, or the actual implementation of the proposal due to the significant time required for these processes.

The research is structured into 7 sections. It commences with an introduction followed by Section 2, which delineates the project plan, the selected research methodology, the research design, and the approach to data collection. Section 3 examines related literature concerning the development of a roadmap for Materials Passport creation and outlines the conceptual framework. Section 4 discusses and summarises the findings derived from the analysis of the current state. Section 5 presents an initial proposal for the creation of a Materials Passport (MP) roadmap. The validity of this initial proposal, formulated in Section 5, will be assessed in Section 6. The final section of the thesis provides conclusions alongside an executive summary, as well as self-evaluation and concluding remarks. The subsequent section delineates the project plan, the selected research methodology, and the data collection methods.

2 Project Plan

The preceding section introduced the business challenge, objectives, and outcome. The current section discusses the implementation of the research, which includes the chosen research approach and the rationale behind it. Subsequently, it presents the research design, delineating its various stages. Finally, it addresses the methods employed for data collection and analysis.

2.1 Research Approach

To achieve the objective of this thesis, the first consideration is selecting the most appropriate research approach. In research, two primary types are distinguished: basic research and applied research (Saunders et al., 2012). Basic research contributes to theory without immediate applicability, while applied research directly addresses specific problems, implementing findings to solve them (Bajpai, 2011). Kothari (2004) emphasises that applied research aims to identify solutions for problems in real-time within industrial or commercial settings.

Applied research, as highlighted by Saunders et al. (2012), focuses on business or management issues, aiming for practical solutions. It operates within tight time

frames and addresses specific objectives set by the organisation facing the problem. Kananen (2013) supports this idea, asserting that applied research combines development and research to produce practical solutions for current issues in real organisations.

On the other hand, a research approach involves how a research problem is tackled. Different research methodologies, often combining qualitative and quantitative data, are chosen based on criteria such as the relationship between theory and practice, research purpose, types of questions, and response formats (Kananen, 2013). The choice between qualitative, quantitative, or mixed research methods is another consideration. Quantitative methods involve numerical data and statistical analysis, while qualitative methods deal with non-numerical data to capture ideas, opinions, or experiences (Bhandari, 2020).

For this thesis, an applied action research approach with a qualitative data collection method was selected, aligning with the objective of creating a roadmap for Materials Passport (MP) creation. The chosen design research approach prioritises understanding and addressing challenges without the immediate implementation or evaluation of the proposed roadmap.

2.2 Research Design

This study comprises four stages. The steps required to accomplish the study's objective and formulate the outcome have been structured into these four stages. Figure 1 illustrates the research design stages in this study.

The objective of this study is to create a roadmap for the creation of a Materials Passport (MP). To progress towards the desired outcome, a systematic arrangement of phases is devised after establishing the research approach. These four (4) stages are depicted in Figure 1 below, outlining the research design of this project.

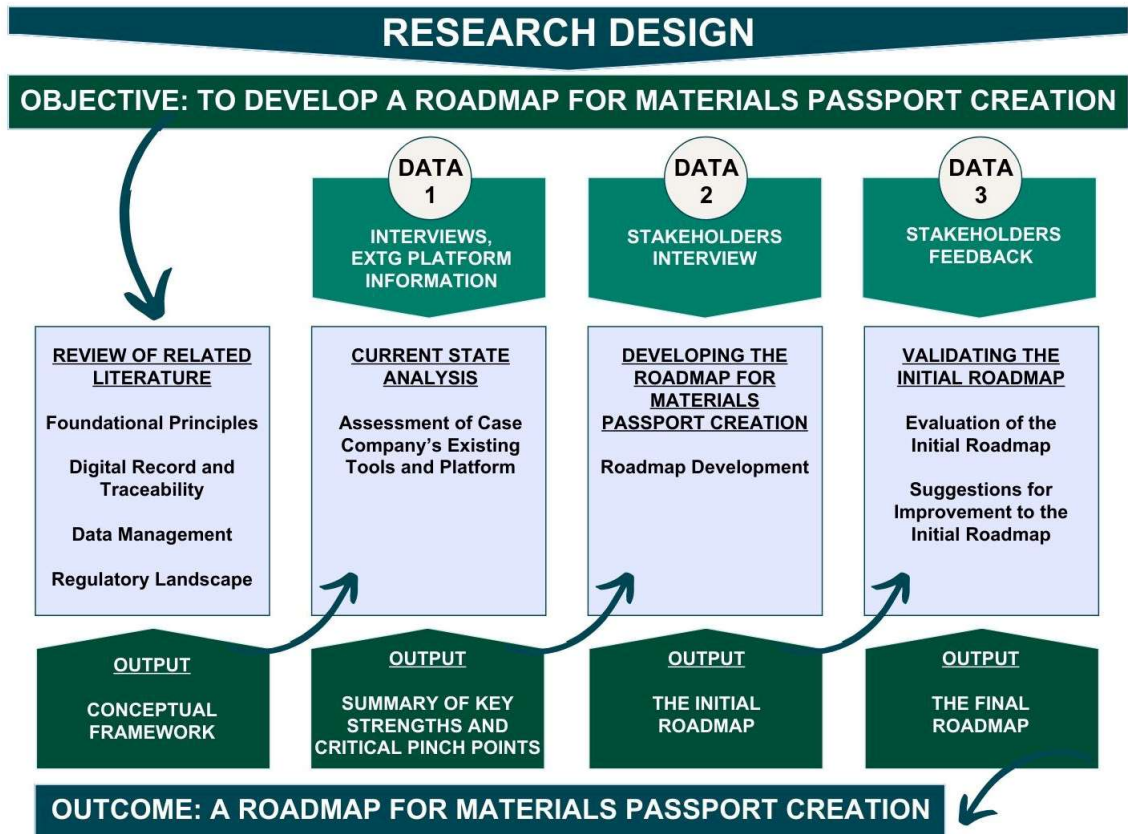


Figure 1. Research Design of this Study.

In Figure 1, Stage 1 involves the review of related literature. This stage entails acquiring crucial information about Materials Passport (MP) and their creation, as well as the foundational principles behind them, along with relevant information about regulations and data management from various sources such as studies, academic journals, articles, and literature. The collected information is then analysed and transformed into a conceptual framework, laying the groundwork for the initial analysis of the roadmap for Materials Passport creation.

Stage 2, as depicted above, represents the initial or starting point for the current state analysis. This stage involves conducting interviews with stakeholders based on the conceptual framework. Through interviews, document reviews, and an assessment of the case company's existing tools, platforms, and industry practices, key components and requirements for the roadmap are gathered and analysed. The findings are summarised to develop the initial proposal for the roadmap for creating Materials Passport.

Stage 3 involves crafting the initial proposal for developing the roadmap for Materials Passport creation. By leveraging interviews, workshops, and insights gathered from the key strengths and critical pinch points identified in the previous stage, the roadmap is formulated. The outcome of this stage is the initial proposal for the Materials Passport creation roadmap.

Stage 4, depicted in Figure 1, is the validation of the initial proposal. The completed initial action plan proposal is presented to the stakeholders, who provide comments, feedback, and suggestions for improvement. These recommendations are then utilised to refine and adjust the initial roadmap proposal, representing the final output of the study.

2.3 Data Plan and Collection

To reach the objective of this research, which is the development of a roadmap for Materials Passport (MP) creation, essential information needs to be gathered. The data for this study resulted from interviews with relevant stakeholders, conducted in three rounds. An overview of the collected data 1-3 is presented in Tables 1, 2, and 3.

DATA 1					
No.	Approach	Informant / Source	Date of Interview	Time	Documentation
1	Document	Access to Software, Website, and Online Reviews	-	-	Field Notes
2	Online Interview	Co-Founder and CTO - 3D Concrete Printing Company, Finland	12/01/2024	16:09 - 16:37	Field Notes, Transcripts, Recordings
3		Business Developer Engineer, Finland	09/02/2024	13:28 - 14:00	Field Notes, Transcripts, Recordings
4		Materials Specialist and Business Developer, Spain & Latin America	09/02/2024	13:29 - 14:00	Field Notes, Transcripts, Recordings
5		Doctoral Researcher - Mineral Based Materials and Mechanics, Finland	09/02/2024	17:24 - 17:58	Field Notes, Transcripts, Recordings
6		Project Engineer - Steel Structures, Finland	09/02/2024	18:25 - 19:01	Field Notes, Transcripts, Recordings
7		QIM, LCA, and Digitalisation Expert, Finland	09/02/2024	14:55 - 15:26	Field Notes
8	In-Person Interview	Architect, Finland	11/02/2024	19:45 - 20:15	Field Notes
9	Email Correspondence	PhD Researcher - Sustainability, UK	23/02/2024	-	Email
10	Virtual Conference (Webinar)	Reuse Now Campaign Lead, UK Associate Sustainability Consultant, UK Managing Director, UK Co-Founder and CPO, UK Associate, UK Senior Lecturer in Architecture, UK Director, UK	01/02/2024	14:30 - 16:00	Field Notes

Table 1. Data 1 Collection for Initial or Starting Point Analysis.

Data 1 as shown above, includes the initial round of data collection, comprising information gathered from interviews and the case company's software and website. The collected data corresponds with the conceptual framework established for this study. This round of data collection is divided into two main parts. Initially, it involves identifying the capabilities and challenges of the existing software offering, obtained by accessing the company website, documents, and the software itself, along with online reviews. The second part involves gathering expert opinions and discerning future target customer needs, primarily sourced from industry professionals and specialists.

DATA 2					
No.	Approach	Informant / Source	Date of Interview	Time	Documentation
1	Online Interview, Email Correspondence	Materials Specialist and Business Developer, Spain & Latin America	08/03/2024	10:55 - 11:15	Field Notes, Transcripts, Recordings, Email
2	Online Workshop	Doctoral Researcher - Mineral Based Materials and Mechanics, Finland	11/03/2024	17:09 - 17:41	Field Notes, Transcripts, Recordings
3		Project Engineer - Steel Structures, Finland			
4		Architect, Finland			

Table 2. Data 2 Collection for Initial Proposal Stage.

In the second round of data collection, Data 2 is gathered through an interview and a workshop aimed at co-creating the initial roadmap proposal. However, due to time differences and geographical constraints, organising a complete workshop with all relevant informants was not feasible. Email inquiries were also utilised for follow-up and additional sharing of information.

DATA 3					
No.	Approach	Informant / Source	Date of Interview	Time	Documentation
1	Online Interview, Email Correspondence	Materials Specialist and Business Developer, Spain & Latin America	09/04/2024	10:59 - 11:16	Field Notes, Transcripts, Recordings, Email
2	In-Person Workshop	Doctoral Researcher - Mineral Based Materials and Mechanics, Finland		17:30 - 18:03	Field Notes
3		Project Engineer - Steel Structures, Finland			
4		Architect, Finland			

Table 3. Data 3 Collection for Validation Stage.

The third and final round of data collection, as illustrated in Table 3 above, focuses on validating the initial proposal. Discussions with stakeholders aim to gather feedback on the initial roadmap. The received recommendations are then used to refine and finalise the ultimate roadmap for Materials Passport creation.

This section has outlined the research approach, research design, and data collection process. The subsequent Section 3 will delve into the findings from related literature, which will serve as the conceptual framework for conducting the initial or starting point for the current state analysis.

3 Review of Related Literature

In the contemporary discourse surrounding sustainable development, the Architecture, Engineering, and Construction (AEC) industry has emerged as a crucial sector for implementing circular economy principles and adopting innovative tools like Materials Passport. This section explores the intersection of Materials Passport and the circular economy within the AEC industry, exploring their role in resource efficiency and traceability. The conceptual framework guiding this study includes foundational principles, digital record and traceability, data management, and an understanding of the regulatory landscape.

3.1 Overview of Sustainability and Circular Economy in the Built Environment

The construction sector in the European Union (EU) is a major contributor to resource consumption and carbon emissions, facing sustainability challenges and environmental impacts. Given that the construction sector contributes substantially to worldwide carbon emissions and material consumption, decarbonising the building stock is critical, especially with the expected growth in the urban built environment by 2050 and rising demand for housing needs. Carbon emissions in buildings occur throughout their lifecycle, including operational and embodied carbon, with efforts to enhance energy efficiency only addressing part of the issue. Recognising the importance of reducing embodied carbon is crucial for effective climate change mitigation in the building industry.

In Europe, the construction sector consumes many materials making the implementation of circular economy principles essential for resource management. This approach offers economic, environmental, and societal benefits, contributing to the decarbonisation of the built environment and enhancing resource productivity and asset utilisation. As global economic expansion strains Earth's natural resources, governments, including the EU, are prioritising resource, climate, and biodiversity concerns in their policy agendas. The EU's Green Deal emphasises resource productivity, innovation, and efficient resource use, with a focus on promoting a Circular Economy to maximise

resource value, extend product lifecycles, and prevent waste. Despite its vital role in economic activity, the construction industry faces sustainability challenges due to its significant environmental footprint, accounting for a third of global material consumption since 1970. Figure 2 shows an overview of Construction Sector's Environmental Impact.

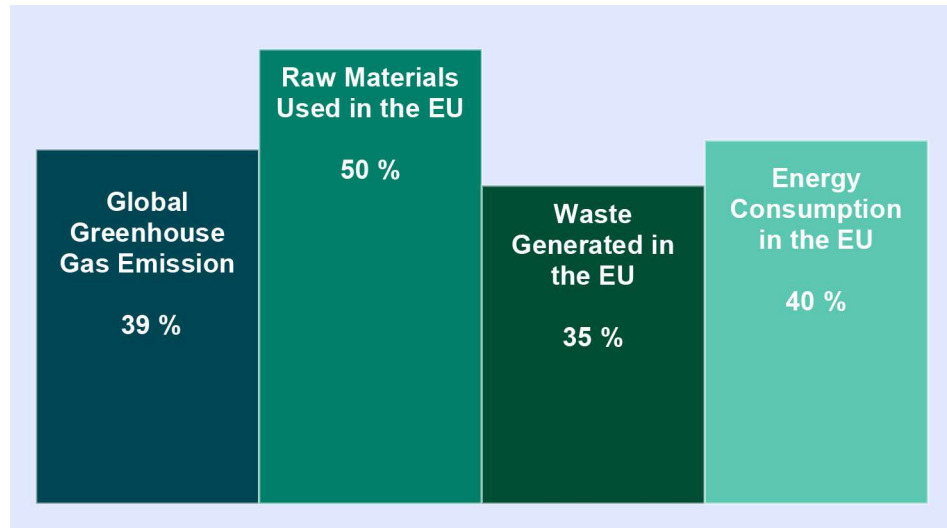


Figure 2. Overview of Construction Sector's Environmental Impact. (Own Illustration)

Figure 2 above provides an overview of the environmental impact of the construction sector, highlighting key metrics such as global greenhouse gas emissions, raw material usage, waste generation, and energy consumption. Each percentage value represents the sector's contribution to the respective environmental aspect, offering insight into its overall environmental footprint.

3.1.1 Circular Economy

The Circular Economy (CE) model lacks a universally standardised definition however, various prominent organisations converge on similar conceptual foundations. It is described as an industrial system aimed at operating within planetary boundaries, creating value by prolonging the lifespan of existing resources and minimising virgin resource use and waste. In contrast to the Linear Economy (LE) model, which follows a "make-take-waste" approach (Saidani et

al., 2017), the Circular Economy (CE) rejects this linear approach. Advocated as an alternative approach under the EU's Green Deal, the CE model tackles issues linked to limited resources and climate change by decoupling economic growth from the consumption of finite resources. Its principles involve minimising resource usage, prolonging product durability, recycling materials, and favouring sustainable production methods. These efforts aim to diminish resource consumption, waste generation, and emissions while underscoring the long-term value of products and materials. What unites these definitions is the CE's unique ability to align sustainable development with economic advantages, which includes benefits such as value generation and cost savings through decreased resource utilisation, environmental advantages such as reduced impact, and social benefits such as employment opportunities (Saidani et al., 2017). The overarching objective of the CE is sustainable development done through enhanced resource efficiency via circularity, demanding a systemic shift in resource use. The Ellen MacArthur Foundation provided a diagram that best represents the Circular Economy Systems which is shown in Figure 3 below.

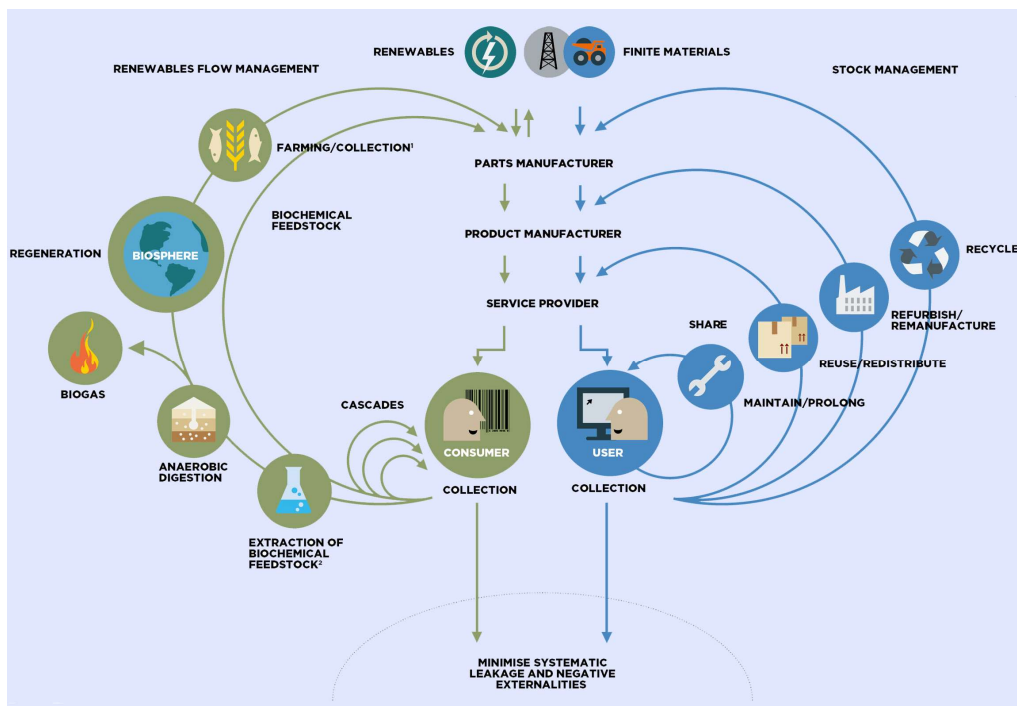


Figure 3. The Circular Economy Systems Diagram. (The Ellen MacArthur Foundation, 2019. Drawing based on Braungart and McDonough)

Figure 3 illustrates how resources flow through the economy in a continuous loop, rather than being used once and discarded. It highlights the pro of designing products, processes, and business models that promote reuse, repair, and recycling to minimise waste and environmental impact while maximising resource efficiency and value creation.

3.1.2 Circularity

Circularity refers to the extent of restoration in the flow of resources and can be evaluated across various systemic levels. These levels encompass the macro level (city, province, region, nation), meso level (eco-industrial parks), micro level (individual companies or consumers), and nano level (buildings, products, components, and materials) (Saidani et al., 2017). The interaction among these levels is critical, as higher levels depend on the functioning of lower ones. Initiating a transition toward a Circular Economy (CE) requires transformative actions at each of these levels. At the nano level, circularity involves two primary aspects: circular material usage and circular design (Geldermans, 2016).

Circular material usage entails selecting materials based on their circularity, emphasising renewability (biological cycles) or reusability after initial use (technical cycles). Circular design involves creating and manufacturing products and components that can be easily disassembled at the end of their lifecycle, facilitating their reuse or recycling in new contexts. In the context of buildings, circularity can be assessed on a scale ranging from 100% linear to 100% circular, serving as a singular attribute indicative of building quality. (Linder et al., 2017)

In terms of product design and life-cycle management, CE requires stakeholders across value chains to access high-quality information for decision-making. Scholars suggest that the existing building stock could serve as a source of materials for future construction or renovations by disassembling products and materials from one building and reusing or recycling them in another. However, the lack of information on materials in buildings, stemming from inadequate documentation, poses challenges to implementing reuse or recycling practices in construction. To bridge this information gap, the idea of material passports (MPs)

has been proposed, offering comprehensive details regarding a product's source, composition, disassembly potential, and end-of-life options.

3.2 Best Practices on Digital Record and Traceability Measures

A range of techniques and approaches are utilised to promote the incorporation of sustainability and circularity principles within the Architecture, Engineering, and Construction (AEC) industry. These include tools such as Life Cycle Assessment (LCA), Renewable Energy Certificates (REC), Material Flow Analysis (MFA), and Environmental Product Declarations (EPD). According to Hossain and Ng (2018), Life Cycle Assessment (LCA) has gained widespread application due to its thorough assessment of the environmental effects of buildings and the built environment over their complete life cycle. Meanwhile, Circularity Passports, also known as Digital Product Passport (DPP) or Materials Passport (MP) specifically tailored for the construction industry, are gaining traction as crucial policy tools aligning with the Circular Economy objectives of the European Union, as noted by Çetin et al. (2023).

The following explores into the crucial insights surrounding measures essential for the creation of Materials Passport, beginning with defining both Digital Product Passport (DPP) and Materials Passport (MP) at lengths, before exploring the various insights, parameters, roadmap proposals, and recommendations from best practices.

3.2.1 Definition of Digital Product Passport (DPP)

Solita and Gaia Consulting (2022) conducted research on the Digital Product Passport (DPP), which is a technological concept aiming to serve as a digital policy tool. The DPP gathers comprehensive information regarding various aspects of products, including their value chain, sustainability, raw materials, and safety, spanning across different industries. Additionally, the DPP has the potential to capture data on product usage, maintenance, recycling, and repurposing. This transparency is intended to promote sustainable manufacturing practices, facilitate the transition to a circular economy, create new business

opportunities, assist authorities in verifying compliance, and empower consumers and end-users to make environmentally conscious choices.

The Digital Product Passport (DPP) forms an integral part of the European Commission's latest circular economy package. Its primary aim is to facilitate the exchange of crucial product-related information essential for enhancing the sustainability and circularity of products among all relevant economic stakeholders. By doing so, the DPP aims to expedite the transition towards a circular economy by bolstering material and energy efficiency, prolonging product lifespans, and refining the design, manufacturing, usage, and end-of-life processes of products. Additionally, the DPP seeks to create fresh opportunities for economic actors by promoting circular value retention and optimisation. This includes initiatives such as product-as-a-service models, improved repair, maintenance, remanufacturing, and recycling, all enabled by better data accessibility. Furthermore, the DPP intends to assist consumers in making sustainable choices by providing transparent information about products' sustainability and circularity aspects. An example of DPP is shown in Figure 4 below.

