Identifying and Aligning Circular Construction Information with Level of Information Needs (LOIN) in Building Information Modeling (BIM)-based Workflows: A Case Study for Structural Elements

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Jurgen C.E.M. van den Eijnden 1892932

Graduation Committee

Chairwoman	Dr. Qi Han
First Supervisor	Dr. Arghavan Akbarieh
Secondary Supervisor	Dr. Payam Poorsolhjouy

Course: Graduation Project CME (7CC40)

Study Load: 40 ECTS

Academic Year: 2024-2025

15-08-2025

[This page is left empty]

Colophon

Title: Identifying and Aligning Circular Construction Information with Level of Information Needs (LOIN) in Building Information Modeling (BIM)-based Workflows: A Case Study for Structural Elements

Student information	Jurgen C.E.M. van den Eijnden
	1892932
	j.c.e.m.v.d.eijnden@student.tue.nl
Master program	Construction Management and Engineering (CME)
University	Eindhoven University of Technology (TU/e)
Graduation Program	Graduation project CME

Academic year	2024-2025
Course	Graduation project 7CC40
Study load	40 ECTs
Thesis defence date	15-08-2025
Version	1.0
Place:	Eindhoven, the Netherlands

Graduation Committee
Eindhoven University of Technology

Chairwoman	Dr. Qi Han Graduation committee q.han@tue.nl
University 1st supervisor	Dr. Arghavan Akbarieh a.akbarieh@tue.nl
University 2nd supervisor	Dr. Payam Poorsolhjouy p.poorsolhjouy@tue.nl

This Master Thesis has been carried out in accordance with the rules of the TU/e Code of Scientific Integrity, which includes Trustworthiness, Intellectual Honesty, Openness, Independence and Societal Responsibility.

Preface

Dear reader,

This thesis marks the result of my master's research and was inspired by my growing interest in how digital information standards can be applied to support sustainable construction practices, and, in particular, how Building Information Modelling (BIM) can enable the transition to a circular built environment.

My interest in BIM began long before this research. Earlier, I had the opportunity to support a company in integrating ISO 19650, a BIM-related standard, into their workflows. This experience strengthened my fascination with the management of digital information exchange and convinced me to pursue my master's degree. The topic of this thesis closely aligns with these interests, as it combines my passion for BIM with my ambition to contribute to digital innovation in the construction industry. Looking ahead, I am determined to continue my career in the BIM field, with a strong focus on advancing digital transformation in the sector.

I would like to thank my 2nd supervisor Dr. Payam Poorsolhjouy, and express my sincere gratitude to my 1st supervisor Dr. Arghavan Akbarieh, for her valuable guidance, constructive feedback, and encouragement throughout the research process. She has been pivotal in helping me grow, both academically and professionally, and has greatly contributed to my preparation for my future career.

My thanks also go to Heijmans for supplying the case study BIM model that formed the basis of this research. I am also grateful to the industry experts who participated in the interviews, generously sharing their time and knowledge, which significantly enriched the practical relevance of this work.

Finally, I am deeply thankful to my family and friends for their support, patience, and encouragement during this journey. Their belief in me has been a constant source of motivation and has made the completion of this thesis possible.

I hope this work contributes to the ongoing dialogue on embedding circularity into digital construction workflows, and inspires further research and innovation in the field.

J. van den Eijnden

12-09-2025

Acknowledgements

This research was supported by Heijmans, who provided access to the case study BIM model that formed the basis for the practical application and validation of the developed methodology. CoBuilder granted an open educational license for their platform and offered technical guidance throughout the project, enabling the integration and testing of circularity properties in a real-world BIM environment.

Contents

1. Introduction 17
   1.1 Background Information 17
   1.2 Problem Definition 19
   1.3 Objectives and Research Question 19
   1.4 Research Design 21
   1.5 Research Contributions 23
   1.6 Reading guide 24
2. Literature Review 25
   2.1 Aim of the Literature Review 25
   2.2 Method of the Literature Review 25
   2.3 Literature Review Results 27
      2.3.1 Circular Economy & BIM 27
      2.3.2 Emerging Digital Technologies as Enablers for Circularity 29
   2.4 Exchange Information Requirement & Level Of Information Need 30
   2.5 BuildingSMART 32
      2.5.1 Industry Foundation Classes (IFC) 32
      2.5.2 BuildingSMART Data Dictionary (bSDD) 33
      2.5.3 Information Delivery Specification (IDS) 34
   2.6 Practical Applications and Case Studies of Open Standards 35
   2.7 Studies on Necessary Data for Decommissioning & Reuse 35
      2.7.1 Origin and Identification Properties 36
      2.7.2 Technical and Structural Properties 38
      2.7.3 Condition and Lifecycle Data Properties 38
      2.7.4 Deconstruction and Disassembly Properties 38
      2.7.5 Circularity Strategy and Impact Properties 39
   2.8 Data Requirements for CE 40
3. Methodology 45
   3.1 Phase 1 & 2: Defining Data Requirements 46
      3.1.1 Literature Review for Foundational Properties 46
      3.1.2 Expert Interviews for Practice-based Insights 47
   3.2 Phase 3: Development of the Exchange Information Requirement (EIR) 51
   3.3 Phase 4: Case Study Application and Validation 52

3.3.1 Model Enrichment 53
3.3.2 Element Selection 54
3.3.3 Enrichment Process in the CoBuilder Require Platform 57
3.3.4 Enriching the IFC model & Validation 60
3.3.5 IDS-based Validation 60
3.4 Phase 5: Evaluation of the Workflow 61
4. Results 63
4.1 Foundational Property List from Literature Review 63
4.2 Practice-Based Insights from Expert Interviews: Informing the Data Needs for Circularity 64
4.2.1 Thematic Analysis Results 64
4.3 Consolidated & Final Property List for Circularity 69
4.3.1 In-depth Analysis of Key Circular Properties: Insights for Future Practice and bSDD Extension 80
4.4 Structured Exchange Information Requirements (EIR) 86
4.4.1 The Structure of the EIR 91
4.5 Case Study Application: Enriching BIM Model with Circular Properties 92
4.5.1 Implementing the EIR in CoBuilder Require 92
4.5.2 Model Enrichment and Technical Verification 94
4.5.3 Populating Property Values using usBIM 95
4.6 IDS-Based Validation 97
4.7 Summary of the Enrichment and Validation Process 99
5. Discussion 101
5.1 Interpretation of Findings 101
5.1.1 Essential Information for Decommissioning and Reuse (SQ1) 101
5.1.2 Structuring Information Requirements with LOIN (SQ2) 103
5.1.3 Embedding and Validating Circularity Data in BIM (SQ3) 105
5.2 Theoretical and Practical Implications 107
5.2.1 Theoretical Implications 107
5.2.2 Practical Implications 108
6. Conclusion 109
6.1 Addressing the Research Questions 109
6.2 Limitations and Recommendations for Future Research 111
7. References 113

Appendix I - Selected Cased Study Elements 123
Appendix II - Semi-Structured Interview Guide Protocol 127
Appendix III - Interview Questions Justification 130
Appendix IV – Informed Consent Sheet for Expert Interviews 131
Appendix V - Detailed Thematic Analysis Results from Semi-Structured Interviews 135
Appendix VI – Practice-Based Properties and Validation Against Literature 148
Appendix VII – Project LOIN in CoBuilder Require 154
Appendix VIII – IDS Validation - XLM Format 163

Summary

This thesis investigates how Building Information Modelling (BIM) can be leveraged to support circular construction by integrating circular data into structural BIM models in a structured and interoperable way. The research responds to the growing need for a circular built environment in which digital information is not only complete but also consistent, machine-readable, and applicable across platforms and stakeholders throughout the building lifecycle.

This research applies circular information to structural elements using Exchange Information Requirements (EIRs) structured according to the Level of Information Need (LOIN). It demonstrates how relevant reuse-related properties can be defined, embedded into IFC models, and validated through machine-readable Information Delivery Specification (IDS) rules, while leveraging openBIM standards such as the buildingSMART Data Dictionary (bSDD) to ensure interoperability and standardization.

A mixed-method approach was adopted, combining a literature review with expert interviews to identify and refine the necessary properties for structural elements. These insights were used to create a structured EIR aligned with the LOIN framework. The EIR was then translated into IDS validation rules and applied to a real case study model from the Willemspoort Zuid development in ’s-Hertogenbosch, provided by Heijmans.

The results show that aligning circularity data with the LOIN framework is technically feasible and enhances interoperability between stakeholders. The developed methodology demonstrates how to move from theoretical requirements to a validated BIM model, ensuring that circular properties are captured at the correct project milestones. In doing so, the study extends current knowledge by providing a reproducible, standards-based circular workflow that addresses data fragmentation and information loss over time.

Samenvatting

Deze thesis onderzoekt hoe Building Information Modelling (BIM) kan worden ingezet om circulair bouwen te ondersteunen door circulaire data op een gestructureerde en operabele manier te integreren in structurele BIM-modellen. Het onderzoek speelt in op de groeiende behoefte aan een circulaire gebouwde omgeving waarin digitale informatie niet alleen compleet is, maar ook consistent, machine-leesbaar en toepasbaar op verschillende platformen en voor verschillende stakeholders gedurende de gehele levenscyclus van een gebouw.

Dit onderzoek past circulaire informatie toe op structurele elementen met behulp van Exchange Information Requirements (EIR's), gestructureerd volgens de Level of Information Need (LOIN). Het laat zien hoe relevante hergebruik-gerelateerde properties kunnen worden gedefinieerd, ingebed in IFC-modellen, en gevalideerd door middel van machine-leesbare Information Delivery Specification (IDS)-regels, waarbij gebruik wordt gemaakt van openBIM-standaarden zoals de buildingSMART Data Dictionary (bSDD) om interoperabiliteit en standaardisatie te waarborgen.

Er is een mixed-method aanpak toegepast, waarbij een literatuurstudie is gecombineerd met expertinterviews om de benodigde properties voor structurele elementen te identificeren en verfijnen. Deze inzichten zijn gebruikt om een gestructureerde EIR op te stellen die aansluit bij het LOIN-framework. De EIR is vervolgens vertaald naar IDS-validatieregels en toegepast op een echt casestudy-model van de Willemspoort Zuid-ontwikkeling in 's-Hertogenbosch, geleverd door Heijmans.

De resultaten laten zien dat het afstemmen van circulariteitsdata op het LOIN-framework technisch haalbaar is en de interoperabiliteit tussen stakeholders vergroot. De ontwikkelde methodologie toont hoe van theoretische eisen kan worden toegewerkt naar een gevalideerd BIM-model, waarbij wordt gegarandeerd dat circulaire properties op de juiste projectmijlpalen worden vastgelegd. Daarmee draagt het onderzoek bij aan de bestaande kennis door een reproduceerbare, op standaarden gebaseerde circulaire workflow te bieden die dataversnippering en informatieverlies in de tijd tegengaat.

Abstract

The transition towards a circular economy in the construction industry is critically dependent on the availability of standardized, machine-readable, and interoperable digital information. While international standards like the Level of Information Need (LOIN) framework and openBIM standards such as the buildingSMART Data Dictionary (bSDD) and the Information Delivery Specification (IDS) provide a foundation for structured data exchange, a clear methodology for their integrated application to support component reuse and deconstruction is largely missing. This research addresses this gap by developing and validating a standards-based workflow for embedding circularity data into BIM models, with a specific focus on structural elements.

A mixed-method approach was employed, combining a systematic literature review with semi-structured expert interviews to identify a consolidated list of properties for decommissioning and reuse. These properties were then structured into a formal Exchange Information Requirement (EIR) table, meticulously aligned with the LOIN framework to define their purpose, responsible actor, and delivery milestone. This EIR was subsequently applied to a real-world case study BIM model. The workflow demonstrated the enrichment of an Industry Foundation Classes (IFC) model with circularity properties, mapped to the bSDD where possible, and its subsequent validation using an automatically generated IDS file.

The results confirm the technical feasibility of aligning circularity data with the LOIN framework using existing standards. The study successfully demonstrates an end-to-end process from requirement definition to a validated BIM model, ensuring that critical knowledge for future reuse is captured. However, the findings also reveal significant gaps in current standards, with a large portion of the identified practice-based properties lacking formal definitions in IFC or the bSDD. This research contributes a reproducible, standards-compliant workflow that bridges the gap between conceptual frameworks and operational BIM processes.

***Keywords**: Building Information Modelling, Level of Information Need, Circular Economy, openBIM, Exchange Information Requirements*

Table of Acronym

Acronym	
AEC	Architecture, Engineering, and Construction
BIM	Building Information Modeling
bSI	buildingSMART International
bSDD	buildingSMART Data Dictionary
CE	Circular Economy
EIR	Exchange Information Requirements
EPD	Environmental Product Declaration
IDS	Information Delivery Specification
IFC	Industry Foundation Classes
ISO	International Organization for Standardization
LOIN	Level Of Information Need
LOD	Level of Development / Detail
SDG	Sustainable Development Goal

List of Figures

Figure 1 - Render of the residential complex in Willemspoort Zuid, 's-Hertogenbosch. The building on the left (blue outline) forms the basis of the case study used in this research. Source: https://willemspoort.nl/ 21
Figure 2 - Research Design Overview 22
Figure 3 - The United Nations Sustainable Development Goals. This research primarily addresses goals 9, 11, 12, and 13 (adopted from United Nations – Sustainable Development Goals). Source: https://sdgs.un.org/goals 23
Figure 4 - Research Structure 24
Figure 5 - Detailed Flowchart of the Systematic Literature Review Process 26
Figure 6 Visual comparison between the linear and circular economy, highlighting the shift from disposal to reuse and recycling 27
Figure 7 Structure of information requirements and deliverables as defined in ISO 19650 ... 30
Figure 8 Overview of the Level of Information Need (LOIN) framework, including its prerequisites and components (adapted from ISO 19650-1:2018) 31
Figure 9 - Three core openBIM standards developed by buildingSMART. IFC provides the model's data structure, bSDD defines the meaning of the data, and IDS validates that the data is correct. 32
Figure 10 Original diagram from the buildingSMART Technical Roadmap, illustrating how generic IFC classes can be semantically enriched with context-specific property sets using the bSDD (buildingSMART International, 2020) 33
Figure 11 Structure of the Design Science Research framework as proposed by Wieringa (2014) 45
Figure 12 - Overview of all steps conducted in Phase 2: Expert Interviews 47
Figure 13 - Fictional Project Phase (Milestones) for the Case Study 51
Figure 14 - The IFC models. Left: structural model; right: architectural model (BIMvision) 53
Figure 15 - The Foundational IFC model (BIMvision) 53
Figure 16 - IfcSlab - Concrete Floor 57
Figure 17 - Screenshot of the project Milestones as defined in the CoBuilder Require platform for the case study. 58
Figure 18 - The various Purposes for the information requirements established within the CoBuilder Require environment. 59
Figure 19 - Screenshot of the Actors (project roles) added to the system to define the "WHO" prerequisite for the information requirements. 59
Figure 20 - Screenshot of the 'Create LOIN' entry section in Cobuilder Require. 60
Figure 21 - Overview of the Results Chapter Workflow. 63
Figure 22 - Thematic Analysis: Count of Code by Theme 64
Figure 23 - Overview of the multiple LOIN entries for the IfcSlab in CoBuilder Require 93
Figure 24 - Enriched IfcSlab element in BIMvision showing the automatically generated CoBuilder_Requirements property set, with Total Reuse Count property highlighted in blue. 94

Figure 25 - Adding a value to the “Total Reuse Count” property of the IfcSlab in usBIM, using the case study example value from the EIR table (usBIM). 96
Figure 26 - The final result of the workflow: the properties of the IfcSlab with the circularity properties successfully populated with example values. 96
Figure 27 - An example of a successful IDS validation, showing the verification (checkmark) of the Total Reuse Count property for the highlighted IfcSlab element (in the usBIM platform). 98
Figure 28 - Overview of Enrichment and Validation Process 99
Figure 29 - IfcWallStandardCase - In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875) 123
Figure 30 - IfcColumn - Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564) 124
Figure 31 - IfcWall - Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595) 124
Figure 32 - IfcBeam - Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485) 125
Figure 33 - IfcColumn - Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732) 125
Figure 34 - IfcSlab - Concrete Floor (Floor: NLRS_23_GdV_FL_betonvloer h=280:1854789) 126
Figure 35 - IfcBeam - In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010) 126
Figure 36 - LOIN in CoBuilder 154

List of Tables

Table 1 - Key items for reuse while defining the level of information needed of a model (Hradil et al., 2020) 37
Table 2 Foundational Property List for Decommissioning and Reuse 40
Table 3 Profile of the interviewed experts 48
Table 4 All IFC elements found in the model analysis 54
Table 5 All IFC elements that are included for property enrichment 56
Table 6 - Definitions of Consolidated & Final Property List 69
Table 7 - Consolidated & Final Property List 76
Table 8 - Pset_Condition Property Set 84
Table 9 - Exchange Information Requirement Table for IfcSlab 87
Table 9 - Thematic Analysis Results 135
Table 10 - Practice-Based Properties 148
Table 11 - EIR Excel Export from CoBuilder Require 155

1. Introduction

The construction industry is under increasing pressure to reduce its environmental impact due to growing concerns about resource depletion and waste. The construction industry contributes to global resource consumption and waste generation, accounting for approximately 32% of natural resource extraction and 25% of global solid waste production (Benachio et al., 2020). There is an urgent need to transition from the traditional linear "take-make-consume-dispose" approach towards a Circular Economy (CE) model, which emphasizes efficient resource use, reuse, recycling, and sustainable material management, thereby minimizing the need for new resources and reducing landfilling (Amudjie et al., 2025; Suchek et al., 2021; Illankoon & Vithanage, 2023; Kirchherr et al., 2023). By applying CE principles, construction materials are no longer viewed as disposable but as valuable assets whose recovery and reuse are planned throughout the entire building lifecycle; from design and construction to decommissioning (Pomponi & Moncaster, 2017).

Digital technologies, particularly Building Information Modeling (BIM), are often positioned as key enablers in this transition. BIM allows for the centralized management of building data in digital models, creating opportunities to embed circularity-related information such as material type, origin, lifespan, and reuse potential (Mercado Siles & Universidade do Minho, 2020). By providing a standardized digital environment, BIM ensures seamless data sharing and enhances the ability to plan and manage building projects effectively (Naghibalsadati et al., 2024, Rao et al., 2025). However, BIM alone is not sufficient; CE workflows rely on the necessary information flow of information, specifically on how it is defined, structured, shared, and validated across stakeholders and software platforms (Mercado Siles, 2020).

1.1 Background Information

BIM is a powerful digital method that supports circular construction by enabling the creation, management, and sharing of detailed project data across a building's lifecycle (Akbari et al., 2024; Charef et al., 2018; Datta et al., 2023). When data on building elements and materials with their reuse potential are added to BIM, it becomes easier to plan for decommissioning and recover valuable elements instead of discarding them.

To ensure structured and standardized information exchange in BIM, several key frameworks have been developed. OpenBIM is a universal approach to designing, building, and managing built assets, based on these open standards (BuildingSMART, 2024; Kładź & Borkowski, 2025). It enables collaboration regardless of the BIM software used, through formats like Industry Foundation Classes (IFC). Defined under ISO 16739-1:2018, IFC is a data schema that enables structured data modeling and exchange in BIM, ensuring interoperability between different models, software and platforms. The STEP Physical Format (SPF or IFC-SPF; with the .ifc extension) is commonly used to store and share IFC-based models in practice (buildingSMART International, 2025). However, IFC alone does not define the level of detail required at different project stages. To address this, Level Of Information Need (LOIN) was introduced as part of ISO 19650-1:2018 and later refined in EN 17412-1:2020. In 2024, it became an international standard as ISO 7817-1 (Hentour et al., 2024). Unlike the older Level of Development (LOD) framework, which primarily focused on graphical detail, LOIN provides a structured approach to define geometric, alphanumeric, and documentation data required at different project

stages (Filardo et al., 2024 ; Safari et al., 2021). This ensures that BIM models contain only necessary information, optimizing both data population and exchange, thereby improving efficiency and clarity in BIM workflows (Oliveira et al., 2024; Godager et al., 2022).

While LOIN defines the required level of detail for different project phases, its effective implementation relies on a structured framework that specifies the information context. This includes its purpose (why), the relevant object (what), the responsible actor (who), and the delivery milestone (when). Exchange Information Requirements (EIRs) provide this structure by formally defining the specific data and deliverables expected throughout a project. By establishing clear requirements, EIRs serve multiple functions for effective information modeling and delivery. They ensure consistency in information exchange, align stakeholder expectations, and facilitate structured data integration within BIM workflows (ISO 19650-2, 2018). Furthermore, EIRs are crucial for enabling clear communication, reducing ambiguity, and establishing a contractual basis for information exchange among project participants (Charef, 2016).

In the context of BIM, an information requirement is a formal specification of the data needed for a project, detailing what information is required, why it is needed, who is responsible for it, and when it should be delivered. To translate these information requirements into a structured format that is machine-readable, buildingSMART developed the Information Delivery Specification (IDS) standard (buildingSMART International, 2024). First proposed in 2020 and officially released in 2024, IDS serves as a standardized specification that helps define and validate information requirements within BIM workflows (Bigai & Santos, 2024). An IDS file consists of three main sections: (1) a description for human readability, (2) an applicability section defining which IFC elements the requirements apply to, and (3) a requirements section detailing necessary properties, classifications, and relationships (Gragnaniello et al., 2023). This structured format makes IDS particularly useful for ensuring that BIM models meet predefined information requirements. As such, IDS helps with improving data accuracy and consistency (Kładź & Borkowski, 2025).

In addition to structuring and validating data, maintaining consistency across projects requires standardized terminology. The bSDD platform (BuildingSMART Data Dictionary, 2025) helps by providing a central repository of terms, classifications, and relationships for BIM elements in line with IFC. It allows users to reference predefined data templates and ensures BIM properties follow international standards like ISO 12006-3 (Building construction, Organization of information about construction works; Part 3: Framework for object-oriented information and a classification system for classes of objects) and ISO 23386 (Building Information Modeling and other digital processes used in construction; Methodology to describe, author and maintain properties for objects in construction works and Civil Engineering works; Filardo et al., 2024).

These standards together create a framework for structuring, exchanging, and validating BIM data in a consistent, interoperable manner. LOIN ensures only relevant data is required at each stage, EIRs define the context, IDS translates requirements into checkable rules, and the bSDD guarantees standard terminology. Platforms such as CoBuilder enable the practical use of these standards to embed and validate circularity-related data in BIM workflows.

1.2 Problem Definition

The transition to a circular built environment requires that information is not only digital but also structured, consistent, and interoperable. Although standardized frameworks and tools for BIM-based circularity exist, their effective application is often hindered by fragmented implementation and inconsistent adoption across the industry, complicating circular construction (Mikulėnas & Šeduikytė, 2025). While powerful, BIM is only effective if it contains the right information in a machine-readable and interoperable format (Sibaii et al., 2025). If different parties define information in their own ways, digital tools cannot consistently understand or exchange this data (Godager et al., 2022). Such a lack of a shared, coherent structure hinders collaboration, automated analysis, and the long-term reuse of building information for circularity (Sun et al., 2025).

To address these challenges, several open standards have been developed. OpenBIM standards such as LOIN, bSDD, and IDS are designed to support structured, interoperable information exchange, yet their practical application to circular construction remains limited. While studies have identified relevant properties for decommissioning and reuse (Akbarieh, Teferle, & O'Donnell, 2023) and specialized ontologies like the Decommissioning and Reuse (DOR) bSDD exist, few examples show an end-to-end workflow that consolidates these properties into structured EIRs, aligns them with LOIN, translates them into machine-readable IDS files, and applies and validates them in an actual IFC model. This lack of integrated examples creates uncertainty and inconsistency in industry adoption and limits the effectiveness of BIM in supporting circular practices.

This study develops and demonstrates a practical, standards-based methodology for integrating circular data into BIM workflows, focusing on structural elements. These components account for the majority of a building's embodied energy and a significant portion of demolition waste by mass, making materials like concrete and steel prime candidates for resource recovery (Charef, 2016; Theißen et al., 2020; Zhu & Feng, 2025). The approach combines existing standardized properties from sources such as the DOR bSDD with additional properties identified through literature and expert input. These are structured according to LOIN and EIR principles and translated into IDS rules for validation within IFC models.

Using a case study based on a real IFC model from the Willemspoort Zuid development in 's-Hertogenbosch, this research demonstrates how LOIN, bSDD, and IDS can be combined to structure and validate circular data for the decommissioning and reuse of structural elements.

1.3 Objectives and Research Question

To address the challenges outlined in section 1.2 Problem Definition, the primary objective of this research is to develop and validate a practical, standards-based workflow for integrating decommissioning and reuse data into BIM workflows, specifically for structural elements. This includes defining a comprehensive set of information requirements for circularity, structuring them according to the LOIN framework, and validating a digital process for their application within a controlled case study. The aim is to bridge the gap between theoretical standards and real-world industry needs by providing a clear and replicable workflow for Architecture, Engineering and Construction (AEC) professionals.

To guide this research and achieve its objectives, the following main research question has been formulated:

How can information modeling for circular construction be aligned with the Level of Information Need (LOIN) using the Decommissioning and Reuse buildingSMART Data Dictionary (bSDD) through a controlled case study?

To support the main research question, the following sub-questions are formulated:

1. *What information requirements are essential for building components and materials, particularly structural elements, in a BIM model to support decommissioning and reuse?*
2. *How can information requirements for decommissioning and reuse be structured according to the Level of Information Need (LOIN)?*
3. *How can structured information related to decommissioning and reuse be effectively embedded into a* Building Information Modeling (*BIM) model and subsequently validated against predefined information requirements?*
4. *What challenges and limitations are encountered when applying Level of Information Need (LOIN) and buildingSMART Data Dictionary (bSDD) for circular information modeling in practice?*

1.4 Research Design

To answer the main research question, this study follows a structured process divided into five phases. Figure 2 provides a visual overview of these phases. The following sections describe each phase in detail.

- Phase 1: Literature Review
  The first stage of the research focused on establishing a strong theoretical foundation. Building upon this theoretical background, the review then systematically identified the established data requirements for decommissioning and reuse. The main outcome of this phase was the "Foundational Property List".
- Phase 2: Expert interviews.
  The second phase was designed to gather practical insights from the industry to complement the theoretical findings. This was achieved by conducting and analyzing semi-structured expert interviews. The sole outcome of this phase was the "Practice-Based Properties".
- Phase 3: Development of the EIR
  This phase involves designing the primary artifact of the research: the final EIR table, which is structured according to the LOIN framework. Before this step, the properties identified from the literature review and expert interviews were consolidated into a single, comprehensive list. This consolidated list serves as the foundation for defining the EIR requirements.
- Phase 4: Case Study Application and Validation
  This phase involves implementing the designed EIR within the chosen case study and validating its performance. The case study is a building from the Willemspoort Zuid development project in 's-Hertogenbosch, the Netherlands, with its IFC model provided by Heijmans. A render of the project is shown in Figure 1. The case study's IFC

Figure 1 - Render of the residential complex in Willemspoort Zuid, 's-Hertogenbosch. The building on the left (blue outline) forms the basis of the case study used in this research. Source: https://willemspoort.nl/

model is enriched with the necessary properties from the finalized EIR, and subsequently checked for compliance using the IDS to ensure the information requirements are correctly added.

- Phase 5: Evaluation & Conclusion
  The final phase involves analyzing and reporting of the findings to assess the overall effectiveness of the proposed workflow. Based on these outcomes, recommendations for industry and future research are formulated.

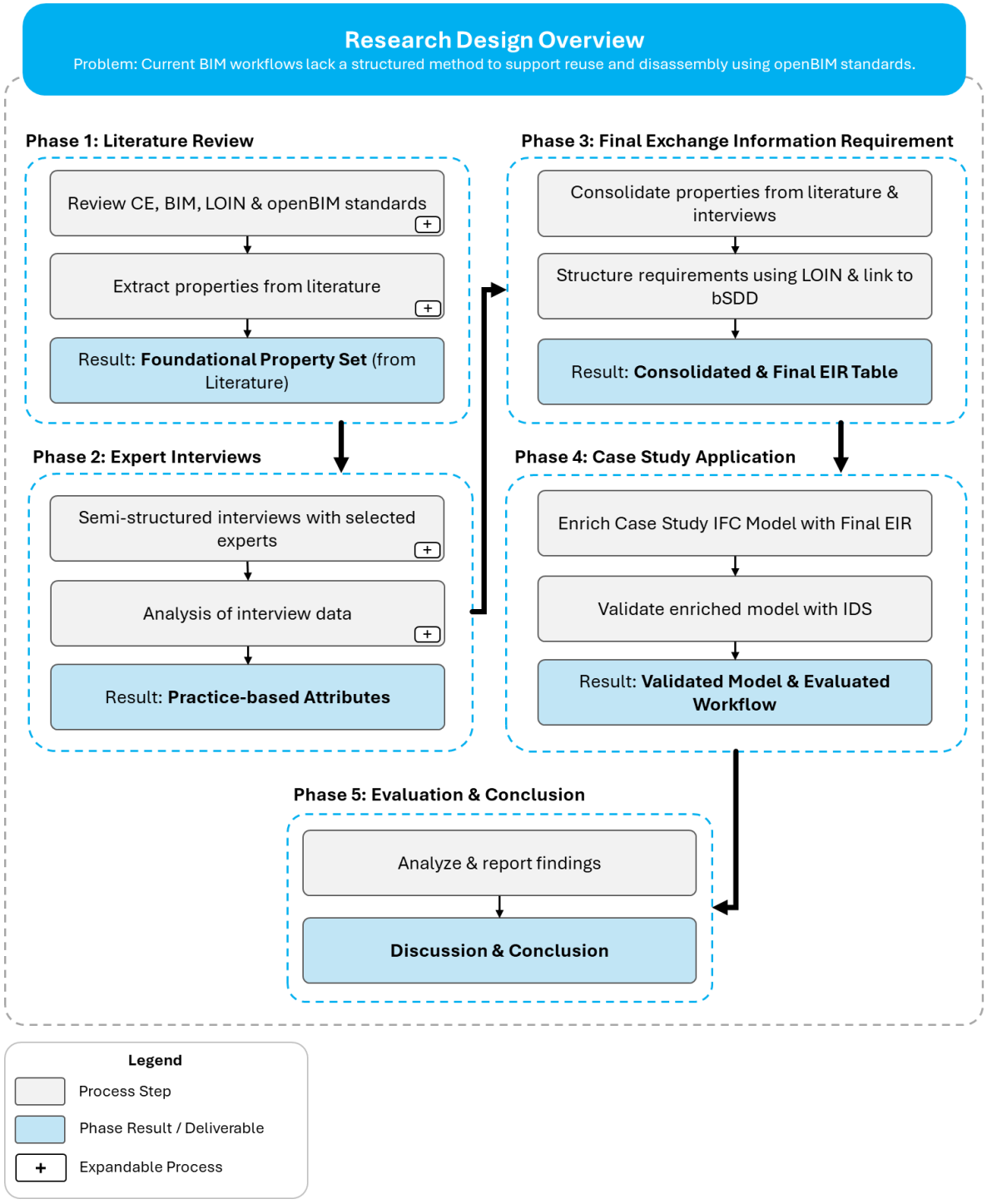


Figure 2 - Research Design Overview

1.5 Research Contributions

From a practical and social perspective, this research provides the AEC industry with a clear and replicable workflow for managing decommissioning and reuse data. It translates open standards into a concrete, step-by-step process that can be adopted for a structured approach to circularity. This helps reduce uncertainty and risk for organizations, unlocking the economic value of building components that would otherwise be treated as waste. On a broader societal level, this research directly contributes to several of the United Nations' Sustainable Development Goals (SDGs). It provides a tangible method to advance SDG 12 (Responsible Consumption and Production) by creating a process that supports a circular flow of materials over the traditional linear model. By enabling more resource-efficient management of the urban building stock and reducing construction waste, it supports SDG 11 (Sustainable Cities and Communities). Furthermore, the development of an innovative digital process for the AEC sector strengthens SDG 9 (Industry, Innovation, and Infrastructure). Finally, by facilitating the reuse of high-impact materials, the process helps reduce the embodied carbon emissions associated with manufacturing new materials, thereby contributing to SDG 13 (Climate Action).

Figure 3 - The United Nations Sustainable Development Goals. This research primarily addresses goals 9, 11, 12, and 13 (adopted from United Nations – Sustainable Development Goals). Source: https://sdgs.un.org/goals

From a theoretical and scientific perspective, this research provides valuable insights into the application of modern OpenBIM standards. It is one of the first studies to demonstrate and evaluate the integrated use of the LOIN framework, the bSDD, and the IDS for the specific purpose of decommissioning and reuse. By testing these standards in a real-world case study, this research identifies their current capabilities, synergies, and limitations, providing valuable feedback for their future development. Furthermore, the comprehensive set of information requirements developed throughout this study serves as a consolidated and validated resource that can be used and expanded upon by future research in this field.

1.6 Reading guide

This research is structured into five chapters. A visual overview of the relationship between these chapters can be seen Figure 4.

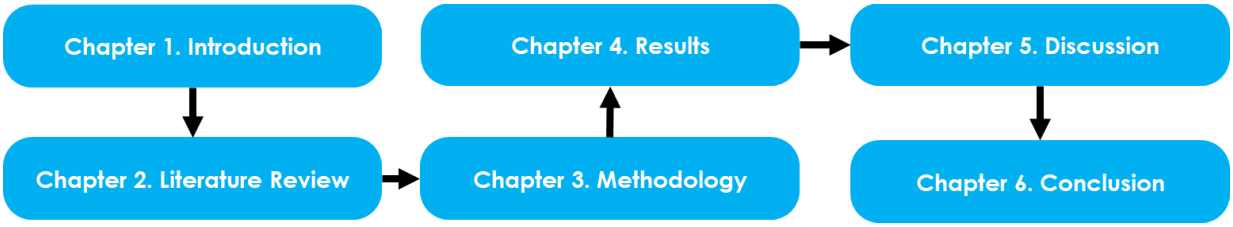


Figure 4 - Research Structure

- Chapter 1: Introduction introduces the research, outlining the context, the core problem, the objectives, and the research design.
- Chapter 2: Literature Review provides the theoretical background, reviewing literature on the Circular Economy, BIM, LOIN, and relevant OpenBIM standards. It also synthesizes existing studies on data requirements for decommissioning and reuse.
- Chapter 3: Methodology details the Design Science Methodology and the step-by-step process followed in this study.
- Chapter 4: Results presents the findings of applying the methodology to the case study, including the model enrichment and validation, and discusses the findings and a gap analysis.
- Chapter 5: Discussion Interprets the results, relates them to existing literature, and discusses implications.
- Chapter 5: Conclusion concludes the thesis by summarizing the findings, answering the research questions, and providing recommendations for industry and future research.

2. Literature Review

In this chapter, the relevant literature is reviewed to provide the background for this research. It covers key concepts related to the CE and BIM, discusses existing standards for structured data, and examines studies on the information needed to support decommissioning and reuse.

2.1 Aim of the Literature Review

The primary aim of the literature review is to establish a theoretical foundation for this research by systematically exploring and synthesizing existing knowledge. This review serves two main purposes, which directly correspond to the first two sub-questions of this research.

First, the review aims to answer sub-question 1: " *What information requirements are essential for building components and materials, particularly structural elements, in a BIM model to support decommissioning and reuse?".* To answer this question, the review collects and analyzes existing studies that mention relevant data properties. Although each study focuses on different aspects, combining them makes it possible to create one complete list of essential properties. This list provides a clear overview of the information that should be included in BIM models to enable the future reuse of building components. Ultimately, the literature review provides the necessary input for developing the initial EIR table, which serves as the baseline for the subsequent research phase.

Second, the review addresses sub-question 2: "*How can information requirements for decommissioning and reuse be structured according to the Level of Information Need (LOIN)?*". To answer this, the review explores how the LOIN framework can be used to clearly define the type and level of information needed in a BIM model (such as geometry, alphanumeric data, and linked documents). In addition, the review examines relevant openBIM standards, including IFC, the IDS, and the bSDD, to demonstrate how they support the structuring, validation, and standardization of circularity-related information in a BIM model.

2.2 Method of the Literature Review

To achieve the research goals, a structured literature review was carried out in two steps as illustrated in Figure 5. The first step (illustrated in the left column) provided a broad understanding of key concepts, while the second step (visualized in the right column) focused on identifying specific data properties relevant to circular construction, resulting in a consolidated list of all literature-based properties (Table 2: Foundational Property Set).

The literature search was primarily conducted using the Scopus and Google Scholar academic databases. The search strategy was iterative, meaning it involved a repeated process of continuous refinement. It started with broad queries and gradually became more specific as relevant information was identified, with each round of searching being informed and improved by the previous attempts.

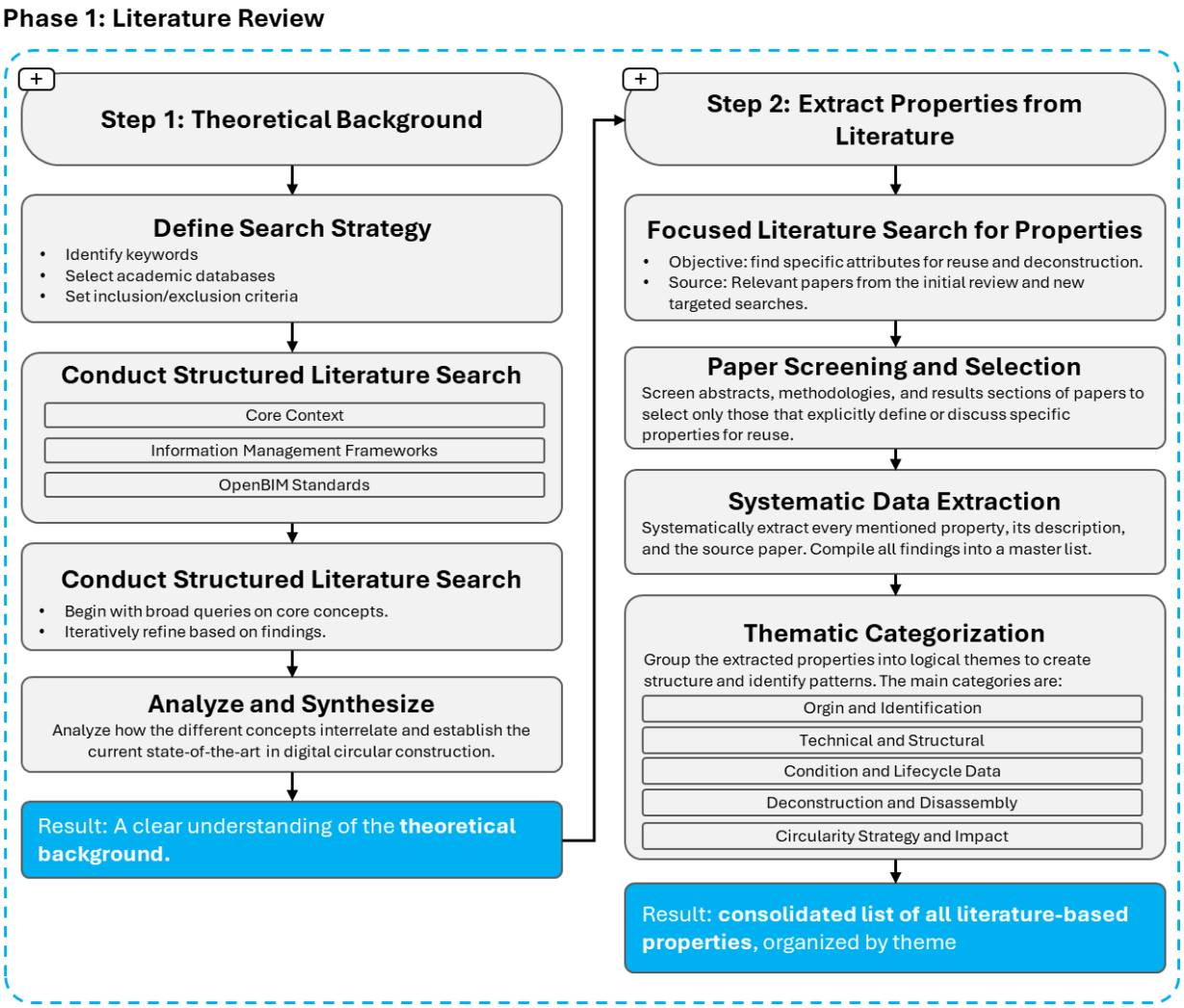


Figure 5 - Detailed Flowchart of the Systematic Literature Review Process

Keywords were grouped into three main categories, to structure the search. Listed below are a few examples of keywords used in the search:

1. Core Context: The intersection of Building Information Modeling and the Circular Economy.
   Keywords included: *"Building Information Modeling", "Building Information Modelling", "BIM", "Circular Economy", "CE", "reuse", "deconstruction", "disassembly", "recycling".*
2. Information Management Frameworks: The application and principles of modern information management standards.
   Keywords included: *"Level of Information Need", "LOIN", " ISO 7817", "ISO 19650", "Exchange Information Requirement", "EIR".*
3. OpenBIM Technologies: The open standards that enable data sharing and interoperability between different software and stakeholders.
   Keywords included: *"buildingSMART", "IFC", "bSDD", "IDS".*

These categories were then used in combination within search queries, employing Boolean operators like "AND" to combine different terms and "OR" to find alternative terms, ensuring a focused and efficient search.
In addition to the database search, the snowballing method was applied, which involves identifying new relevant studies by examining the reference lists of selected papers (backward snowballing) and by finding newer studies that have cited these papers (forward snowballing) until no new significant sources emerge (Gomes et al., 2024; Ting et al., 2025). The reference lists of key, relevant articles were manually scanned to identify further significant studies that may not have been captured by the initial keyword search. The following exclusion criteria were applied to filter the results:

- Articles not written in the English language;
- Articles that only made brief references to the core topics without providing a thorough analysis;
- Studies that were not related to the AEC industry;
- Papers that did not offer new empirical findings or significant conceptual contributions.

After applying the exclusion criteria based on title and abstract screening, a final set of 39 articles were identified for in-depth analysis and systematic data extraction.

2.3 Literature Review Results

2.3.1 Circular Economy & BIM

The construction industry faces significant sustainability challenges due to its traditional linear approach, characterized by high resource consumption and substantial waste generation (Akanbi et al., 2019; Naghibalsadati et al., 2024). The global economy mostly follows a linear resource consumption model, often referred to as the "take-make-consume-dispose" pattern (Akanbi et al., 2019). This linear model assumes that materials are easily accessible and cheap to dispose of. However, this method results in environmental harm and resource depletion. The CE aims to reduce environmental harm and resource depletion by emphasizing efficient use, reuse, and recycling of materials, minimizing the need for new resources and landfilling waste (Topraklı, 2024). This transition from linear to circular principles is illustrated in Figure 6, which contrasts the traditional linear process with the circular approach that loops materials back into the value chain.

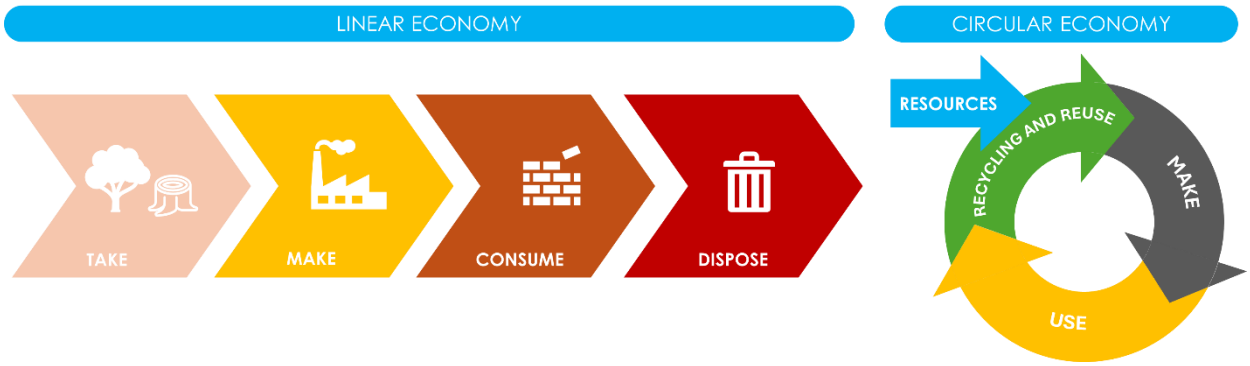


Figure 6 - Visual comparison between the linear and circular economy, highlighting the shift from disposal to reuse and recycling

A circular approach treats buildings not merely as static structures but as dynamic resources or "material banks," aiming to reuse or repurpose building materials effectively once their original service life has ended. This approach turns potential waste into valuable new resources (De Wolf et al., 2024; Charef, 2024; Rao et al., 2025). Efficient use and reuse of materials minimize construction costs and preserve the embodied energy within materials, significantly reducing construction and demolition waste and their associated environmental impacts (Akanbi et al., 2019).

Structured management and exchange of information throughout the lifecycle of building materials and components are central to achieving the transition to circular economy within the AEC sector. Structured data, captured in digital information models, enhances material traceability and transparency, significantly improving the possibilities for reuse and recycling at the end of the material's lifecycle. Digital documents, such as material passports, are valuable tools that provide detailed material information, including composition, origin, environmental impacts, and reuse potential. These structured documents substantially reduce uncertainty and increase the likelihood of successful material and component recovery and reuse (Rao et al., 2025).

Within this context, Design for Disassembly (DfD) emerges as a fundamental enabler of circularity. DfD is a proactive design strategy that ensures buildings are assembled in ways that allow for easy, non-destructive disassembly of components at the end of their service life. Rather than treating demolition as inevitable, DfD anticipates the need for separation and reuse by prioritizing reversible connections (e.g., bolted instead of welded joints), modular construction, and comprehensive documentation of assemblies (Rios et al., 2015; Rasmussen et al., 2019). These design decisions reduce the environmental and economic costs of deconstruction while preserving the residual value of materials. Recent research confirms that DfD contributes significantly to resource efficiency by extending the useful life of components, facilitating their reuse in new projects, and supporting circular workflows in practice (Emeka, 2025; Ostapska et al., 2024).

BIM is a comprehensive digital method used in construction that creates a digital representation of a built asset, encompassing detailed information about its physical and functional characteristics. BIM is not only about creating a three-dimensional model but also involves a collaborative process among architects, engineers, contractors, facility managers and other relevant stakeholders (Doan et al., 2019). This collaboration allows the coordinated and structured management of building data from the initial design stage through construction, operation, and eventually decommissioning and reuse (Tomczak et al., 2024; Kuzminykh et al., 2023). By providing a standardized digital environment, BIM ensures seamless data sharing and enhances the ability to plan and manage building projects effectively across their entire lifecycle (Doan et al., 2019; Tomczak et al., 2024; Kuzminykh et al., 2023).

While BIM inherently represents information in a structured way, to effectively use it for decommissioning and reuse, however, the completeness and consistency of this structured data, particularly regarding circularity-specific properties, are essential. Structured BIM data significantly improves collaboration among stakeholders involved in circular construction. It

provides clear and consistent information that is easy to understand and use by stakeholders. By integrating BIM workflows with openBIM standards (which enable software-independent, interoperable data exchange) such as IFC, bSDD, and IDS, data can be effectively shared, validated, and accurately managed. This standardized integration ensures better communication between different software tools, reduces the likelihood of errors, and enhances the reliability of data used for making decisions in CE projects (Tomczak et al., 2024; Sanchez et al., 2024). This structured method addresses common issues in unstructured workflows, including incomplete documentation, limited traceability (meaning difficulty in tracking a component's history, origin, or properties across its lifecycle), and inadequate lifecycle assessments, all of which negatively impact material reuse and recycling efforts (Basta et al., 2020; Xing et al., 2020).

Well-defined properties, such as connection types, material characteristics, and sequences for disassembly, within BIM's structured data allow detailed analysis for deconstruction and reuse, which affects the environmental benefits of reuse strategies (Akanbi et al., 2019). Additionally, using structured data that meets standards and is checked by IDS enables automated validation, making decision-making for circular strategies easier (Tomczak et al., 2024). The consequences of relying on unstructured or poorly structured data often result in increased decommissioning costs, lower recovery rates, and higher volumes of demolition waste (Naghibalsadati et al., 2024). Similarly, the absence of structured data complicates material tracking, which greatly reduces chances for reuse. This, in turn, worsens environmental problems like increased carbon emissions and resource depletion, and also raises economic costs (Topraklı, 2024).

2.3.2 Emerging Digital Technologies as Enablers for Circularity

During the literature review, beyond the crucial role of BIM, other important emerging digital technologies were identified as playing a significant role in enabling a CE in the construction sector. These technologies primarily contribute by improving the generation and management of data (De Wolf et al., 2024). For instance, Reality Capture (Scan-to-BIM) uses technologies like LiDAR (Light Detection and Ranging) and photogrammetry to create accurate 3D models of existing buildings, which is essential for developing a digital inventory of materials available for reuse (De Wolf et al., 2024). Additionally, a Digital Twin acts as a dynamic virtual replica of a physical building, using real-time sensor data to continuously monitor a component's condition and more accurately assess its reuse potential (Xing et al., 2020; Naghibalsadati et al., 2024). While both BIM models and Digital Twins are digital representations of built assets, BIM primarily focuses on static models for design and construction, whereas a Digital Twin is a dynamic, real-time replica used for operational monitoring, often built upon a BIM model. Artificial Intelligence (AI), particularly through computer vision, further automates tasks such as identifying and classifying building materials from images, which accelerates the creation of material inventories for deconstruction planning. To ensure the integrity and transparency of this data, Blockchain technology is also being explored to provide a secure and decentralized ledger for a component's Material Passport, creating a trustworthy record of its history and ownership across multiple lifecycles (De Wolf et al., 2024).

2.4 Exchange Information Requirement & Level Of Information Need

The LOIN defines the amount, granularity, and quality of information that is required at different stages of a construction project (Dervishaj et al., 2023; ISO, 2024; Mellenthin et al., 2024; Pan et al., 2023). It provides a standardized method for specifying the necessary information to support decision-making throughout the asset lifecycle. To formalize LOIN's application and ensure consistent standardization, the international standard ISO 7817-1: *Building information modelling (BIM) — Level of information need — Part 1: Concepts and principles* was recently published in 2024. This study adopts the structured framework from this new standard. To fully understand LOIN and its purpose, it is essential to explain the ISO 19650 framework first. ISO 19650 provides the foundation for managing information during the delivery and operational phases of assets, and LOIN is a key part of this standard.

The ISO 19650 series outline the organization and digitization of information about buildings and civil engineering works using BIM. First published in 2018, the ISO 19650 defines concepts such as:

- LOIN- defining the required level of detail;
- Organizational Information Requirements (OIR) - information needed for an organization's overall goals;
- Asset Information Requirements (AIR) - information needed for managing a built asset in operation;
- Asset Information Model (AIM) - the digital model of the operational asset;
- Project Information Requirements (PIR) - information needed for project delivery goals;
- EIR - contractual information required from appointed parties;
- Project information Model (PIM) - the digital model created during project delivery.