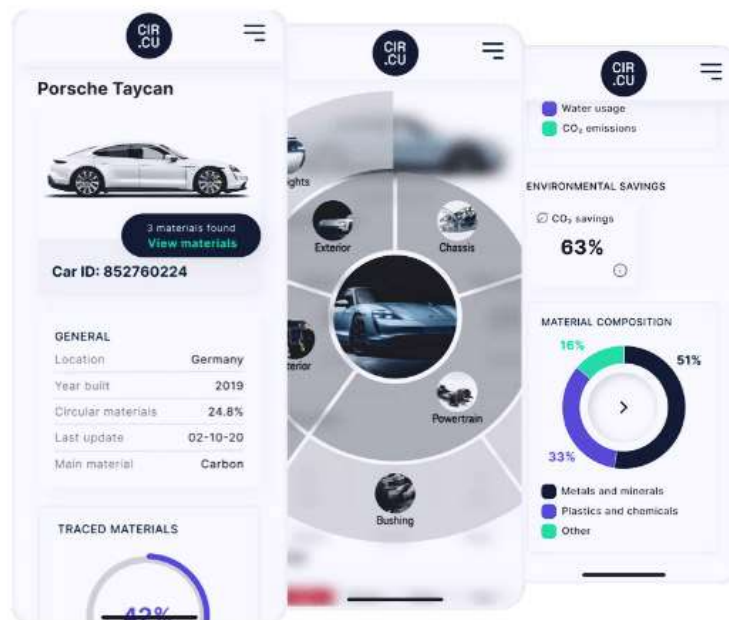


Figure 4. Example of a Digital Product Passport for the Automotive Industry. (Circularise, 2024)

Figure 4 depicts Circularise's Digital Product Passport (DPP) designed for the automotive sector. This innovative passport utilises a blockchain traceability platform to store data across the entire automotive value chain, facilitating the realisation of a sustainable, responsible, and circular automotive industry. Circularise, a Dutch software provider specialising in supply chain transparency, leverages blockchain technology to enable the widespread adoption of circular economy principles within the automotive sector.

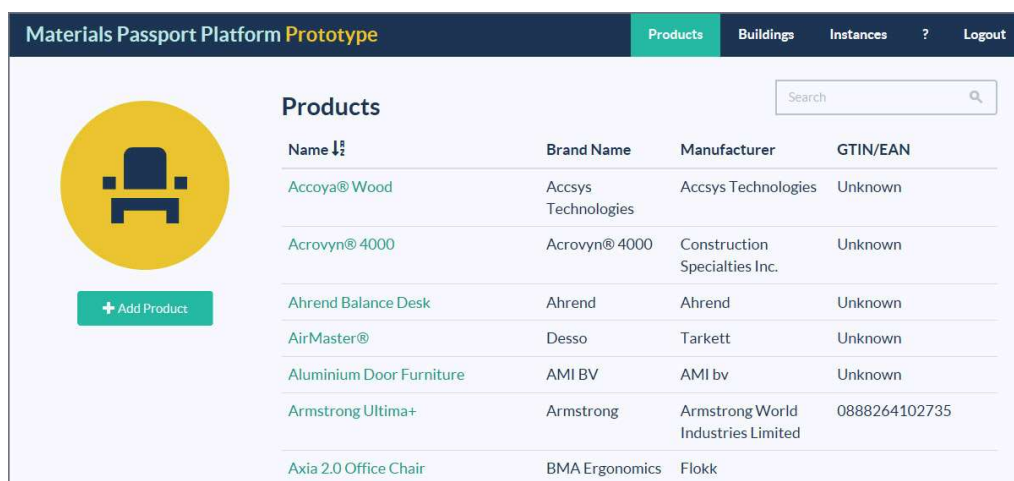
3.2.2 Definition of Materials Passport (MP)

The Circular Economy (CE) is seen as a viable strategy for achieving sustainable production and consumption of the Earth's resources. However, successful implementation of CE hinges on having comprehensive information about materials across various lifecycle phases. A promising solution to tackle this challenge involves leveraging digital technologies to establish a digital identity for materials, known as the Materials Passport (MP). Panza et al. (2022) added that MP can be conceptualised as a digital information system where stakeholders in the value chain input all the necessary material-related information, thereby ensuring transparency throughout the material's lifecycle.

Various terms are utilised to refer to passports, including Data Templates (Mêda et al., 2021), Product Circularity Data Sheets (Mulhall et al., 2022), Materials Passport (Heinrich and Lang, 2019), Digital Product Passport (Jansen et al., 2022), Digital Battery Passports (Berger et al., 2022), and Circular Materials Passport (Göswein et al., 2022). Certain passport initiatives, like the Product Circularity Sheet (Mulhall et al., 2022), aim to serve diverse industries, while others have a specific focus, such as Digital Battery Passports (Berger et al., 2022) tailored for the automotive sector. A Materials Passport is a digital dataset containing product-related information, specifically designed for the construction industry. It facilitates registration, processing, and sharing among businesses, authorities, and consumers. The passport offers a diverse set of information, including origin, material composition, disassembly possibilities, and end-of-life options. It is also proposed as a unique identifier providing life cycle data for value chain actors. Its recent attention from policymakers, including the European

Commission (EC), underscores its potential implementation in various policy proposals.

To achieve these goals, access to high-quality and verifiable product information throughout the lifecycle is crucial. Projects like the EU-funded Horizon 2020 initiative "Buildings as Material Banks" (BAMB) have been actively involved in this investigation, along with several other projects. According to BAMB (2020), a Materials Passport is an electronic dataset that describes the properties of materials within products, thus improving their potential for recovery or reuse. Furthermore, Madaster (2019) defines the Materials Passport as a digital record that identifies all construction materials used in a building. Another extensive definition, provided by Mullhall et al. (2017), characterises Materials Passport (MP) as digital datasets outlining specific attributes of materials and components within products and systems. These attributes confer value for current use, recovery, and reuse. Serving as an informational and educational tool, MPs address inquiries often overlooked by other documents or certifications related to building products, with a particular emphasis on product circularity. MPs do not independently assess data output and do not function as evaluators, instead, they offer information supporting assessments and certifications by other parties. Additionally, existing assessments and certifications can be incorporated into the passport as uploaded documents. Part of the BAMB Materials Passport (MP) platform prototype can be observed below in Figure 5.



Name	Brand Name	Manufacturer	GTIN/EAN
Accoya® Wood	Accsys Technologies	Accsys Technologies	Unknown
Acrovyn® 4000	Acrovyn® 4000	Construction Specialties Inc.	Unknown
Ahrend Balance Desk	Ahrend	Ahrend	Unknown
AirMaster®	Desso	Tarkett	Unknown
Aluminium Door Furniture	AMI BV	AMI bv	Unknown
Armstrong Ultima+	Armstrong	Armstrong World Industries Limited	0888264102735
Axia 2.0 Office Chair	BMA Ergonomics	Flokk	

Figure 5. The BAMB Materials Passport Platform Prototype. (BAMB, 2020)

The BAMB Materials Passport Platform Prototype, as depicted in Figure 5 above is a digital tool designed to track and manage the lifecycle of construction materials. It allows users to create and maintain passports for building materials, containing essential information such as composition, origin, and reuse potential. Another example of a Materials Passport is the one created by ORMS, an architectural firm in the UK, in collaboration with Lancaster University. It is depicted in Figure 6 below.



Figure 6. A Part Example of a Materials Passport Vision by ORMS. (ORMS, 2021)

Figure 6 illustrates ORMS's Materials Passport Vision, which outlines a strategy for tracking and managing building materials throughout their lifecycle. This vision aims to enhance sustainability in the construction industry by promoting the reuse, recycling, and responsible sourcing of materials.

Proposal and Recommendations for Roadmap to MP Adoption

Figure 15 below illustrates the evolution of materials passports in the Architecture, Engineering, and Construction (AEC) industry over the years. Based on this progression, Costa and Hoolahan (2024) have constructed a roadmap comprising proposals and recommendations for the efficient and effective utilisation of materials passports. The roadmap steps are enumerated in the following page.

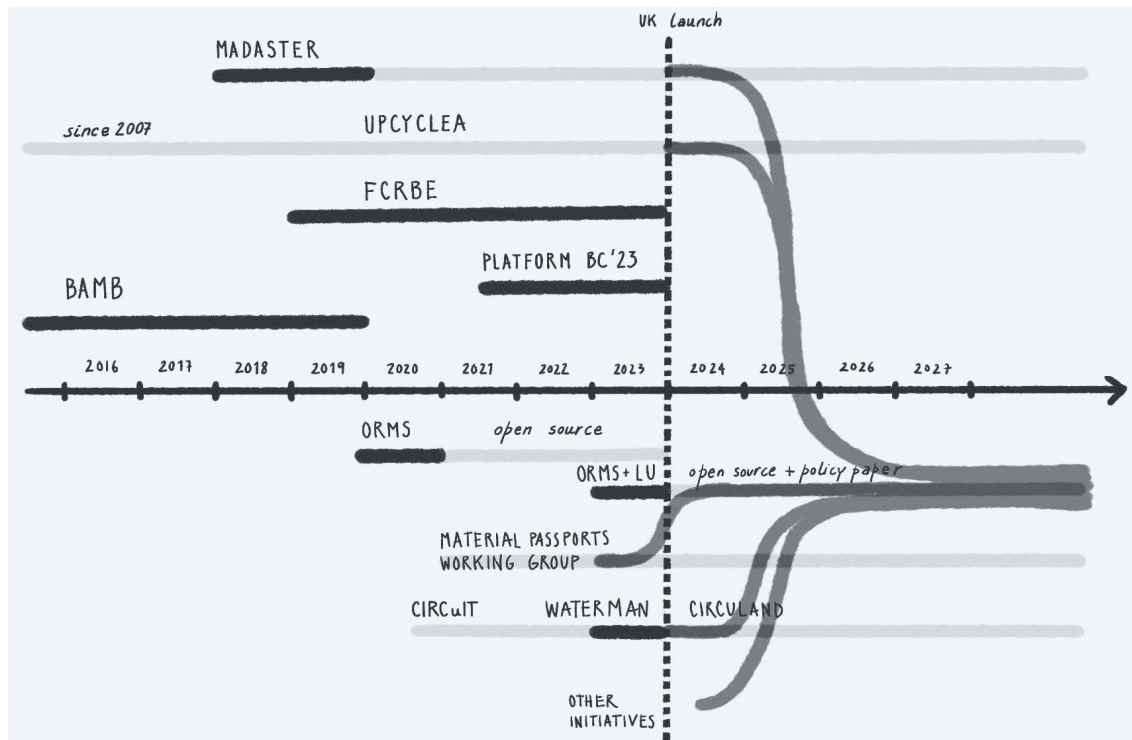


Figure 7. Costa and Hoolahan's (2024) Proposal and Recommendations for Roadmap to Materials Passport Adoption.

- 1) Implement materials passports as a fundamental requirement in every construction project. Utilise a standardised materials passports database template for semi-standardised data collection, enabling potential interoperability between platforms and accommodating various project constraints. (Costa and Hoolahan, 2024)
- 2) Foster collaboration among stakeholders to effectively implement materials passports and capitalise on their potential benefits. Align existing local authority materials reporting policies through consultation and coordination to support proposed standardisation. (Costa and Hoolahan, 2024)
- 3) Supplement project processes with open-source templates and tools applicable to projects of all scales and experiences. Utilise cloud-based database programs for organisation and linkage of digital passports to physical ones, with manual adjustments as per project requirements. (Costa and Hoolahan, 2024)

- 4) Utilise commercially available platforms for materials passports creation and storage, along with the Building Passport platform. Seek an interoperability agreement between these platforms to ensure seamless data portability, especially during building ownership changes. (Costa and Hoolahan, 2024)
- 5) Direct future research efforts towards materials passports data sharing and storage to address challenges and leverage digital technologies for efficient data collection. (Costa and Hoolahan, 2024)
- 6) Emphasise the transition towards a circular economy by treating materials as treasures and promoting material reuse, facilitated by widespread adoption of materials passports. (Costa and Hoolahan, 2024)
- 7) Address barriers such as cost, time, and risk hindering the full implementation of sustainability strategies in the construction industry. Establish feedback loops for data from buildings in use to address knowledge and performance gaps. (Costa and Hoolahan, 2024)
- 8) Encourage widespread adoption of materials passports through local policies, triggering collaboration among stakeholders and promoting sustainability initiatives. (Costa and Hoolahan, 2024)
- 9) Enable design teams to transparently demonstrate their ambition through manageable deliverables such as Materials Passports Strategy and Disclosure Page, facilitating consideration by local authorities during the planning process. (Costa and Hoolahan, 2024)
- 10) Pioneering project teams and clients can lead by adopting recommendations, while policymakers can support the evolution of materials passporting by welcoming these recommendations and collaborating with the industry. (Costa and Hoolahan, 2024)
- 11) Propose the inclusion of materials passports as key deliverables in every construction project from 2025 onwards, recognising the need for industry

upskilling, debate, and collaboration to establish best practices. Prioritise meaningful circularity strategies and material reuse in materials passports databases, even if they start small. (Costa and Hoolahan, 2024)

3.2.3 Insights on Parameters for Materials Passport Creation

In essence, a Materials Passport is a digital document housing data pertinent to the circular economy. This information is entered into and extracted from a centralised database in the shape of personalised reports that cater to the various requirements of users, as described by Luscuere and Mulhall (2017). According to Luscuere L. (2016), the Materials Passport's scope is oriented toward various hierarchical levels, encompassing materials, components, products, and systems constituting a building. At the material level, a Materials Passport may specify its recovery value. Concerning products and systems, it can outline general characteristics that render them valuable for recovery, such as their design for disassembly. Additionally, it can examine into the specifics of an individual product or system in its application, understanding how a product is linked to a building is crucial in determining its recovery value.

As per Göswein et al. (2022) model, the aim of Materials Passport extends beyond merely quantifying materials, it seeks to establish an identity for a specific product and attribute value to it, requiring a comprehensive array of diverse parameters. These parameters includes general information, the product's context in terms of usage and location, and its potential for circularity. Ultimately, the objective is to furnish ample details regarding the product's origins, purpose, identity, and quantity, as shown in Table 4 below.

Parameter	Description
Passport ID	Provides a unique number attributed to the CMP
Name	Identifies the name of the product
Category	Classifies the product into a particular category
Function	Describes the function(s) of the product
Manufacturer	Identifies the manufacturer of the product
Data source	Identifies the data sources used to create the passport
Parameter	Description
Building identification	Address and identification of building type in which product is installed/implemented
Installation date	Year of installation of the product
Location	Specific location of the product within the building
Service lifespan	Expected service lifespan of the product
Maintenance	Information about the best maintenance to extend the product's service lifetime
End-of-life	Estimate of end-of-life occurrence
Parameter	Description
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.
Disassembly instructions	Provides additional information for the material or product disassembly at the end-of-life for quality assurance
Quantity	Indicates the weight of the product or of its components
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.
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.
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.

Table 4. Input Parameters for (Circular) Materials Passport. (Göswein et al., 2022)

Table 4 presents an example of Input Parameters for Materials Passport which shows the product's overall data in the first section, particularly focusing on its technical details. Following this, the second segment shows the current products within a structure, detailing their usage and origin to assess their potential for

future reuse and recovery. Lastly, the third section outlines the possibilities for reusing, recovering, and recycling of the materials.

On the other hand, Heinrich and Lang (2019a) provided one of the first comprehensive overview of information requirements or parameters of Materials Passport categorised into physical, chemical, biological and process-related properties in Figure 8.

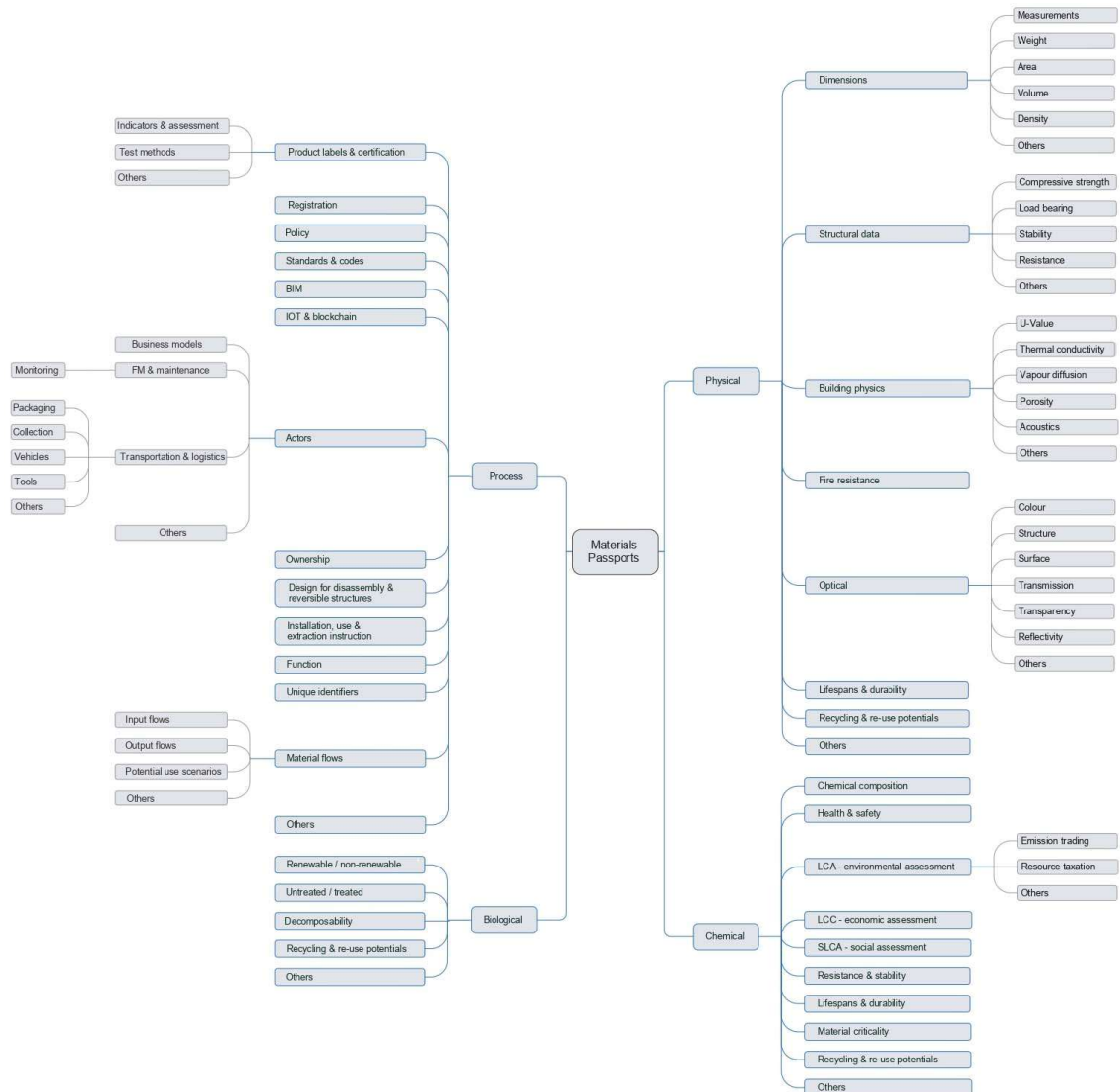


Figure 8. BAMB Materials Passport Overview. (Heinrich and Lang, 2019a)

While the case company possesses the necessary information capabilities for implementing the Materials Passport, the parameters outlined in previous research, as well as those in Table 4 and Figure 8, offer the necessary constraints

and guidelines. These parameters offer various methods for organising data and establishing connections between relevant categories.

3.2.4 Insights on Frameworks for Materials Passport Creation

This part provides valuable insights into frameworks pivotal for Materials Passport creation, including an exploration of Life Cycle Assessment (LCA), Environmental Product Declaration (EPD), and Building Information Modelling (BIM) methodologies. These are the very same methods that can be used in building the required framework for the Materials Passport (MP). LCA, EPD, and BIM serve as information and design optimisation tool and enables the generation and comparison of data thus supporting the decision-making process.

Life Cycle Assessment (LCA)

The European Environment Agency defines Life Cycle Assessment (LCA) as a method for assessing the environmental impact of a product throughout its entire life cycle, with the aim of enhancing resource efficiency and reducing environmental impact. LCA can examine either the environmental effects of a product directly or those associated with its intended function. It is commonly referred to as a "cradle-to-grave" assessment. The essential components of LCA include: (1) recognising and measuring the environmental impacts, such as energy and resources utilised, emissions emitted, and waste produced; (2) assessing the possible environmental impacts of these burdens; and (3) assessing the available alternatives for mitigating these environmental effects. According to the Finnish Environment Institute, Life Cycle Assessment (LCA), it serves as a crucial decision-support tool for policymakers, authorities, businesses, and researchers, enabling the identification of environmental hotspots and the formulation of relevant actions to mitigate the environmental consequences of human activities. LCA is an ISO-standardised analytical method designed to simultaneously quantify multiple environmental impacts throughout the entire life cycle of a product or service. It stands out as a unique tool for exploring the consequences of various decisions and understanding the factors

that influence potential impacts. The Building Life Cycle Information and its corresponding Life Cycle Stages are illustrated in Figure 9 below.

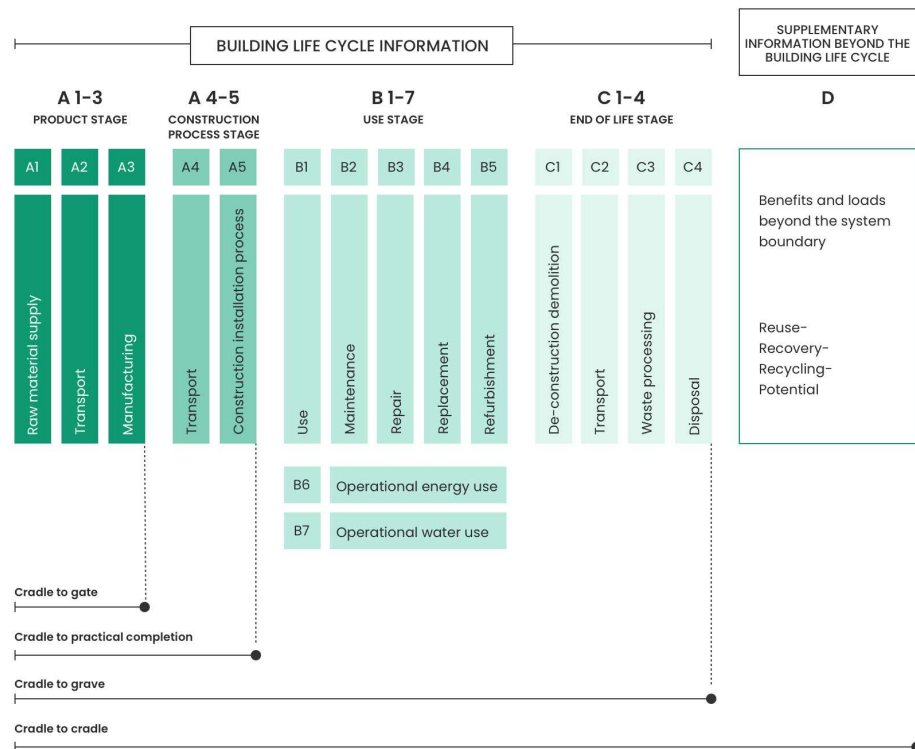


Figure 9. Life Cycle Stages. (One Click LCA, 2023)

Figure 9 illustrates the Life Cycle Stages in construction, depicting the various phases that a building or infrastructure project goes through from inception to completion and beyond. These stages typically include planning, design, construction, operation, maintenance, and end-of-life phases.