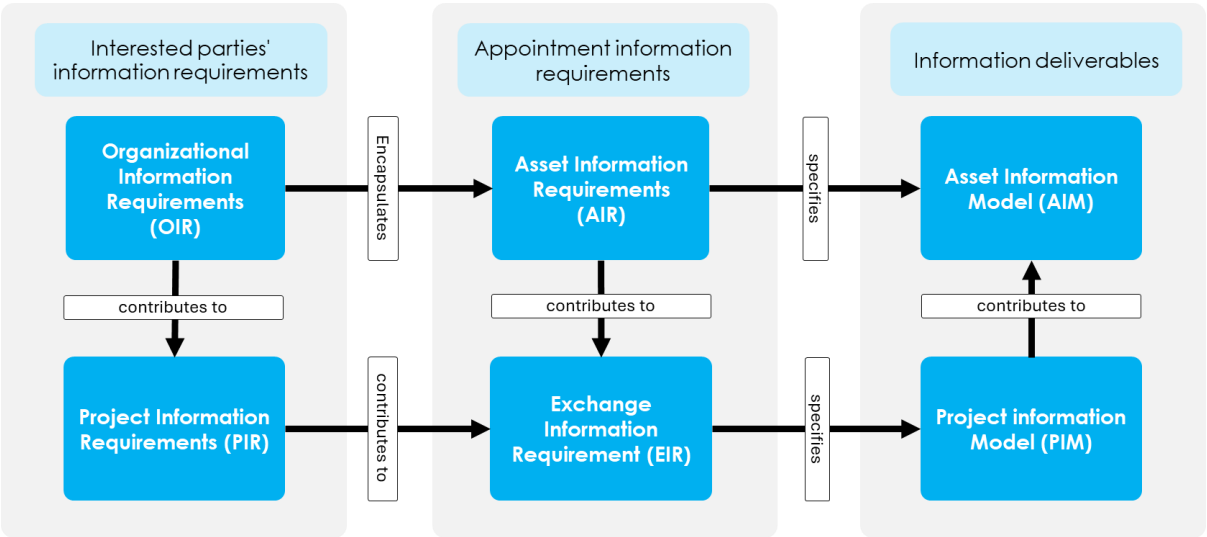


Figure 7 - Structure of information requirements and deliverables as defined in ISO 19650

Together, these concepts aim to improve information management and ensure consistency in the exchange and use of information across all project phases (ISO, 2018). The standard specifies that an appointing party, such as the client or asset owner, must define its information needs and ensure that appointed parties (such as designers, contractors, and consultants)

deliver the required information in accordance with project objectives (ISO, 2018; Malla, Tummalapudi, & Delhi, 2023). The relationship between these requirements and deliverables is illustrated in Figure 7.

Within the ISO 19650 process, the LOIN contributes directly to the development of the EIR (Oliveira et al., 2024). The EIR defines what information is required by the appointing party and when it must be delivered. On the other hand, LOIN describes how detailed and complete that information should be to ensure it is accurate, appropriate, and fit for its intended purpose. Unlike earlier approaches such as Level of Detail (LOD) and Level of Development (also known as LOD), LOIN deliberately avoids prescribing explicit levels of detail. Instead of assigning fixed levels, like LOD approaches, LOIN focuses on defining information requirements based on the specific context and purpose for which the information is needed. This is achieved by establishing prerequisites that define the context of the information requirement, including the purpose (why), the information delivery milestone (when), the actor (who), and the object (what) the requirement refers to. This object can represent a single building element, a system, or an entire asset, depending on the specific information need (Tomczak et al., 2022). These key prerequisites are illustrated in the upper part of Figure 8.

Following the definition of these prerequisites, LOIN specifies three main areas of information: geometrical information, alphanumerical information, and documentation (Dervishaj et al., 2023; ISO, 2024). Geometrical information includes the shape, dimensions, location, appearance, and parametric behavior of objects. Alphanumerical information refers to properties such as material type and performance data, while documentation covers supplementary deliverables such as construction drawings, manuals, product data sheets, and certificates (Dervishaj et al., 2023; ISO, 2024; Tomczak et al., 2022). These three main areas of information are shown in the lower part of Figure 8.

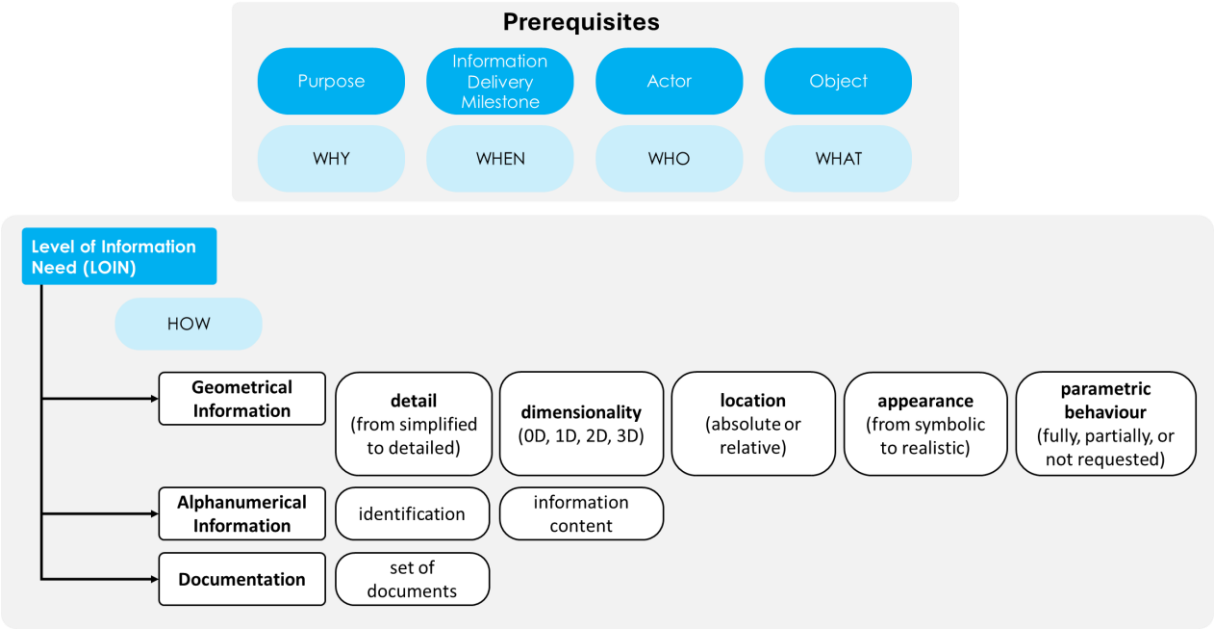


Figure 8 - Overview of the Level of Information Need (LOIN) framework, including its prerequisites and components (adapted from ISO 19650-1:2018)

Despite the benefits of LOIN, the standard is still relatively new, and its practical application is an emerging area of research. Studies have shown that there is a lack of consistent interpretation and implementation of LOIN across different countries and organizations (Zima & Mitera-Kiełbasa, 2022). Yet, several studies have begun to explore its potential, which will be outlined further in Chapter 2.6. These studies demonstrate the growing potential of LOIN, but they also highlight the need for a more consistent and formalized framework to guide its application.

2.5 BuildingSMART

BuildingSMART International (bSI) organization is dedicated to developing and maintaining open standards for the built environment. Its mission is to enhance digital information workflows and ensure interoperability across software platforms through openBIM standards (BuildingSMART, n.d.). These standards include the IFC, bSDD, and IDS, all of which form the backbone of the openBIM philosophy (Figure 9). openBIM was introduced in 2012 to help users work independently of specific software tools. The main goal is to support consistent workflows by focusing on data and process compliance instead of software limitations. The "open" in openBIM means that everyone has access to the same definitions of data and data formats. This means data can be written and read from different sources, all parties can collaborate on the data, and data access is retained throughout the life of a project and beyond. Essentially, it allows everyone to take control of their digital destiny without being forced into using a specific software tool or workflow (BuildingSMART, n.d.). OpenBIM relies on active support from the industry. Without it, information exchange between different software tools would be difficult, as each vendor uses their own native file formats, interfaces, and solutions (Kładź & Borkowski, 2025).

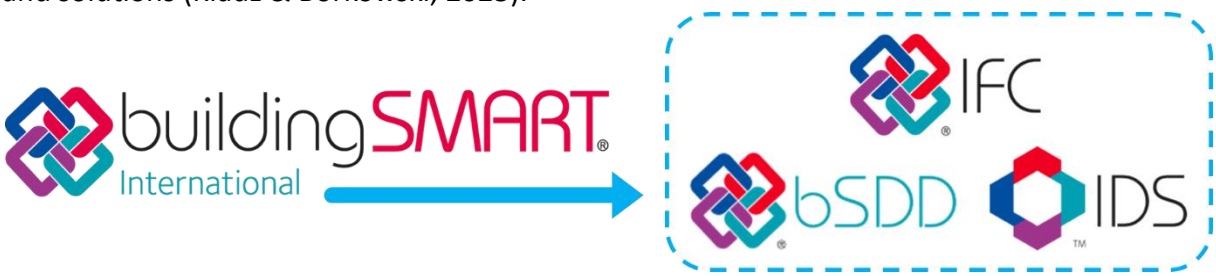


Figure 9 - Three core openBIM standards developed by buildingSMART. IFC provides the model's data structure, bSDD defines the meaning of the data, and IDS validates that the data is correct.

2.5.1 Industry Foundation Classes (IFC)

One of the most recognized standards developed by buildingSMART is the IFC. IFC is an open data schema and set of formats used to store and exchange OpenBIM data. It enables machine interpretability of information, which allows for the automation of workflows. The standard is vendor-neutral, freely accessible, and supports consistent exchange of both graphical and non-graphical data across various software platforms throughout the lifecycle of a project. IFC data can be serialized in multiple formats, such as .ifc (STEP), .ifcXML, or .ifcZIP, depending on the use case. However, IFC is more than just a file format. It is fundamentally a data schema that defines how to organize objects, their properties, relationships, quantities, classifications, and more (BuildingSMART, n.d.). Moreover, IFC is a flagship initiative maintained by buildingSMART.

In its latest version (IFC4 Add2), IFC also supports environmental impact data through predefined property sets such as PSet_EnvironmentalImpactIndicators. Furthermore, users can define modular, extendable property sets beyond the schema to enhance semantic precision (Theißen et al., 2020).

The latest official version of IFC is 4.3.2.0. This version is commonly referred to as IFC 4.3 and is also published by ISO as a final ISO 16739-1 standard (BuildingSMART, n.d.). There were many previous versions of the standard, with the popular 2x3 (2005), IFC4 (2013) and IFC4 ADD2 TC1 from 2018 (Theißen et al., 2020).

2.5.2 BuildingSMART Data Dictionary (bSDD)

The bSDD complements IFC by offering a centralized platform for defining standardized properties, classifications, and values. It helps ensure semantic clarity across software systems and facilitates the alignment of project data with domain-specific and international requirements. Its main goal is to help users add more meaning (semantics) to the data in their models, by linking objects to standardized classifications and properties. This is especially useful when project teams need to apply country-specific or use-case-specific terminology, while still staying aligned with standards like IFC (buildingSMART International, 2020).

Figure 10 illustrates how the bSDD builds on top of the IFC data structure to enable semantic specialization and localization. At the core of the hierarchy lies the IFC Kernel, which defines fundamental elements such as geometry, materials, and spatial structure. Building on this, IFC entities like IfcProduct and IfcDoor can be further specialized into context-specific concepts such as “Front Door” or “Custom SmartDoor.” These more specific terms are not part of the IFC schema itself but can be introduced through bSDD using tailored classification systems and property sets. For example, a wooden exterior front door may differ across regions, yet still be linked to IfcDoor. bSDD allows such specializations to be added while maintaining compatibility with openBIM standards. In the context of circularity, bSDD enables the integration of circular economy data, such as material type, origin, recyclability, and reuse potential into BIM models, supporting traceability and decision-making for reuse (Kładź & Borkowski, 2025).

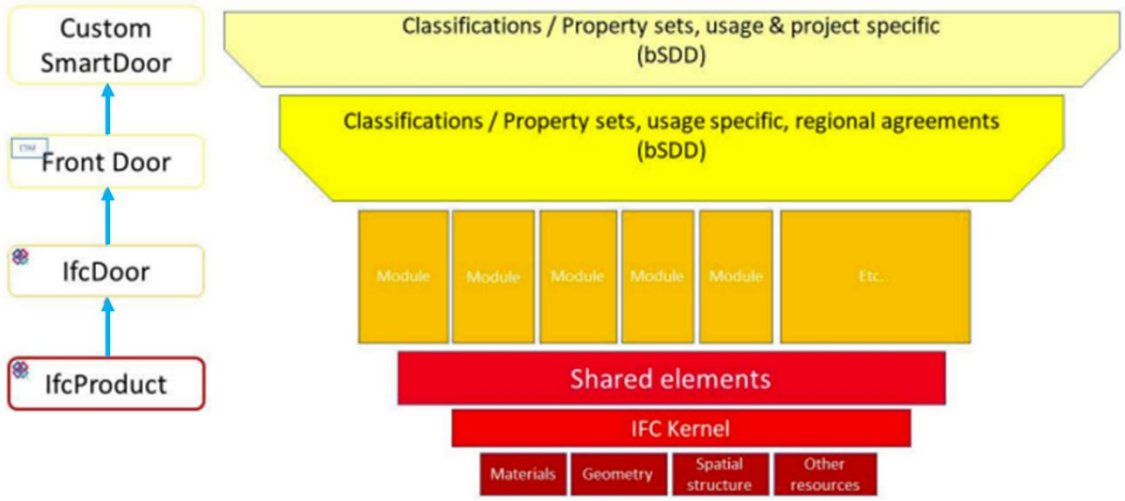


Figure 10 - Original diagram from the buildingSMART Technical Roadmap, illustrating how generic IFC classes can be semantically enriched with context-specific property sets using the bSDD (buildingSMART International, 2020)

The bSDD organizes data in a layered structure that builds on top of IFC. This structure allows users to: extend IFC with new domain-specific or regional classifications; define their own sets of properties for objects; link these definitions back to IFC classes (or use them independently, if needed). The bSDD can also work without IFC links when needed, allowing greater flexibility. Most importantly, it supports semantic enrichment, helping users add more detailed and meaningful information to their BIM datasets (buildingSMART International, 2020).

In openBIM workflows, bSDD plays a central role by standardizing how additional information is added to BIM models. While IFC handles geometry and basic data structures, bSDD focuses on making sure that the properties and classifications added to objects are clear, consistent, and machine-readable. This becomes especially important in use cases like sustainability, maintenance, or material reuse, where specific technical or environmental information is needed (Kładź & Borkowski, 2025).

For the complex domain of circularity, a dedicated dictionary is necessary. The Decommissioning and Reuse (DOR) ontology, developed by Akbarieh (2023), provides the formal vocabulary and semantic structure for such a specialized dictionary. Key concepts within the DOR ontology include 'Circular Potential', which offers a nuanced classification of End of Life possibilities (e.g., reuse, remanufacturing, recycling), and 'Circular Requirement', which defines the specific conditions needed to realize that potential. Together, these create a rich, logical definition of a component's true reusability.

Based on the DOR ontology , a specialized Decommissioning and Reuse bSDD is established. This dictionary provides the standardized vocabulary needed to capture circular properties. For this research, this specific bSDD is used as the foundational framework for the case study, ensuring that all data related to component decommissioning and reuse is structured, interoperable, and machine-readable for the subsequent analysis.

2.5.3 Information Delivery Specification (IDS)

IDS is another initiative developed by buildingSMART to improve how information requirements are defined, shared, and validated in BIM workflows. IDS provides a structured, standardized method to specify which information should be included in a model, and whether it has been delivered accordingly (BuildingSMART, n.d.). It plays a critical role in enabling consistent, openBIM-based data exchange by making information requirements both human-readable and machine-interpretable (Tomczak et al., 2024). It works in conjunction with IFC and bSDD to automate the verification of information requirements.

IDS files are written in XML and are made up of two main parts: metadata and specifications. The metadata includes general information such as who created the file, when it was made, and what it is intended for. The specifications section defines what information is required in the model (BuildingSMART, n.d.). Each specification includes an applicability filter, which selects the objects it applies to, for example, all IfcDoor elements or only those with certain materials. It then lists the specific information these objects must contain, such as a property like FireRating or a required classification (Tomczak et al., 2024).

As part of the buildingSMART ecosystem, IDS is fully aligned with the openBIM philosophy. It enhances interoperability by offering a consistent way to define and check information requirements across different software tools and stakeholders (De Marco et al., 2024).

2.6 Practical Applications and Case Studies of Open Standards

The practical application of international standards, such as the EIR and LOIN, and openBIM standards, such as the IDS, is a growing field of research. Recent case studies demonstrate the versatility and potential of these frameworks in various contexts. For instance, research has shown that LOIN can be effectively used to specify the exact data needed to assess the reuse potential of precast concrete elements in a circular economy workflow (Dervishaj et al., 2023). Another application of the LOIN in practice is provided by a case study of a Moroccan heritage building (Ksar Loudaghir in Figuig). The LOIN framework, based on ISO 7817-1, was used for pathology diagnosis, specifically for analyzing erosion. The study systematically defines the prerequisites for the information delivery, such as the purpose (pathology diagnosis), milestone (feasibility stage), involved actors, and objects. Subsequently, the required geometrical, alphanumerical, and documentation information is detailed (Hentour et al., 2024).

In the field of information validation using IDS, several relevant studies have also been conducted. Gragnaniello et al. (2024) present a methodology for the BIM-based design and setup of a Structural Health Monitoring system for a viaduct in Italy. Within this case study, LOINs for different project phases (preliminary design, executive design, and setup) are defined, which are then used to generate IDS files for automated validation of the information models. The authors developed a script, the 'IDS-SHM-generator', for this purpose to verify the consistency of the exchanged information. Another practical application has been to encode requirements of a Brazilian standard for BIM objects. Unlike the object-oriented IFC structure, this standard is based on 'model uses', such as clash detection or cost calculation. The case study, a simple house modeled in Revit, successfully validates an IDS file that checks the requirements for the 'Architectural Design' model use (Bigai & Santos, 2024). De Marco et al. (2024) address workflow issues in public tenders, where information requirements are typically shared as PDFs. In collaboration with the province of South Tyrol, they developed the “IDS Collab Tool” to automate the import of IDS-based requirements into authoring tools. The tool supports compliance checks and enriches models with standardized metadata via the bSDD. Finally, the study by Cerovsek & Omar (2024) provides insight into the 'checkability' of information requirements with IDS, based on a case study of a large construction project (15,000 m²). They categorize requirements as explicit, implicit, or unsupported and provide practical examples of how complex, informal rules can be translated into the logic of IDS.

2.7 Studies on Necessary Data for Decommissioning & Reuse

Literature shows that various data properties are consistently identified as vital for decommissioning and reusing building components (Akbarieh, 2023; Sanchez, 2021; Tomczak et al., 2024; Toprakli, 2024; Xing et al., 2020). Although individual papers focus on different topics, they all identify the same core information requirements. These shared properties are the basis for any data-driven CE approach in construction.

It is important to note that the reviewed literature places a strong emphasis on the reuse of structural components, such as steel and concrete elements. This is because of several reasons. First, these parts account for most of a building's embodied energy and carbon footprint, so reusing them offers substantial sustainability gains. (Theißen et al., 2020; Charef, 2016). Second, structural components often outlast the buildings they support, making them well-suited for a second life in new projects (Marzouk et al., 2019). Third, evaluating and re-certifying load-bearing elements is technically complex, which makes this area both critical and challenging for researchers (Pereiro et al., 2023; Sanchez et al., 2024). For these reasons, the data properties discussed in the following sections are primarily focused on decommissioning and reusing structural components.

To provide a clear and logical structure, the identified *properties* have been organized into five thematic categories. This structure is based on the distinct types of information required throughout the assessment process for decommissioning and reuse, moving from foundational data to practical application and strategic value.

1. Origin and Identification Properties: This category includes all data needed to uniquely identify a component and trace its origin. This information is the starting point for any reliable reuse assessment.
2. Technical and Structural Properties: This category covers the essential technical details that define a component's physical performance and load-bearing ability. This information is necessary for engineers to decide if the component can be safely reused in a new structure.
3. Condition and Lifecycle Data Properties: This category describes the current condition of a component based on its past. It includes information about any degradation, damage, or repairs, which is crucial for estimating its remaining lifespan and current value.
4. Deconstruction and Disassembly Properties: This category contains all data about the physical process of taking an element apart. It focuses on the methods and steps required for the safe and efficient removal of a component from the existing structure.
5. Circularity Strategy and Impact Properties: This category holds strategic information for decision-making. It includes properties that define the planned future for a component (e.g., reuse or recycling) and measure the economic or environmental benefits of that decision.

2.7.1 Origin and Identification Properties

This category of properties serves as a critical starting point for any reuse assessment, as it answers the basic questions of "What is this component?" and "Where did it come from?". Without this data, no reliable assessment for reuse is possible. The literature consistently highlights the necessity of a *Unique Component ID*, often linked to a physical tag like a QR code or RFID chip, to ensure traceability throughout the component's entire lifecycle (Xing et al., 2020; Hradil et al., 2020). This unique identifier acts as the primary key for all other associated information. The need for a Unique Component ID is already met, to a large extent, by the IFC schema itself. Every entity that inherits from *IfcRoot* carries a *GlobalId*, a compressed representation of a Universally Unique Identifier (UUID) that conforms to ISO/IEC 11578 and

ISO/IEC 9834-8. During export, the 128-bit UUID is converted to a 22-character string using a base-64 encoding (buildingSMART, 2020).

The identification is complemented by basic descriptive data, including the specific *Material Type* and its detailed *Material Composition*, which is crucial for recycling processes and health assessments (Rao et al., 2025; Tomczak et al., 2024; Topraklı, 2024). Information on the component's *Dimensions/Geometry* (Hradil et al., 2020; Sanchez et al., 2024), its original *source/Manufacturer*, and its *Age/Construction Date* (Hradil et al., 2020) are also considered essential provenance data. Finally, to understand its journey, a log of its *Product History* and a record of *Ownership* are required, which is particularly important for leasing models and establishing legal responsibility (Xing et al., 2020).

For components like reclaimed steel (structural steel elements that have been recovered from existing buildings or structures for direct reuse), detailed identification properties are essential. This is due to the inherent uncertainties in their exact properties and the consequent need for re-certification and avoiding costly re-testing. As a concrete example of the type of information required for such elements in a BIM model, Table 1 (Hradil et al., 2020) illustrates key 'items' (properties) essential for a reclaimed steel element being considered for a second life cycle. This table highlights how specific data, from origin and fabrication records to measured material properties and dimensions, is crucial for making it easier to track and re-certify the part for future use.

Table 1 - Key items for reuse while defining the level of information needed of a model (Hradil et al., 2020)

Item	Commentary
Steel origin	"Reclaimed-UK" or "New-UK"
Date of first erection	1975
Local of first erection	Leeds
Steel Fabricator first erection	"Fabricator 1"
Structural design first application	"Consultants 1"
Date of second erection	2019
Local of second erection	London
Structural design second application	"Consultants 2"
Steel Fabricator second erection	"Fabricator 2"
Fabricator ID from second erection	"CL01"
Stockholder/manufacturer	This item can represent also the steel producer for new steel.
Stockholder/manufacturer certificate number	This item can represent also the material certificate number from the producer for new steel.
Steel grade and subgrade	"S355JR", Exact wording as in the material standard.
Material in compliance with the standard	"EN10025-2" – This may not be applicable; for example, if the minimum elongation according to the code is not justified. Alternative would be EN1090-2 5.1
Design yield strength (N/mm^2)	355
Design tensile strength (N/mm^2)	470
Recorded yield strength (N/mm^2)	405
Recorded tensile strength (N/mm^2)	520
Recorded elongation at failure (%)	23
Measured Carbon Equivalent Value (CEV)	0.45
Profile size	IPE500, or as in the product standard.
Section Dimensions	"EN 10365", or another relevant standard
Section Tolerances	"EN 10034", or another relevant standard

2.7.2 Technical and Structural Properties

To assess if a component can be safely reused, especially in a structural capacity, its technical performance characteristics must be known. This includes its *Structural Integrity* or material grade, measured mechanical properties like *Yield & Tensile Strength*, and its *Fire Resistance* properties (Hradil et al., 2020; Tomczak et al., 2024). The status of the component such as *Load-Bearing* or *Prefabricated* is also a key factor in determining its reuse potential (Akanbi et al., 2019; Basta et al., 2020).

2.7.3 Condition and Lifecycle Data Properties

This group of properties describes the state of the component in its lifecycle, which is critical for determining its value and suitability for ~~a~~ reuse. A general *Condition Assessment* is often mentioned as a starting point (Rao et al., 2025; Xing et al., 2020). This can be supported by more specific metrics, depending on the material, such as the *Corrosion Level* for steel components or the degree of *Deformation* (Mercado Siles, 2020).

Crucially, the assessment must also include information on potential hazards. This includes noting any *Fire Exposure* the component may have suffered and, most importantly, the presence of any *Hazardous Materials* or level of *Contamination*, which could prevent reuse or require special handling procedures (Akanbi et al., 2019; Akbarieh, 2023). The component's past is further detailed through its *Maintenance History*, which provides a log of all repairs and modifications, offering insight into its past stresses (Morganti & Bragadin, 2025; Tomczak et al., 2024). This historical data is essential for estimating a component's various lifetime metrics, including its *Service Life* (the functional period within a single use cycle), its total *Design Life* (the potential lifespan across multiple cycles), and its *Remaining Useful Life*, which collectively determine its reusability potential. (Charef, 2016; Theißen et al., 2020; Akbarieh, 2023).

2.7.4 Deconstruction and Disassembly Properties

This category contains the most practical information needed by deconstruction teams to plan and execute the safe and efficient removal of components. The most frequently cited and arguably most critical property is the *Connection Type*, as this largely determines whether a component can be removed non-destructively (Akbarieh, 2023; Basta et al., 2020; Pereiro et al., 2023). The literature distinguishes between different types of connections, such as: reconfigurable, bolted, or welded connections, with a strong preference for reversible methods.

More advanced frameworks propose capturing the entire removal logic in a machine-readable format. This includes defining a clear *Disassembly Sequence* to ensure a safe order of operations (Marzouk & Elmaraghy, 2021; Sanchez et al., 2021). To enable automated clash detection during removal, geometric data on *Physical Motion Constraints* (defining the exact path an element must take) and relational information like *Hosted Components* (defining what is attached to what) are also required (Sanchez et al., 2024; Marzouk & Elmaraghy, 2021). The concept of *Clearances* (the minimum space required around an element for tool access) is also identified as a key graphical and spatial property (Piazzi et al., 2022). Finally, process-related properties such as the estimated *Disassembly Time/Effort* are important for applying Lean Deconstruction principles (Marzouk et al., 2019).

2.7.5 Circularity Strategy and Impact Properties

This final group of properties is used to guide decision-making and measure the success of circular strategies. The literature proposes defining a designated *End-of-Life (EOL) Scenario* or *Circular Potential* for each component, such as Reuse, Recycle, Remanufacture, or Dispose (Akbarieh, 2023; Mercado Siles, 2020). This high-level classification guides all subsequent actions.

This strategic choice can be supported by quantitative metrics. Several studies propose a calculated *Reusability/Deconstructability Score* to provide a clear, objective rating of a component or design's circularity potential (Akanbi et al., 2019; Basta et al., 2020). To build a business case and assess sustainability, data on *Economic Impact* (e.g., cost savings, profitability ratios) and *Environmental Impact* from LCA (e.g., embodied carbon, GWP) are also considered essential (Pereiro et al., 2023; Theißen et al., 2020). This information is typically collected in standard *Reference Documentation*. Common examples include material passports, which act like an ingredient list for a building component, and Environmental Product Declarations, which report on a product's environmental impact (Oliveira et al., 2024; Charef, 2016). For all these properties to be used interoperable, the use of standardized terminology, often linked to a data dictionary like the bSDD, is identified as a prerequisite (Kładź & Borkowski, 2025; Akbarieh, 2023).

The Decommissioning and Reuse bSDD, as mentioned, functions as a specialized data dictionary to ensure interoperability for circularity . A central feature of this ontology is the concept of 'Circular Potential'. This moves beyond a simple binary 'reusable/not reusable' designation, allowing users to specify a component's various End-of-Life possibilities, such as reuse, remanufacturing, or recycling (Akbarieh, 2023).

While not directly classified as circularity strategy properties themselves, EIR (Mitera-Kiełbasa & Zima, 2024; Oliveira et al., 2024; Mellenthin Filardo et al., 2024) and Standardized Terminology (Akbarieh, 2023; Tomczak et al., 2024; Kładź & Borkowski, 2025; buildingSMART , 2020) were frequently mentioned as crucial overarching concepts for enabling the effective use and interoperability of all circularity properties. Their importance is also emphasized and integrated within this research, as EIRs ensure structured data delivery and standardized terminology guarantees consistent understanding across systems. To support the standardized storage of this crucial environmental data, newer versions of the IFC schema (IFC4.3) now include a dedicated property set for this purpose: Pset_EnvironmentalImpactIndicators,. This property set provides a structured way to embed key environmental performance indicator. It includes specific properties for the LifeCyclePhase the data applies to, ClimateChangePerUnit (which corresponds to GWP or embodied carbon), and ResourceDepletionPerUnit, among others.

2.8 Data Requirements for CE

Having reviewed the existing literature on data requirements for a CE in construction, a comprehensive set of data properties essential for decommissioning and reuse has been compiled. The following table presents this Foundational Property List (Table 2). This inventory serves as a complete overview of the current state of knowledge and forms the starting point from which a formal EIR will be developed for the case study.

Table 2 - Foundational Property List for Decommissioning and Reuse

Property	Description	Source(s)
Origin and Identification Properties		
Unique Component ID	A unique identifier (e.g., QR code, RFID tag, GUID) physically on the element and linked to the BIM model for traceability and life-cycle tracking.	Banihashemi et al. (2024), De Wolf et al. (2024), Kuzminykh et al. (2023), Xing et al. (2020), Mercado Siles (2020), Hradil et al. (2020)
Material Type	The primary material of the component (e.g., Steel, Concrete, Timber), often classified using a standard system.	Akanbi et al. (2019), Rao et al. (2025), Topraklı (2024), Hradil et al. (2020), Charef (2016)
Material Composition	Detailed breakdown of the materials and substances used in a product or composite component, essential for recycling and health assessments.	Topraklı (2024), Tomczak et al. (2024), Akbarieh (2023)
Manufacturer Details	Name, contact information, and other details of the original manufacturer.	Tomczak et al., (2024), Topraklı (2024), Hradil et al. (2020), Rao et al. (2025)
Age / Construction Date	The date of original manufacturing or installation, crucial for assessing degradation and compliance with past standards.	Hradil et al. (2020), Akbarieh (2023)
Product History	Information about the previous life cycles, uses, and locations of the component.	Topraklı (2024), De Wolf et al. (2024), Xing et al. (2020), Akbarieh (2023)
Ownership	Records of the current and past owners of the component, important for leasing models and legal responsibility.	Xing et al. (2020)
Technical & Structural Properties		
Structural Integrity / Grade	Assessed capacity of the component to perform its structural function (e.g., steel	Hradil et al. (2020), Tomczak et al. (2024)

	grade, concrete strength class).	
Geometrical Specs / Dimensions	Precise measurements including length, width, height and profile.	Xing et al., (2020), Hradil et al., (2020), Sanchez et al. (2024), Piazzi et al. (2022)
Net Weight	The weight of the component after subtracting holes, cuts, and other modifications, crucial for logistics and structural calculations.	Mercado Siles, (2020), Basta et al. (2020)
Material Properties	The specific grade and standard of the material (e.g., Steel Grade S355JR according to EN10025-2).	Xing et al. (2020), Mercado Siles, (2020)
Yield & Tensile Strength	Measured mechanical properties of the material, essential for reuse in structural applications.	Hradil et al. (2020)
Fire Resistance / Fireproofing	The component's ability to withstand fire, and whether the fireproofing system itself is reusable or hinders disassembly.	Basta et al. (2020), Hradil et al. (2020)
Load-Bearing Status	A boolean or descriptive tag indicating if the element is part of the primary structure.	Mercado Siles (2020), Basta et al. (2020)
Prefabrication Status	Indicates if a component was prefabricated off-site, which often correlates with higher standardization and reusability.	Akanbi et al. (2019), Basta et al. (2020)
Condition & Lifecycle Data Properties		
Condition Assessment	A general assessment of the current state of the component.	Rao et al. (2025), Xing et al. (2020)
Corrosion Level	The degree of corrosion present on the component's surface (e.g., high, moderate, low).	Mercado Siles (2020)
Contamination Level	Indicates if the component is contaminated with substances that may affect its reuse or recycling potential.	Akanbi et al. (2019)
Deformation	The extent of physical bending, warping, or other geometric distortions in the component.	Mercado Siles (2020)
Fire Exposure	A record of whether the component has been exposed to a significant fire event.	Mercado Siles (2020)

Hazardous Materials*	Indicates if the component contains or is coated with hazardous substances (e.g., lead, asbestos), often linked to a waste code. *This property is a part of the Material Source in the DOR bSDD.	Topraklı (2024), Akanbi et al. (2019), Akbarieh (2023)
Maintenance History	A log of all maintenance, repair, and refurbishment activities performed on the component.	Morganti & Bragadin (2025), Xing et al. (2020), Tomczak et al. (2024)
Service Life	The expected or remaining service life of the component.	Theißen et al. (2020), Tomczak et al. (2024), Charef (2016), Akbarieh (2023)
Deconstruction & Disassembly Properties		
Connection Type	The method used to connect the component (e.g., bolted, welded, reconfigurable, reversible vs. irreversible). A primary factor for deconstructability.	Pereiro et al. (2023), Sanchez et al. (2021), Basta et al. (2020), Akbarieh (2023)
Disassembly Instructions	Human-readable instructions or links to documentation detailing the steps for safe removal.	Tomczak et al. (2024), Sanchez et al. (2024)
Disassembly Sequence	A defined, machine-readable order of operations for removing components to ensure safety and prevent damage.	Marzouk & Elmaraghy (2021), Sanchez et al. (2021), Tomczak et al., 2024
Disassembly Time / Effort	An estimation of the time or effort required to dismantle the component, relevant for Lean Deconstruction planning.	Marzouk et al. (2019)
Disassembly Method	The recommended method for removal (e.g., perfect disassembly, destructive disassembly, selective demolition).	Sanchez et al., (2024)
Hosted Components / Connections	Relational data defining which other components are structurally dependent on or attached to the current one.	Sanchez et al. (2024)
Physical Constraints (Motion)	The six degrees of freedom (+/- x,y,z) defining possible paths for removing a component without clashing with others.	Sanchez et al. (2024)
Circularity Strategy & Impact Properties		

Circular Potential / EOL Scenario	The designated plan or assessed potential for the component after deconstruction (Reuse, Recycle, Remanufacture, Repurpose, Dispose).	Akbarieh (2023), Mercado Siles (2020), Basta et al. (2020), Charef (2016)
Reusability / Deconstructability Score	A calculated score or rating indicating the potential for a component to be reused or easily deconstructed. (e.g. Deconstructability Assessment Scoring System (SS-DAS))	Akanbi et al. (2019), Basta et al. (2020), Mercado Siles (2020)
Environmental Impact (LCA)	Data on the environmental footprint (e.g., embodied carbon, GWP), often linked to an external EPD or LCA database.	Naghibalsadati et al. (2024), Theißen et al. (2020), Pereiro et al. (2023), Tomczak et al. (2024)
Economic Data	Information related to the costs and economic benefits of reuse, such as material cost savings or profitability ratios.	Pereiro et al. (2023), Xing et al. (2020)
Reference Documentation	Links to external documents like Material Passports, EPDs, warranties, manuals, or stakeholder information.	Oliveira et al. (2024), Charef (2024), Tomczak et al. (2024)

[This page is left empty]

3. Methodology

This chapter outlines and justifies the research methodology used to answer the main research question: *"How can information modeling for circular construction be aligned with the Level of Information Need (LOIN) using the Decommissioning and Reuse buildingSMART Data Dictionary (bSDD) through a controlled case study?".* To address this challenge, the study adopts the Design Science Methodology. This provides a rigorous scientific framework for creating and evaluating artifacts that solve real-world problems (Glaser & Strauss, 2017). The multi-phase research design used in this thesis, which was visualized in the flowchart in the introduction, is structured according to the Design Science framework proposed by Wieringa (2014).

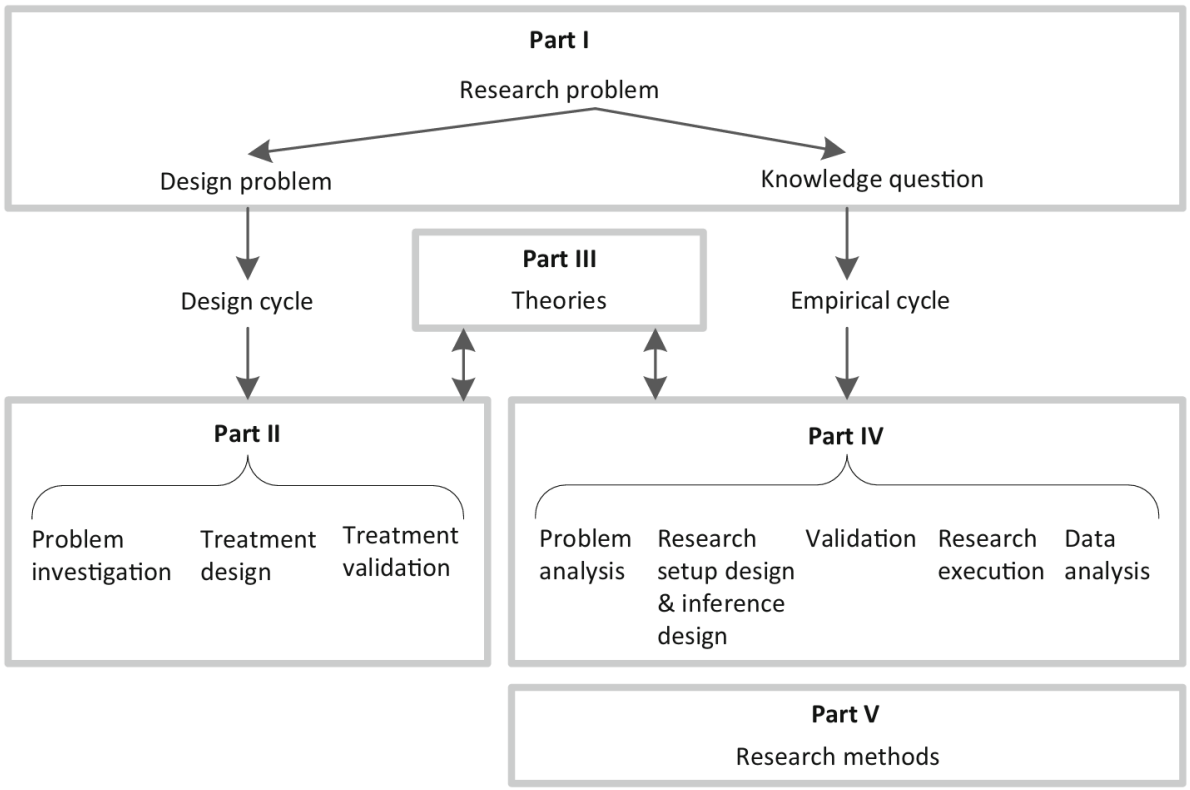


Figure 11 - Structure of the Design Science Research framework as proposed by Wieringa (2014)

This framework (Figure 11) distinguishes between a 'design problem' and a 'knowledge question'. As this research aims to create and evaluate a practical workflow, it follows the 'design cycle' path. Wieringa's design cycle consists of three core stages: problem investigation, treatment design, and treatment validation. The five phases of this research (as presented in the Introduction) map directly onto this structure:

- Problem Investigation: This stage focuses on understanding the problem context and defining the requirements for a solution. In this research, this directly corresponds to Phase 1 (Systematic Literature Review) and Phase 2 (Expert Interviews). These initial phases were crucial for systematically identifying and defining the necessary information requirements for decommissioning and reuse (directly addressing sub-question 1)

- Treatment Design: This stage involves conceptualizing and designing an artifact or 'treatment' to solve the investigated problem. In this study, this is represented by Phase 3 (Development of the EIR). During this phase, the EIR was created, which was then structured according to the LOIN framework (directly addressing sub-question 2).
- Treatment Validation & Evaluation: This final stage focuses on implementing the designed artifact and assessing its performance and effectiveness in a real-world context. This is covered by Phase 4 (Case Study Application and Validation) and Phase 5 (Evaluation of the Workflow). Phase 4 involved the practical implementation where the designed EIR was applied by enriching an IFC model from a real-world case study. The model was then checked to make sure all information requirements were correctly added using IDS (directly addressing sub-question 3). Phase 5 was a final review, where a Gap Analysis was performed to see the overall effectiveness and novelty of the proposed methodology and identify challenges and limitations encountered in practice (directly addressing sub-question 4).

3.1 Phase 1 & 2: Defining Data Requirements

The initial stage of this research is dedicated to the 'Problem Investigation' phase of the Design Science cycle. The primary objective is to establish a comprehensive set of data requirements necessary to support a circular workflow. As shown in Phase 1 and Phase 2 of the research design overview (Chapter 1), this was achieved through a systematic literature review and semi-structured interviews with industry experts.

3.1.1 Literature Review for Foundational Properties

The initial 'Problem Investigation' stage of this research was conducted through a Systematic Literature Review. This is a research method that uses a structured and transparent process to find, analyze, and synthesize existing studies. This approach was chosen to ensure the findings are objective and reproducible. The goal of employing an Systematic Literature Review was to provide an objective and comprehensive foundation, which is critical because, as stated by Boote & Beile (2005), "a researcher cannot perform significant research without first understanding the literature in the field". Using an a Systematic Literature Review is an established practice for building knowledge in this field. For example, Suchek et al. (2021) successfully employed a multi-phase Systematic Literature Review to map the key topics at the intersection of innovation and the CE, demonstrating the method's suitability for this field. Following the stages outlined by Randolph (2007) and Carrera-Rivera et al. (2022), the Systematic Literature Review was executed in a structured, two-step process , as described in Figure 5 in section 2.2. Step 1 focused on foundational scoping and initial gap identification, while Step 2 concentrated on systematic property extraction for decommissioning and reuse.

A detailed description of this review's methodology, including the databases, keyword pillars, and filtering criteria, is provided in Chapter 2. The main output of the literature review was the "Foundational Property Set."

3.1.2 Expert Interviews for Practice-based Insights

While the Systematic Literature Review provided a robust theoretical foundation, it also revealed that most identified properties were already represented in existing frameworks like the Decommissioning and Reuse (DOR) bSDD. This suggested that to develop a truly innovative and practical workflow, more practice-based knowledge was needed. To address this gap and gather this practical knowledge, a qualitative approach using expert interviews was adopted. The qualitative research interview is one of the most important data collection methods for exploring complex phenomena in-depth, allowing researchers to learn about the world from the perspective of their participants (Qu & Dumay, 2011). This method was chosen to strengthen the research. By using interviews alongside the literature review, the findings from one method could be confirmed by the other, a process known as methodological triangulation (Ruslin et al., 2022). Furthermore, consulting experts is a recognized strategy for complementing a theoretical background with empirical knowledge (Kallio et al., 2016). The following sections explain each step taken in Phase 2, from preparation to data analysis. Figure 12 provides an overview of all steps conducted in this phase.

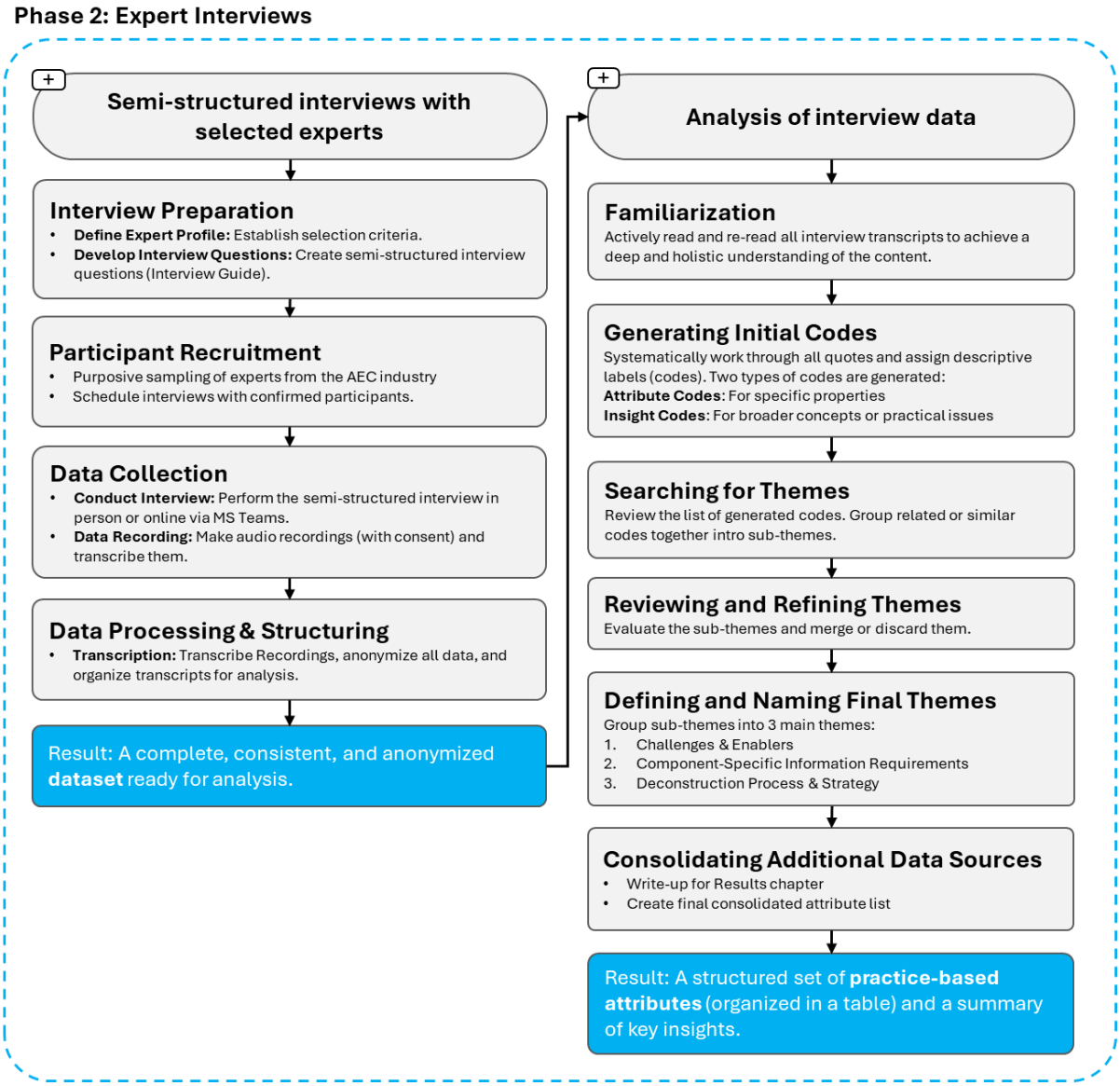


Figure 12 - Overview of all steps conducted in Phase 2: Expert Interviews

3.1.2.1 Participant Selection

A total of nine experts from the AEC industry were selected to participate in this study. The selection was conducted using purposive sampling. This method was chosen because qualitative interviews are most appropriate when a researcher aims to understand the subjective perspective of a specific, knowledgeable group, rather than generating generalizable data from a large population (McGrath et al., 2019). The goal was to gain in-depth information from a targeted group of experts, selected based on their expertise in structural engineering, construction materials, BIM (for including practical property implementation challenges), and/or practical experience with the reuse or deconstruction of building components. This ensured that a multi-faceted, experienced, and fresh perspective was brought to the research in order to check what properties re necessary for structural reuse. The anonymized profiles of the participants are show in Table 3.

Table 3 - Profile of the interviewed experts

ID	Role	Years of Experience	Gender	Spoken Language
1	Structural Engineering	10+	Male	Dutch
2	Structural Engineering	20+	Male	Dutch
3	Manager Sustainability & Innovation at a Concrete Manufacturer	18+	Male	Dutch
4	Structural Engineering	9+	Male	English
5	Professor of Sustainment of Concrete Structures	35+	Male	Dutch
6	BIM Manager with Structural Engineering background	25+	Male	Dutch
7	University Lecturer in Structural Design	10+	Female	Dutch
8	Advisor Circular Projects	21+	Male	Dutch
9	Sustainable Structural Engineering Consultant	22+	Male	Dutch

Experts were approached via professional networks. Prior to the interviews, each participant received a summary of the research project to inform them of its purpose and to build rapport (McGrath et al., 2019). Participation was voluntary, informed consent (Appendix IV) was obtained, and all data was anonymized to ensure confidentiality (Qu & Dumay, 2011).

3.1.2.2 Interview Design and Protocol

The interviews were conducted using a semi-structured format. This approach is considered highly effective because it combines the strengths of both structured and unstructured methods; it uses a prepared set of questions based on prior knowledge but also enables the researcher to improvise follow-up questions based on the participant's responses (Qu &

Dumay, 2011). This provides an ideal balance between maintaining focus on the research topics and allowing for the discovery of new, in-depth information (Ruslin et al., 2022). The interviews were performed from May to June 2025.

A formal interview guide (Appendix II) was developed in advance. This preparation ensured the interviews were conducted in a standardized manner and allowed the researcher to be thoroughly prepared, which is fundamental to the study's quality (Kallio et al., 2016). The guide was structured around five core, open-ended questions designed to elicit spontaneous and in-depth responses from the participants. The protocol also involved beginning the interview with easy questions to make the interviewee comfortable before moving to more complex topics (McGrath et al., 2019). A detailed justification for each core question is provided in Appendix III. The interviews (lasting approximately 30 minutes) were conducted either in person or online, audio-recorded with consent, and transcribed, a common practice for preparing qualitative data for analysis (McGrath et al., 2019). The following five main questions were used to guide the interviews:

1. *In your experience, which properties of a structural component are most critical for determining whether it can be reused?*
2. *When it comes to disassembling structural elements, which factors do you think have the most impact on whether an element can be removed without damage?*
3. *If we want to include properties for decommissioning and reuse in a BIM model, how would you suggest structuring this information so that it is both clear (machine-readable) and useful?*
4. *In practice, what visible signs or characteristics do you look for to get a first impression of a component's suitability for reuse?*
5. *Looking beyond existing properties, are there any new types of data or properties you believe should be included in BIM models to better support reuse and decommissioning?*

3.1.2.3 Data Processing and Analysis

To systematically analyze the qualitative data from the interview transcripts, a thematic analysis was employed. This is a well-established method for identifying, analyzing, and reporting patterns (or "themes") within qualitative data. The process was guided by the six-phase framework for thematic analysis proposed by Braun & Clarke (2006), which ensures a robust and transparent analytical process. The analysis proceeded as follows:

1. Familiarizing oneself with the data: The analysis began with a close and repeated reading of all the interview transcripts to achieve deep familiarization with the content. Initial ideas and potential patterns were written down during this phase.
2. Generating initial codes: This phase involved a systematic, line-by-line coding of the entire dataset. This was a primarily inductive process, where codes were derived directly from the data. During this coding, a critical distinction was made between properties, referring to specific data points or properties of a component (e.g., "Material Type & Quality," "Reinforcement Details"), and insights, representing broader perspectives, challenges, or strategic recommendations from the experts (e.g., "Data loss destroys the economic value of reusable elements"). This initial coding was

performed on all interviews, resulting in a comprehensive list of over 100 unique codes that captured the raw data in a granular manner.