The LCA process involves four main stages: defining goals and scope, compiling data inventory, conducting impact assessment, and interpreting and disseminating results. By examining the entire lifecycle and considering various environmental effects, LCA helps prevent the shifting of issues among different impacts and throughout the value chain. Data inventory plays a pivotal role in any LCA analysis, entailing the gathering of all pertinent inputs and outputs of the system under scrutiny. Inputs comprise raw materials, energy, and water, while outputs include by-products, waste, and emissions. Common impact categories

assessed typically include climate change, toxicity, eutrophication, resource utilisation, acidification, particulate matter, ozone depletion, and land use.

Environmental Product Declaration (EPD)

The Environmental Product Declaration (EPD) is an extensive document that openly presents factual, comparable, and independently verified information regarding the environmental performance of products and services throughout their entire lifecycle, as defined by the International EPD® System. It is founded on a life cycle assessment (LCA), which evaluates a product's environmental performance over its entire lifecycle, from material extraction to end-of-life treatment.

EPDs are type III environmental declarations, compliant with the ISO 14025 standard, and are created and registered within programs like the International EPD® System. They comprise two key documents: the underlying LCA report, which provides a full summary of the LCA project for third-party verification, and the Public EPD document, which communicates the LCA results and other EPD content to the public. In Europe, adherence to the European Standard EN 15804 is mandatory for EPDs of construction products. This standard ensures a uniform methodology, standardised environmental indicators, and a common reporting format. EN 15804 EPDs cover four life cycle stages: product stage (A1-A3), construction stage (A4-A5), use stage (B1-B7), and end-of-life stage (C1-C4), facilitating comparisons among construction products.

EPDs undergo independent verification and are registered and published within programs adhering to ISO 14025 requirements. These programs are widespread across Europe, America, and Australasia. While possessing an EPD does not inherently denote a product with low environmental impact, it serves as a tool for providing environmental information and enabling comparative assessments at the building level. EPDs encompass a wide range of environmental impact indicators, including Global Warming Potential (GWP), Acidification (AP), Eutrophication (EP), Stratospheric Ozone Depletion Potential (ODP), Photochemical Ozone Creation Potential (POCP), Abiotic Depletion (Elements)

(ADPE), and Abiotic Depletion (Fossil Fuels) (ADPF). Additionally, they provide details on primary energy consumption, renewable and non-renewable energy sources, recycled material content, and material, fuel, or energy recovery at the end of the product's life. An example of an EPD for a Light Brick is shown in Table 5 below.

Environmental impact, Light brick (max. lime content)								
Parameter	Unit	A1-A3	A4	C1	C2	C3	C4	D
Global warming potential	kg CO ₂ -eqv	9,86E+1	1,21E+1	2,59E+0	4,33E+0	4,96E+0	2,25E+0	-9,82E+0
Depletion of stratospheric ozone layer	kg CFC11-eqv	1,31E-5	2,40E-6	5,71E-7	8,56E-7	8,78E-7	7,43E-7	-1,04E-6
Formation of photochemical ozone	kg C ₂ H ₄ -eqv	3,43E-2	1,92E-3	3,89E-4	6,87E-4	1,11E-3	8,16E-4	-2,97E-3
Acidification	kg SO ₂ -eqv	2,07E+0	3,23E-2	8,44E-3	1,15E-2	3,22E-2	1,66E-2	-5,57E-2
Eutrophication	kg PO ₄ 3--eqv	3,95E-1	4,32E-3	1,14E-3	1,54E-3	6,06E-3	2,85E-3	-7,96E-3
Abiotic depletion of non fossil resources	kg Sb-eqv	7,69E-4	7,59E-5	4,24E-6	2,71E-5	1,40E-5	7,53E-6	-2,04E-4
Abiotic depletion of fossil resources	MJ	1,24E+3	1,98E+2	3,04E+1	7,06E+1	8,30E+1	6,36E-1	-1,40E+2
Waste, Light brick (min. lime content)								
Parameter	Unit	A1-A3	A4	C1	C2	C3	C4	D
Hazardous waste	kg	8,75E-2	5,26E-3	4,07E-4	1,88E-3	7,13E-3	3,80E-3	-6,42E-3
Non-hazardous waste	kg	5,33E+1	1,70E+1	1,79E-1	6,09E+0	1,02E+2	4,20E+2	-3,31E+0
Radioactive waste	kg	1,29E-2	1,37E-3	9,56E-4	4,90E-4	5,86E-4	4,22E-4	-6,27E-4

Table 5. An Extract from an EPD Data of a Light Brick. (Wienerberger Oy Ab, 2021)

Table 5 displays an excerpt from an EPD dataset. Such datasets typically encompass information on environmental impact, resource usage, energy consumption, and other environmental indicators linked to the manufacturing, utilisation, and disposal of a product.

Building Information Modelling (BIM)

According to Eastman et al. (2011), Building Information Modelling (BIM) is described as a collaborative method for storing, exchanging, and managing multidisciplinary data across all phases of a building project, including planning, design, construction, operation, maintenance, and eventual demolition. Autodesk characterises BIM as a comprehensive process for creating and overseeing information related to a constructed asset. By employing an intelligent model and supported by a cloud platform, Building Information Modelling (BIM)

amalgamates structured, cross-disciplinary data to produce a digital depiction of an asset throughout its lifecycle phases, consisting of initial planning and design through construction to continuous operations. With BIM technology, precise virtual models of buildings are digitally constructed, aiding in design phases, and offering superior analysis and control compared to manual methods. Upon completion, these computer-generated models contain accurate geometry and data essential to support construction, fabrication, and procurement activities necessary for realising the building (Eastman et al., 2011).

Figure 10 illustrates that Building Information Modelling (BIM) primarily encompasses 3D modelling concepts, along with information database technology and interoperable software, within a desktop computer environment. Architects, engineers, and contractors can utilise BIM for facility design and construction simulation. This technology facilitates project team members to create a virtual model of the structure and its systems in 3D, enabling seamless information sharing. Furthermore, the model incorporates essential elements such as drawings, specifications, and construction details, including attributes like building geometry, spatial relationships, component quantities, and geographic information. These attributes enable the project team to promptly identify and address design and construction issues within a virtual environment well before the Construction Phase begins in the physical world.

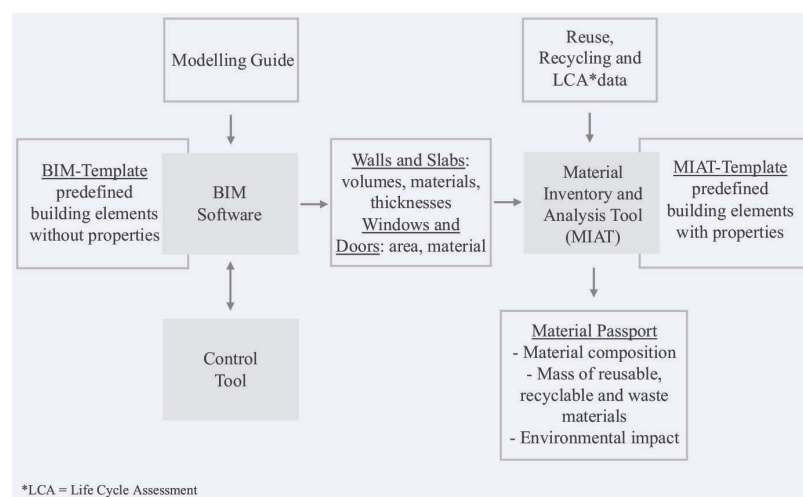


Figure 10. BIM-Based Workflow for the Generation of a Materials Passport. (Adapted from Honic et al. 2019a)

Honic et al. (2019a) developed an automated method to create MPs using BIM, as shown in Figure 10. This method helps optimise designs by reducing waste and environmental impacts. It allows for comparison of different design options. Proper modelling in BIM is essential for automating MP generation, including using correct BIM objects, geometry, and materials. The researchers offer a framework, templates, and modelling guidelines to support users in applying the MP method. They integrated environmental impact assessment into the MP, focusing on global warming potential (CO₂ emissions), acidification potential (SO₂ emissions), and primary energy intensity. Understanding and improvements can occur across different levels, ranging from materials and components to building elements. Lastly, BIM primarily serves as a process for generating and managing building data throughout a project's lifecycle. It typically employs three-dimensional, real-time, dynamic building modelling software to enhance productivity in building design and construction.

3.2.5 Insights on Circular Construction Principles and Practices

This section focuses on insights about Circular Construction Principles and Practices, exploring into the 9R Framework, Design for Disassembly and Deconstruction (DfD), Design for Adaptability and Renovation (DfA), and Design for Longevity (DfL) strategies.

The 9R Framework

The shift towards a circular economy strives to achieve the closure of material loops, thereby reducing waste, enhancing resource efficiency, and minimising environmental impacts. However, companies can adopt strategies to accomplish this. In addressing this question, Potting et al. (2017) present a valuable framework outlining 9 R-strategies grouped into three primary circularity groups, prioritised based on circularity principles. The highest priority strategy entails the creation and utilisation of smarter products which include refuse (R0), rethink (R1), and reduce (R3). The next set of strategies focuses on prolonging product and component lifespans, encompassing re-use (R3), repair (R4), refurbish (R5),

remanufacture (R6), and repurpose (R7). Finally, the lower priority strategies involve material application through recycling (R8) and energy recovery (R9).

- 1) 'Refuse' entails rendering a product redundant by either abandoning its function or offering the same function with a different product (Potting et al., 2017).
- 2) 'Rethink' is characterised by the enhanced utilisation of products, notably through product sharing or the introduction of multifunctional products in the market (Potting et al., 2017).
- 3) 'Reduce' involves increasing production efficiency and reducing the consumption of natural products and materials (Potting et al., 2017).
- 4) 'Reuse' refers to the practice of reutilising products that are still functional by another consumer (Potting et al., 2017).
- 5) 'Repair' is the restoration of a defective product to regain its original function (Potting et al., 2017).
- 6) 'Refurbish' refers to the process of revitalising an outdated product until it reaches contemporary standards, as defined by Potting et al. (2017).
- 7) 'Remanufacture' involves reusing components from a discarded product in a new product with the same function (Potting et al., 2017).
- 8) 'Repurpose' refers to the reuse of a discarded product or its components in a new product, but with a different function from the original (Potting et al., 2017).
- 9) 'Recycle' is the process of processing materials within products to obtain high-grade or low-grade materials (Potting et al., 2017).

10) 'Recover' entails the incineration of materials with energy recovery (Potting et al., 2017).

Figure 11 below illustrates the 9R model proposed by the PBL Netherlands Environmental Assessment Agency (2017).

Circular economy		Strategies	
Increasing circularity	Smarter product use and manufacture	R0 Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
		R1 Rethink	Make product use more intensive (e.g. by sharing product)
		R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
	Extend lifespan of product and its parts	R3 Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function
		R4 Repair	Repair and maintenance of defective product so it can be used with its original function
		R5 Refurbish	Restore an old product and bring it up to date
		R6 Remanufacture	Use parts of discarded product in a new product with the same function
		R7 Repurpose	Use discarded product or its parts in a new product with a different function
	Useful application of materials	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
		R9 Recover	Incineration of material with energy recovery
Linear economy			

Figure 11. The 9R Framework. Adapted from Potting et al. (2017)

The 9R model in Figure 11 outlines ten strategies aimed at achieving circularity, facilitating the development of efficient product and material flows. Each strategy involves leveraging various business models, infrastructures, relationships with stakeholders, and potentially policies to enhance circular practices.

Design for Disassembly and Deconstruction (DfD)

DfD, formerly known as design for deconstruction, refers to the incorporation of building parts (such as dismantled elements and connectors) into new constructions. The Circular Buildings Toolkit (CBT), a collaboration between Arup and The Ellen MacArthur Foundation, defines Design for Disassembly (DfD) as

a strategy aimed at facilitating the disassembly potential at the end of the service life. Certain elements within buildings have a lifespan that extends beyond their period of active service within a system. It is essential to intentionally plan for the efficient disassembly of components to reclaim remaining value once they reach the end of their useful life. ISO 20887 delineates seven design principles for disassembly: accessibility, autonomy, minimising unnecessary treatments and finishes, supporting reuse business models, simplicity, standardisation, and ensuring disassembly safety. This strategy is applicable to all sites and building typologies.

The key performance indicator for disassembly and recovery potential involves scoring Ease of Recovery + Ease of Reuse and Recycling, defined by EU Level(s) Indicator 2.4 Design for Deconstruction (Assessment methodology based on DGNB TEC1.6 Ease of recovery & recycling). The benefits of DfD are comprised of reduced embodied carbon emissions and material extraction over the long term, enabling future reuse of building components, and preserving each asset's value at the end of its service life. However, challenges associated with DfD include the potential for higher material quantities during the initial use, although this is considered beneficial over the entire life cycle.

Design for Adaptability and Renovation (DfA)

The Circular Buildings Toolkit (CBT), developed by Arup and The Ellen MacArthur Foundation, introduces Design for Adaptability (DfA) as a crucial strategy in maximising a building's potential to adapt to new functions throughout its usage stage. DfA focuses on versatility and convertibility, enabling buildings to maintain their value by accommodating future changes in use.

Key performance indicators include the Adaptability Score, which assesses a building's adaptability potential. Benefits of DfA include reducing embodied carbon emissions and material extraction over the long term, while challenges involve initial material quantities and environmental impacts. DfA is particularly beneficial for timber-based buildings, emphasising proactive and reactive measures for future proofing. Design considerations are comprised of flexibility,

generality, and modularity, among others. Building adaptability is viewed as aligning with durability, with layer design facilitating flexibility and retrofitting. Specific proposals for enhancing adaptability in each layer include designing versatile façades, modular structures, and adaptable floor plans. Connections and details should prioritise simplicity and mechanical connections. DfA shares similarities with Design for Disassembly (DfD) but focuses on different stages in a building's lifespan.

Design for Longevity (DfL)

Also included in the list is Design for Longevity (DfL), which The Circular Buildings Toolkit (CBT), developed collaboratively by Arup and The Ellen MacArthur Foundation, defines as a strategy aimed at maximising the value of a building and its components over time. It emphasises optimal value retention and recovery potential, operating at both the building and component levels.

The Key Performance Indicators for DfL include assessing value retention and recovery over the entire life cycle, measured by the Life Cycle Cost (according to EU Level(s) Indicator 6.1 Life Cycle Costs). This assessment considers the real functional service lives of the building and individual components, as well as potential returns from sell-back schemes and the high residual value of components. The benefits of DfL encompass long-term reductions in embodied carbon emissions and material extraction, enabling future tenants to adapt spaces to their needs, facilitating the future reuse of building components, and lowering costs over the entire building life cycle. However, challenges associated with DfL include the potential for higher material quantities during the initial use, though these are still considered beneficial over the total life cycle. Additionally, there may be higher environmental impacts during the first use, but these are outweighed by the long-term benefits over the total life cycle.

3.2.6 Insights on Plan for Technology Changes and Adoption Measures

It is crucial for companies across sectors to commence preparations for Digital Product Passport (DPP) implementation to align with future reporting requirements and embrace circular economy practices. While the case company possesses the necessary tools for constructing the Materials Passport (MP), there remains a requirement for collaborative efforts to implement the entire system. This demands the cooperation of various stakeholders to address the issue of data silos within the entire supply chain. Additionally, as the concept of MP is relatively new, embracing the concept may still pose a challenge for some actors within the value chain. Figure 12 below outlines four essential actions companies can undertake, along with immediate steps to commence this journey promptly.

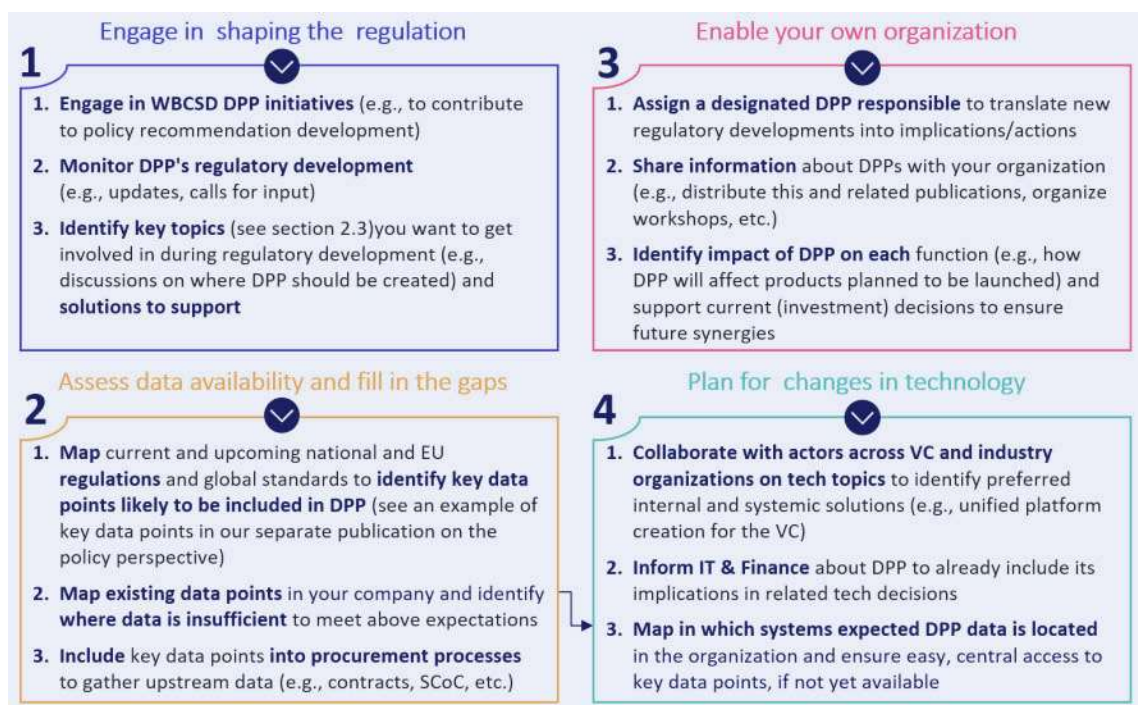


Figure 12. Four Actions with Immediate Next Steps to Prepare for the DPP. (BCG & WBCSD, 2023)

Figure 12 outlines the Four Actions with Immediate Next Steps to Prepare for the DPP based on the research by Boston Consulting Group (BCG) & World Business Council for Sustainable Development (WBCSD). Companies can proactively engage in shaping regulations surrounding Digital Product Passport (DPP) to ensure their effectiveness, contributing expertise through stakeholder consultations, and advocating for practical applications to avoid bureaucratic burdens. Concurrently, they can assess existing data availability and identify gaps, leveraging existing regulations and standards to kickstart data collection efforts and establish links with ESG reports and Life Cycle Assessments. Additionally, companies can prepare their organisations for DPP implementation by appointing dedicated experts to facilitate cross-departmental collaboration and raise awareness of the upcoming regulations. This includes leveraging DPP not only as compliance tools but also as assets to enhance marketing, product design, and customer engagement efforts. Moreover, companies should anticipate technological changes needed by DPP implementation, evaluating suitable options for data storage and access, and ensuring interoperability across systems within the company and across value chains. By taking these proactive steps, companies can position themselves to seamlessly integrate DPP into their operations and navigate forthcoming regulatory requirements without overinvestment or operational disruptions.

In conclusion, engagement, assessment, sharing, and planning are crucial for successful preparation for Digital Product Passport (DPP) implementation. These same principles can be applied to Materials Passport (MP) creation, ensuring alignment with regulatory frameworks, and maximising the benefits of data-driven approaches. By proactively engaging in regulatory shaping, assessing data availability, preparing organisational structures, and anticipating technological changes, companies can seamlessly integrate product passport or materials passport into their operations and effectively navigate forthcoming regulatory requirements.

3.3 Best Practices on Data Management Strategies

The importance of data management has become evident in the adoption of Digital Product Passport (DPP). Firstly, data collection methods involve techniques for gathering information about the materials used in construction projects. This can include conducting surveys or audits to identify and document the types of materials presents, their origins, specifications, and relevant environmental data. Other methods may involve leveraging existing databases or repositories containing material information. Research highlights a notable scarcity of data concerning processes like recycling, reusing, repairing, and remanufacturing (Berglund-Brown et al., 2022; Munaro and Tavares, 2021). Munaro and Tavares (2021) also emphasise the importance of collecting data from diverse stakeholders throughout a product's lifecycle to improve its potential for reuse, recycling, or remanufacturing and to support decision-making processes. Moreover, the absence of a comprehensive knowledge base on end-of-life product management underscores the significance of data collection initiatives, as noted by Munaro et al. (2020). Overcoming such challenges can be facilitated through the implementation of DPP, which aims to include a wide range of product data from inception to end-of-life management.

On the other hand, data analysis techniques focus on processing and interpreting the collected material data. This may involve analysing material composition, assessing environmental impacts using environmental product declarations (EPD) or life cycle assessment (LCA) methods, and identifying opportunities for material reuse, recycling, or disposal. Advanced data analysis techniques, such as machine learning algorithms, may also be used to extract insights from large datasets. In addition, ensuring the quality of data is essential for maintaining the integrity and reliability of the information.

Data quality assurance measures may include validating material information against industry standards, verifying data accuracy through independent audits, and addressing inconsistencies or errors in the dataset. Quality assurance processes help build trust in the system and its ability to provide accurate

information. Material data availability is vital for a functional circular economy, particularly in the construction sector where buildings and components have long lifespans and may change ownership multiple times. Maintaining up-to-date data and ensuring its systematic transfer to relevant stakeholders are essential. Incentives are necessary to encourage participation across the supply chain. Prompt action is required within the industry to establish a circular economy, which is essential for sustainable development and a more circular future.

3.3.1 Insights on Data Requirements

Defining data requirements involves specifying the types of information needed to support sustainable material management practices. This includes identifying the key parameters to be captured in the passport, such as material composition, environmental performance, durability, and recyclability. Clear data requirements ensure that the Materials Passport (MP) system effectively meets the needs of stakeholders and facilitates sustainable construction practices. Materials Passport data collection needs to span the entire lifespan of a product, but currently lacks end-of-life (EOL) information. Future requirements will likely demand the inclusion of EOL details, which should extend beyond material recycling or energy production to encompass potential component-level reuse options. Table 6 presents a summary of the ongoing discourse regarding the prerequisites for Digital Product Passport (DPP) systems, which is anticipated to undergo further elaboration and refinement with additional research in the future. These same categories of requirements can be equally applicable to Materials Passport.

Requirement Categories	Identified Requirements
Legal obligations	<ul style="list-style-type: none"> - Ensure compliance with the Proposal for the new Ecodesign for Sustainable Products Regulation (ESPR) - Ensure compliance with Extended Producer Responsibility (EPR) and EU government legislation “right to repair” - Ensure compliance with the General Data Protection Regulation (GDPR)
Functional suitability	<ul style="list-style-type: none"> - Need to fit the respective sector, industry, and use case - Allow actors to make statements exclusively for the information for which they are responsible - Allow decentralized data storage locations for the DPP information - Enable the decentralized collection of the information required for a DPP
Security, confidentiality, and IP protection	<ul style="list-style-type: none"> - Ensure nonrepudiation - Enable data verification - Ensure data sovereignty - Ensure secure data storage
Interoperability	<ul style="list-style-type: none"> - Provide clear semantics - Standardize data schemas describing the products - Provide an application interface (API) for data provision and data request
Modularity and modifiability	<ul style="list-style-type: none"> - Ensure flexibility to add/edit/remove actors, products, or product attributes - Ensure readiness for broader, international use
Accessibility	<ul style="list-style-type: none"> - Allow the determination and implementation of access rules - Ensure participation opportunities for actors who do not have their own information system
Availability and time behavior	<ul style="list-style-type: none"> - Ensure appropriate availability of the DPP information (depends on use case) - Enable real-time data if needed (depends on use case)
Portability	<ul style="list-style-type: none"> - Ensure that product identifiers and the DPP information are transferable from one software system to another - Avoid a centrally managed register for the product identifiers - Ensure that product identifiers are referenceable and harmonizable throughout the entire EU

Table 6. Overview of Identified DPP Systems Requirements. (Jansen et al., 2023)

Table 6 illustrates key areas such as Legal compliance, Functional appropriateness, Security, Confidentiality, and Intellectual Property (IP) protection, Interoperability, Modularity and adaptability, Accessibility, Availability, and Timeliness, as identified requirements for DPP systems. These requirement categories and identified requirements can serve as a basis for further research on Digital Product Passport (DPP) system, as well Materials Passport (MP) requirements.

3.3.2 Insights on Data Gap Identification and Integration

Data integration involves combining information from several sources to create a comprehensive database of material data. This may include integrating data from suppliers, manufacturers, certification bodies, and regulatory agencies into a unified dataset. Data integration enables a holistic view of material information and facilitates more informed decision-making regarding material selection and

management. Research emphasises the significance of data modelling for tracking and tracing materials and components to advance Circular Economy (CE) objectives and extract value from circular practices. To effectively implement Digital Product Passport (DPP) or Materials Passport (MP), it's essential to collect product-related data throughout their lifecycle from various digital systems.

Data gaps and inconsistencies pose significant obstacles to the collection, integration, and accessibility of essential data for the creation of Materials Passport (MP). The scarcity of available data points underscores the urgent need for an integrated data management system capable of maintaining life cycle data in a standardised format. Çetin et al. (2023) have proposed a comprehensive framework aimed at addressing these data gaps by leveraging digital technologies and engaging various stakeholders. Illustrated in Table 7, this framework offers a structured approach to tackling identified data deficiencies.

Data category	Digital technologies and human actors			Life cycle phase
	Data collection	Data integration	Data analysis	
A- Building General Information	 Automated data retrieval from public records Employees of SHOs	 Data harmonisation in the central data system, BIM, data lake or alternatively in an MP Platform Employees of SHOs and external stakeholders	 Big data analytics; machine learning	All life cycle phases <i>(ideally data should be collected in the design stage)</i>
B- Product General Information	 Automated data retrieval from third-party websites Project managers or maintenance managers of SHOs	 Data harmonisation in the central data system, BIM, data lake or alternatively in an MP Platform Employees of SHOs and external stakeholders	 Web scraping; machine learning	All life cycle phases <i>(ideally data should be collected in the design stage)</i>
C- Product Properties	 Sensing and scanning technologies (e.g., Lidar systems) Site inspectors (e.g., pre-demolition auditors)	 Data harmonisation in the central data system, BIM, data lake or alternatively in an MP Platform	 Computer vision; machine learning Site inspectors and reuse experts (e.g., consultants)	Use and end-of-use phases <i>(ideally data should be collected in the design stage)</i>
D- Product Safety, Health & Env. Aspects	 Drones to capture building images; data retrieval from waste repositories, building registers, satellite images, etc. Safety inspectors and experts	 Data harmonisation in the central data system, BIM, data lake or alternatively in an MP Platform	 Computer vision; machine learning Safety inspectors and experts	Use and end-of-use phases <i>(ideally data should be collected in the design stage)</i>
E- Product Operational Aspects	 Drones to capture building images; data retrieval from satellite images, etc. Maintenance managers or contractors, inspectors or experts	 Data harmonisation in the central data system, maintenance system, BIM, data lake or alternatively in an MP Platform Maintenance managers or contractors (to update data)	 Computer vision; machine learning; augmented reality; virtual reality Inspectors or experts	Use phase <i>(ideally data should be collected in the design stage)</i>
F- Product End-of-Life Aspects	 Scanning technologies, drones to capture building images; data retrieval from satellite images, etc. Reuse companies, consultants or architects	 Data harmonisation in the central data system, maintenance system, BIM, data lake or alternatively in an MP Platform	 MP; computer vision; machine learning; simulations Reuse companies, consultants or architects	End-of-use phase <i>(data can be obtained during design and use stages)</i>
Digital technologies Stakeholders (potential users of MPs)				

Table 7. MP Framework to Address Identified Data Gaps. (Çetin et al., 2023)

Table 7 outlines the integration of advanced digital tools such as AI and scanning technologies to bridge data gaps and apply principles of circularity, including narrow, slow, close, and regenerate strategies. By providing a roadmap for

enhancing data provision, this framework serves as a valuable guide for advancing research and innovation in support of circular practices in construction, renovation, and maintenance.

3.3.3 Insights on Database Creation

Data sources, as depicted in Table 8, encompass the origins or repositories of material information utilised within the system. This can include databases maintained by industry associations, certification bodies, government agencies, and research institutions. Leveraging diverse data sources enable Materials Passport (MP) to access comprehensive and up-to-date information on building materials, supporting informed decision-making throughout the building lifecycle. Encouraging a circular economy in construction requires extensive access to information, some of which is scattered across different sources. Certain data is unavailable due to intellectual property rights protection. Transparency and traceability of data origin are essential, with some aspects categorised as metadata, including creator and creation year.

Source	Description
Life Cycle Assessment (LCA)	Methodology to assess environmental impacts of products from raw material extraction to disposal. Data from research, journals, databases, and product reports.
Environmental Product Declarations (EPD)	Detailed documents providing verified environmental impact data based on LCA. Available from manufacturers or industry organisations.
Building Information Modelling (BIM)	Digital representation of building characteristics. Contains material details and environmental attributes. Accessed through BIM libraries and repositories.
Specifications and Bill of Materials (BOM)	Detailed material requirements for construction projects. Found in project documentation and specifications documents.
Material Suppliers and Manufacturers	Providers of building materials. Information sourced from industry directories, databases, and supplier websites.

Table 8. Recommended Sources of Material Information for Passport Creation. (Own Illustration)

Table 8 outlines the recommended sources for gathering material information essential for creating Materials Passport. These sources include Life Cycle

Assessment (LCA) studies, Environmental Product Declarations (EPDs), Building Information Modelling (BIM) databases, Bill of Materials (BOM) records, as well as direct engagement with material suppliers and manufacturers. Leveraging these sources provides comprehensive data on the environmental impact, composition, and other key attributes of materials, facilitating the accurate and detailed documentation necessary for effective Materials Passport creation.

Developing a Materials Passport (MP) database involves several key steps to ensure its effectiveness and usability. The first step entails clearly defining the purpose of the Materials Passport by understanding the project goals and client requirements. This initial understanding guides the development of an appropriate strategy for implementing Materials Passport within the project context. Next, it is essential to determine the format and location of the database. Considering the scope and scale of the data to be collected is crucial before proceeding. While a basic spreadsheet format offers flexibility and simplicity, it may become challenging to manage for larger projects. Therefore, exploring alternative options such as collaboration software for BIM or cloud-based services can provide a more sophisticated and scalable solution. Moreover, it is important to consider how the database will be utilised throughout the building's life cycle. The database serves as a repository for itemised inventories of physical assets within the building, inputted by various stakeholders during design and construction. Responsibilities for data population and accuracy checks should be clearly assigned to designated parties to ensure data integrity.

Finally, the database needs to be accessible and consistently updated throughout the entire lifespan of the building, from design phase to demolition. If continuous access is not feasible, maintaining an archived copy for future reference is essential. This archived data can facilitate validation surveys by future design teams before deconstruction, ensuring the smooth transition of information across project phases. This comprehensive approach to creating and managing a Materials Passport (MP) database, as proposed by Costa and Hoolahan (2024) in Figure 13, ensures its effectiveness in promoting sustainability and circular economy principles in the construction industry.

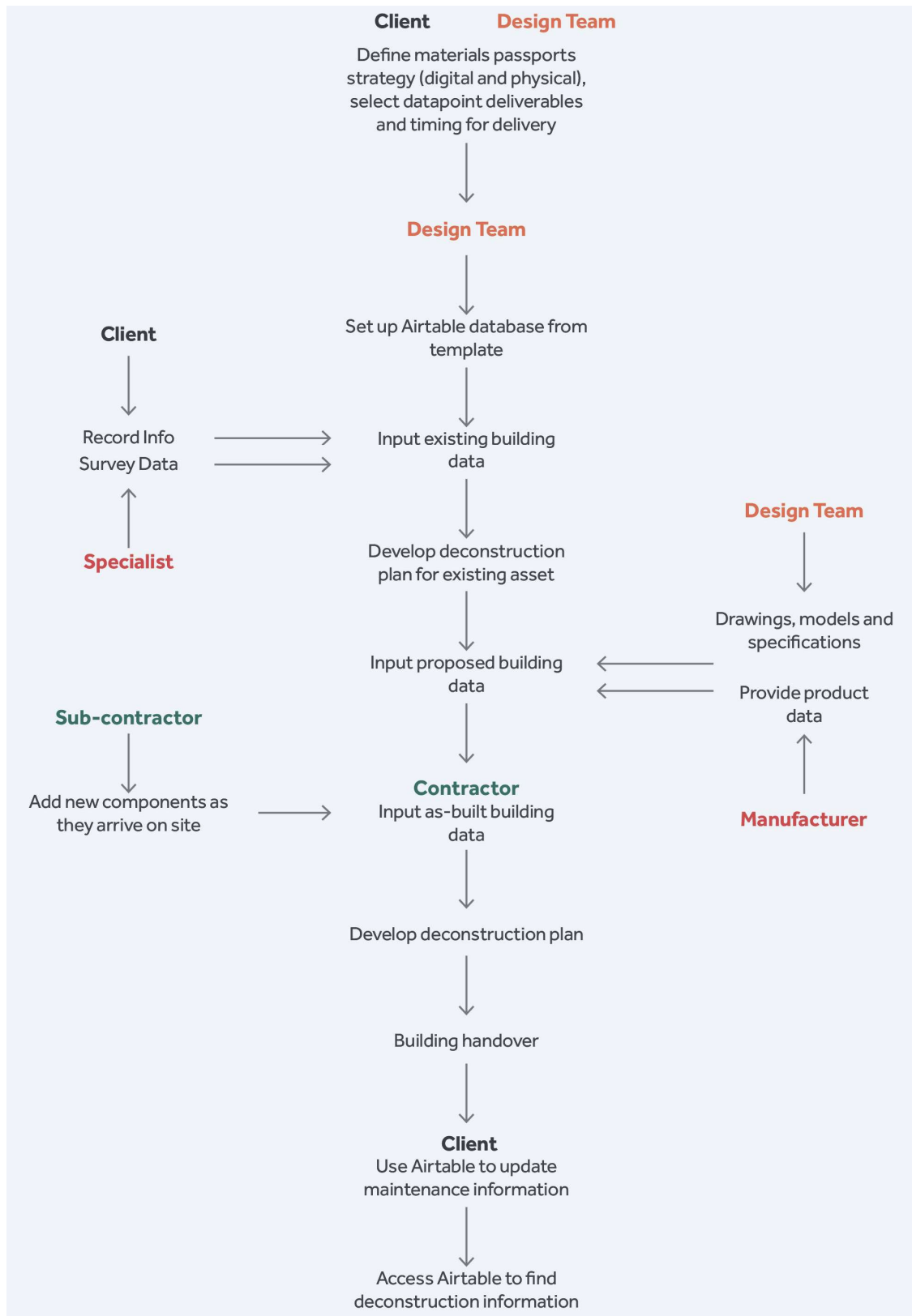


Figure 13. Building a Database Flow Chart. (Costa and Hoolahan, 2024)

3.3.4 Insights on Physical Passporting Strategy

The implementation of a Physical Passporting Strategy is highly recommended to establish a clear connection between digital records and physical objects within the construction industry. While not mandatory, this strategy enhances traceability and accessibility of data. At a minimum, objects should bear a simple label with a clearly printed unique identifier, facilitating easy data retrieval from the database. Additionally, the use of data carriers, such as QR codes, RFID tags, or NFD tags, can establish a direct digital link between physical objects and their digital passports. The choice of data carriers should be agreed upon, considering factors like accessibility, visibility, and longevity. For instance, QR codes may encourage future scanning but may require maintenance to prevent failure. It's essential to identify which systems, products, or materials will receive labels and data carriers, specifying requirements for their size and placement in each discipline's specification. This ensures data visibility without being visually intrusive, preventing removal by building occupants. By incorporating a Physical Passporting Strategy, the construction industry can streamline data access and enhance overall efficiency in managing material information (Costa and Hoolahan, 2024).

3.3.5 Insights on Data Collaboration Across Value Chain

It is vital to share successful methods and educate every part of the supply chain, industry, and government to move towards a circular economy. This means creating a common vision with commitment from everyone to aim for the future. Companies should provide training for their staff and promote hands-on learning and experimentation to turn ideas into reality and improve industry expertise. Working together effectively across the industry is crucial, as shown in Figure 14 below.

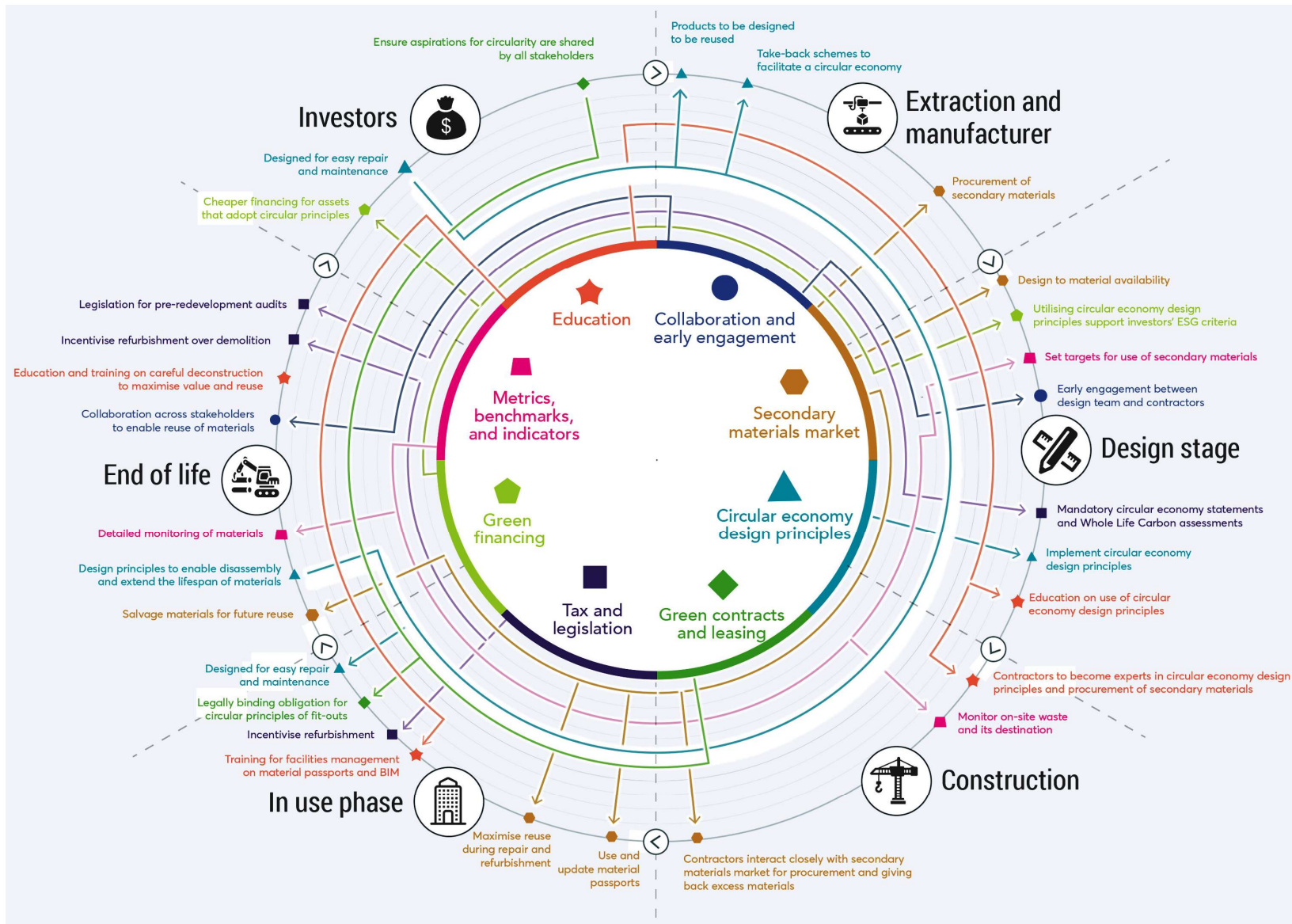


Figure 14. Industry Enablers and Collaboration Across Value Chain. (UKGBC, 2023)

Figure 14 illustrates how various stakeholders can contribute to advancing sustainability and circular economy principles in the construction industry. The stakeholder actions outlined contain various policy and industry measures aimed at promoting sustainability and circularity in the construction sector. Among these actions, the incorporation of material passports emerges as a significant recommendation, emphasising their role in facilitating the identification and traceability of materials for future disassembly and reuse. Stakeholders, including developers, architects, engineers, and occupiers, are encouraged to explore the integration of material passports into projects, thereby enhancing transparency and promoting the reuse of materials throughout the building lifecycle. Additionally, actions such as conducting detailed audits, establishing takeback schemes, and sharing reuse information underscore the collective effort needed to foster a more sustainable built environment.

Professional institutions play a crucial role by providing skill mapping and standard training, elevating industry standards. Moreover, collaboration between business associations, NGOs, and businesses is essential for sharing best practices and promoting sustainability initiatives. Furthermore, developers, investors, and agents need to recognise the value of materials within buildings and shift towards viewing them as assets, fostering a culture of reuse. Architects and engineers should adopt diverse design principles tailored to building longevity, educating clients on circular economy principles.

Collaboration among architects, engineers, and contractors is vital to understanding the impact of design choices on building disassembly and salvaging materials. Also, demolition contractors should transition into skilled deconstruction contractors, focusing on dismantling products for reuse. Contractors and demolition contractors should receive additional education on material value and reuse implications, while cost consultants and project managers need to integrate circularity considerations into cost assessments. Engineers and manufacturers should engage with insurers to address concerns about reused items. Moreover, educational institutions should incorporate circular economy principles into design courses, emphasising design for disassembly.

Lastly, stakeholders should advocate for long-term thinking in policymaking to promote circular economy practices.

3.4 Best Practices on Regulatory Landscape Initiatives

The Regulatory Landscape plays a pivotal role in this research as it provides an essential framework and context for analysis. It comprises the legal framework within which businesses and organisations operate, shaping compliance requirements, market dynamics, and policy implications. Understanding the Regulatory Landscape allows for the identification of emerging trends, compliance challenges, and potential risks relevant to the research. Additionally, it facilitates international comparisons and insights into global regulatory trends and best practices.

3.4.1 Insights on Compliance

Transitioning to a circular and dynamic built environment requires combined efforts from a diverse array of stakeholders. Engaging stakeholders effectively involves raising awareness, providing education, and equipping them with the necessary tools to participate meaningfully in the transition. Recognising both short and long-term benefits, stakeholders must understand the incentives of a circular built environment and be encouraged to embrace change in their practices. Moreover, transitioning to a circular economy demands sustained commitment and vision from stakeholders, companies, and governments. Transparency, communication, and collaboration are pivotal in this process, facilitating shared objectives and enabling the development of circular solutions through information sharing. Access to reliable and consistent data is imperative for informed decision-making, while digitalisation acts as a crucial enabler, streamlining processes and enhancing efficiency. Concrete implementation, supported by collaborative projects, is essential to drive and sustain the transition, providing tangible support for the overarching goals (Sharp, J. et al., 2019).

Sharp, J. et al. (2019), in their Building as Materials Bank (BAMB) research on the Framework for Policies, Regulations, and Standards, a co-funded project by

the Horizon 2020 Framework Programme of the EU, concluded that extensive research, including state-of-the-art analysis, engagement with policy frameworks, best practice reviews, and policy impact assessments, has revealed recurring themes for future policy recommendations. These themes draw from both successful policy factors and identified gaps. Detailed explanations of these themes are outlined in the subsequent Table 9.