3. Searching for themes: In this phase, the extensive list of individual codes was organized and refined. This involved systematically reviewing and comparing all codes to identify relationships and patterns based on their semantic similarity and conceptual relevance to the research questions. Related codes were then collated and grouped together into a smaller number of broader, potential 'sub-themes'. For example, codes such as “Change in Loading History” and " Need for Fire Resistance Data " were grouped under the potential sub-theme "Performance & History," as they all described aspects of a component's condition and past state.
4. Reviewing potential themes: The potential sub-themes were then reviewed at two levels. First, the collated codes within each sub-theme were checked for internal coherence and consistency. This ensured that all codes within a sub-theme meaningfully contributed to its central idea. Second, the validity of each sub-theme in relation to the entire dataset was considered, ensuring that they captured the nuances of the interview data and were distinct from other sub-themes. This iterative process of refinement, merging (e.g., combining related concepts if found to be consistently discussed together by experts), or discarding initial sub-themes (if they lacked sufficient supporting data or distinctness).
5. Defining and naming themes: After grouping similar ideas into sub-themes, the final step was to combine these into larger, main themes. This involved looking at the findings from a broader perspective, bringing them together into clear, main themes. These main themes summed up the core requirements for supporting circularity in construction, directly connecting with the overall research goals and problem definition. Clear and concise names were given to each main theme and sub-theme. This was done to ensure the analysis could be easily understood and repeated, clearly showing how specific data points contributed to broader conceptual categories. The main themes and their corresponding sub-themes that emerged from this analysis were:
    - Challenges & Enablers: This theme captured overarching contextual factors, systemic barriers, and facilitative aspects related to CE implementation.
        - *Sub-themes:* Data Management, Circular Economy & Business Models, Assessment & Strategy
    - Component-Specific Information Requirements: This theme focused on the intrinsic data elements necessary to describe a building component for reuse.
        - *Sub-themes:* Foundational Properties, Performance & History, Documentation & Provenance.
    - Deconstruction Process and Strategy: This theme encompassed information vital for the practical and logistical aspects of disassembling components.
        - *Sub-themes:* Connection, Disassembly Logistics & Planning, Design for Disassembly (DfD).
6. Producing the report: The final phase involves the write-up of the analysis, which is presented in the Results chapter.

The next step in this research involved comparing these thematic results. This meant systematically comparing the specific properties for decommissioning and reuse (found from the expert interviews) against the 'Foundational Property Set' (from the literature review). This comparison helped to confirm what was already known and to find new, practice-based properties. In the end, a final consolidated list of all data requirements was created, bringing together the properties from both the interviews and the literature.

3.2 Phase 3: Development of the Exchange Information Requirement (EIR)

The primary objective of this phase was to translate the consolidated findings into a formal and structured EIR. In the context of this research, the EIR serves as a detailed data template that specifies the necessary information to support decommissioning and reuse workflows. This provides the definitive guide for the practical application and validation in the subsequent case study. To achieve this, the LOIN framework, as defined in ISO 19650-1 and ISO 7817-1, was systematically applied. This process involved structuring each property from the final list according to the core components of the LOIN framework: the prerequisites and the information requirements themselves.

For this case study, a simplified yet structured approach was taken to establish a clear project timeline, which is crucial for defining the Milestone, a key prerequisite in the LOIN framework for each information requirement. A hypothetical project duration of two years, from January 1, 2026, to January 1, 2028, was established to provide a realistic context for information delivery. This period is divided into four key phases, which serve as the defined Milestones in the EIR. These phases are illustrated in Figure 13.

Figure 13 - Fictional Project Phase (Milestones) for the Case Study

The Milestone defines the specific project phase by which information must be complete and added to the model.

Once the context was established, the next step was to detail the content of the information itself. Each property was categorized according to the three core LOIN dimensions:

- Geometrical Information: Properties defining the shape, dimensions, and location of a component.
- Alphanumerical Information: Properties containing text or numerical data, such as material grade, strength class, or a detachability score. This was the most common category for the identified properties.
- Documentation: Properties that link to external documents, such as material certificates, original engineering drawings, or maintenance logs. For each alphanumerical property,

further specifications were defined, including its required data type (e.g., text, integer, boolean), units, and potential value ranges or lists.

The last step involved mapping the properties to bSDD's. Properties in the EIR were first checked against the specialized DOR bSDD. If a matching definition was not found there, a broader search was conducted across other relevant bSDD domains and standard IFC property sets (Psets). Only when no suitable standard definition could be found across these established sources was an property defined as a project-specific property.

The final output of this phase is the EIR Table, which represents the core artifact of this research. In the EIR, each row represents one property, while each column corresponds to a key dimension of the information requirement. This detailed data template, structured according to the LOIN framework, is organized into several key columns. It first defines the contextual prerequisites of the information requirement, including the Object, Purpose (WHY), Actor (WHO), and Milestone (WHEN). The table then specifies the properties themselves (HOW). Finally, it includes columns for standardization and interoperability, detailing the LOIN Dimension, IFC Mapping, and the bSDD Identifier (URI).

The purpose of this detailed table is to first, give an overview on how to enrich the IFC model with reuse- and decommissioning-related data, and second, to function as a reference for verifying that each property is correctly implemented. During the development of the EIR table, the DOR bSDD served as a main reference. This helped to optimize the property structure by merging similar concepts (e.g., Recoverability and Circular Potential) into clearer, standardized definitions. In cases where no suitable concept could be found in the DOR bSDD, other bSDD vocabularies were explored. The structure and level of detail of the EIR table was aligned with the requirements for generating IDS files in later phases, enabling validation based on the defined properties.

3.3 Phase 4: Case Study Application and Validation

The case study application and validation forms part of the treatment design and treatment validation phase within Wieringa's design cycle. To evaluate the practical implementation of structured circularity-related information modeling, this research applies its proposed method to a real-life case study. The case study is based on IFC models from the Willemspoort Zuid development project in 's-Hertogenbosch, the Netherlands. This large-scale residential project, developed by Heijmans, consists of approximately 500 housing units, including a variety of dwelling types. The IFC models used for this research represent one of the planned buildings: a 22-story apartment complex. At the time of writing, construction has not yet started. Due to unresolved nitrogen emission issues, the Province of Noord-Brabant has not granted a building permit.

3.3.1 Model Enrichment

The BIM data for the case study consists of three separate IFC models (in IFC2X3 format), each representing a different design discipline:

- A foundation model (Figure 15);
- A structural model (Figure 14);
- An architectural model (Figure 14).

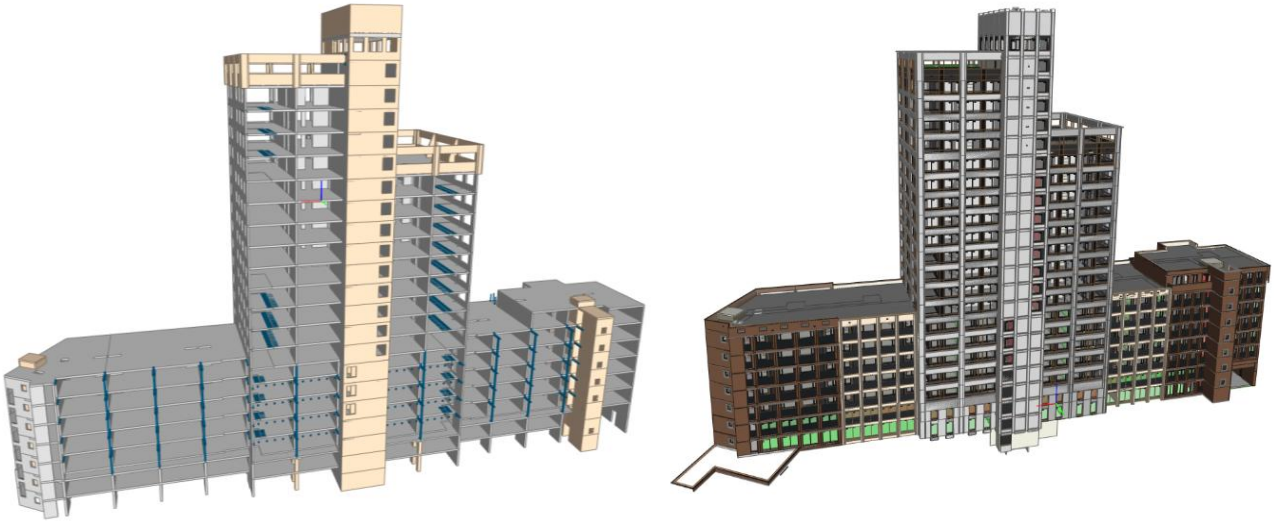


Figure 14 - The IFC models. Left: structural model; right: architectural model (BIMvision)

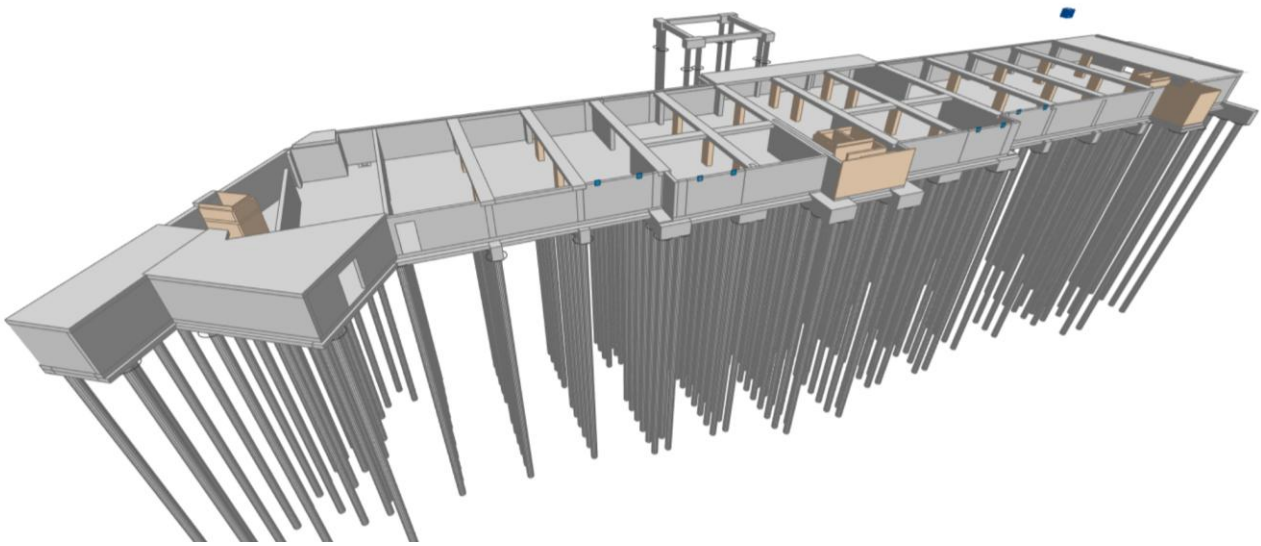


Figure 15 - The Foundational IFC model (BIMvision)

The models were exported in IFC format by Heijmans and delivered as-is, without access to the original authoring environment. A visual representation of the project's models is shown in Figure 14 and Figure 15. The IFC models were initially reviewed and analyzed using BIMvision, a lightweight, openBIM-compliant viewer. BIMvision was chosen for its efficiency and its ability to handle large files without crashing, especially important for the architectural

model which exceeded 800 MB in size. The original model was created in Autodesk Revit by an external BIM modeler.

It is important to note that the IFC models are treated as static snapshots of the BIM models at the time of export. While the native model (like the original Revit model) remains the single source of truth and the live working version, the IFC model represents a fixed version of the data at the specific moment it was exported. The primary purpose of the IFC format is to facilitate interoperability, enabling various project stakeholders to share and view a model using different software platforms. In a standard workflow, the native BIM model remains the single source of truth. If changes are required, they are made in the native model, which is then re-exported as a new IFC file.

As delivered, the IFC models did not contain structured properties relevant to circular construction, such as disassembly methods, reuse potential, or condition indicators.

While all three models were reviewed as part of the initial research, the structural and architectural models proved to be too large for the CoBuilder platform, which was selected for the practical enrichment phase. Therefore, the more manageable foundation model was used for the enrichment process. This was a suitable choice, as the foundation model contains the same key IFC elements (e.g., columns, beams, walls) as the larger structural model, allowing for a full demonstration of the enrichment methodology on the relevant elements.

3.3.2 Element Selection

A full inventory was created of all element types present in the structural and architectural models, as shown in Table 4. This inventory includes all IFC classes encountered in the three discipline-specific models: foundation, structural, and architectural.

Table 4 - All IFC elements found in the model analysis

IFC Element	Model	General Description/Example
IfcBeam	Structural (structural and foundation), Architectural	Horizontal structural elements (e.g. floor and roof beams).
IfcColumn	Structural (structural and foundation), Architectural	Vertical structural supports.
IfcSlab	Structural (structural and foundation), Architectural	Floors and horizontal plates.
IfcWallStandardCase	Structural (structural and foundation Architectural	Regular walls with standard geometry.
IfcWall	Structural (structural and foundation), Arch.	Irregular or detailed walls.
IfcPile	Structural (structural and foundation)	Foundation elements.
IfcWindow	Architectural	Windows in facades.

IfcDoor	Architectural	Internal and external doors.
IfcStairs	Architectural	Staircases between floors.
IfcMember	Architectural	Secondary elements (e.g. facade profiles, sills).
IfcRailing	Architectural	Guardrails in balconies and staircases.
IfcCovering	Architectural	Ceiling systems and other surface finishes.
IfcFurnishingElement	Architectural	Interior furnishings, including kitchens.
IfcDistributionChamberElement	Architectural	Technical service enclosures (e.g. electrical cabinets).
IfcPlate	Architectural	Thin panels or aluminum facade elements.
IfcBuildingElementProxy	Architectural	Unclassified building elements (used for shafts).
IfcFlowTerminal	Architectural	Fixtures such as emergency overflow outlets.

To ensure that the research focuses on the most meaningful and demonstrable elements, a targeted selection was made. This selection was guided by a combination of insights from the literature (see Chapter 2) and practical observations during the inspection of the IFC models.

Four main criteria were used to determine which elements to include:

1. Circularity potential: This criterion ensures the research focuses on elements with the highest potential for decommissioning and reuse. Based on insights from the literature, structural elements are generally considered to have the highest potential for decommissioning and reuse, particularly when they are prefabricated or modular in nature. For this reason, all structural elements identified in the model were included by default in the analysis.
2. Consistency and availability of geometric data: This criterion makes the research feasible. By selecting only elements with complete and reliable data, the study avoids being compromised by unusable information.
3. Feasibility of property enrichment: This criterion confirms that the selected elements are logically structured to support the meaningful addition of new properties. While it is technically possible to add data to any IFC element, the study focuses on elements with a clear and consistent classification, as elements with a generic or undefined classification (e.g., an IfcBuildingElementProxy) cannot provide a reliable basis for a standards-based methodology.

4. Representation of diverse use cases: This criterion broadens the applicability of the findings. Including a variety of elements, such as prefabricated and non-prefabricated components, ensures that the developed methodology is not limited to a single case but is potentially applicable to a wider range of building components.

The elements that met these criteria were selected for further analysis and enrichment. Each of the selected elements was eventually enriched with circular data. Based on insights from the literature, structural elements are generally considered to have the highest potential for decommissioning and reuse, particularly when they are prefabricated or modular in nature. Therefore, all structural elements identified in the model were included by default. Table 5 explains the reasoning for including each of the selected IFC elements in this study.

Table 5 - All IFC elements that are included for property enrichment

IFC Element	Model(s)	Justification for Inclusion
IfcWall / IfcWallStandardCase	Structural, Architectural	This element is frequently modeled as a modular, load-bearing or non-load-bearing component with repetitive geometry, indicating high prefabrication and reuse potential.
IfcBeam	Structural	Regular geometry and spacing suggest standardized, prefabricated elements. Some beams contain voids indicating possible lifting points.
IfcColumn	Structural	Uniform cross-sections and alignment with the structural grid suggest modular use. Their reuse potential is high, provided their material and structural history are well-documented.
IfcSlab	Structural	Slabs are a fundamental structural component, with high potential for disassembly and reuse, particularly when their installation method allows for non-destructive removal.

Despite being a structural element, the IfcPile class was excluded from this study's scope. While it is technically possible to reuse foundation piles, it is a complex and costly process that is not yet common practice. The primary challenges are the difficulty of extracting piles without damage, the high cost of verifying their structural integrity, and various logistical issues. Although a digital system could make it more efficient to check and approve piles for reuse, particularly the set of properties required for assessing in-situ reuse (i.e., leaving the pile in the ground for a new building), falls outside the focus of this study. The research concentrates on developing a methodology for the deconstruction and reuse of above-ground, prefabricated structural components, which requires a different set of properties.

Based on the selected IFC objects, a representative set of IFC elements from the Willemspoort Zuid project's BIM model was chosen for enrichment. The complete list of these elements, including their descriptions, is provided in Appendix I. All listed elements were used in the enrichment process to add the relevant property sets. The IfcSlab (Concrete Floor) is used throughout this thesis as the illustrative example for demonstrating the workflow (see Figure 16).

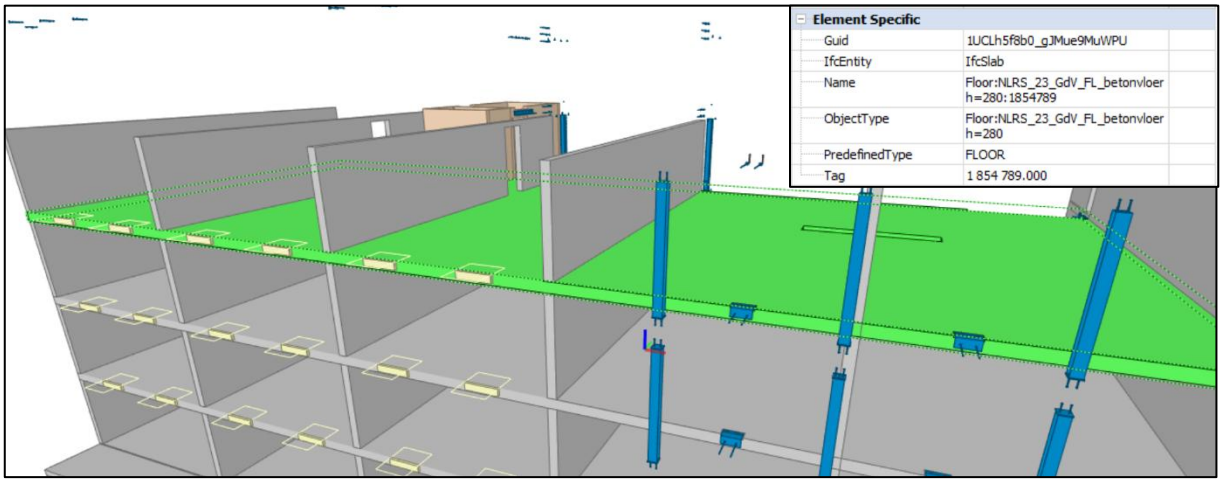


Figure 16 - IfcSlab - Concrete Floor

3.3.3 Enrichment Process in the CoBuilder Require Platform

After defining the EIR's, the next step involved embedding this EIR into the CoBuilder Require Platform. CoBuilder Require, is a digital platform designed to structure, enrich, and validate information in compliance with international standards such as ISO 7817-1:2024 for LOIN and buildingSMART's IDS framework (CoBuilder, n.d.).

CoBuilder is a digital construction technology company that develops solutions for managing structured product data across the construction lifecycle. Its platforms are designed to improve data quality, interoperability, and standardization in BIM workflows. At the core of CoBuilder's offering is the ability to create, manage, and exchange structured product data based on standardized data dictionaries such as the bSDD. By enabling consistent terminology, classification, and property structures across digital models, CoBuilder addresses common issues in construction such as fragmented data sources, non-standard properties, and limited machine-readability of product information (CoBuilder, n.d.). One of CoBuilder's primary tools for project-based information management is CoBuilder Require. This platform enables users to define project-specific information requirements in line with ISO 7817-1:2024 (LOIN) and ISO 19650. Require allows users to:

- Define data requirements for different object types and use cases,
- Select and apply properties from standardized data dictionaries like bSDD (or internal company templates),
- Automatically generate IDS files for validation,
- Enrich IFC or native BIM models with the required data,
- Export structured outputs for use in authoring tools or for compliance checking.

In contrast to more general-purpose BIM tools, which often rely on manual property creation or lack built-in support for openBIM standards, CoBuilder Require is explicitly designed to align with current international specifications such as ISO 7817-1 and buildingSMART's IDS. Its native integration with bSDD and support for automatic IFC enrichment make it particularly suitable for circular construction workflows, where consistency, traceability, and machine readability of properties are critical.

In the context of this research, an academic license was granted to access CoBuilder Require. This enabled the testing of structured circularity-related information enrichment in an IFC-based BIM model. This made it possible to directly apply the EIR developed in this study, embed relevant properties into IFC elements, and validate the enriched model against those requirements using IDS. The following sections explain the process of integrating the information requirements into Cobuilder Require.

3.3.3.1 Project setup in CoBuilder Require

A new project environment was created in CoBuilder Require. Basic project details such as the project name, reference number, country, and building type were entered. Next, the platform was configured with relevant data dictionaries and classification systems, including the bSDD, to ensure that all properties would be aligned with standardized terminology. Contributors could also be added to assign roles and responsibilities.

3.3.3.2 Defining the LOIN prerequisites

Following the initial project setup, the next step was to define the LOIN prerequisites within the CoBuilder environment. First, the project Milestones were established, as shown in Figure 17. Next, the various Purposes for the information requirements were defined (Figure 18). Finally, the different Actors or project roles were added to the system, as illustrated in Figure 19.

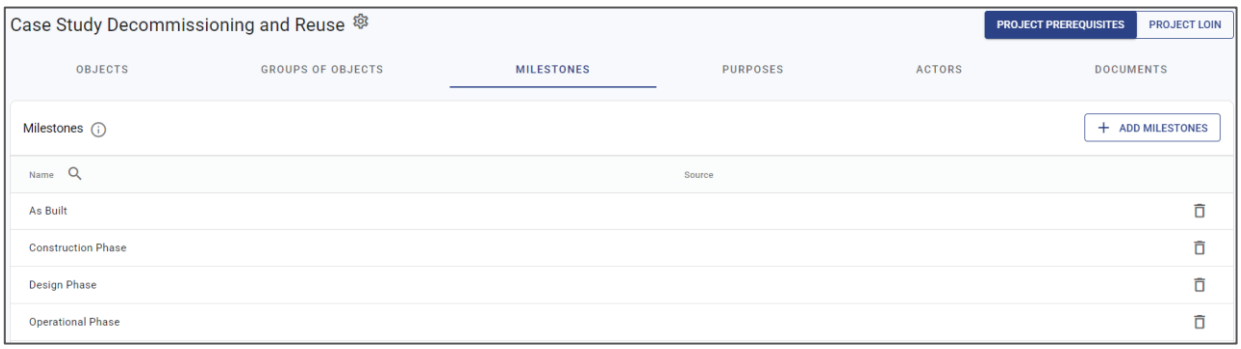


Figure 17 - Screenshot of the project Milestones as defined in the CoBuilder Require platform for the case study.

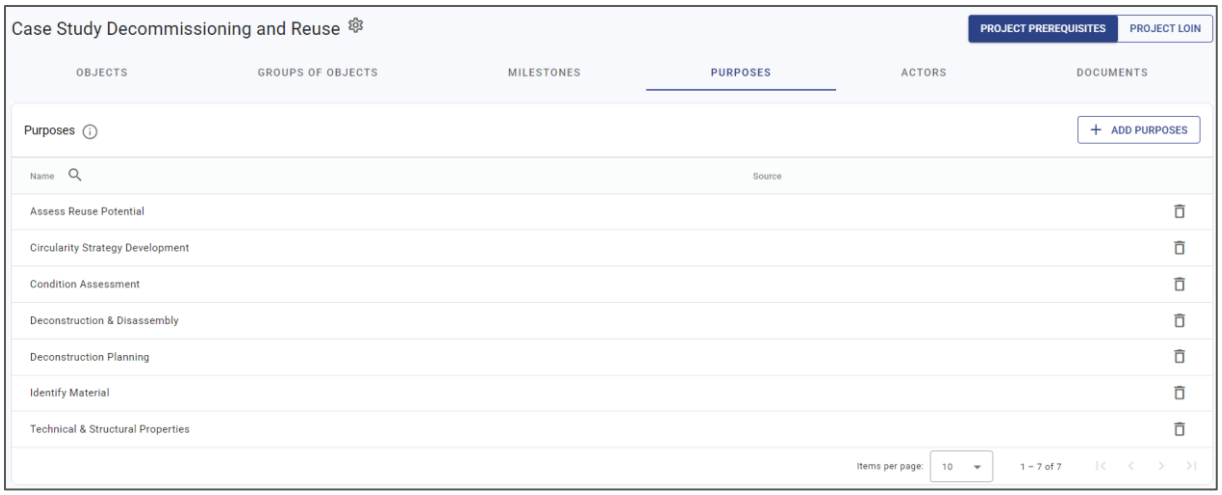


Figure 18 - The various Purposes for the information requirements established within the CoBuilder Require environment.