Data	Data for monitoring; data consistency; provision of data repositories as knowledge centres; ability to update policy based on better information from monitoring and measuring
Benchmarking	Use of quantitative tools to allow meaningful evaluation
Enforcement	Requirements for meaningful monitoring; sanctions for non-compliance or incentives for compliance; consistency of enforcement approach and interpretation
Impact evaluation	Understanding the cost and the benefits and broader value of the policy; articulating the cost of compliance compared to the cost of non-compliance for stakeholders
Internalisation of external costs	Accounting for external costs to society and environment in calculating value of a project so that financial value creation is not the only consideration in decision making
Consistency	Overcoming issues of fragmentation at different levels of policy implementation (supra-national, national, regional, city); and reducing the likelihood of perverse effects caused by siloed thinking
Time	Noting that policy implementation takes time and that time can be utilized to maximise policy impact, e.g. through communication, stakeholder engagement; foresight for policy provided through tools and assessment, experimentation
Stakeholder input	Encouraging buy-in; engaging different perspectives to spot potential issues, including loopholes
Communication	Effective communication of policies, clarity in the policy and the use of experimentation as a means to communicate
Flexibility, adaptability and experimentation	Remaining open to different approaches which support the overall ambitions of the policy; ability to adapt the policy if required to optimise impact or respond to changing conditions; policy framework should encourage innovation, variation in approaches, experimentation and demonstration
Out of the box	Regulations and policies which take a unique approach and can provide inspiration and leadership

Table 9. Success Factors and Gaps in Policy Making. (Sharp, J. et al., 2019)

Table 9 enumerates the crucial factors pivotal for efficacy of policy development and implementation. First, it underscores the significance of reliable data, advocating for its role in monitoring and informing policy updates. Quantitative tools for benchmarking are highlighted as essential for meaningful evaluation, while enforcement mechanisms are deemed necessary for compliance. Moreover, understanding the costs and benefits of policies, including societal and environmental impacts, is emphasised. Consistency across different levels of policy implementation is vital to mitigate fragmentation and ensure uniform interpretation. Time is recognised as a resource to maximise policy impact through stakeholder engagement and foresight. Stakeholder input is encouraged to identify potential issues supported by clear and effective communication

strategies. Additionally, flexibility, adaptability, and experimentation are promoted to accommodate varying approaches and changing conditions. Finally, the list advocates for out-of-the-box thinking, endorsing innovative policy approaches for inspiration and leadership.

3.4.2 Insights on Regulatory Shaping Initiatives

Digital Product Passport (DPP) offers a valuable opportunity to modernise product data, supporting the industry's move towards carbon neutrality and circular practices. They are seen as essential for empowering consumers and incentivising producers to improve product sustainability (CISL and Wuppertal Institute, 2022). Some of the examples of initiatives to be considered in policy and regulations are listed in Table 10 below.

Recommendations	
Change in Design Culture	
Regulate	Existing EU level laws on energy performance, waste management and construction product regulations (by integrating Material Passports and Reversible Building Design Principles) should be extended to support the implementation of dynamic and reversible buildings. The design link of the value chain needs to be targeted by regulation. This might include consideration of material loops from the perspective of design to transition from a value chain to a value network.
Realise	Provision of a set of technical guidelines by a government should be considered as a mechanism to promote a change in design culture.
Stimulate	Public procurement should be used to promote change: for example using solution-free requests (performancebased) rather than prescriptive specifications stimulates innovation.
Inspire	Innovative policy instruments should be given space for implementation. Implementing mechanisms which promote change in design can act as a driver and example for other authorities to follow.
Change in Value Definition	
Regulate	External environmental and societal costs should be integrated in the value calculation of any new policy. Quantitative (rather than qualitative) milestones should be used as they are more effective in promoting change.
Realise	A framework which requires accurate data to support monitoring and definition of targets should be part of regulation to ensure value definition can be defined. The use of a mixture of legislative, taxation and budgetary measures should be considered in order to promote the transition to dynamic building.
Stimulate	Public procurement policies should be harnessed as a mechanism to internalise external costs. Authorities should ensure that room for experimentation is included in policy and regulation.
Inspire	The setting of an overarching vision should be considered, as it provides strong leadership for action.
Change in Collaboration Across All Actors	
Regulate	Enforcement of regulations is key to their take-up and there needs to be a clear line of responsibility for the regulation to ensure compliance. All actors should be actively engaged in the development of regulation in order to avoid a missing link which would result in reduced impact.
Realise	Assessment tools target stakeholders at an early stage of the construction lifecycle. They could therefore be used to promote data collection and sharing and collaborative processes. Collection, assurance and analysis of high quality data should be sought, as it increases trust between different parts of the value network and promotes interaction between stakeholders. Policy and regulation provides an effective way for agencies to work together and to cooperate, particularly where solutions are not articulated at a higher level.
Stimulate	Public procurement should be used to effect a change in division of roles between client and contractor, for example by giving the (expert) contractor the freedom to provide innovative solutions to difficult problems; it should also support new types of business models and ownership which will lead to other types of collaboration. Development of platforms and tools for industry stakeholders should be considered, as these bring actors together and allow for collaboration and knowledge-sharing.
Inspire	High profile frameworks and policies should be harnessed as an effective tool for communication and collaboration amongst stakeholders. A collaborative approach in developing policy should be taken to ensure that policy changes take into account the reality of stakeholder groups and that targets set for actors are appropriate and likely to be adopted. Public authorities have an important role in sharing information on best practices to demonstrate leadership and inspire.

Table 10. A Blueprint to Enable a Circular Built Environment. (Sharp, J. et al., 2019)

For change in design culture, recommendations involve extending existing EU laws to support dynamic and reversible buildings, as well as promoting a shift in design culture through technical guidelines and innovative policy instruments. Regarding change in value definition, the focus is on integrating external costs into value calculations, employing quantitative milestones, and ensuring accurate data collection and regulation frameworks. Concerning change in collaboration across all actors, the emphasis lies in enforcing regulations, involving all actors in regulation development, utilising assessment tools for data collection and collaboration promotion, and fostering collaboration through public procurement and the development of industry platforms and tools. Additionally, collaborative policy development and information sharing by public authorities are underscored as crucial elements for inspiration and leadership (CISL and Wuppertal Institute, 2022).

The coherence and consistency of Digital Product Passport (DPP) are crucial for their effective implementation. This involves aligning upcoming EU regulations with the proposed approach for the Ecodesign for Sustainable Products Regulation (ESPR) and drawing from experiences with initiatives like the EU Battery Passport. Interoperability and compatibility of digital infrastructure and software are essential to ensure seamless integration with existing systems. The EU should take the lead in governance, providing clear guidelines and creating an enabling environment through common standards and interoperability frameworks. Leveraging existing international initiatives can prevent redundancy and streamline efforts. DPP should play a role in green public procurement and serve as substantiation tools for ecolabels. Additionally, they should facilitate standardised information exchange on aspects like recycled content and carbon footprints in complex supply chains, fostering a common framework for voluntary product information sharing leadership (CISL and Wuppertal Institute, 2022).

The strategy for flexibility and exploration entails starting with small-scale DPP testing and pilots promptly, following a phased approach that allows for continuous expansion and refinement to facilitate iterative learning. It advocates commencing with a range of clearly defined products and sectors as pilots to

assess the general approach and identify commonalities across different product groups. Moreover, it emphasises that detailed data included in DPP should be specific to product groups to ensure reliability and comparability, avoiding a one-size-fits-all approach. Additionally, most businesses prefer a decentralised approach to product information storage over a centralised one leadership (CISL and Wuppertal Institute, 2022).

Transparency and accountability in Digital Product Passport (DPP) are crucial for enabling informed decision-making among consumers, businesses, and investors regarding sustainability criteria. To achieve this, sufficient data must be provided, with each piece of information tailored to specific user benefits throughout the product life cycle. Additionally, mandatory product information within DPP should balance data access and protection needs to ensure default transparency while respecting confidentiality concerns. Operational implementation of DPP should involve trusted intermediaries possessing technical expertise and a grasp of DPP broader policy objectives, thereby upholding strong governance principles to support the transition to a circular economy leadership (CISL and Wuppertal Institute, 2022).

3.4.3 Insights on Adapting to Policy Changes

The corporate perspective plays a pivotal role in shaping policy discussions, especially regarding uncertain elements in Digital Product Passport (DPP) regulation. By actively engaging in these discussions, businesses can mitigate the risk of unexpected and adverse outcomes that may affect their operations. Being proactive in anticipating and adjusting to shifts in regulatory demands allows businesses to plan ahead and ensure compliance. This approach also helps in managing risks associated with disruptions in supply and fluctuations in prices, particularly for scarce resources, by enhancing transparency on critical raw material use and product design. Stakeholders can unlock benefits by getting ready for the implementation of DPP or MP at an early stage, as depicted in Figure 15.

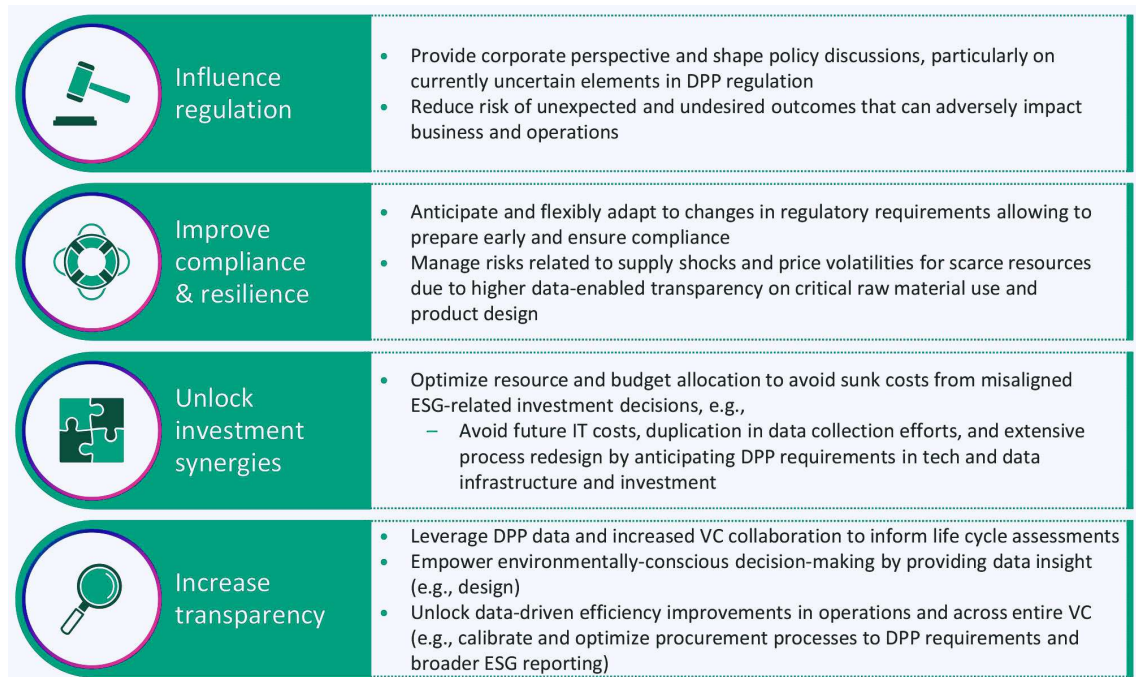


Figure 15. Actions to Adapt to Policy Changes. (BCG and WBCSD, 2023)

Figure 15 outlines crucial actions to navigate policy changes effectively. These actions include influencing regulations to align with organisational objectives, enhancing compliance measures to meet evolving requirements, leveraging investment synergies for sustainable growth, and increasing transparency to promote trust and accountability.

Figure 15 also shows that efficient resource and budget allocation is facilitated by optimising investment decisions aligned with Environmental, Social, and Governance (ESG) considerations. Anticipating DPP requirements in technology and data infrastructure investment helps prevent future IT expenses, redundant data collection, and significant process change. Leveraging DPP data and fostering increased collaboration with venture capitalists (VCs) can inform life cycle assessments and empower environmentally conscious decision-making. This approach also facilitates data-driven efficiency improvements across operations and the entire value chain, such as calibrating and optimising procurement processes to meet DPP requirements and broader ESG reporting standards (BCG and WBCSD, 2023).

3.4.4 Timeline for DPP Implementation

Figure 16 below provides a chronological overview of key events, strategies, and developments associated with the implementation of Materials Passport initiatives.

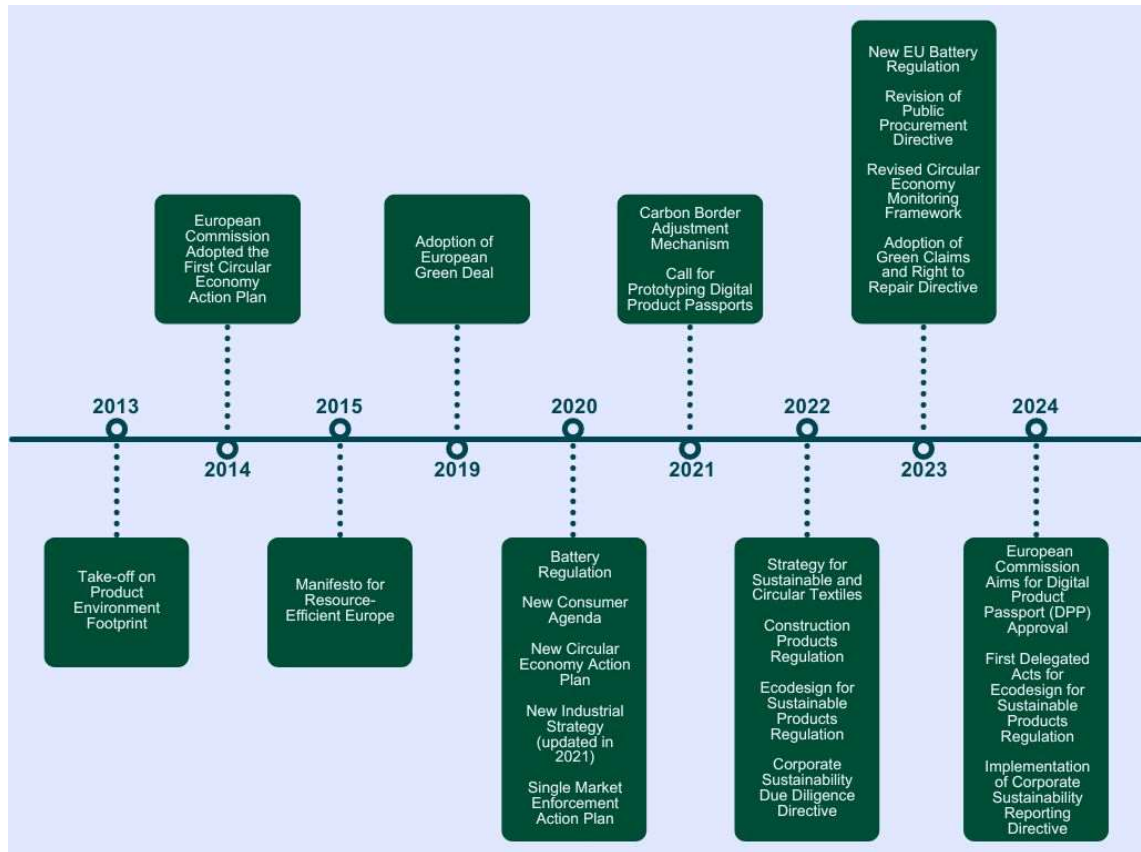


Figure 16. Timeline of Actions and Initiatives Related to the Introduction of Materials Passport. (Own Illustration)

According to the World Business Council for Sustainable Development and the Boston Consulting Group's 2022 Report, the European Commission aims to achieve Digital Product Passport (DPP) approval by 2024, as illustrated in Figure 16. Implementation details are expected to be provided in delegated acts, with initial product categories anticipated to be covered by DPP regulation in 2026/7. Delegated acts for each product group may include eco-design and performance requirements, thereby advancing circularity across various industries. However, the implementation timeline beyond these initial indications remains uncertain.

3.5 Conceptual Framework

The conceptual framework of this study comprises four main components. Firstly, it involves identifying the "why" of the study, which serves as the foundational principle. Secondly, it entails determining the "what," focusing primarily on the intricate dynamics of the Materials Passport (MP). Lastly, it addresses the "how," which includes important supporting topics such as the regulatory landscape and data management. This conceptual framework provides a structured approach to guide the research process and ensure clarity in addressing key aspects of the study. The conceptual framework is visualised in Figure 17.

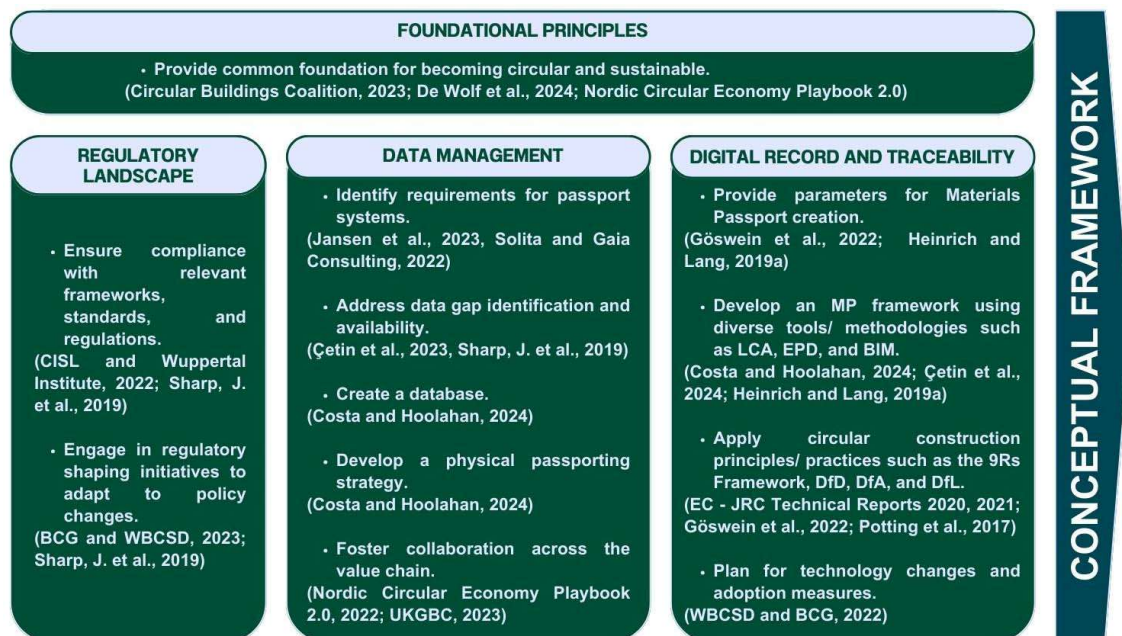


Figure 17. The Conceptual Framework of this Study.

Figure 17 begins with the Foundational Principles, which serve as the cornerstone of the roadmap for Materials Passport creation. These principles provide the rationale for why the circular economy is relevant and underscore its importance in guiding the development of Materials Passport initiatives. With increasing concerns regarding environmental sustainability, resource scarcity, and waste management, prioritising sustainability and circularity in the built environment is paramount. These principles serve as the foundation of the proposal, underlining the importance of developing a roadmap.

Digital Record and Traceability measures takes focus in the Materials Passport creation process. The sustainable material management tools and methodologies and circular construction strategies and actions facilitate efficient tracking and management of data related to material sourcing, usage, and disposal throughout the lifecycle of built assets. By leveraging various methodologies and tools, transparency and accountability in supply chains can be achieved, facilitating informed decision-making among industry stakeholders. Digital record and traceability mechanisms are crucial for capturing and managing diverse datasets, including environmental performance metrics, regulatory requirements, and industry standards.

Considerations regarding Data Management and the Regulatory Landscape are also integral to the development of the Materials Passport roadmap. Effective data management practices ensure the accuracy, reliability, and accessibility of information within Materials Passport. Robust data management processes enable the integration of diverse datasets, allowing stakeholders to make informed decisions based on comprehensive and reliable information. Understanding the regulatory landscape is essential for ensuring compliance with relevant laws, standards, and guidelines governing material usage and disclosure. By aligning with regulatory requirements, the roadmap mitigates legal risks and enhances the credibility of Materials Passport within the industry.

The conceptual framework developed in this section serves as the foundation for creating a current state analysis (CSA) interview guideline aimed at assessing the current capabilities of the case company's existing tools and platform, as well as general industry practices. The findings obtained from the CSA interviews are then integrated with the conceptual framework to formulate the initial proposal for the case company. Consequently, the next section provides an overview of the results obtained from the initial analysis investigations.

4 Current State Analysis

In the previous chapter, related literature was reviewed to understand the concept of Materials Passport, including their foundational principles, the regulatory landscape, and the data management requirements. The conceptual framework was built in accordance with these concepts, which will be used in this chapter.

This section discusses the data collected and the outcomes of the inquiries conducted as a preliminary step before formulating the initial proposal. It consists of three subsections. The first subsection offers an overview of the gathered data. It proceeds to assess the current state of the case company's offerings and discusses the present state of the industry. Lastly, this section summarises the strengths and pinch points identified in both assessments, detailed in Table 6.

4.1 Overview of the Current State Analysis

The current state analysis concentrates on two main aspects: firstly, evaluating the software capabilities of the case company, and secondly, identifying strengths and pinch points. This analysis proceeded through three steps. Initially, assessments were conducted to provide comprehensive background information. Subsequently, data collection took place, followed by data analysis and the identification of key findings.

The key informants comprised both internal and external stakeholders with diverse roles, selected based on their expertise and competence. Most of them work as professionals in the built environment sector, while some are affiliated with academia. They are located in countries such as Finland, Spain, and the United Kingdom. The objective of these discussions was to evaluate and identify the strengths and pinch points of the case company's software capabilities and current industry practices.

The data collection began by examining the case company's capabilities, including its software offerings, databases, integrations, adherence to global compliance standards, and data security measures. This was followed by

interviews with experts regarding current industry practices and their knowledge of Materials Passport (MP) in general. All meetings were conducted online for the convenience of the informants, allowing for adjustments to their schedules and accommodating their geographical locations. Every interview took approximately 30 minutes. Additionally, data was gathered by participating in a virtual conference (webinar) held in the United Kingdom.

4.2 Assessment of the Case Company's Software Offerings

This section provides an evaluation of the current tools and platforms offered by the case company, focusing on their capabilities in facilitating automated calculation of environmental impacts in building and infrastructure projects. The software capabilities of the case company are depicted in Figure 18 below.

The Figure 18 schematic diagram depicts the 5 key modules of the Case Company's offering, comprising the software itself, the database, integrations, global compliance standards, and data security.

As of the time of writing, the software is subdivided into three categories: design and construction, manufacturing, and enterprise. Under design and construction, the tools include Life Cycle Assessment, Early Design Carbon Optimisation, Embodied Carbon Calculation, Life Cycle Costing, Circularity, Infrastructure LCA, Carbon Strategy Tool, Net-Zero Solutions, Biodiversity, MEP Whole Life Carbon, and Parametric Carbon Optimisation. Meanwhile, the manufacturing category includes Pre-verified EPD Generator, EPD Generator, Product Carbon Footprint, Concrete EPD Generator, Luminaires EPD Generator, FDES for the French market, and Branded Assemblies.

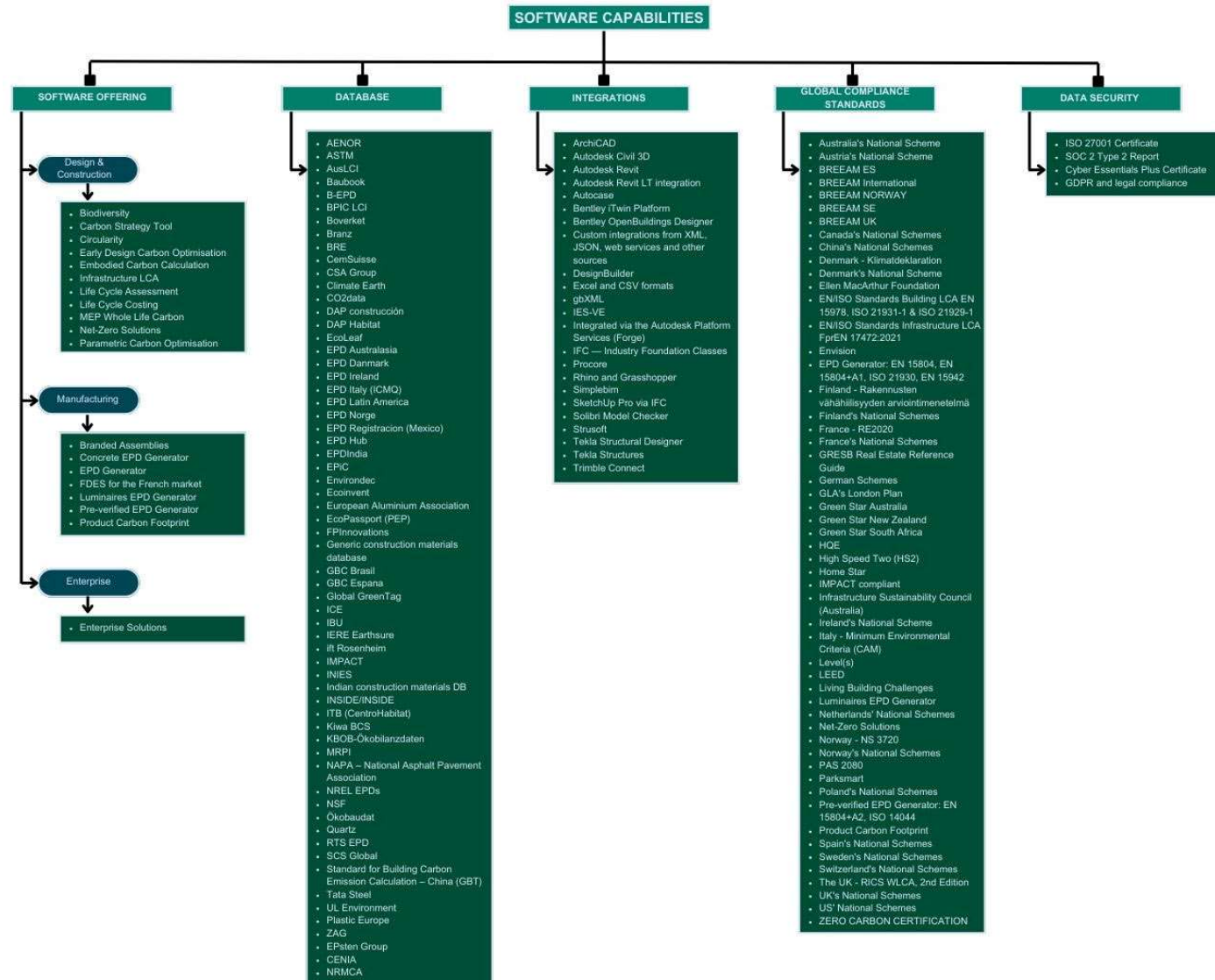


Figure 18. Schematic Diagram of the Case Company's Platform Offering as of March 2024. (Own Illustration)

Regarding the database, the company boasts over 200,000 data points, integrating various sources of environmental construction data worldwide. These databases encompass Generic construction materials database, Ecoinvent, EPD Hub, European Aluminium Association, Tata Steel, Indian construction materials, Standard for Building Carbon Emission Calculation – China (GBT), ASTM, and EPD Australasia, among others. The company extends its global reach by assimilating data from nearly every EPD platform worldwide, ensuring an exhaustive range of environmental product declarations. Additionally, the company maintains a globally recognised standard of data quality, with all EU database entries meeting the EN 15804 standard, and North American datasets adhering to the ISO 14040/44 standard, enabling seamless cross-border project planning and execution. Furthermore, the database includes specific data from numerous European and international building material producers, as well as country-specific average data like Ökobaodat and INIES, supporting initial project planning.

The decarbonisation software supports multiple design environments, ensuring seamless integration with different workflows through advanced data integration capabilities such as ArchiCAD, Autodesk Revit, Excel, and CSV formats, IFC — Industry Foundation Classes, Rhino and Grasshopper, and Tekla Structures.

Additionally, the company's global software aids AEC project teams in complying with essential building regulations, standards, and requirements across Europe, Latin America, North America, and the Asia-Pacific regions, including EN 15978 and Level(s) in the EU, as well as commercial certifications like LEED, BREEAM, GLA's London Plan, Green Star Australia, and PAS 2080, among others.

Furthermore, the company has achieved a significant milestone by acquiring ISO 27001 certification, the most rigorous cybersecurity standard globally. Combined with demonstrated GDPR and legal compliance, the software is cyber-secure, operationally sound, and compliant.

4.2.1 Digital Record and Traceability Capabilities

The assessment of the case company's digital record and traceability capabilities offers several strengths, including the ability to compare design options, optimise carbon footprint, cost, and circularity throughout the design process, enabling more sustainable decision-making practices. The platform specialises in providing automation for conducting whole life-cycle assessments and offers an easy solution for manufacturers to produce third-party verified Environmental Product Declarations (EPDs) based on international standards.

Additionally, stakeholders can calculate and optimise products' life-cycle impacts, enabling the identification of opportunities for environmental improvement. This functionality is complemented by the ability to benchmark products' sustainability within a building context, facilitating the evaluation of environmental performance relative to competitors. Moreover, these capabilities empower stakeholders to set targets and benchmark projects within their portfolios, enhancing accountability and transparency in sustainability efforts. Furthermore, the capacity to report greenhouse gas emissions supports compliance with regulatory requirements and facilitates the communication of environmental performance.

Insights from stakeholder interviews underscore the growing recognition of sustainability considerations in the construction industry. Stakeholders acknowledge the importance of material composition, repairability, and recyclability, indicating an evolving awareness of sustainable practices. Moreover, there is a consensus regarding the necessity to track emissions across various aspects of construction, reflecting a commitment to environmental accountability. Stakeholders also demonstrate awareness of the significance of Materials Passport, recognising their potential to enhance sustainability practices and promote transparency in the industry.

However, several critical pinch points hinder the effective implementation of digital record and traceability solutions. Clients' hesitancy to adopt new technologies poses a significant barrier, potentially impeding progress in sustainability initiatives. Addressing this reluctance requires targeted efforts to

demonstrate the value and benefits of these solutions. Additionally, a knowledge gap among stakeholders underscores the need for education and training initiatives to enhance understanding and uptake of digital record and traceability tools. Challenges in determining the composition of building materials further complicate implementation efforts, highlighting the importance of improving data collection and management practices. Moreover, concerns about the integrity of reused elements emphasise the need for stringent quality assurance measures and importance of robust tracking and monitoring mechanisms to maintain accountability throughout the lifecycle of construction materials.

Below are some examples of what the informants mentioned when asked about their perception of the current state of sustainability and circularity practices in the built-environment industry and the importance of a Materials Passport (MP) feature for enhancing circular alignment and resource traceability:

One informant affirmed: "Materials Passport is essential for implementing Circular Economy, but there's a knowledge gap requiring clarity. People need to understand their actions, building types, and the relevance for renovation works." Data 1-Informant 2

Another respondent emphasised that: "Material composition is paramount, as without knowledge of its contents, designing becomes exceedingly difficult. Following that, durability and recyclability are considered the next crucial factors." Data 1-Informant 5

On the other hand, the online conference revealed that - while 87% of attendees reported that they had not yet implemented Materials Passports, 61% stated they had plans to incorporate Materials Passports into their projects within the next year - a clear indication of the untapped potential in this sector.

4.2.2 Data Management Capabilities

The data management capabilities of the platform offer a robust infrastructure for handling construction-related information, leveraging a vast repository of over 200,000 up-to-date and verified construction Life Cycle Assessment (LCA) datapoints. This extensive dataset provides users with comprehensive insights into the environmental impact of various construction materials and processes. Moreover, the platform's intuitive interface facilitates easy access to LCA data and Environmental Product Declarations (EPDs), enabling users to make choices regarding material selection and project planning.

In terms of security, the platform adheres to rigorous standards, holding certifications such as SOC 2 and ISO 27001, which attest to its commitment to maintaining enterprise-grade data protection. This ensures that sensitive information remains confidential and secure throughout its lifecycle within the platform.

Another key strength of the platform lies in its seamless integration with over 20 Building Information Modelling (BIM) and Building Energy Modelling (BEM) software, as well as Application Programming Interfaces (APIs) for additional customisation. This interoperability allows users to seamlessly incorporate LCA data and EPDs into their existing workflows, enhancing efficiency and productivity.

Furthermore, the platform boasts an extensive database sourced from reputable organisations and standards bodies, including Quartz, Ecoinvent, Environdec, and many others. This diverse range of data sources ensures that users have access to a comprehensive dataset covering various construction materials and processes.

Despite these strengths, users have identified several pinch points that warrant attention. Challenges in software integration and the need for additional plug-ins have been noted, indicating opportunities for further development and enhancement of the platform's functionality. Additionally, users have expressed

concerns about the deficiency in the material database and generic content, highlighting the importance of continuously updating and expanding the platform's data sources and a possible gap in creating Materials Passport. Moreover, the informants have reported a lack of direct experience in creating or utilising Materials Passport, underscoring the need for education and training initiatives to promote adoption and usage. Finally, challenges in combining digital and physical data to effectively reuse materials have been identified, signalling the importance of refining data management processes to streamline material reuse efforts and promote circularity within the construction industry.

The responses from the informants varied for some questions, with some being somewhat similar. For instance, when asked if they used the case company's software, Informants 1, 6, and 7 responded affirmatively, whereas Informants 4 and 5 were aware of the case company but had not utilised the software. Regarding their opinions on the software, here are some insights from the informants:

One informant noted this: *“One missing information and could not calculate anymore.”* Data 1: Informant 1

Another interviewee commented: *“The software is good, but there are areas for improvement. There are predominantly generic materials in the database, making it more challenging to select the materials actually used in a project.”* Data 1-Informant 6

A third informant expressed: *“Most complaints and requests from clients are related to integration.”* Data 1-Informant 3

4.2.3 Regulatory Landscape Capabilities

In this part of the assessment, the regulatory landscape capabilities of existing tools and platforms are analysed. This involves examining the extent to which these tools integrate regulatory requirements and standards relevant to sustainable construction and material management, ensuring compliance and

alignment with legal frameworks. The regulatory landscape framework of the case company encompasses over 80 global compliance standards, each playing a crucial role in ensuring alignment with sustainable practices. Noteworthy standards include EU Taxonomy alignment, GLA's London Plan, UK's RICS WLCA 2nd Edition, France's RE2020, Denmark's Klimatdeklaration, Finland's Rakennusten vähähiilisyiden arviointimenetelmä, and Norway's NS 3720, among others. These standards cover diverse areas such as infrastructure and building life cycle assessment (LCA), environmental product declarations (EPD), and carbon neutrality certifications.

However, pinch points are revealed in anticipating impending regulations in Finland and the EU. The regulatory landscape exhibits proactive readiness for evolving sustainability mandates. Nevertheless, critical pinch points arise from clients' inquiries regarding material listing under new regulations and the necessity for policy changes to adapt to emerging technologies, signalling areas requiring attention and resolution.

4.3 Summary of Key Strengths and Critical Pinch Points

The current state analysis of both the case company's software capabilities and current industry practices revealed numerous advantages along with areas for improvement. The summary of the findings is listed in Table 11 below.

In this study, the terms 'key strengths' and 'critical pinch points' were used instead of 'strengths' and 'weaknesses' to provide a more nuanced and contextually appropriate description of the analysis findings. While 'strengths' typically refer to aspects of a system or process that perform well or are advantageous, 'weaknesses' denote areas that are deficient or underperforming. However, in this case, 'critical pinch points' refer to areas that serve as focal points crucial for achieving success or addressing vulnerabilities. Similarly, referring to positive aspects as 'key strengths' highlights their significance and importance within the overall analysis context. This terminology underscores the strategic value of

these aspects and emphasises their role in contributing to achieving the desired outcome.

	KEY STRENGTHS	CRITICAL PINCH POINTS
DIGITAL RECORD AND TRACEABILITY	<ol style="list-style-type: none"> 1) Recognition of the importance of material composition, repairability, and recyclability. 2) Recognition of the necessity to track emissions in various aspects of construction. 3) Awareness and recognition of Material Passports' importance. 	<ol style="list-style-type: none"> 1) Clients' hesitancy to adopt new technologies. 2) Challenges in determining composition for building materials. 3) Challenges in reusing elements due to integrity concerns.
DATA MANAGEMENT	<ol style="list-style-type: none"> 1) 200,000+ up-to-date, verified construction LCA datapoints. 2) Easy and intuitive LCA and EPDs. 3) SOC 2 & ISO 27001 certificates, enterprise-grade security. 4) 20+ BIM & BEM integrations and APIs. 5) Some participants are considering a platform to assist them in creating material passports. 	<ol style="list-style-type: none"> 1) Challenges in software integration and requests for new plug-ins. 2) Deficiency in the material database and generic content. 3) Lack of direct experience in creating or utilising Material Passports. 4) Challenges in combining digital and physical data to reuse materials effectively.
REGULATORY LANDSCAPE	<ol style="list-style-type: none"> 1) More than 80 global compliance standards. 2) Anticipation and preparation for impending regulations in Finland and the EU. 	<ol style="list-style-type: none"> 1) Clients' inquiries about material listing under new regulations. 2) Policy changes required for adaptation to new technologies.

Table 11. Summary of Key Strengths and Critical Pinch points of the Study.

Table 11 presents several findings identified, which are further grouped into three main topics based on the conceptual framework: digital record and traceability, regulatory landscape, and data management.

All the data collected and listed in Table 11 will be utilised and addressed in Section 5 and will form the foundation of both the initial and final roadmap proposals. The next section (Section 5) of this research focuses on creating the roadmap for Materials Passport (MP) creation. The key strengths and critical pinch points identified in the CSA are leveraged in conjunction with the Conceptual Framework from Section 3. This roadmap will integrate the existing key strengths and best practices from the conceptual framework to address the critical pinch points to co-create the roadmap proposal.

5 Developing the Initial Roadmap

In this section, the key concepts identified in the conceptual framework were merged with the CSA findings to collaboratively develop the initial roadmap proposal. This section comprises an overview, a description of the roadmap development process, and a summary of the proposed initial roadmap.

5.1 Introduction to Roadmap Development

With all the necessary data gathered and the key strengths and critical pinch points identified, the next step in achieving the objective of this study is to develop the roadmap for Materials Passport (MP) creation.

The same stakeholders who participated in the earlier data collection stage were invited, as they already possessed a good understanding of the topic. Due to time differences and geographical constraints, it was not feasible to convene all informants for a single workshop. Therefore, data collection for this stage occurred through two separate sessions: an interview (with email correspondences) and a workshop, both conducted online. The focus of these meetings was to establish the initial roadmap to address critical pinch points, leveraging the key strengths in CSA, and concepts outlined in the conceptual framework. Each meeting lasted approximately 30 minutes, with active participation from the informants throughout. Both sessions commenced with a presentation of the conceptual framework and findings, which highlighted the key strengths and critical pinch points of the case company's tools and platforms where the Materials Passport will be integrated. Following the presentation, open discussions ensued, with the author facilitating opportunities for participants to contribute their ideas and share insights.

The initial proposal was collaboratively developed by the author and experts, drawing upon the data collected from interviews and workshop findings. Based on these findings, identified development needs and steps to construct the roadmap were proposed. The conceptual framework, along with the key

strengths and critical pinch points identified in the CSA, were integrated to formulate the initial proposal. This proposal served as the initial roadmap for creating the Materials Passport.

5.2 The Roadmap Development

The foundational inputs for constructing the proposal encompass three main components: 1) insights learned from the Conceptual Framework (CF) extracted from related literature, 2) findings derived from Data Collection 1 (CSA), and 3) insights gathered during Data Collection 2, conducted as part of this co-creation process. Data Collection 2 specifically aims to capture recommendations from key stakeholders and propose actionable steps for developing a roadmap for Materials Passport creation across three focus areas: 1) digital record and traceability, 2) data management, and 3) regulatory landscape.

The subsequent table presents a summary of the collaborative insights obtained from both the author and key stakeholders, serving as inputs for the initial proposal. The ideas from the CF are combined with the key strengths to build general roadmap steps where reinforcement actions are also proposed to add weight and additional focus, which in turn address the pinch points. This draft proposal for the roadmap draws upon best practices in digital product passport creation, supplemented by recommended actions designed to address the identified pinch points uncovered during the current state analysis, thereby enhancing the viability of the overall roadmap proposal.

5.2.1 Digital Record and Traceability Measures

The co-created proposal under Digital Record and Traceability is shown in Figure 19 below.

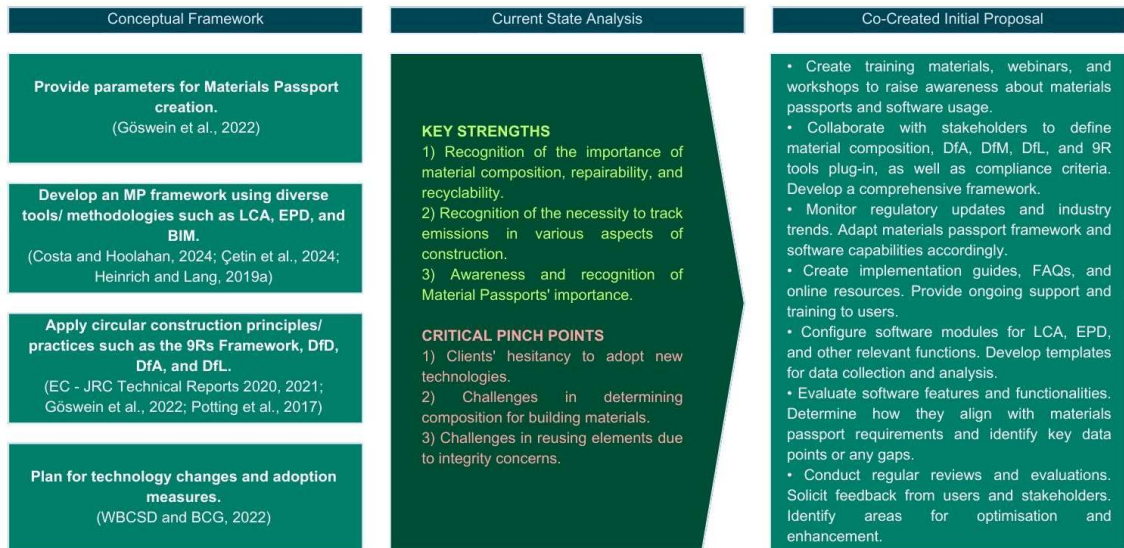


Figure 19. Draft Proposal Under Digital Record and Traceability.

Figure 19 depicts the key components of the proposal which include the development of a comprehensive framework for Materials Passport (MP) creation, collaboration with stakeholders to define material composition and sustainability criteria, and the adaptation of software capabilities to regulatory updates and industry trends. Additionally, the key stakeholders believe that the proposal should advocate for awareness-raising initiatives, ongoing support and training for users, and continuous evaluation and enhancement of software functionalities. Through these actions, the proposal seeks to overcome challenges such as clients' hesitancy to adopt new technologies and uncertainties in determining material composition, thereby advancing the adoption of circular construction principles and practices. Below are some of the excerpts from the brainstorming meeting:

One informant stated that: *“Stakeholder engagement is crucial and it's actually one of the most important aspects. If stakeholders aren't actively involved and don't contribute, it can hinder progress.”* Data 2-Informant 2

Another informant expressed: *“LCA and EPD are important existing offerings that can be utilised as they already provide significant value in*

terms of the materials information necessary for the creation of Materials Passport.” Data 2-Informant 7

5.2.2 Data Management Strategies

Figure 20 shows the co-created proposal under the data management category.

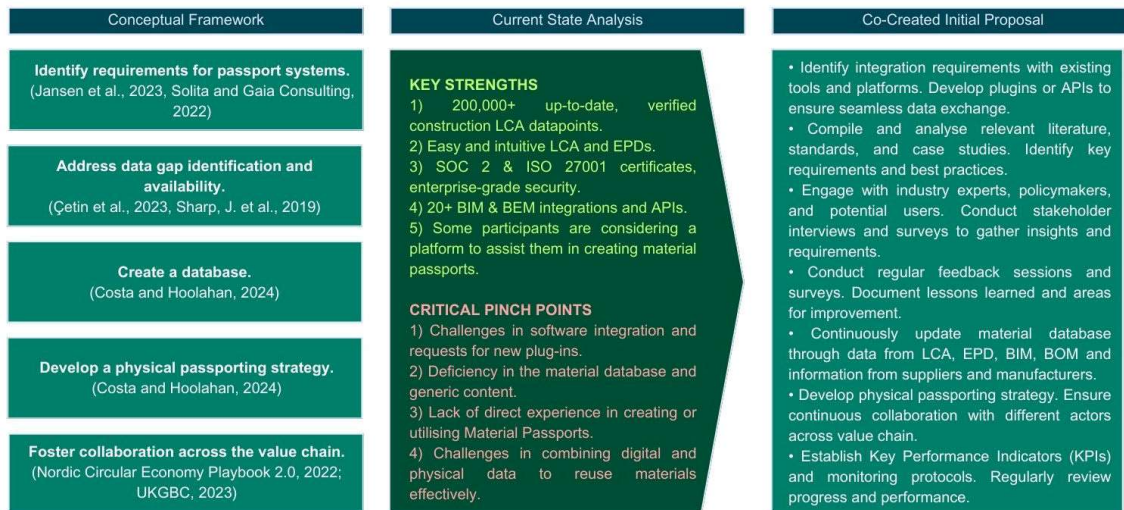


Figure 20. Draft Proposal Under Data Management.

The key informants agreed that the initial proposal draft in Figure 20 should incorporate various actions, including identifying integration requirements, compiling relevant literature, engaging stakeholders, and conducting feedback sessions. They also expressed the opinion that continuous updates to the material database and the development of a physical passporting strategy should be prioritised. Additionally, they suggested establishing key performance indicators and monitoring protocols to ensure regular review of progress and performance.

During the discussion, additional considerations were also raised, including incorporating feedback from pilot testing, defining success criteria for pilot projects, and ensuring continuous collaboration across the value chain. These elements collectively form a comprehensive roadmap for effective data management in Materials Passport creation. Comments from the informants include the following:

An informant highlighted: *“It is important to establish achievable goals for every phase and strive to optimise. Ensure that communication channels are established on a weekly or biweekly basis to facilitate discussions and track progress effectively.”* Data 2-Informant 4

One informant cited: *“I think continuous improvement is the key to everything because it ensures the ongoing enhancement and refinement of tools, processes, methodologies, and outcomes related to the project.”* Data 2-Informant 7

5.2.3 Regulatory Landscape Initiatives

Figure 21 below depicts the co-created proposal under the regulatory landscape.