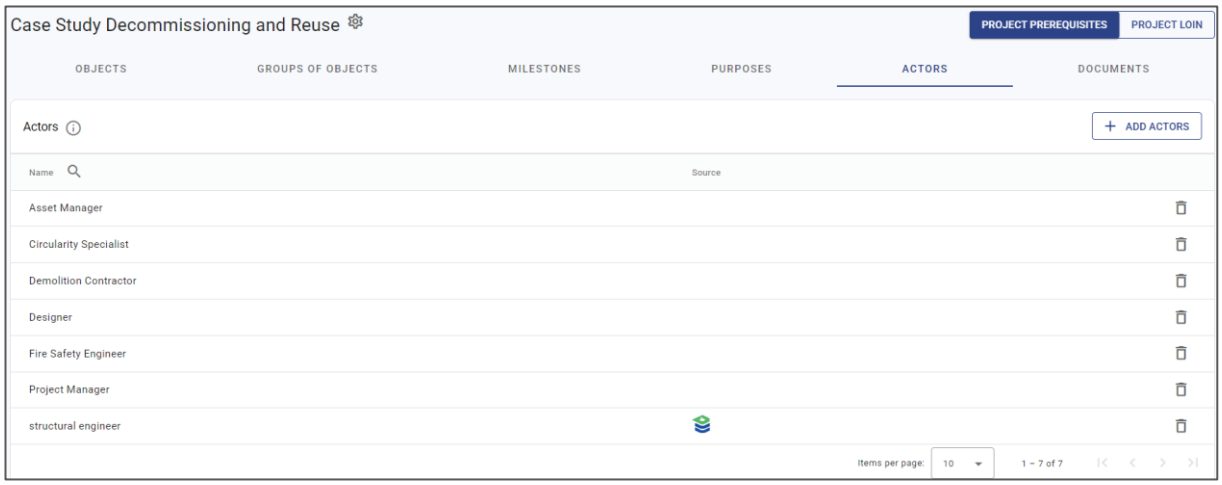


Figure 19 - Screenshot of the Actors (project roles) added to the system to define the "WHO" prerequisite for the information requirements.

3.3.3.3 Structuring data requirements based on LOIN

This process involved manually implementing the structured EIR by creating a 'LOIN entry' for each unique combination of prerequisites for a given object class (e.g., IfcSlab). The platform's user interface is systematically organized around the LOIN framework, which facilitates this process. Within each LOIN entry (Figure 20), the specific properties from the EIR were assigned according to the three main LOIN dimensions:

- Alphanumerical Information: This is managed under the 'Properties' and 'Classifications' sections. The 'Properties' section allows for linking standardized properties directly from the bSDD or defining custom properties.
- Documentation: Requirements for external documents are handled in the 'Documents' section.
- Geometrical Information: This is detailed in the 'Geometry' section, which includes specific menus for Detail, Dimensionality, Location, Appearance, and Parametric Behaviour, directly reflecting the components of the LOIN standard.

The detailed outcomes of this implementation are presented in the Results chapter (Chapter 4).

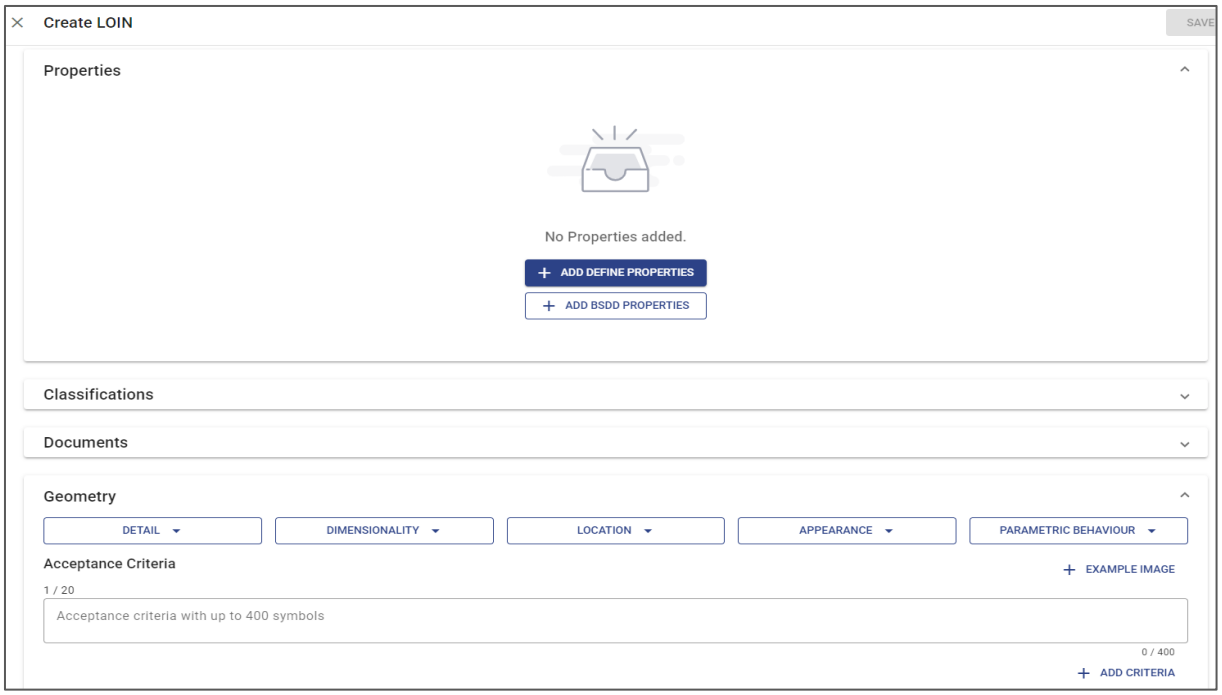


Figure 20 - Screenshot of the 'Create LOIN' entry section in Cobuilder Require.

3.3.3.4 Exporting IDS and Excel formats

Once the information requirements were assigned to the relevant elements, the Require platform automatically generated IDS (XLM) files based on the defined structure. A key aspect of this process is that the platform generates these specifications on an actor-by-actor basis. This means a separate IDS file is created for each defined Actor (e.g., Designer, Demolition Contractor), containing only the information requirements for which that specific role is responsible. These IDS files allow for software-based validation of IFC models. In addition to the IDS, an Excel version of the requirements was exported for human-readable reference, and a Revit Shared Parameter File was also generated to support integration with Revit-based workflows.

3.3.4 Enriching the IFC model & Validation

Using the platform's Enrich IFC feature, the selected properties were embedded directly into the IFC model. It is important to note that this enrichment process adds the properties themselves, but at this stage, they do not yet contain any values. Populating these empty properties with data is the next crucial step. In a standard project workflow, these values would be added within the native BIM authoring tool (e.g., Autodesk Revit) by the responsible actor. However, to demonstrate the full data workflow for this case study, the open-source platform usBIM was used to add example values. usBIM is a certified IFC viewer and editor that allows for the editing of properties directly within an IFC file (usBIM, n.d.). After the enrichment process, IDS was used to validate the predefined requirements.

3.3.5 IDS-based Validation

As described in the previous section, the final step in the workflow involved validating the enriched IFC model against the predefined requirements using the generated IDS files. In this study, the IDS was generated directly from the CoBuilder Require platform based on the EIR created in earlier steps. The IDS file was structured as an XML schema that specified which

IfcElements should contain which properties, value types, and classifications, mapped according to the LOIN dimensions (geometrical, alphanumerical, and documentation).

However, because CoBuilder's Enrich IFC feature had already applied the information requirements directly to the correct elements during enrichment, the model already included all the required data in the correct locations. As a result, the IDS validation in this study was mostly confirmatory. No major errors or missing information were expected, and the validation step did not provide significant additional analytical value in this specific research setting.

Nonetheless, the use of IDS remains highly relevant in practical BIM workflows, especially in cases where: Data is entered manually, information is added across multiple tools or project participants, or enrichment occurs outside a controlled environment. In those cases, automated validation helps ensure that information is complete, consistent, and correctly placed. This is especially relevant in circular construction, where the quality of information directly affects reuse decisions. In this study, the IDS file mainly served as a proof of concept, showing how structured information requirements can be validated automatically and how the proposed method can be applied in more complex or collaborative environments.

3.4 Phase 5: Evaluation of the Workflow

The final phase of this research is the evaluation of the developed workflow, which aims to answer the fourth research sub-question: *What challenges and limitations are encountered when applying Level of Information Need (LOIN) and buildingSMART Data Dictionary (bSDD) for circular information modeling in practice?* To address this a evaluation of the entire workflow was performed. The core of the evaluation is to analyze how well the EIR, structured with the LOIN framework, served for defining circular data. Furthermore, this evaluation will discuss the critical role of openBIM standards. It will analyze how the bSDD was necessary for providing semantic consistency to the circular data, and how the IDS was used to enable the automated validation of the enriched BIM model. The findings from this evaluation will form the basis for the discussion and final recommendations.

[This page is left empty]

4. Results

This chapter presents the results of the research, showing how the research progressed from identifying reuse-related properties to validating them in a BIM environment. To guide the reader, Figure 21 provides a visual overview of the workflow that is detailed in this chapter.

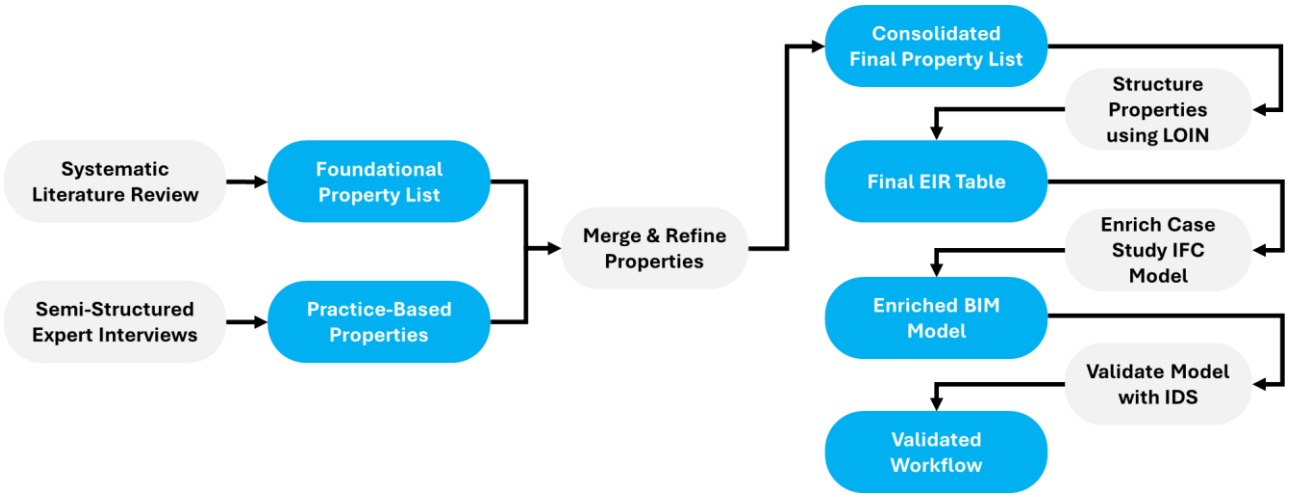


Figure 21 - Overview of the Results Chapter Workflow.

This diagram illustrates the main stages of the research process presented in this chapter. It begins with the separate identification of properties from literature and expert interviews, which are then merged into a single Consolidated Final Property List. This list is subsequently structured into a formal EIR table according to the LOIN. Finally, the structured properties are practically applied to enrich, and ultimately validate, the case study's BIM model using an IDS.

4.1 Foundational Property List from Literature Review

The initial phase involved a systematic literature review, which yielded a "Foundational Property Set" for decommissioning and reuse. This set of properties is consistently highlighted across academic studies as essential for enabling decommissioning and reuse within the construction sector. As detailed in Chapter 2, these properties were categorized into five thematic groups: (1) Origin and Identification, (2) Technical and Structural, (3) Condition and Lifecycle Data, (4) Deconstruction and Disassembly, and (5) Circularity Strategy and Impact. The full compilation of these initial properties is presented in Table 2 (Chapter 2). This foundational set served as the theoretical baseline for understanding the existing knowledge on data requirements for CE.

4.2 Practice-Based Insights from Expert Interviews: Informing the Data Needs for Circularity

The thematic analysis of the expert interviews systematically identified key information requirements, challenges, and opportunities for circular construction. The findings were structured by first creating codes from expert quotes. These codes were then categorized into sub-themes, which were finally consolidated into three main themes: (1) Challenges & Enablers, (2) Component-Specific Information Requirements, and (3) Deconstruction Process and Strategy. Figure 22 provides a visual overview of these themes. It clearly shows that the

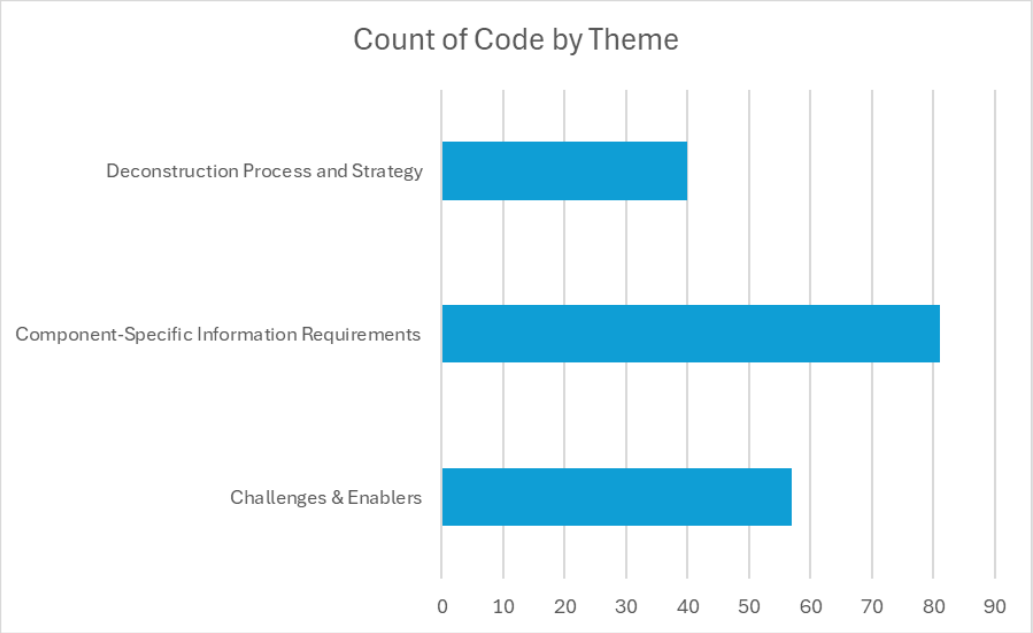


Figure 22 - Thematic Analysis: Count of Code by Theme

experts' primary focus was on Component-Specific Information Requirements, highlighting the importance of gathering detailed, practical data for building elements. The complete, detailed thematic analysis, which links every expert quote to its corresponding code and theme, is presented in Appendix V. The next step was to filter the detailed analysis to extract only the specific, usable properties that can be directly implemented in a BIM model. This process resulted in the final list of practice-based properties, which is presented in Appendix VI.

4.2.1 Thematic Analysis Results

This section presents the detailed findings from the thematic analysis of the expert interviews, per category, offering a practice-based perspective on information requirements and challenges for circular construction.

4.2.1.1 Challenges & Enablers

This theme encapsulates the broader contextual factors influencing the adoption of circular construction. Experts consistently highlighted the critical need for robust data management practices. The significant value of long-term data archiving was strongly emphasized, as neglecting it leads to substantial data loss, which then makes reusing building parts not worth the cost. One expert noted, "If you lose that data... it costs you so much effort to retrieve that

data that it is often not worth it" (ID5). On the other hand, a common problem identified was the lack of reliable "as-built" records, as expert ID8 pointed out, "My experience is that I have yet to come across the first good archive of a building". Experts called for a regularly updated database that includes details from engineering, delivery, and assembly. They highlighted the need for a "living digital twin" that gets updated throughout a building's life. The potential of AI for document interpretation was also noted as a future enabler by expert ID2, who mentioned that "AI that can understand documents" would be useful. However, current BIM limitations, such as the inability to assign properties to specific faces or parts of an element, were recognized as practical hurdles by expert ID6.

Discussions on CE and business models revolved around the foundational necessity of CE due to finite resources. Expert ID6 stated, "Everything is finite, right? I think we need to be very careful with our resources... reuse is much more interesting. It will run out one day". A significant insight highlighted that demolition is often driven by functional obsolescence rather than structural failure. Expert ID4 explained, "All buildings are temporary... residential buildings last around 50 years, office buildings 20-30 years... We do not demolish them because of structural damage, but because we don't want that building there anymore. It's a huge waste of materials". This view highlighted the massive waste in the traditional linear system and pushed for a change in mindset away from always wanting new things. One expert mentioned, "I think people are still very attached to new things being good, but used things can be just as good... It's a real shift in mindset" (ID6). The economic viability of reuse remains a major barrier due to the low cost of new materials and the associated high costs and risks of investigation, handling, and storage. Expert ID8 highlighted this by stating, "New materials are still too cheap, actually, to make reuse and circular use very interesting and clients therefore always find it... a hassle". A notable insight highlighted the impact of component guarantees limiting reuse, as expert ID3 explained, "the supplier of the hoisting anchors said, 'Yes, it's nice that you want to do that, but I actually only guarantee hoisting once. So during assembly and disassembly, I don't guarantee the strength of those hoisting anchors'". This led to a suggestion for a "data for reuse obligation" (ID3), similar to current warranty rules. The fragmented market and lack of a standardized approach for circular materials were also acknowledged challenges, with one expert noting, "you just notice that the whole market is still very much searching" (ID6).

Regarding assessment and strategy, experts emphasized the importance of initial data before performing costly tests, noting that "if you have no info to start with, it's not worth doing tests" (ID1). This is because "the investment to do that becomes, especially at this moment, far too large" (ID3). Experts underscored that "the highest possible certainty for reuse" drives information needs (ID1), and "for that you want as much information as possible" (ID1). The process typically begins with a "shopping list" of required properties to filter available elements, as described by expert ID6. A critical insight was the need for a "long-term (50-year) building vision" (ID2), shifting focus to a building's end-of-life from its design phase. The prioritization of high-impact materials (environmental/economic) for reuse was also suggested to maximize sustainability gains, as ID8 highlighted, "you mainly look at where the environmental impact is, but also where the money is, right?".

4.2.1.2 Component-Specific Information Requirements

At the core of assessing any component for reuse are its fundamental properties. Experts consistently highlighted the high importance of ***geometry* and *material properties***. As ID5 stated, "Geometry and the material properties" are crucial. This encompasses specific dimensions, profile numbers for standardized elements like steel beams, and detailed information on material types such as concrete, timber, or steel. Expert ID7 further reinforced this, stating that "dimensions, strength class, what kind of material it is, material type" are key. Expert ID4 also noted the importance of ***dimensions and weight*** for transport.

For concrete parts, the exact layout of ***internal reinforcement*** was seen as essential. Expert ID5 emphasized, "For concrete elements, the details of the internal reinforcement are essential information," and clarified that knowing "where which bar is located" is more useful than just the quantity of reinforcement. Expert ID2 also noted the importance of reinforcement information for concrete elements, mentioning that while typically done via details, some companies add reinforcement to 3D models. Expert ID6 explicitly stated the need for modeled reinforcement, especially at connections, noting "reinforcement is actually not modeled... that is actually very useful information". Expert ID8 inquired about the quantity and cover of reinforcement. The ***presence of openings*** within an element also needs to be documented (ID1).

Furthermore, the **strength class** and **environmental class** of materials were consistently highlighted (ID3). Expert ID2 noted that class designations for concrete immediately convey many other properties, and the same applies to reinforcing steel standards. Expert ID8 stressed the importance of strength class for timber and concrete quality.

The importance of ***geometric tolerances*** for accurately assessing a component's fit in a new structure was also emphasized (ID1). Expert ID4 highlighted that understanding the original out-of-straightness is important to differentiate it from permanent deformation that occurred during lifetime. Expert ID6 also mentioned that it is usually only modeled in 3D for complex nodes where vertical and horizontal reinforcement meet, or for connection to a console.

The exact ***composition of materials***, including any added substances, was considered vital for long-term health and recycling checks. As expert ID3 explained, "you also really want to know, if I am going to modify it or reuse it in a building, you also want to know what was in it". This includes identifying hazardous materials like asbestos, which were once accepted but are now regulated due to health risks (ID3). Expert ID2 highlighted a challenge with non-standard materials (e.g., cement-free concrete) that may have the same classification but different properties.

A component's ***age*** was also a significant factor, especially for concrete, due to how carbonation affects the steel inside. Expert ID4 noted, "it would be good to know the age of the elements... The concrete chemically... protects them from corrosion, but this effect is gradually decreasing throughout time". Expert ID6 stated that a "best before" date or design life of typically 50 years is important, but clarified that this is a reference period and not an absolute expiry date.

The ***degree to which a product is assembled*** (whether it's a single item or part of a bigger system) also affects its reusability (ID8). Expert ID9 mentioned the need for surface finishes information, especially for coatings like Chromium 6 on steel, which can complicate reuse due to high cleaning costs.

Information about a component's past use and condition is essential for thorough reuse evaluations. This involves capturing ***as-built performance data*** and understanding any differences between what was initially designed and what was actually constructed. Expert ID8 noted this common challenge: "… it is also always the question if it was made as it was designed". The load history (how much weight it carried), particularly for parts in bridges, and any changes in how the building was used (which could mean different loads), were mentioned as vital for re-evaluating if a part is still strong enough. Expert ID1 highlighted, "Any change in the building's function should be recorded, as this implies a change in the loading history of the components". ***Proven strength data***, derived from actual performance rather than solely design load, was considered more valuable. Expert ID3 highlighted that ***actual vs. theoretical deflection data*** is a key indicator, noting that a theoretical deflection might be 11-12mm, while in practice it's only 3-4mm, suggesting a hidden strength reserve. Expert ID5 stressed that storing calculated capacity is less useful than raw properties.

For visual assessment, details such as crack formation and corrosion level were highlighted. However, experts cautioned that "not all cracks are critical" (ID5), as some do not compromise structural integrity. Data on the ***original shape*** or any initial imperfections was also suggested by ID4. This helps to determine if any current deformation is original or occurred during the component's lifetime, as "we will not know that this was the original shape or this is some kind of permanent deformation that occurred during its lifetime". A ***formal condition assessment***, possibly adhering to standards like NEN 2767, was proposed by ID8 to systematically quantify defects, noting that "defects are defined in the NEN2767".

Thorough ***documentation and clear origin information*** are crucial for building trust and tracking materials in CE. This includes having ***original production and design data***, such as calculations and design choices (ID2). Expert ID5 also emphasized the need for manufacturing date and original specifications to determine normative sufficiency. Expert ID9 stated the need for original production drawings and technical specifications from tenders to be part of the BIM model.

Manufacturer data was considered important for quality control and warranties (ID1). ***Material certificates*** are essential for legal and insurance purposes in reuse situations. As expert ID4 explained, "often with the reuse structures the question of insurance comes up, and usually the insurers require this kind of certificate". Expert ID9 also explicitly stated the need for Material Certificates. Experts stressed the need to directly link as-built and production data to the BIM model; Expert ID6 emphasized, "make sure that the final production data... is linked in one way or another".

There was a strong call for a ***unique ID or material passport*** for each element to track its history across multiple projects, potentially leveraging technologies like Blockchain (ID2, ID7). The ***classification and specific standard (including the year of publication)*** of materials are

vital for understanding their properties over time, a point raised by expert ID2. Expert ID2 also highlighted the value of linking PDF documents for future-proofing, as they may become machine-readable.

Quality Control / Assurance records are essential to ensure the component meets quality standards when built (ID7). Expert ID9 mentioned that knowing the material qualities of steel and concrete, and the amount of reinforcement applied, is critical because it's not visible from the outside.

4.2.1.3 Deconstruction Process and Strategy

This main theme encompasses the practical and logistical information vital for disassembling components without damage, along with strategic considerations for their future reuse.

When focusing on ***connections***, their type and how they are fastened are crucial, as they directly impact how easily a component can be separated. The distinction between "wet" (e.g., cast-in-place concrete) and "dry" (e.g., bolted steel) connections was consistently emphasized, with dry connections being preferred for reuse due to their ease of separation. ***Connection accessibility*** is also a key factor. Expert ID1 insightfully noted that "most money is often from disassembling connections," underscoring that their efficient removal is a significant economic driver. The challenge of modeling multi-material connections in current BIM workflows was highlighted by ID2, who explained that "in practice, you often have to look at two different models to understand the connections. Typically, there is a concrete model and a steel model. In many cases, the connections aren't modeled at all". The need for a **standardized coding system for connection types** was also raised by expert ID6 to facilitate machine readability. Expert ID3 mentioned the "Detachability Index" as a grading system for connections (0 to 1 score) to quantify ease of disassembly.

For ***disassembly logistics and planning***, information concerning the ease of retrieval and the potential for damage during removal is crucial. ***Disassembly time and effort*** were identified as key economic factors, particularly for labor-intensive processes. ID4, reflecting on elements with numerous screws, noted, "it just takes too much time to take them all the way." Experts suggested a ***disassembly score or rating*** (e.g., a 0-1 scale) or a ***detachability index*** to quantify ease of disassembly. ID3 specifically mentioned, "Are you familiar with the Detachability Index? ... It's a kind of grading where connections are assessed and they get a score from 0 to 1". The recommended ***disassembly technique*** and a defined ***disassembly sequence*** (e.g., from top to bottom) were also highlighted as important properties. The need for ***predetermined cut lines*** in the design phase to facilitate future removal was also noted (ID4). The contribution of a component to overall structural stability is essential to understand, as it affects the disassembly sequence; ID8 stated that if an element "contributes to the stability of a whole, you can't just take it away." The importance of proper ***post-demolition handling***, including transport and storage was also strongly emphasized (ID4). Logistics and availability information were identified as major bottlenecks in the reuse process, highlighting the need for organized data on ***material availability*** and location. Furthermore, ID8 pointed out the "need for product-specific knowledge/equipment for disassembly," citing a case where a party "had too little knowledge of how that product and that system works." Lastly, while on-site

modifications like cutting are practical, ID6 noted that "this kind of thing cannot be recorded, of course," making pre-definition difficult.