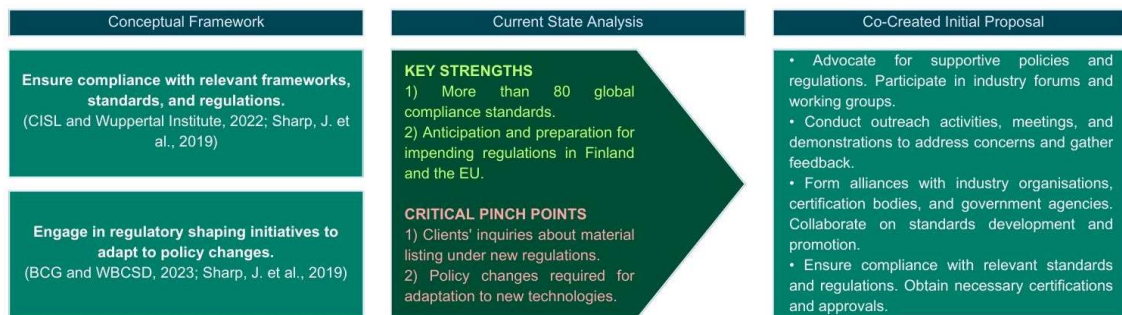


Figure 21. Draft Proposal Under Regulatory Landscape.

The proposal as outlined in Figure 21 listed strategic actions across three main areas: compliance, stakeholder engagement, and regulatory adaptation. The key stakeholders' recommendations include advocating for supportive policies, conducting outreach activities for feedback collection, forming alliances with relevant organisations, and ensuring compliance with standards and regulations. This comprehensive approach aims to navigate challenges while advancing the adoption of Materials Passport (MP) in alignment with regulatory requirements and industry best practices. Some of the insights from the informants include the following:

An informant noted this: *“The regulatory changes are like changing all the time. So, you have to be all the time checking the standards because they are changing constantly too. I would say also, maybe, in the continuous improvement and monitoring, to keep in contact with the stakeholders, you know, because some of them, when the regulatory changes, they don’t know. We have to communicate also to them, like, you know, this standard changed.”* Data 2: Informant 2

Another participant expressed: *“I think one of the most important things to consider is to constantly engage with government agencies that make the policies and explore how private companies can play a more active role in policymaking. After all, we are the ones working in the industry, knowledgeable about the in and out, and considered experts in the field. Also, we are the ones interacting with customers on a regular basis.”* Data 2: Informant 5

5.3 The Initial Roadmap

The initial proposal for creating a roadmap for Materials Passport (MP) is derived from the general measures, initiatives, and strategies co-created by the author and the informants, as described in the above process. Figure 22 presented in the next page, illustrates the process of co-creation and the initial proposal building stage. The Conceptual Framework (CF) represents how things were done - what works, or what does not, while the Current State Analysis (CSA) illustrates what is the current state - what is available or lacking thereof. Then, the general roadmap steps are then categorised and grouped into phases.



Figure 22. The Initial Roadmap Co-Creation Process.

As illustrated in Figure 22, the initial roadmap consists of six phases aimed at developing the Materials Passport (MP) creation system. The measures, strategies, and initiatives collected during the co-creation stage were methodically and logically combined and arranged. Subsequently, corresponding

tasks, timelines, durations, responsible teams, and progress were also included, thus forming the initial roadmap proposal. Table 12 below offers an overview of the co-created initial roadmap proposal.

Phase 1 involves researching and analysing relevant literature, software features, and stakeholder insights. Phase 2 focuses on developing the Materials Passport framework, including defining essential components and utilising software capabilities. Phase 3 emphasises stakeholder engagement and awareness through educational materials, client outreach, and collaboration with policymakers. Phase 4 includes pilot testing and validation to ensure compliance with regulatory requirements. Phase 5 focuses on scaling and implementation, refining the framework, developing guidelines, and establishing partnerships. Finally, Phase 6 prioritises continuous improvement and monitoring, including implementing monitoring mechanisms, identifying opportunities for improvement, and staying updated on regulatory changes and emerging technologies.

This concludes the initial proposal, and the next section of the research is the validation of the proposed roadmap.

TASK	REQUIRED ACTION	START DATE	END DATE	DURATION	RESPONSIBLE	PROGRESS
Phase 1: Research and Analysis						
Task 1: Literature review, analysis of standards and regulations.	Compile and analyse relevant literature, standards, and case studies. Identify key requirements and best practices. Analyse competitor.	01/05/2024	31/07/2024	91	Product Marketing & Data Team	5 %
Task 2: Analysis of the software.	Evaluate software features and functionalities. Determine how they align with materials passport requirements and identify key data points or any gaps.	01/05/2024	30/06/2024	60	Product Marketing & Data Team	5 %
Task 3: Identify key stakeholders and gather insights.	Engage with industry experts, policymakers, and potential users. Conduct stakeholder interviews and surveys to gather insights and requirements.	01/05/2024	31/07/2024	91	Product Marketing & Data Team	5 %
Phase 2: Development of Materials Passport Framework						
Task 1: Define essential components of the materials passport.	Collaborate with stakeholders to define material composition, DfA, DfM, DfL, and 9R tools plug-in, as well as compliance criteria. Develop a comprehensive framework.	30/07/2024	30/09/2024	62	Technology Team	3 %
	Continuously update material database through data from LCA, EPD, BIM, BOM and information from suppliers and manufacturers.					3 %
Task 2: Utilise software capabilities to establish framework.	Configure software modules for LCA, EPD, and other relevant functions. Develop templates for data collection and analysis.	30/09/2024	30/11/2024	61	Technology Team	3 %
	Develop physical passporting strategy. Ensure continuous collaboration with different actors across value chain.					3 %
Task 3: Address challenges related to software integration.	Identify integration requirements with existing tools and platforms. Develop plugins or APIs to ensure seamless data exchange.	30/11/2024	31/01/2025	62	Technology Team	3 %
Phase 3: Stakeholder Engagement and Awareness						
Task 1: Develop educational materials and training programs.	Create training materials, webinars, and workshops to raise awareness about materials passports and software usage.	30/01/2025	31/03/2025	60	Marketing Team	3 %
Task 2: Engage with clients and industry partners.	Conduct outreach activities, meetings, and demonstrations to address concerns and gather feedback.	30/01/2025	31/03/2025	60	Marketing Team	3 %
Task 3: Collaborate with policymakers.	Advocate for supportive policies and regulations. Participate in industry forums and working groups.	30/01/2025	31/03/2025	60	Marketing Team	3 %
Phase 4: Pilot Testing and Validation						
Task 1: Select pilot projects.	Identify pilot project sites and stakeholders. Define success criteria and project scopes.	30/01/2025	30/04/2025	90	Product Marketing & Data Team	3 %
Task 2: Gather feedback from pilot participants.	Conduct regular feedback sessions and surveys. Document lessons learned and areas for improvement.	30/04/2025	30/06/2025	61	Product Marketing & Data Team	3 %
Task 3: Validate materials passport against regulatory requirements.	Ensure compliance with relevant standards and regulations. Obtain necessary certifications and approvals.	30/01/2025	30/04/2025	90	Product Marketing & Data Team	3 %
Phase 5: Scaling and Implementation						
Task 1: Refine materials passport framework.	Incorporate feedback from pilot testing. Update templates, guidelines, and procedures as needed.	30/09/2024	30/06/2025	273	Technology Team	3 %
Task 2: Develop guidelines and resources.	Create implementation guides, FAQs, and online resources. Provide ongoing support and training to users.	30/01/2025	30/04/2025	90	Product Marketing & Data Team	3 %
Task 3: Establish partnerships.	Form alliances with industry organisations, certification bodies, and government agencies. Collaborate on standards development and promotion.	30/01/2025	30/06/2025	151	Product Marketing & Data, Marketing & Sales Team	3 %
Phase 6: Continuous Improvement and Monitoring						
Task 1: Implement monitoring mechanisms.	Establish Key Performance Indicators (KPIs) and monitoring protocols. Regularly review progress and performance.	30/04/2025	31/12/2026	610	Marketing & Sales Team	3 %
Task 2: Identify opportunities for improvement.	Conduct regular reviews and evaluations. Solicit feedback from users and stakeholders. Identify areas for optimisation and enhancement.	30/04/2025	31/12/2026	610	Product Marketing & Data, Technology Teams	3 %
Task 3: Stay abreast of regulatory changes and emerging technologies.	Monitor regulatory updates and industry trends. Adapt materials passport framework and software capabilities accordingly.	30/04/2025	31/12/2026	610	Product Marketing & Data, Technology Teams	3 %

Note: The dates and progress indicated are for illustration purposes only.

Table 12. The Initial Roadmap for Materials Passport Creation.

6 Validating the Initial Roadmap

The preceding section outlined the initial roadmap collaboratively developed with key informants. Section 6 provides an overview of the validation process for the initial roadmap concerning Materials Passport (MP) creation. The first sub-section contains an overview of the proposal validation stage, while the second sub-section reviews the findings of Data Collection 3. At the end of this section, the final roadmap is presented.

6.1 Overview of the Validation Stage

The proposal underwent validation by presenting it to selected key stakeholders, both internal and external, and gathering their feedback. This feedback aimed to assess the feasibility of the proposed roadmap and its ability to address the business challenge outlined in section 1 of this study.

Due to time zone differences and busy schedules, convening all stakeholders for a single workshop was impractical. Therefore, data collection for this phase occurred through two separate sessions: an interview and a workshop, both conducted online and in person, as well as via email correspondences. The first session involved the participation of a materials specialist and a business developer, while the second session included a researcher and two built-environment professionals. Both sessions followed a similar structure, commencing with an overview of the conceptual framework and the current state analysis. Subsequently, the initial roadmap created earlier was presented, discussed, evaluated, and subjected to feedback by the participants, generating Data 3 for this study. Based on Data 3, some adjustments were made to the initial roadmap to form the final roadmap for Materials Passport creation.

6.2 Evaluation of the Initial Roadmap

The initial roadmap received enthusiastic feedback and was viewed as a promising proposal for Materials Passport (MP) creation. The overall effort was

commended, with most recommendations readily embraced. The initiative to tackle such a critical topic was acknowledged, and the outcomes were perceived as beneficial for the company. In the words of the informants:

One informant remarked: *"I think it's really complete and it's like you're working inside the company."* Data 3: Informant 2

Another stated: *"In my opinion, it's a solid roadmap proposal to begin with."* Data 3: Informant 5

6.3 Suggestions for Improvement to the Initial Roadmap

The majority of the proposed actions were well-received, with only minor comments raised regarding the addition of key performance indicators and measures, as well as about the assignment of teams to each task, particularly concerning the involvement of the sales team from the beginning. One informant mentioned the importance of having measurable goals, while another stressed that it would be helpful to include KPIs to quantify the goals set in the roadmap. Taking into account the valid points raised by the informants, the process for constructing the roadmap follows specific parameters to ensure the attainability of its objectives. The roadmap will adhere to specific, measurable, achievable, relevant, and time-bound criteria. By utilising these five benchmarks, the developed roadmap can delineate clear goals and actionable steps, ensuring that the pertinent tasks remain on course, given the mandate for Materials Passport (MP) implementation by 2027. Below are some of the recommendations from the informants, with the changes shown in Table 13:

A key stakeholder mentioned: *"I know that salespeople are also involved at the beginning. They are often the first ones to emphasise the necessity of a product or service. Like, I talked to these clients, and they ask about it. However, in cases where clients specifically request it, the sales team is also involved from the outset."* Data 3: Informant 2

One informant stated: *“What is most important for us in research is to establish achievable goals for every phase. Based on my experience, I have observed that this aspect is extremely important.”* Data 3-Informant 4

Another expert stressed: *“I believe including KPIs is important because they can enhance transparency, mitigate risks, ensure compliance, and provide a measure of the roadmap's status or progress.”* Data 3-Informant 7

TASK	REQUIRED ACTION	START DATE	END DATE	DURATION	RESPONSIBLE	PROGRESS	KEY PERFORMANCE INDICATOR	MEASURE
Phase 1: Research and Analysis								
Task 1: Literature review, analysis of standards and regulations.	Compile and analyse relevant literature, standards, and case studies. Identify key requirements and best practices. Analyse competitor.	01/05/2024	31/07/2024	91	Product Marketing & Data Team	5 %	Information coverage and requirement identification accuracy.	Percentage of relevant literature compiled and analysed. Number of key requirements accurately identified and documented.
					Business Development Team		Competitor insight depth.	Depth of analysis achieved.
Task 2: Analysis of the software.	Evaluate software features and functionalities. Determine how they align with materials passport requirements and identify key data points or any gaps.	01/05/2024	30/06/2024	60	Technology Team	5 %	Assessment of software features and functionalities.	Evaluation score of 8/10 or higher.
					Product Marketing & Data Team		Identification of gaps in alignment with materials passport requirements.	Identification of at least 10 gaps.
Task 3: Identify key stakeholders and gather insights.	Engage with industry experts, policymakers, and potential users. Conduct stakeholder interviews and surveys to gather insights and requirements.	01/05/2024	31/07/2024	91	Business Development Team	5 %	Number of stakeholder interviews and surveys conducted.	50 key stakeholder interviews and 500 survey responses collected.
					Marketing & Sales Team		Insights and requirements gathered.	Detailed report outlining key insights and requirements.
Phase 2: Development of Materials Passport Framework								
Task 1: Define essential components of the materials passport.	Collaborate with stakeholders to define material composition, DIA, DMI, DIL, and SR tools plug-in, as well as compliance criteria. Develop a comprehensive framework.	30/07/2024	30/09/2024	62	Technology Team	3 %	Components of the materials passport framework defined.	Framework document with at least 10 components outlined.
	Continuously update material database through data from LCA, EPD, BIM, BCM and information from suppliers and manufacturers.				Product Marketing & Data Team		Material database update and response to customer request.	Weekly update of database.
Task 2: Utilise software capabilities to establish framework.	Configure software modules for LCA, EPD, and other relevant functions. Develop templates for data collection and analysis.	30/09/2024	30/11/2024	61	Technology Team	3 %	Configuration of software modules for relevant functions.	Completed software configuration.
	Develop physical passporing strategy. Ensure continuous collaboration with different actors across value chain.				Product Marketing & Data Team		Development of physical passporing strategy.	Templates for physical passporing strategy.
Task 3: Address challenges related to software integration.	Identify integration requirements with existing tools and platforms. Develop plugins or APIs to ensure seamless data exchange.	30/11/2024	31/01/2025	62	Technology Team	3 %	Identification of integration requirements with existing tools and platforms.	Integration requirements document.
					Product Marketing & Data Team		Development of plugins or APIs for seamless data exchange.	Plugins or APIs developed.
Phase 3: Stakeholder Engagement and Awareness								
Task 1: Develop educational materials and training programs.	Create training materials, webinars, and workshops to raise awareness about materials passports and software usage.	30/01/2025	31/03/2025	60	Marketing & Sales Team	3 %	Creation of training materials, webinars, and workshops.	4 webinars and 1 workshop conducted every month.
					Business Development Team		Conduct of training sessions.	500 attendees trained every session.
Task 2: Engage with clients and industry partners.	Conduct outreach activities, meetings, and demonstrations to address concerns and gather feedback.	30/01/2025	31/03/2025	60	Marketing & Sales Team	3 %	Number of outreach activities, meetings, and demonstrations conducted.	5 meetings and 3 demonstrations conducted.
					Product Marketing & Data Team		Feedback received from clients and partners.	Summary report of feedback received.
Task 3: Collaborate with policymakers.	Advocate for supportive policies and regulations. Participate in industry forums and working groups.	30/01/2025	31/03/2025	60	Marketing & Sales Team	3 %	Advocacy efforts for supportive policies and regulations.	Policy briefing submitted to government agency.
					Product Marketing & Data Team		Participation in industry forums and working groups.	Attendance at 2 industry forums every month.
Phase 4: Pilot Testing and Validation								
Task 1: Select pilot projects.	Identify pilot project sites and stakeholders. Define success criteria and project scopes.	30/01/2025	30/04/2025	90	Product Marketing & Data Team	3 %	Pilot project sites and stakeholders identified.	3 pilot project sites selected.
					Business Development Team		Success criteria and project scopes defined.	Success criteria and scopes documented.
Task 2: Gather feedback from pilot participants.	Conduct regular feedback sessions and surveys. Document lessons learned and areas for improvement.	30/04/2025	30/06/2025	61	Business Development Team	3 %	Number of feedback sessions and surveys conducted.	10 feedback sessions and 100 surveys conducted.
					Marketing & Sales Team		Lessons learned and areas for improvement documented.	Lessons learned report with at least 10 insights documented.
Task 3: Validate materials passport against regulatory requirements.	Ensure compliance with relevant standards and regulations. Obtain necessary certifications and approvals.	30/01/2025	30/04/2025	90	Product Marketing & Data Team	3 %	Compliance with relevant standards and regulations verified.	Compliance report with regulatory approval obtained.
					Business Development Team		Necessary certifications and approvals obtained.	Certifications and approvals obtained.
Phase 5: Scaling and Implementation								
Task 1: Refine materials passport framework.	Incorporate feedback from pilot testing. Update templates, guidelines, and procedures as needed.	30/09/2024	30/06/2025	273	Technology Team	3 %	Incorporation of feedback from pilot testing.	Updated framework document with feedback incorporated.
					Product Marketing & Data Team		Updates made to templates, guidelines, and procedures as needed.	Revised templates and guidelines document issued.
Task 2: Develop guidelines and resources.	Create implementation guides, FAQs, and online resources. Provide ongoing support and training to users.	30/01/2025	30/04/2025	90	Product Marketing & Data Team	3 %	Creation of implementation guides, FAQs, and online resources.	Implementation guide and FAQs published.
					Business Development Team		Provision of ongoing support and training to users.	Support and training sessions conducted.
Task 3: Establish partnerships.	Form alliances with industry organisations, certification bodies, and government agencies. Collaborate on standards development and promotion.	30/01/2025	30/06/2025	151	Business Development Team	3 %	Alliances formed with industry organisations, certification bodies, and government agencies.	5 partnerships established.
					Marketing & Sales Team		Collaboration on standards development and promotion.	Collaboration agreement signed.
Phase 6: Continuous Improvement and Monitoring								
Task 1: Implement monitoring mechanisms.	Establish Key Performance Indicators (KPIs) and monitoring protocols. Regularly review progress and performance.	30/04/2025	31/12/2026	610	Business Development Team	3 %	Establishment of Key Performance Indicators (KPIs) and monitoring protocols.	KPI dashboard set up and monitoring plan implemented.
					Product Marketing & Data Team		Regular review of progress and performance.	Monthly progress review meetings held.
Task 2: Identify opportunities for improvement.	Conduct regular reviews and evaluations. Solicit feedback from users and stakeholders. Identify areas for optimisation and enhancement.	30/04/2025	31/12/2026	610	Product Marketing & Data Team	3 %	Regular reviews and evaluations conducted.	Quarterly review reports prepared.
					Technology Team		Feedback solicited from users and stakeholders.	Feedback survey conducted annually.
Task 3: Stay abreast of regulatory changes and emerging technologies.	Monitor regulatory updates and industry trends. Adapt materials passport framework and software capabilities accordingly.	30/04/2025	31/12/2026	610	Product Marketing & Data Team	3 %	Monitoring of regulatory updates and industry trends.	Quarterly regulatory update reports prepared.
					Technology Team		Adaptation of materials passport framework and software capabilities accordingly.	Updates and enhancements documented.

Note: The dates and progress indicated are for illustration purposes only.

Table 13. Changes Made to the Initial Recommendations.

As presented in Table 13, the changes are indicated in red text. Amendments were made under the 'Responsible' column, where tasks have been redistributed among designated key groups, as suggested by a key stakeholder. Diversifying the teams allows for greater productivity, considering the nature of the tasks and actions required for each phase of the project. Additionally, relevant Key Performance Indicators (KPIs) and measures were incorporated, as highlighted by one of the informants. KPIs and measures are crucial in this roadmap as they provide tangible benchmarks for evaluating the success and effectiveness of the proposed actions. By tracking these metrics, it can be ensured that efforts are aligned with the objectives set, and teams can make informed decisions throughout the project lifecycle.

However, it is important to note that the addition of KPIs and measures in the initial roadmap will not be included within the scope of this proposal. Instead, it will be considered as part of another micro task or subtopic outside the scope of this book. Further explanations regarding this concern will be highlighted in Chapter 7 under 'Practical Next Steps Recommendation.'

The above-mentioned changes will be implemented into the final roadmap in the next subsection.

6.4 The Final Roadmap

As a result of extensive collaboration among stakeholders during previous stages, the initial proposal presented during validation meetings was already refined and feasible. The final proposal for the roadmap for Materials Passport (MP) creation is outlined in Table 14 below. The concluding section of the study summarises the work, recommends next steps towards implementing the roadmap, and provides a self-evaluation of the study. This final section of the thesis offers conclusions with an executive summary, along with a self-evaluation of the thesis and some closing remarks.