Regarding DfD, experts discussed the importance of clear hoisting provision locations and the overall ability to lift elements. ID3 mentioned the need for "where your ***hoisting provisions*** are" as an property. The ability to reuse hoisting anchors was specifically raised, alongside the insight from ID3 that guarantees might limit this. The need for data on the replaceability of ***vulnerable parts*** was highlighted by ID4, who observed that "If we foresee already in the design that some elements might be damaged... then these elements should be easily replaceable." Finally, ID7 explicitly identified that "***modularity*** increases reusability" significantly, especially when compared to unique, single-use elements, suggesting a preference for standardized components in designs intended for circularity.

4.3 Consolidated & Final Property List for Circularity

The primary objective of this phase was to merge the properties identified in the literature review with those gathered from expert interviews into a Consolidated & Final Property List. This list forms the definitive set of properties required to support circular workflows, with a particular focus on structural elements. To ensure a shared and consistent understanding of each property, Table 6 presents the definitions applied in the Consolidated & Final Property List in alphabetical order. These definitions are derived either from established literature or from the practical insights provided by the interviewed experts.

Table 6 - Definitions of Consolidated & Final Property List

Property	Definition
Acoustic Rating	Acoustic rating for this object. It is provided according to the national building code. It indicates the sound transmission resistance of this object by an index ratio.
Actual (vs. Theoretical) Deflection Data	This property provides measurements of a floor or structural component's real-world deflection (bending or displacement under load), which are then compared against its theoretically calculated deflection values from the original design. This comparison is important because it shows the component's true performance over time, helping engineers understand its current strength and decide if it's suitable for reuse in a new building.
Admixture Description	A description of the chemical or other admixtures used in the material.
Applied Standard	The specific standard and its year of publication (e.g., ISO 22965-1:2007).
Assessment Condition	Overall condition rating (e.g., Good, OK, Poor).
Assessment Date	Date on which the overall condition is assessed.
Assessment Description	Qualitative description of the condition (e.g., visible damages, cracks, spalling, corrosion).
Assessment Method	External reference to assessment method or application used (e.g., NEN 2767, visual inspection).
Certification requirement	Certification requirements refer to the specific criteria or standards that need to be met in order to obtain certification for certain products, processes, or components within the context of Circular Economy practices. Unlike Classification and Standard which details inherent material properties and design

	compliance, this property specifies the additional validation and documentation required to formally confirm the component's fitness for a new use within Circular Economy practices.
Circular Potential	The designated plan or assessed potential for the component after deconstruction (e.g., Reuse, Recycle, Remanufacture, Repurpose, Dispose).
Composition Proportions	The proportions of each main component (e.g., cement, aggregate, water) in the material mix.
Connection Accessibility	This property indicates the ease with which a component's connections can be physically reached and manipulated for various purposes, including routine inspection, maintenance (like tightening bolts or replacing parts), or ultimately, disassembly for reuse. It considers factors such as whether the connection is exposed, concealed within another element, requires specialized tools for access, or necessitates the removal of other components to reach it.
Connection Type	A superclass that allows to describe the type of the connections. Different connection types facilitate different circular and End-of-Life possibilities, including: (1) Deconstruction, i.e., a building is taken apart into products; (2) Demounting, i.e., a product is taken out of a building; (3) Disassembling, i.e., a product is separated into components or sub-parts; (4) Dismantling, i.e., a product is separated into individual materials. It also specifies the properties of the connection itself (e.g. reversible bolted connections with exact fastener details (M20, hexagonal head)).
Contribution to Overall Stability	This property quantifies or describes the critical role a specific component plays in maintaining the overall structural integrity and stability of the entire building or a significant section of it. It goes beyond simply identifying a component as "load-bearing" and specifies how its removal might impact the surrounding structure.
Current Reuse Count	Current Use Count represents the number of use counts that product is currently being used, from the total reuse count that the product is designed for. The current reuse count reflects the ongoing utilization of the product compared to the total reuse count.
Data Archiving Format	Specifies the long-term format and accessibility strategy for digital building and component data to mitigate file format obsolescence risk.
Decoupling Ease Score	This property provides a quantifiable score, on a scale from 0 (very hard) to 1 (very easy), that measures how easily the integrated layers of a composite component can be separated.
Design Calculations Link	Link to original structural or other relevant design calculations.
Design Choices	Record of specific design choices and underlying principles by the designer, within the context of Circular Economy practices.
Design Life	Design Life is considered as a useful period of life time where major modifications are not needed. The value of the Design Life is the specific number of years for which an object is designed to function effectively or remain operational. A reusable element can have one design life and multiple service lives, whereas a conventional element usually has the same design life as a service life. The Design Life is defined in years.
Disassembly Score	Rating that quantifies how easily a building component can be deconstructed or disassembled for future reuse, from 1 (very low effort, easily demountable) to 10 (very high effort, complex and labor-intensive disassembly).

Disassembly Sequence	Outlines the preferred, ordered series of operations for removing multiple components from a structure. This property ensures safety (e.g., preventing structural collapse during removal), maintains structural integrity of the remaining parts, and enables efficient material recovery. It dictates what comes out when, and can preferably include machine-readable sequences to facilitate automated planning and execution.
Deviation Description	Detailed description of the deviation from design.
Economic Data	This property provides information related to the financial aspects and benefits of reusing a component. It includes metrics such as estimated material cost savings compared to purchasing new materials, or profitability ratios associated with the reuse process.
Economic Life	Economic Life refers to the amount of time an element is in service before it is more economically advantageous to decommission or replace it. The Economic Life can be used in cases where the exact service life or design life is not known, or if it does not match the expected service life of an existing building. The Economic Life is defined in years.
Embedded Services Information	Details about any services (e.g., insulation, water pipes, heating installations) that are cast-in or otherwise permanently integrated into composite prefabricated elements.
Environmental Impact	Data on the environmental footprint (e.g., embodied carbon, GWP), often linked to an external EPD or LCA database.
Exposure Class	Environmental conditions the component was exposed to (e.g., Interior_Dry, Exterior_Exposed).
Fire Exposure	A record of whether the component has been exposed to a significant fire event during its service life.
Fire Resistance Rating	Measure of the fire resistance rating in hours (e.g., 1.5 hours, 2 hours, etc.).
First Installation Date	The date on which the component was first installed in its initial location or project, regardless of subsequent removals or re-installations.
Geometric Tolerances	The permissible variations or deviations from the ideal dimensions, shape, or position of a component, established during its original manufacturing or design. These tolerances are crucial for assessing a component's fit and compatibility for reuse in new structures, especially in contexts of modularity and standardization. For example, understanding a beam's length tolerance determines if it can be directly reused in a different building with slightly varying column sizes without costly re-manufacturing, thanks to adaptive connections.
Guarantee Status for Reuse	This property documents whether existing product guarantees (e.g., from original manufacturers or installers) extend to a component's reuse in a new context, or if these guarantees become void after its initial installation or decommissioning.
Handling Guidelines	General guidelines for safe handling (e.g., protect exposed rebar ends).
Has Deviation	Boolean flag indicating if a deviation exists (TRUE/FALSE).
Hazardous Material	According to the Waste Directive 2008/98/EC, hazardous materials are sourced from the type of resources that will cause health damage to humans, animals, plants, living organisms, and the environment. (Guidance on the classification and assessment of waste (1st Edition v1.2.GB) Technical Guidance WM3).

Hoisting Provision Locations	Maps the precise locations of hoisting anchors, lifting points, or other provisions on the component for safe lifting and maneuvering. For example, this could specify the exact coordinates or a clear diagram showing pre-installed lifting anchors in a prefabricated concrete column, or designated pick-up points on a steel beam.
Hosted Components	Relational data defining which other components are structurally dependent on or attached to the current one.
Is Non-Destructive	Boolean indicating if the method is non-destructive (TRUE/FALSE).
Last Maintenance Date	Date of the last recorded maintenance activity.
Load-Bearing Status	A boolean or descriptive tag indicating if the element is part of the primary structural system.
Location Data (for local sourcing)	Geographic information indicating a component's origin or current placement. This is crucial not only for understanding where raw materials come from but also for identifying existing building elements in proximity to new projects that could benefit from reclaimed materials, thus supporting a local Circular Economy by minimizing transport impacts.
Maintenance Log	Link to a detailed log of all maintenance/repair activities.
Manufacturer	The organization that manufactured and/or assembled the item.
Manufacturer Contact Information	Contact information for the manufacturer.
Material Certificates	Links to official documents (e.g., digital certificates) that formally verify the specific properties, quality, and compliance of the materials used in a component. This property is crucial as it provides the legal and verifiable proof that a material meets stated standards (like its Material Quality/Grade), crucial for legal and insurance purposes in reuse.
Material Type	The primary material of the component (e.g., Steel, Concrete, Timber).
Model Maintenance Plan Link	Link to a plan or protocol detailing how the BIM model and its associated data should be updated and maintained throughout the building's lifecycle.
Modularity Degree	This property offers a quantifiable indication of how modular or standardized a specific element is. A high degree of modularity means the component is designed with standard dimensions, interfaces, and connections, which significantly influences the ease and cost-effectiveness of its re-integration into new designs.
Net Weight	The weight of the component after subtracting holes, cuts, and other modifications, crucial for logistics and structural calculations.
Owner-Managed Model Link	Link to information indicating if the BIM model is managed and updated by the building owner for maintenance and management purposes.
Ownership	Records of the current and past owners of the component, important for leasing models and legal responsibility.
Personnel Requirement	In the context of circular requirements, Personnel refers to the human resources (with or without particular qualifications or skills) needed to carry out specific tasks related to deconstruction, disassembly, reassembly, or other circular practices within a project.
Physical Constraints	The six degrees of freedom (+/- x,y,z) defining possible paths for removing a component without clashing with others.

Post-Demolition Destination Readiness	Information on whether a suitable next project or storage facility is identified/secured for the component immediately after demolition.
Predetermined Cut Lines	These are specific lines or areas pre-planned in the design of a building part where controlled cuts can be made. This makes it easier to remove or change that part in the future. For example, a large concrete floor might have these lines to help cut it into smaller pieces that can be reused. This planning makes taking buildings apart more efficient, reduces waste, and helps save parts for new projects.
Prefabrication Status	Indicates if a component was prefabricated off-site, which often correlates with higher standardization and reusability.
Preferred Method	The recommended method for removal (e.g., SawCutting, LiftingWithCrane, ControlledBreaking).
Presence of Openings	This property documents any intentional openings (e.g., designed voids for windows or doors) and unintentional openings (e.g., holes drilled for later installations) within a component. This information is crucial for assessing its remaining structural capacity, fit in new designs, and the planning of modifications.
Previous Location	Unique identifier or address of the previous building/location.
Previous Use Type	Description of the component's previous functional use.
Proven Strength Data	Actual performance data or verified load-bearing capacity of a component, obtained through real-world observation or specific load tests conducted on the installed element. This data is crucial because it reflects the actual strength demonstrated by the component after being subjected to real-world loads during its service life, offering empirical evidence that may confirm or deviate from its original design calculations or theoretical material quality/grade.
Quality Check Reports	Link to quality control and assurance reports.
Rebar Layout Diagram Link	Link to a detailed 2D drawing or 3D model view showing the exact placement, diameter, and bending of all reinforcement bars.
Rebar Type	The quality/grade of the steel reinforcement used (e.g., B500B, Ribbed, Smooth).
Reference Documentation	Links to external documents like Material Passports, EPDs, warranties, manuals, or stakeholder information.
Required Disassembly Tools	Lists the specific tools or equipment necessary for the safe and efficient disassembly of a component.
Return Guarantee by Manufacturers	Guarantee from the original manufacturer of a component to take back the product at the end of its initial service life for reuse, refurbishment, or recycling.
Reusability Score	This property provides a calculated score or rating that quantifies a component's potential for being reused. Such a score offers an objective measure of circularity potential, allowing stakeholders to quickly assess and compare different components.
Reuse Obligation Status	Indicates if there is a formal obligation for parties to provide and maintain reuse data.
Specialized Knowledge Needed	Description of specialized skills required (e.g., for complex connections).
Step-by-Step Guide Link	Link to detailed step-by-step disassembly guide.
Storage Requirements	This property specifies the precise conditions and environmental parameters necessary for storing a component after its removal from the building to maintain its quality, integrity, and suitability

	for future reuse. This goes beyond general handling and addresses long-term preservation. Examples include requirements for a dry, sheltered environment to prevent corrosion or moisture damage, protection from direct sunlight to avoid material degradation (e.g., UV exposure for plastics or wood), specific temperature and humidity ranges, or proper ventilation to prevent mold or rot.
Strategy Description	This property gives a description of the design strategy for separating different functional layers that are combined within a single, composite building element. While element layers are often modeled as separate elements, this property is specifically for components where multiple layers (e.g., structure, insulation, and finish) are modeled as one object.
Strength Class	The characteristic compressive/tensile strength class of the material.
Thermal Transmittance	Thermal transmittance coefficient (U-Value) of an element, within the direction of the thermal flow.
Total Reuse Count	The total number of reuses (or cycles) for which a product is designed.
Transport Method	Recommended transport method (e.g., Flatbed Truck, Lowboy Trailer).
Type of Cement	The specific type of cement used in the material (e.g., CEM III/B 42.5 N).
Ultimate Stress	A measure of the ultimate stress (Tensile Strength) of the material.
Unique Component ID	A unique identifier (e.g., QR code, RFID tag, GUID) physically linked to the element and/or in the BIM model enabling traceability and lifecycle tracking.
Yield Strength	This quantitative mechanical property defines a material's resistance to permanent deformation (yield strength) under tension. It provides the precise numerical values (e.g., 355 N/mm²) that underpin a material's quality/grade, essential for detailed structural calculations, re-engineering, and verifying a component's capacity for reuse in load-bearing scenarios.

Following the presentation of the property definitions, Table 7 presents the Consolidated & Final Property List. This list contains the properties as defined in the previous table and represents the definitive set of properties required to support circular workflows for structural elements. The list was created through a systematic process that merged insights from both the literature review and expert interviews. Four key steps were taken to transform the initial raw list into a structured, coherent, and practical set of information requirements.

1. Merging Similar Concepts for a Unified Definition

A primary step was to identify and merge properties from both the literature and interviews that described the same concept, often using slightly different terminology. This prevented redundancy and created a single, more robust definition for each key piece of information.

- Example: Disassembly Effort. The literature identified Disassembly Time/Effort, while experts discussed Disassembly Labor/Effort data. These were consolidated into a single, more comprehensive property set named Disassembly Effort. This final set not only captures the core idea but was also enriched with more specific sub-properties

suggested by experts, such as a Disassembly Score, making the concept more measurable and practical for project planning.

- Example: Condition Assessment. The literature provided separate properties like Condition Assessment, Corrosion Level, and Deformation. Experts discussed similar ideas under Physical State Assessment and Visual Damage Assessment. These were all combined into a single, structured property set: Physical Condition Assessment. This new set uses standardized fields like Assessment Condition, Assessment Description, and Assessment Method to capture this information in a consistent way, which is far more useful for data management than having multiple, overlapping properties.

3. Establishing a Hierarchical Structure with Property Sets

A key outcome of the consolidation process was the organization of properties into a logical hierarchy using property sets. Instead of a flat list, related properties were grouped under a relevant property set. This structure is highly beneficial for several reasons:

- Organization: It logically groups related information, making the data easier to understand and manage.
- Alignment with BIM Standards: This structure aligns well with IFC standards, which use property sets to attach information to building objects.
- Scalability: It allows for new properties to be added to an existing set in the future without disrupting the overall structure.

For instance, all information related to a component's history, such as Product History from the literature and Usage History from interviews, was grouped under the Lifecycle History property set. It should be noted that the use of property sets was a deliberate choice for structuring complex information, and therefore not all properties were categorized this way. This hierarchical structure was primarily applied to refine broader concepts into a group of specific, actionable properties. Many properties that were already clear and specific remain as standalone entities.

4. Incorporating Novel, Practice-Based Properties

A key outcome was the identification of several ~~novel~~ properties that were not previously documented in the reviewed academic literature. The expert interviews proved invaluable in capturing forward-looking, practical concepts that address the strategic, economic, and legal dimensions of circularity. Examples of these new, practice-based properties include:

- Return Guarantee by Manufacturers;
- Actual (vs. Theoretical) Deflection Data;
- Predetermined Cut Lines;
- Hoisting Provision Locations;
- Post-Demolition Destination Readiness.

Before reviewing Table 7 (Consolidated & Final Property List), it is important to understand its structure. The table presents both property sets with their corresponding properties, as well as individual properties that do not belong to any property set. When an property is not part of a property set, the property set column is marked with a '–'. Most property sets consist of

multiple properties, which are listed underneath each other in the table. For each property, the source is indicated, showing whether it originated from the literature review, the expert interviews, or both.

Table 7 - Consolidated & Final Property List

Category	Suggested Property Set	Property Set Definition	Property	Property Source
Origin and Identification Properties				
	Lifecycle History	Information about the component's previous life cycles, including its uses, locations, exposure conditions, and any changes in loading history or function.	• Previous use Type • Previous location • Exposure class	Expert + Literature
	Manufacturer details	Name, contact information, and other relevant details of the original manufacturer of the component or material.	• Manufacturer • Manufacturer Contact Information	Literature
	Material composition	A detailed breakdown of all materials and substances, including any additives, used in a product or composite. For concrete, this includes specific types of cement, aggregates, water, and chemical admixtures and their proportions. This information is essential for recycling, health assessments, and understanding the material's inherent nature. Furthermore, for future reuse, this data allows for the identification of potentially hazardous materials that might have been permissible during original production but are now restricted or considered harmful, enabling informed decisions on safe handling or disposal.	• Type of cement • Admixture description • Composition proportions	Expert + Literature
	Original Design Data	Comprehensive information from the initial design and manufacturing of a component, including its specific standard (e.g., NEN-EN 13670:2009 for concrete) to which it inherently adheres, including its year of publication. This also details calculations and the specific design choices made by the designer. This data is crucial because knowing the exact standard, its publication year, and the material's grade allows engineers to verify compliance with historical building codes and material properties, defining the component's inherent characteristics and how it was originally created. This ensures it meets established regulations and can be efficiently assessed for potential reuse without extensive re-testing.	• Applied Standard • Design Choices • Design Calculations Link	Expert + Literature
	-	-	Certification Requirement	Literature
	-	-	Component Age	Expert + Literature
	-	-	Location Data (for local sourcing)	Expert + Literature
	-	-	Material Type	Expert + Literature
	-	-	Ownership	Literature

	-	-	Unique Component ID	Expert + Literature
Technical & Structural Properties				
	Material Quality	The specific quality, strength class, or grade of the material (e.g., C45/55 for concrete, S355JR for steel, C24 for timber) that defines its mechanical properties and structural performance. This also encompasses other key performance indicators such as its overall heat transfer coefficient (U-value) for thermal insulation properties, acoustic performance characteristics (e.g., sound reduction index).	• Strength Class • Thermal Transmittance • Acoustic Rating	Expert + Literature
	Reinforcement Geometry	Precise details on the location, diameter, and arrangement of reinforcement bars within concrete elements, essential for structural assessment and potential modifications. Clear and precise geometry is vital for assessing reuse potential, determining how a component fits into new designs, and understanding if it requires modifications like cutting. Modelled geometry is optimal for this purpose.	• Rebar Layout Diagram Link • Rebar Type	Expert + Literature
	-	-	Fire Resistance Rating	Expert + Literature
	-		Geometric Tolerances	Expert + Literature
	-	-	Hazardous Material	Expert + Literature
	-	-	Load-Bearing Status	Literature
	-	-	Net Weight	Literature
	-	-	Prefabrication Status	Literature
	-	-	Presence of Openings	Expert
	-	-	Proven Strength Data	Expert + Literature
	-	-	Ultimate Stress	Literature
	-	-	Yield Strength	Literature
Condition & Lifecycle Data Properties				
	As-built Deviation Data	Explicitly documents any observed differences between planned design specifications and actual constructed conditions (which may include deviations if exceeding original manufacturing characteristics or acceptable tolerances). This includes variations that might exceed original manufacturing characteristics or acceptable tolerances (e.g. pre-fabricated concrete beam designed for 6.00 meters is actually installed at 6.02 meters). This data is crucial for assessing a component's precise characteristics for potential reuse.	• Has Deviation • Deviation Description	Expert + Literature
	Lifecycle Maintenance	A comprehensive log of all maintenance, repair, and refurbishment activities, alongside detailed records of quality checks, inspections, and formal assurance processes performed on the component throughout its entire lifecycle. This property provides a verifiable history of the component's	• Maintenance Log • Quality Check Reports • Last Maintenance Date	Expert

		upkeep and its adherence to specified quality requirements and standards over time.		
	Physical Condition Assessment	This property provides a comprehensive, overall evaluation of a component's current physical condition. It is primarily based on visual inspections, noting observable signs of damage or deterioration such as cracks, spalling (flaking concrete), and the degree of corrosion present on material surfaces. The assessment quantifies the extent of any physical bending, warping, or other geometric distortions (deformation) in the component. This property may also encompass the results of a formal condition assessment adhering to recognized standards (e.g., NEN 2767), providing a systematic quantification of defects. This evaluation is crucial for determining a component's remaining lifespan, current value, and overall suitability for reuse.	• Assessment Date • Assessment Condition • Assessment Description • Assessment Method	Expert + Literature
	-	-	Actual (vs. Theoretical) Deflection Data	Expert
	-	-	Current Reuse Count	Literature
	-	-	Design Life	Expert + Literature
	-	-	Economic Life	Expert + Literature
	-	-	Fire Exposure	Literature
	-	-	Material Certificates	Literature
	-	-	Total Reuse Count	Literature
Deconstruction & Disassembly Properties				
	Disassembly Effort	This property provides a quantifiable estimation of the effort required to dismantle a specific component from a structure. This can be expressed through time-based metrics (e.g., in hours per unit or per square meter), human labor (e.g., person-hours), or a comparative score. For example, a score from 1 (very low effort, easily demountable) to 10 (very high effort, complex and labor-intensive disassembly) can provide a quick assessment. This data is crucial for project planning and economic assessment in circular construction, as high effort can make a component economically unviable for reuse.	• Disassembly Score	Expert + Literature
	Disassembly Instructions	Provides specific instructions or data on how a component can be safely and efficiently detached or separated from the structure. This includes information about specialized knowledge or equipment required for disassembly.	• Step-by-Step Guide Link • Specialized Knowledge Needed	Expert + Literature
	Disassembly Method	Suggests the optimal overarching strategy or technique for removing the component to minimize damage, preserve its reusability, or achieve specific end-of-life goals. Examples include non-destructive disassembly (prioritizing intact component recovery), controlled demolition (for materials that will be recycled), or	• Preferred Method • Is Non-Destructive	Expert + Literature

		specific lifting techniques like crane removal.		
	Layer Decoupling Strategy	This property documents the design strategy for separating different functional layers that are combined within a single, composite building element. While element layers are often modeled as separate elements, this property is specifically for components where multiple layers (e.g., structure, insulation, and finish) are modeled as one object. This approach enables easier selective deconstruction, allowing individual layers or components to be removed independently and non-destructively.	• Strategy Description • Decoupling Ease Score	Expert
	Post-Demolition Handling Instructions	This property provides specific, actionable guidelines or requirements for the safe handling, lifting, and initial transportation of a component immediately after its removal from the structure. These instructions are crucial to prevent damage to the component during its transfer from the demolition site to either a temporary storage area or its next destination.	• Handling Guidelines • Transport Method	Expert
	-	-	Connection Accessibility	Expert + Literature
	-	-	Connection Type	Expert + Literature
	-	-	Contribution to Overall Stability	Expert
	-	-	Disassembly Sequence	Expert + Literature
	-	-	Embedded Services Information	Expert
	-	-	Hoisting Provision Locations	Expert
	-	-	Hosted Components	Literature
	-	-	Personnel Requirement	Literature
	-	-	Physical Constraints	Literature
	-	-	Predetermined Cut Lines	Expert
	-	-	Required Disassembly Tools	Expert
	-	-	Storage Requirements	Expert + Literature
Circularity Strategy & Impact Properties				
	Legal Requirement	Legal requirements is a circular requirement that refers to the regulations, rules, and/or design and implementation standards that govern the treatment, handling, and reuse of components. By including legal requirements as part of the information models, stakeholders can ensure that the necessary legal considerations are observed.	• Guarantee Status for Reuse • Reuse Obligation Status	Expert
	-	-	Circular Potential	Literature
	-	-	Data Archiving Format	Expert
	-	-	Economic Data	Literature
	-	-	Environmental Impact	Literature
	-	-	Model Maintenance Plan Link	Expert
	-	-	Modularity Degree	Expert
	-	-	Owner-Managed Model Link	Expert

-	-	Post-Demolition Destination Readiness	Expert
-	-	Reference Documentation	Literature
-	-	Return Guarantee by Manufacturers	Expert
-	-	Reusability Score	Literature

Note: If properties are grouped together, they are represented under a property set. Otherwise, the properties are presented individually.

4.3.1 In-depth Analysis of Key Circular Properties: Insights for Future Practice and bSDD Extension

Some property sets and individual properties need further explanation beyond their definition to fully demonstrate their practical use and significance. Therefore, this section provides a more in-depth explanation of a few specific property sets and individual properties. These specific properties and property sets were chosen based on two criteria:

1. Novelty: Properties identified through expert interviews that are not yet widely established in academic literature or standards (e.g., Return Guarantee by Manufacturers).
2. Complexity: Properties whose simple definition does not fully capture their practical role or impact on workflows (e.g., As-built Deviation Data).