TASK	REQUIRED ACTION	START DATE	END DATE	DURATION	RESPONSIBLE	PROGRESS	KEY PERFORMANCE INDICATOR	MEASURE
Phase 1: Research and Analysis								
Task 1: Literature review, analysis of standards and regulations.	Compile and analyse relevant literature, standards, and case studies. Identify key requirements and best practices. Analyse competitor.	01/05/2024	31/07/2024	91	Product Marketing & Data Team	5 %	Information coverage and requirement identification accuracy.	Percentage of relevant literature compiled and analysed. Number of key requirements accurately identified and documented.
					Business Development Team		Competitor insight depth.	Depth of analysis achieved.
Task 2: Analysis of the software.	Evaluate software features and functionalities. Determine how they align with materials passport requirements and identify key data points or any gaps.	01/05/2024	30/06/2024	60	Technology Team	5 %	Assessment of software features and functionalities.	Evaluation score of 8/10 or higher.
					Product Marketing & Data Team		Identification of gaps in alignment with materials passport requirements.	Identification of at least 10 gaps.
Task 3: Identify key stakeholders and gather insights.	Engage with industry experts, policymakers, and potential users. Conduct stakeholder interviews and surveys to gather insights and requirements.	01/05/2024	31/07/2024	91	Business Development Team	5 %	Number of stakeholder interviews and surveys conducted.	50 key stakeholder interviews and 500 survey responses collected.
					Marketing & Sales Team		Insights and requirements gathered.	Detailed report outlining key insights and requirements.
Phase 2: Development of Materials Passport Framework								
Task 1: Define essential components of the materials passport.	Collaborate with stakeholders to define material composition, DfA, DfM, DfL, and 9R tools plug-in, as well as compliance criteria. Develop a comprehensive framework.	30/07/2024	30/09/2024	62	Technology Team	3 %	Components of the materials passport framework defined.	Framework document with at least 10 components outlined.
	Continuously update material database through data from LCA, EPD, BIM, BOM and information from suppliers and manufacturers.				Product Marketing & Data Team		Material database update and response to customer request.	Weekly update of database.
Task 2: Utilise software capabilities to establish framework.	Configure software modules for LCA, EPD, and other relevant functions. Develop templates for data collection and analysis.	30/09/2024	30/11/2024	61	Technology Team	3 %	Configuration of software modules for relevant functions.	Completed software configuration.
	Develop physical passporting strategy. Ensure continuous collaboration with different actors across value chain.				Product Marketing & Data Team		Development of physical passporting strategy.	Templates for physical passporting strategy.
Task 3: Address challenges related to software integration.	Identify integration requirements with existing tools and platforms. Develop plugins or APIs to ensure seamless data exchange.	30/11/2024	31/01/2025	62	Technology Team	3 %	Identification of integration requirements with existing tools and platforms.	Integration requirements document.
					Product Marketing & Data Team		Development of plugins or APIs for seamless data exchange.	Plugins or APIs developed.
Phase 3: Stakeholder Engagement and Awareness								
Task 1: Develop educational materials and training programs.	Create training materials, webinars, and workshops to raise awareness about materials passports and software usage.	30/01/2025	31/03/2025	60	Marketing & Sales Team	3 %	Creation of training materials, webinars, and workshops.	4 webinars and 1 workshop conducted every month.
					Business Development Team		Conduct of training sessions.	500 attendees trained every session.
Task 2: Engage with clients and industry partners.	Conduct outreach activities, meetings, and demonstrations to address concerns and gather feedback.	30/01/2025	31/03/2025	60	Marketing & Sales Team	3 %	Number of outreach activities, meetings, and demonstrations conducted.	5 meetings and 3 demonstrations conducted.
					Product Marketing & Data Team		Feedback received from clients and partners.	Summary report of feedback received.
Task 3: Collaborate with policymakers.	Advocate for supportive policies and regulations. Participate in industry forums and working groups.	30/01/2025	31/03/2025	60	Marketing & Sales Team	3 %	Advocacy efforts for supportive policies and regulations.	Policy briefing submitted to government agency.
					Product Marketing & Data Team		Participation in industry forums and working groups.	Attendance at 2 industry forums every month.
Phase 4: Pilot Testing and Validation								
Task 1: Select pilot projects.	Identify pilot project sites and stakeholders. Define success criteria and project scopes.	30/01/2025	30/04/2025	90	Product Marketing & Data Team	3 %	Pilot project sites and stakeholders identified.	3 pilot project sites selected.
					Business Development Team		Success criteria and project scopes defined.	Success criteria and scopes documented.
Task 2: Gather feedback from pilot participants.	Conduct regular feedback sessions and surveys. Document lessons learned and areas for improvement.	30/04/2025	30/06/2025	61	Business Development Team	3 %	Number of feedback sessions and surveys conducted.	10 feedback sessions and 100 surveys conducted.
					Marketing & Sales Team		Lessons learned and areas for improvement documented.	Lessons learned report with at least 10 insights documented.
Task 3: Validate materials passport against regulatory requirements.	Ensure compliance with relevant standards and regulations. Obtain necessary certifications and approvals.	30/01/2025	30/04/2025	90	Product Marketing & Data Team	3 %	Compliance with relevant standards and regulations verified.	Compliance report with regulatory approval obtained.
					Business Development Team		Necessary certifications and approvals obtained.	Certifications and approvals obtained.
Phase 5: Scaling and Implementation								
Task 1: Refine materials passport framework.	Incorporate feedback from pilot testing. Update templates, guidelines, and procedures as needed.	30/09/2024	30/06/2025	273	Technology Team	3 %	Incorporation of feedback from pilot testing.	Updated framework document with feedback incorporated.
					Product Marketing & Data Team		Updates made to templates, guidelines, and procedures as needed.	Revised templates and guidelines document issued.
Task 2: Develop guidelines and resources.	Create implementation guides, FAQs, and online resources. Provide ongoing support and training to users.	30/01/2025	30/04/2025	90	Product Marketing & Data Team	3 %	Creation of implementation guides, FAQs, and online resources.	Implementation guide and FAQs published.
					Business Development Team		Provision of ongoing support and training to users.	Support and training sessions conducted.
Task 3: Establish partnerships.	Form alliances with industry organisations, certification bodies, and government agencies. Collaborate on standards development and promotion.	30/01/2025	30/06/2025	151	Business Development Team	3 %	Alliances formed with industry organizations, certification bodies, and government agencies.	5 partnerships established.
					Marketing & Sales Team		Collaboration on standards development and promotion.	Collaboration agreement signed.
Phase 6: Continuous Improvement and Monitoring								
Task 1: Implement monitoring mechanisms.	Establish Key Performance Indicators (KPIs) and monitoring protocols. Regularly review progress and performance.	30/04/2025	31/12/2026	610	Business Development Team	3 %	Establishment of Key Performance Indicators (KPIs) and monitoring protocols.	KPI dashboard set up and monitoring plan implemented.
					Product Marketing & Data Team		Regular review of progress and performance.	Monthly progress review meetings held.
Task 2: Identify opportunities for improvement.	Conduct regular reviews and evaluations. Solicit feedback from users and stakeholders. Identify areas for optimisation and enhancement.	30/04/2025	31/12/2026	610	Product Marketing & Data Team	3 %	Regular reviews and evaluations conducted.	Quarterly review reports prepared.
					Technology Team		Feedback solicited from users and stakeholders.	Feedback survey conducted annually.
Task 3: Stay abreast of regulatory changes and emerging technologies.	Monitor regulatory updates and industry trends. Adapt materials passport framework and software capabilities accordingly.	30/04/2025	31/12/2026	610	Product Marketing & Data Team	3 %	Monitoring of regulatory updates and industry trends.	Quarterly regulatory update reports prepared.
					Technology Team		Adaptation of materials passport framework and software capabilities accordingly.	Updates and enhancements documented.

Note: The dates and progress indicated are for illustration purposes only.

Table 14. The Final Roadmap.

In the final roadmap shown in Table 14, the project is meticulously organised into six phases, each subdivided into specific tasks delineating required activities, start and end dates, durations, progress tracking, responsible teams, key performance indicators (KPIs), and corresponding measures. These phases include comprehensive stages of development and implementation of materials passports, commencing with research and analysis, progressing through framework development, stakeholder engagement, pilot testing, scaling, and continuous improvement, and monitoring. Tasks within these phases entail activities such as literature review, software evaluation, stakeholder engagement, pilot project selection, refining the framework, developing educational materials, establishing partnerships, and monitoring progress. Through systematic planning and execution, the roadmap aims to guide the effective adoption and integration of materials passports in the case company's existing offering.

7 Conclusion

The concluding part of this research includes an executive summary, suggestions for future actions, a self-assessment of the study and its outcomes, and concluding remarks.

7.1 Executive Summary

The focus of this thesis centres on a Finnish Software-as-a-Service (SaaS) company specialising in cloud-based software tailored for the construction sector. With a core feature set including automated life cycle assessment (LCA) capabilities and support for Environmental Product Declarations (EPDs), the platform serves a global audience. However, a notable challenge arises from the absence of a Materials Passport (MP) feature, particularly in light of impending European Union (EU) regulations mandating Digital Product Passport (DPP). The primary objective is to integrate a Materials Passport (MP) module into the existing offering, thereby enhancing circular alignment and resource traceability, and contributing to revenue growth.

The study's scope includes a comprehensive analysis of the existing tools and platform and formulating a roadmap for Materials Passport creation. It comprises seven sections, including research design, literature review, current state analysis, initial proposal, validation, and conclusions. Through a thorough literature review and stakeholder engagement, a conceptual framework is developed, addressing foundational principles, digital record and traceability, regulatory landscape, and data management. Strengths and critical pinch points are identified, providing valuable insights into the initial proposal for the roadmap.

The roadmap development process involves collaborative sessions with stakeholders that help build the general recommendations from the conceptual framework and current state analysis, and at the same time address critical pinch points. It comprises three primary components: digital record and traceability, regulatory landscape, and data management. The initial roadmap has six phases:

research and analysis, development of the framework, stakeholder engagement, pilot testing, scaling and implementation, and continuous improvement. Validation by key stakeholders confirms the feasibility and potential impact of the proposed roadmap, paving the way for its implementation.

The thesis concludes with recommendations for next steps along with a self-evaluation of the study's process and outcomes. Closing remarks underscore the importance of continuous improvement and collaboration in driving sustainability efforts within the construction industry, emphasising the need for ongoing adaptation to evolving regulatory landscapes and industry practices.

7.2 Practical Next Steps Recommendations

This subsection provides recommendations for the practical next steps that the case company could undertake. The proposed roadmap outlines detailed tasks, timelines, actions, and measures, derived from the outcomes of this study. It is imperative that tasks outlined in the roadmap are reviewed carefully to provide a jumpstart for the entire project, given the dynamic nature of policies and the frequent introduction of new directives. Gathering feedback and insights from both internal and external stakeholders is crucial as it can help identify risks and opportunities. Furthermore, this feedback can contribute to refining the implementation strategy and ensuring alignment with stakeholder expectations.

In terms of the KPIs and measures recommended to be added to the roadmap during the validation in section 6, integrating them could potentially add value. However, it has been determined that this aspect falls outside the immediate scope of the current proposal. Therefore, it will be addressed separately as part of another micro task or subtopic not covered within the confines of this book. The ultimate goal is to empower project stakeholders to enhance project effectiveness and achieve successful outcomes.

It is essential to recognise that the implementation of the roadmap is not a one-time process but rather an ongoing effort. Continuous development, improvement, and monitoring of existing tools are necessary to adapt to changing

regulatory landscapes and evolving market dynamics. Additionally, maintaining awareness of relevant regulations and new materials introduced in the market, as well as understanding stakeholders' sentiments, is vital for the success of the project. Regular updates and adjustments to the implementation strategy based on feedback and changing circumstances will be key to achieving the desired outcomes and ensuring the long-term sustainability of the initiative.

7.3 Self-Evaluation of the Thesis

This thesis was meticulously created, adhering to a systematic and comprehensive approach in line with the prescribed structure and guidelines of research methodology. The literature review was conducted diligently, drawing upon a number of academic sources, given that the concept of Materials Passport (MP) is relatively new. The research design was meticulously followed, and a thorough assessment of the current state yielded valuable insights, albeit with the challenge of identifying significant weaknesses, hence the adoption of the term 'pinch points.' In terms of informant selection, all participants come from the built-environment industry, each bringing diverse expertise and specialisations that greatly enrich and inform the proposal. The initial improvement proposal was meticulously structured, synthesising insights from the literature review, current state analysis, and input from key stakeholders. Validation of the initial proposal by stakeholders resulted in only minor adjustments, indicating its alignment with the earlier insights and recommendations. Subsequently, the final improvement proposal was formulated based on this validation process.

Throughout the research, the scope of the thesis expanded, reflecting the technical intricacies of the systems and processes involved in developing the roadmap. Consequently, the roadmap was formulated with a more general approach. Nevertheless, the thesis successfully addressed all identified pinch points and achieved the objectives set at the beginning.

In terms of transferability, this research has garnered interest from several entities keen on implementing the proposal and utilising the Materials Passport in projects

related to logistics traceability and construction demolition waste management. While the presented roadmap can serve as a guide, further research is warranted to ensure its applicability in the said areas, as comprehensive details have not been covered in this study. During the course of the research, the author has had the pleasure of being invited as a resource person on the same topic. However, there remains much to learn about the ever-evolving industry, as well as in process development.

Overall, there is opportunity for further improvement of the proposal, particularly considering the continuous introduction of new technologies, ideas, and policies in the AEC industry.

7.4 Closing Words

In conclusion, meticulous research and analysis have uncovered valuable insights and laid out a roadmap for Materials Passport (MP) creation. Moving forward, it is crucial to maintain a commitment to innovation, circularity, and sustainability, continuously striving to improve practices and make a positive impact in the built-environment industry.

References

Akanbi, L. A., Oyedele, L. O., Omoteso, K., Bilal, M., Akinade, O. O., Ajayi, A. O., Delgado, J. M. D., & Owolabi, H. A. (2019). Disassembly and deconstruction analytics system (D-DAS) for construction in a circular economy. *Journal of Cleaner Production*, 223, 386-396. ISSN 0959-6526. DOI: 10.1016/j.jclepro.2019.03.172. <https://doi.org/10.1016/j.jclepro.2019.03.172>

Badi, Sulafa & Murtagh, Niamh. (2019). Green supply chain management in construction: A systematic literature review and future research agenda. *Journal of Cleaner Production*. 223. 10.1016/j.jclepro.2019.03.132

Bajpai, N. (2011). *Business Research Methods*. Pearson Education India. ISBN 9332511756, 9789332511750.

Berg, H., Jansen, M., Meisen, T., Plociennik, C., Pomp, A., & Windholz, W. (2023). Stop Guessing in the Dark: Identified Requirements for Digital Product Passport Systems. *Systems*, 11, 123. <https://doi.org/10.3390/systems11030123>

Berglund-Brown, Juliana & Kedir, Firehiwot & Riabova, A & Hall, Daniel. (2022). Assessing Circular Information Flow in Industrialized Construction: a framework for evaluating data for circular construction. *IOP Conference Series: Earth and Environmental Science*. 1078. 012005. 10.1088/1755-1315/1078/1/012005.

Boston Consulting Group (BCG) & World Business Council for Sustainable Development (WBCSD). (2023, January). Enabling circularity through transparency: Introducing the EU Digital Product Passport.

Boston Consulting Group (BCG) & World Business Council for Sustainable Development (WBCSD). (2023, January). Navigating uncertainties of the EU Digital Product Passport (DPP): How to prepare now as a company.

Boston Consulting Group (BCG) & World Business Council for Sustainable Development (WBCSD). (2023, January). The EU Digital Product Passport shapes the future of value chains: What it is and how to prepare now.

Byers, B., & De Wolf, C. (2023, October). QR Code-Based Materials Passports for Component Reuse Across Life Cycle Stages in Small Scale Construction. Retrieved from <https://doi.org/10.3929/ethz-b-000634760>

Çetin, S., Raghu, D., Honic, M., Straub, A., & Gruis, V. (2023). Data requirements and availabilities for Materials Passports: A digitally enabled framework for improving the circularity of existing buildings. *Sustainable Production and Consumption*, 40, 422-437. <https://doi.org/10.1016/j.spc.2023.07.011>

Circular Buildings Coalition. (2023, June). Towards a Circular Economy in the Built Environment: Overcoming market, finance, and ownership challenges.

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

De Wolf, C., Çetin, S., & Bocken, N. (2024). A Circular Built Environment in the Digital Age. <https://doi.org/10.1007/978-3-031-39675-5>

Eastman, C., Eastman, C. M., Teicholz, P. et al. (2011). *BIM Handbook: A Guide to Building Information Modeling for Owner, Manager, Designer, Engineers and Contractors* (p. 243). Hoboken, NJ: John Wiley & Sons.

European Commission. (n.d.). European Commission. Retrieved from https://commission.europa.eu/index_en

Geldermans, R. J. (2016). Design for Change and Circularity – Accommodating Circular Material & Product Flows in Construction. *Energy Procedia*, 96, 301-311. ISSN 1876-6102. DOI: 10.1016/j.egypro.2016.09.153. <https://doi.org/10.1016/j.egypro.2016.09.153>

Göswein, V., Carvalho, S., Cerqueira, C., & Lorena, A. (2022). Circular Materials Passports for buildings – Providing a robust methodology for promoting circular buildings. IOP Conference Series: Earth and Environmental Science, 1122, 012049. <https://doi.org/10.1088/1755-1315/1122/1/012049>

Heinrich, Matthias & Lang, Werner. (2019). Materials Passport - Best Practice - Innovative Solutions for a Transition to a Circular Economy in the Built Environment.

Honic, Meliha & Kovacic, Iva & Rechberger, Helmut. (2019). Improving the recycling potential of buildings through Material Passports (MP): An Austrian case study. Journal of Cleaner Production. 217. 10.1016/j.jclepro.2019.01.212.

JRC Technical Reports, Level(s) indicator 2.3: Design for adaptability and renovation. User manual: overview, instructions, and guidance (Publication version 1.0).

JRC Technical Reports, Level(s) indicator 2.4: Design for deconstruction. User manual: introductory briefing, instructions, and guidance (Publication version 1.1).

Kothari, C. R. (2004). Research Methodology: Methods and Techniques (Illustrated, Revised Edition). New Age International. ISBN 8122415229, 9788122415223.

International Organisation for Standardisation - ISO 20887. (2020). Reference number ISO 20887:2020(E).

Hossain, M. U., & Ng, S. T. (2019). Influence of waste materials on buildings' life cycle environmental impacts: Adopting resource recovery principle. Resources, Conservation and Recycling, 142, 10-23. ISSN 0921-3449. DOI: 10.1016/j.resconrec.2018.11.010.

<https://doi.org/10.1016/j.resconrec.2018.11.010>

Jansen, M.; Meisen, T.; Plociennik, C.; Berg, H.; Pomp, A.; Windholz, W. Stop Guessing in the Dark: Identified Requirements for Digital Product Passport Systems. *Systems* 2023, 11, 123. <https://doi.org/10.3390/systems11030123>

Kananen, J. (2013). *Design Research (Applied Action Research) as Thesis Research: A Practical Guide for Thesis Research*. JAMK University of Applied Sciences.

Linder, M., Boyer, R. H. W., Dahllöf, L., Vanacore, E., & Hunka, A. (2020). Product-level inherent circularity and its relationship to environmental impact. *Journal of Cleaner Production*, 260, 121096. ISSN 0959-6526. DOI: 10.1016/j.jclepro.2020.121096. <https://doi.org/10.1016/j.jclepro.2020.121096>

Luscuere, L., & Mulhall, D. (2018). Circularity information management for buildings: The example of materials passports. In *Designing for the Circular Economy* (1st Edition, pp. 12). Routledge. eBook ISBN 9781315113067.

Mêda, Pedro & Calvetti, Diego & Kifokeris, Dimosthenis & Kassem, Mohamad. (2022). A process-based framework for digital building logbooks. 10.35490/EC3.2022.183.

Munaro, Mayara & Tavares, Sergio. (2021). Materials passport's review: challenges and opportunities toward a circular economy building sector. *Built Environment Project and Asset Management*. ahead-of-print. 10.1108/BEPAM-02-2020-0027.

Nordic Innovation & Accenture. (2022). *Nordic Circular Economy Playbook 2.0: Transform & Scale*.

Potting, José & Hekkert, M.P. & Worrell, Ernst & Hanemaaijer, Aldert. (2017). *Circular Economy: Measuring innovation in the product chain*.

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

Saidani, Michael, Bernard Yannou, Yann Leroy, and François Cluzel. 2017. "How to Assess Product Performance in the Circular Economy? Proposed Requirements for the Design of a Circularity Measurement Framework" *Recycling* 2, no. 1: 6. <https://doi.org/10.3390/recycling2010006>

Saunders, Mark & Lewis, P. & Thornbill, A.. (2000). *Research Methods for Business Studies*.

Sharp, J., Hobbs, G., Henrotay, C., Steinlage, M., Debacker, W., De Regel, S., Sjögren, C. (2019, January). BAMB - Framework for Policies, Regulations and Standards.

Solita & Gaia Consulting. (2022, October). *Digital Product Passport*.

The UK Green Building Council. (2023, January). *System Enablers for a Circular Economy*.

University of Cambridge Institute for Sustainability Leadership (CISL) & Wuppertal Institute. (2022). *Digital Product Passport: The ticket to achieving a climate neutral and circular European economy*. Cambridge, UK: CLG Europe.

World Economic Forum (n.d.). World Economic Forum. Retrieved from <https://www.weforum.org/>

Yeheyis, Muluken & Hewage, Kasun & Alam, M. Shahria & Eskicioglu, Cigdem & Sadiq, Rehan. (2012). An overview of construction and demolition waste management in Canada: A lifecycle analysis approach to sustainability. *Clean Technologies and Environmental Policy*. 15. 10.1007/s10098-012-0481-6.

Appendix 1: CSA Interview Questions Guide (Internal Stakeholders)

1. Can you please briefly introduce yourself, your role, and what do you do?
2. Have you used or made Materials Passport or related tool before?
3. What challenges or gaps do you perceive due to the absence of a comprehensive Materials Passport feature in the current offering?
4. In your opinion, how critical is a Materials Passport feature for enhancing circular alignment and resource traceability within the platform?
5. How do you envision the integration of a Materials Passport module into the existing circularity offering?
6. How do you anticipate the addition of a Materials Passport feature will impact existing clients?
7. Do you see potential benefits in terms of client retention and attracting new clients with this addition?
8. What steps do you believe are necessary to establish the process of incorporating a Materials Passport module into the circularity offering?
9. Are there specific challenges you foresee in this process?
10. Can you identify specific functionalities or tools that stakeholders would find valuable in enhancing circularity within the platform?
11. Is there a specific functionality or feature that you believe should be prioritised in the Materials Passport module? Please rank the following list from the most important to the least important in developing the Materials Passport or circularity tool (1 being the most important, 10 being the least important):
 - Durability
 - Upgradability
 - Material composition
 - Maintenance
 - Recyclability
 - Refurbishment
 - Repairability
 - Recycled material
 - Second-life information
 - Disposal

Appendix 2: CSA Interview Questions Guide (External Stakeholders)

1. Can you please briefly introduce yourself, your role, and what do you do?
2. How do you perceive the current state of sustainability and circularity practices in the built-environment industry?
3. Have you used or made Materials Passport or related tool before?
4. From your perspective, what role do Materials Passport play in advancing circularity within the built-environment industry?
5. What challenges do you observe in the industry concerning circular alignment and resource traceability?
6. In your expert opinion, why is a Materials Passport feature essential for a company specialising in life cycle assessment (LCA)?
7. Are you a user or customer of the case company's software?
8. How do you view the role of technology, particularly software solutions, in driving sustainability and circularity in the built-environment industry?
9. Are there emerging trends or innovations that you believe could shape the future of materials traceability and circularity in the built-environment industry?
10. In your line of work, do you use any tools or methodologies that have positively impacted sustainability and circularity practices?
11. Is there a specific functionality or feature that you believe should be prioritised in the Materials Passport module? Please rank the following list from the most important to the least important in developing the Materials Passport or circularity tool (1 being the most important, 10 being the least important):
 - Durability
 - Upgradability
 - Material composition
 - Maintenance
 - Recyclability
 - Refurbishment
 - Repairability
 - Recycled material
 - Second-life information
 - Disposal