For each selected property and property set, a practical reuse scenario is used to illustrate its real-world value. Furthermore, for some properties and property sets, this section will explore how these ideas can help improve future practices and suggest extensions to digital frameworks, particularly the DOR bSDD. The detailed definitions for the properties are not repeated in this section, as they are already presented in Table 6. Instead, the focus is on using practical examples to better explain the practical importance of each property or property set. The following property sets and properties are selected for further explanation and illustration:

- Material Composition (Property Set)
- Original Design Data (Property Set)
- Lifecycle History (Property Set)
- As-built Deviation Data (Property Set)
- Physical Condition Assessment (Property Set)
- Location Data (Property)
- Connection Accessibility (Property)
- Predetermined Cut Lines (Property)
- Return Guarantee by Manufacturers (Property)

Material Composition

One expert (ID3) emphasized the importance of knowing "what was in it" if one is going to modify or reuse a building component, as it may contain hazardous materials that were permissible during original production, but are now restricted or considered harmful. "Asbestos is the best example... you want to know what was inside it" (ID3). When an element

gets decommissioned, enabling informed decisions on safe handling or disposal. This detailed breakdown of composition extends beyond typical material type information in current standards. While the DOR bSDD already includes Material Source with a Hazardous Material property (which indicates the type of hazardous material), Material Composition provides a more comprehensive breakdown of all substances present in an element.

Practical Insight and Reuse Scenario:
In the future, a building is decommissioned, and its material composition information is added to the model.

- Scenario A (Poor Data): A deconstruction company is processing concrete rubble from a 30-year-old building to be used as recycled aggregate. The records only indicate "Concrete." During crushing, dust is created. Without knowing the exact Material Composition, the company is unaware that the concrete mix contained specific additives that are now considered harmful when airborne. This exposes workers to health risks and violates modern safety regulations. Furthermore, the resulting aggregate is considered "of unknown origin" and can only be used in low-grade applications like road fill, significantly reducing its economic value.
- Scenario B (Rich Data): The BIM model for the building has a complete Material Composition property set. It details the Type of cement, the specific Admixture Description, and confirms the absence of any hazardous materials according to today's standards. The deconstruction company can implement the correct safety procedures for handling the material. Knowing the exact composition, a recycling facility can confidently process the rubble into certified aggregate for use in new structural concrete. This not only protects worker health, but also enables a recycling pathway.

Original Design Data
One expert (ID2) emphasized that "Everything from production must be added: calculations, standards, stability systems, design choices etc." Another expert (ID6) further highlighted the need for all design parameters to be in the model to make it reusable, noting that knowing the original design assumptions is vital for future evaluations. This information is crucial because details such as the exact applied design standard, its publication year, and the material's grade allows engineers to verify compliance with historical building codes and material properties.

Practical Insight and Reuse Scenario:
Decades after construction, a building is decommissioned, and its prefabricated concrete floor slabs are evaluated for reuse.

- Scenario A (Poor Data): The only available record describes the slabs as “precast concrete, 200 mm thick” with no reference to their original design standard, reinforcement layout, or load calculations. A contractor interested in reusing them for a residential building must commission core drilling, reinforcement scanning, and lab testing to establish strength and durability. This process is costly, time-consuming, and carries a risk of damaging otherwise reusable slabs.
- Scenario B (Rich Data): The BIM model contains full Original Design Data for the slabs, including the *Applied Standard*, the *Design Choices* outlining maximum span, live load

assumptions, and reinforcement layout, and a *Design Calculation Link* to the original structural files. Engineers can instantly verify that the slabs meet current performance requirements for the intended new building. This eliminates costly testing, enables rapid certification, and allows the slabs to be directly integrated into the new structure.

Lifecycle History

One expert (ID1) highlighted that "Any change in the building's function should be recorded, as this implies a change in the loading history of the components". Expert ID4 further stressed the importance of Load History, especially for fatigue loading in elements like those used in bridges. One expert (ID2) emphasized the need for linking element history across projects (potentially via IFC or Blockchain) to track a reused element's journey.

Practical Insight and Reuse Scenario:

It's 2075, and an engineer is assessing a steel beam for reuse.

- Scenario A (Poor Data): The digital records are incomplete and only show the beam's most recent location in an office building. Unknown to the engineer, this beam actually spent its first 20 years as part of a bridge, where it experienced constant vibrations and heavy stress (fatigue loading). Based on the incomplete data, the engineer assumes the beam has had an easy life and approves it for a structurally important role in a new building. This creates a serious safety risk, as the beam is more fatigued and weaker than its records suggest.
- Scenario B (Rich Data): This time, the BIM model has a complete Lifecycle History. The engineer can clearly see the beam's entire journey: its time on the bridge from 2025-2045, the type of loads it endured, and its subsequent use in the office building. With this rich data, the engineer can accurately calculate the beam's remaining strength. They can now make a safe decision, either by assigning it to a less demanding role or by correctly identifying that it is no longer suitable for structural use.

Contribution to DOR bSDD: While the DOR bSDD includes Exposure Requirement, which broadly covers historical environmental conditions and necessary future storage conditions for preservation, Lifecycle History is maintained as a distinct property. It provides a broader, comprehensive log of a component's entire past journey, extending beyond just environmental exposure to encompass uses and functional changes.

Location Data

This property refers to geographic information indicating a component's origin or current placement. It is important to clarify that Location Data is not solely about local sourcing of raw materials, but also about the local sourcing of building elements for reuse. Ideally, when designing and constructing a new building, this property would enable stakeholders to identify and utilize suitable existing elements that become available from deconstructed nearby buildings. This would enable a more dynamic reuse market for entire components.

Practical Insight and Reuse Scenario:

Location Data transforms a BIM model from being just a design for a single building into a potential entry in a regional "material bank," enabling architects and contractors to design with locally available resources.

- Scenario A (Poor Data): An architect wants to find reclaimed steel columns for a new project to achieve sustainability goals. They search online marketplaces and find suitable columns, but the supplier is 300 kilometers away. The high costs and CO2 emissions from transport make it cheaper and easier to just buy new steel locally. The circular ambition is defeated by logistical inefficiency.
- Scenario B (Rich Data): The architect uses a digital platform that uses data from buildings scheduled for deconstruction. Using the Location Data property, they can filter for available structural components within a 50-kilometer radius. The platform identifies an old warehouse being dismantled just 10 kilometers from their project site, which contains the exact columns they need. The transport is cheap and quick, making the reuse of the beams a success.

As-built Deviation Data

This property explicitly documents any observed differences between planned design specifications and actual constructed conditions, including variations that might exceed original manufacturing characteristics or acceptable tolerances.

Practical Insight and Reuse Scenario:

An engineer plans to reuse a concrete beam.

- Scenario A (Poor Data): The original BIM model shows the beam is exactly 8.00 meters long. Based on this data, they design and fabricate new steel connections. However, when the beam is removed from the old building, it measures 8.02 meters long because of an undocumented adjustment made during the original construction. The new connections do not fit, causing expensive delays and rework on the new project site.
- Scenario B (Rich Data): The engineer checks the BIM model and finds the As-built Deviation Data property. The As-built Deviation Flag is set to "TRUE" and the description says: "Actual length is 8.02m." Knowing the real dimensions from the start, the engineer designs the connections correctly. The reuse process is smooth and efficient because it was based on reliable data that reflected the physical reality.

How the bSDD can be improved: The bSDD could define a standard property set to handle this common issue in a consistent way. A new property set, for example, Pset_AsBuiltVerification, could be created to structure this information. This set could include standard properties (as shown in Table 7*)* such as:

- Has Deviation: A True/False value to easily filter for components with known differences;
- Deviation Description: A text field to explain the difference.

Physical Condition Assessment

This property provides a comprehensive, overall evaluation of a component's current physical condition. It is primarily based on visual inspections, noting observable signs of damage or deterioration such as cracks, spalling, corrosion, and the degree of physical bending or warping. For the physical state of a component, the IFC schema provides a standardized property set: Pset_Condition. This Pset is designed to store the results of a formal condition assessment and can effectively serve as a container for several of the specific aspects identified for Physical Condition Assessment. The various properties within the Pset_Condition Property Set, as detailed in the IFC documentation (adapted from buildingSMART), directly support this as seen in Table 8.

Table 8 - Pset_Condition Property Set

Name	Description
AssessmentDate	Date on which the overall condition is assessed.
AssessmentCondition	The overall condition of a product based on an assessment of the contributions to the overall condition made by the various criteria considered. For instance, overall condition measured on a scale of 1 - 10 or by assigning names such as Good, OK, Poor.
AssessmentDescription	Qualitative description of the condition.
AssessmentType	Category of latest condition assessment report of the asset.
AssessmentMethod	External reference to assessment method or application used to perform the Assessment.
LastAssessmentReport	Reference to latest condition (state of health) report.
NextAssessmentDate	Date of next condition inspection.
AssessmentFrequency	Indicates how often the equipment should be assessed, to have a clear estimation on its working state, based on which the maintenance staff can decide whether it requires maintenance or requires to be updated or replaced.

Connection Accessibility

This property indicates the ease with which a component's connections can be physically reached and manipulated for various purposes, including inspection, maintenance, or disassembly.

Practical Insight and Reuse Scenario:

A deconstruction team plans to remove a steel beam connected with bolts.

- Scenario A (Poor Data): On site, they discover the bolts are hidden behind a permanent plaster wall. They must spend extra time and money demolishing the wall just to access the connection, which also creates unnecessary waste.
- Scenario B (Rich Data): The BIM model contains the Connection Accessibility property, which states: "Concealed - requires removal of access panel." The team arrives knowing exactly what to do. They can quickly remove the panel, access the bolts, and efficiently remove the beam. The process is predictable and cost-effective because the accessibility was documented.

Property in the bSDD: The need for this property is already recognized within the 'Circularity' bSDD. Specifically, a custom property for Accessibility to Connection (ATC) exists within the custom property set Pset_CircularityPerComponent.

Predetermined Cut Lines

These are specific lines or areas pre-planned in the design of a building part where controlled cuts can be made. One expert (ID4) explicitly stated, "If it has to be cut somewhere, it would be good to know where. Maybe already in the design process. Some predetermined cut lines could be included".

Practical Insight and Reuse Scenario:

A deconstruction team needs to remove a large concrete floor.

- Scenario A (Poor Data): Without any guidance, they make random cuts, accidentally hitting major steel reinforcement and creating oddly shaped pieces. The damaged, irregular sections cannot be reused.
- Scenario B (Rich Data): The building's BIM model includes data for Predetermined Cut Lines on the same concrete floor. These lines are strategically placed to avoid reinforcement and to create several standardized 2m x 4m panels. The deconstruction team follows these digital guides, making precise cuts. The cut concrete panels can be directly reused in a new project.

How the bSDD can be improved/extended: In the bSDD, a new property set, for example Pset_Deconstruction, could be created to structure this information. This set could include:

- HasCutLines: A True/False value to quickly identify elements with this feature.
- CutLineDescription: A reference to the geometric data in the model that shows the exact cutting path.

Return Guarantee by Manufacturers

This property documents whether a guarantee from the original manufacturer exists, obligating them to take back a component at the end of its initial service life for reuse, refurbishment, or recycling. One expert (ID9) mentioned this as an interesting concept where producers would take back their goods, incentivizing them to track their products ("Because then they suddenly want to know what they are picking up again, because then they want to sell it again").

Practical Insight and Reuse Scenario:

A project developer is selecting facade elements for a new office building designed to be adaptable for 50 years or more.

- Scenario A (Poor Data): The developer chooses a standard facade product. The manufacturer has no long-term responsibility for the product after it is sold. There is little incentive for them to provide detailed data for reuse or to design the product for easy disassembly. At the end of its life, the facade is likely to become demolition waste.
- Scenario B (Rich Data): The developer chooses a facade from a manufacturer that offers a Return Guarantee. This agreement is recorded in the BIM model. Because the manufacturer is contractually obligated to take the product back, they are now motivated

to design it for durability and easy disassembly. They provide a high-quality BIM object complete with detailed data on materials and disassembly instructions, as this data helps them recover a valuable asset in the future.

Potential for bSDD Extension: This represents a new category of information that is not well-represented in current technical data dictionaries. A new property set like Pset_CircularAgreement could be proposed and defined within the bSDD. It could include:

- ReturnGuaranteeStatus: A True/False value.
- ReturnDescription: According to contract X, the manufacturer provides a return guarantee for the element after its first service life. The buy-back value is ...% of the original purchase price, contingent upon a formal condition assessment. For complete details, please refer to contract X.

4.4 Structured Exchange Information Requirements (EIR)

This phase translates the Consolidated & Final Property List into a structured EIR table. The purpose of this step is to transform the final list of properties into a set of requirements in the form of a table that can be directly applied to BIM objects. For clarity in presentation, the EIR is demonstrated using the IfcSlab (Concrete Floor) as the representative element, as it accommodates the full range of identified properties. Table 9 presents the final structured EIR for the IfcSlab used in this research.

Table 9 - Exchange Information Requirement Table for IfcSlab

Prerequisites			Level Of Information Need (LOIN): Geometrical -, Alphanumerical Information & Documentation (HOW)							
Purpose (WHY)	**Actor (WHO)**	**Milestone (WHEN)**	**Property Category**	**Property Set**	**Property**	**Case Study Example (Value)**	**Value Type**	**LOIN Dimension**	**IFC Mapping / Reference**	**Property Source (URI)**
Origin and Identification Properties										
Track and Trace (Orgin and Identification for Reuse)	BIM Coordinator	Design Phase			Unique Component ID	This is covered by the IFC IfcRoot.GlobalId. An example value would be "a1b2c3d4-e5f6-7890-1234-567890abcdef"	Text (GUID)	Alphanumeric al	IfcRoot.GlobalId	Standard IFC Property
Identify Material (Orgin and Identification for Reuse)	Designer	As-Built Phase			Material Type	Main material type of the floor is concrete, so the value would be "Concrete"	Text (Enum)	Alphanumeric al	IfcSlab → IfcRelAssociatesMaterial → IfcMaterial	Standard IFC Property
Asses Reuse Potential (Orgin and Identification for Reuse)	Concrete Supplier	As-Built Phase		Material Composition	*Type of cement*	The type of cement used is "CEM III"	Text (Enum)	Alphanumeric al	IfcSlab→ IfcMaterial → Pset_MaterialComposition (Custom Property Set) → CementType	ETIM bSDD: https://identifier.buildingsmart.org/uri/etim/etim/10.0/prop/EF010438
Health and Safety (Orgin and Identification for Reuse)	Concrete Supplier	As-Built Phase			*Admixture Description*	"Polycarboxylate ether based superplasticizer added to improve workability and lower the water-cement ratio."	Text	Alphanumeric al	IfcSlab → IfcMaterial → Pset_MaterialConcrete (IFC Pset) / Pset_MaterialComposition (Custom Property Set) → Admixtures Description	Standard IFC Property
Material Assessment (Orgin and Identification for Reuse)	Concrete Supplier	As-Built Phase			*Composition Proportions*	"Portland cement (CEM I): 350 kg/m³, Sand (0-4mm): 750 kg/m³, Gravel (4-16mm): 1100 kg/m³, Water: 150 L/m³."	Text	Alphanumeric al	IfcSlab→ IfcMaterial → Pset_MaterialComposition (Custom Property Set) → Composition Proportions (Custom Property)	Custom Property
Quality Control (Orgin and Identification for Reuse)	General Contractor	Construction Phase		Manufacturer Details	*Manufacturer*	Manufacturer of this element is "Heijmans"	Text	Alphanumeric al	IfcSlab → IfcRelAssignsToProduct → IfcActor → IfcOrganization → Pset_ManufacturerTypeInformation (Property Set) → Manufacturer	Standard IFC Property
Quality Control (Orgin and Identification for Reuse)	General Contractor	As-Built Phase			*Manufacturer Contact Information*	"Email: info@heijmans.nl"	Text	Alphanumeric al	IfcSlab → IfcRelAssignsToProduct → IfcActor → IfcOrganization → Pset_ManufacturerTypeInformation (Property Set)→ Manufacturer (here also add contact info of the manufactere) Or use a custom property: IfcPropertySet (custom) → Custom Property	Custom Property
Condition Assessment (Orgin and Identification for Reuse)	Asset Manager	Operational Phase			First Installation Date	First installation of element X on "01-02-2026".	Text (Date)	Alphanumeric al	IfcSlab → IfcRelDefinesByProperties → Pset_InstallationOccurrence (Custom Property Set)→ Component Age (Custom Property)	Custom Property
Assess Reuse Potential (Orgin and Identification for Reuse)	Circularity Specialist	As-Built Phase		Lifecycle History	*Previous Use Type*	"Used as a floor in a previous residential building."	Text	Alphanumeric al	IfcSlab → Pset_LifeCyleHistory (Custom Property Set) → PreviousUseType (Custom Property)	Custom Property
Traceability (Orgin and Identification for Reuse)	Circularity Specialist	As-Built Phase			*Previous Location*	Previous building location: "Eindhoven, NL0452"	Text	Alphanumeric al	IfcSlab → Pset_LifeCyleHistory (Custom Property Set) → PreviousLocation (Custom Property)	Custom Property
Condition Assessment (Orgin and Identification for Reuse)	Circularity Specialist	Operational Phase			*Exposure Class*	For a concrete element on an exterior facade, the value would be "Exterior_Exposed" or "XC3"	Text (Enum)	Alphanumeric al	IfcBuiltElement → IfcSlab → Pset_ConcreteElementGeneral (IFC Pset) / Pset_LifeCyleHistory (Custom Property Set) → ExposureClass	Standard IFC Property
Resource Sourcing (Orgin and Identification for Reuse)	Circularity Specialist	Operational Phase			Location Data (for local sourcing)	Current building location: 's-Hertogenbosch, The Netherlands". Alternatively, more precise coordinates could be used, such as "51.6983° N, 5.3052° E"	Text	Alphanumeric al	IfcSlab → IfcRelDefinesByProperties → Pset_CircularRequirement (Custom Property Set) → LocationData	Custom Property
Re-certify Component (Orgin and Identification for Reuse)	Structural Engineer	As-Built Phase		Original Design Data	*Applied Standard*	"The standard governing concrete works is "ISO123, 2025"	Text	Alphanumeric al	IfcSlab → Pset_OriginalDesignData (Custom Property Set) → AppliedStandard (Custom Property)	Custom Property
Disassembly Planning (Orgin and Identification for Reuse)	Designer	Design Phase			*Design Choices*	"The choice was made to use a bolted connection between the steel beam and the concrete slab to enable easy disassembly and reuse, rather than a welded connection, which would require destructive removal."	Text	Alphanumeric al	IfcSlab → Pset_OriginalDesignData (Custom Property Set) → DesignChoices (Custom Property)	Custom Property
Structural Re-evaluation (Orgin and Identification for Reuse)	Structural Engineer	Design Phase			*Design Calculations Link*	The calculations Link for this element is: "https://projectdocs.com/structural-calcs.pdf" or the calculation code link is "CALC-001".	Text	Documentatio n	IfcSlab → IfcRelAssociatesDocument → IfcDocumentReference OR IfcSlab → Pset_OriginalDesignData (Custom Property Set) → DesignCalculationsLink (Custom Property)	Custom Property
Asses Reuse Potential (Orgin and Identification for Reuse)	Circularity Specialist	As-Built Phase			Certification Requirement	In the context of CE the "ISO 0100xx" certification is required for this floor.	Text	Alphanumeric al	IfcSlab → IfcRelDefinesByProperties → Pset_OriginalDesignData (Custom Property Set)/ Pset_CircularRequirement (DOR bSDD Pset) → CertificationRequirement	DOR bSDD: https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2/prop/CertificationRequirement
Legal Responsibility (Orgin and Identification for Reuse)	Asset Manager	As-Built Phase			Ownership	For the case study, the current owner is "Willemspoort Owner".	Text	Alphanumeric al	IfcSlab → Pset_Ownership (Custom Property Set) → Ownership (Custom Property) Also possible in IFC (not very practical): IfcOrganization (the owner) → is assigned the role of IfcOccupant → which is then linked to the IfcSlab → using an IfcRelAssignsToActor relationship.	Custom Property

			Technical & Structural Properties							
Ensure Design Compliance & Safety (Technical & Structural)	Designer	Design Phase			Geometric Tolerances	The permissable value from the ideal dimensions of this floor is "3mm"	Decimal (mm)	Geometrical	IfcSlab → Pset_ConcreteElementGeneral or custom property set → GeometricTolerances	Custom Property
Structural Re-evaluation (Technical & Structural)	Structural Engineer	As-Built Phase		Reinforcement Geometry	*Rebar Layout Diagram*	Link to the Rebar Layout Diagram: "https://LinkToRebarLayout.pdf" Or The Rebar Layout Diagram code is "RYD01", corresponding to specific type op rebar layout diagram (document)	URL	Documentation	IfcSlab → IfcRelAssociatesDocument → IfcDocumentReference Or IfcSlab → Pset_ReinforcementGeometry (Custom Property Set) → RebarLayoutDiagram (Custom Property)	Custom Property
Structural Re-evaluation (Technical & Structural)	Structural Engineer	As-Built Phase			*Rebar Type*	The Rebar Type of the Reinforcement Geometry is "B500B, Ribbed".	Text (Enum)	Alphanumerical	IfcSlab → Pset_ReinforcementGeometry (Custom Property Set) → RebarType Also possible in IFC (every rebar needs to be modeled): IfcSlab → IfcReinforcingBar → IfcReinforcingBarType	Custom Property
Structural Re-evaluation (Technical & Structural)	Structural Engineer	As-Built Phase			Presence of Openings	"The concrete floor contains an opening of 100mm x 100mm. This opening was drilled a ventilation shaft to pass through." Or Type of opening: "unintentional"	Text (Enum)	Alphanumerical	IfcSlab → CustomPset → PresenceOfOpening	Custom Property
Establish Component Identity & Properties (Technical & Structural)	Structural Engineer	Design Phase		Material Quality	*Strength Class*	The concrete strength class of this slab is "C45/55".	Text (Enum)	Alphanumerical	IfcSlab → IfcRelAssociatesMaterial → IfcMaterial → Pset_MaterialConcrete → StrengthClass Or Custom Property	Standard IFC Property
Assess Component Condition & Performance (Technical & Structural)	Designer	Design Phase			*Thermal Transmittance*	The U-value of the concrete floor is "1.1".	Decimal	Alphanumerical	IfcSlab → IfcSlabCommon → ThermalTransmittance Or (example use of bSDD) IfcSlab → ThermalPerformance (Custom Property Set) → EF010083 (Thermal transmittance value (U)) (ETIM bSDD Property)	Standard IFC Property
Assess Component Condition & Performance (Technical & Structural)	Designer	Design Phase			*Acoustic Rating*	The value could be "50dB" for the sound reduction index.	Decimal	Alphanumerical	IfcSlab → Pset_SlabCommon → AcousticRating	Standard IFC Property
Assess Component Condition & Performance (Technical & Structural)	Structural Engineer	Operational Phase			Proven Strength Data	"After 50 years of carrying a continuous static load, the Proven Strength is set at 550 kg/m²" Or The link to a document containing the verified load is "https://Wall123-LoadTest_2023.pdf".	Text	Alphanumerical	IfcSlab → Pset_TechnicalProperties (Custom Property Set) → ProvenStrengthData (Custom Property) Or IfcBuiltElement → IfcRelAssociatesDocument → IfcDocumentReference	Custom Property
Ensure Design Compliance & Safety (Technical & Structural)	Fire Safety Engineer	Design Phase			Fire Rating	The fire resistance rating for this element is "120" minutes.	Integer	Alphanumerical	IfcSlab → Pset_SlabCommon → FireRating	Standard IFC Property
Plan Deconstruction & Logistics (Deconstruction & Disassembly)	General Contractor	As-Built Phase			Net Weight	The net weight of this element is "166.80" kg.	Decimal	Alphanumerical	IfcSlab → Qto_SlabBaseQuantities → NetWeight	Standard IFC Property
Structural Re-evaluation (Technical & Structural)	Structural Engineer	As-Built Phase			Yield Stress	The yield strength of this slab is "355 N/mm²".	Decimal (IfcPressureMeasure)	Alphanumerical	IfcSlab → Pset_TechnicalProperties (Custom Property Set) → Yieldstress (Custom Property) Or map it to reinforcement Bar of the slab (has to be modeled: IfcSlab → (contains) IfcReinforcingBar → IfcMaterial → Pset_MaterialSteel → YieldStress Or in Ifc for steel materials: IfcSlab → IfcMaterial → Pset_MaterialSteel → YieldStress	Custom Property / Existing in IFC
Structural Re-evaluation (Technical & Structural)	Structural Engineer	As-Built Phase			Ultimate Stress	The tensile strength of the steel in the slab is "470 N/mm²".	Decimal (IfcPressureMeasure)	Alphanumerical	IfcSlab → Pset_TechnicalProperties (Custom Property Set) → UltimateStress (Custom Property) Or map it to reinforcement Bar of the slab (has to be modeled: IfcSlab → (contains) IfcReinforcingBar → IfcMaterial → Pset_MaterialSteel → UltimateStress Or in Ifc for steel materials: IfcSlab → IfcMaterial → Pset_MaterialSteel → UltimateStress	Custom Property / Existing in IFC
Establish Component Identity & Properties (Technical & Structural)	Designer	Design Phase			Load-Bearing	This element is part of the primary load-bearing structure, so the value is "TRUE".	Boolean	Alphanumerical	IfcSlab → Pset_SlabCommon → LoadBearing	Standard IFC Property
Ensure Design Compliance & Safety (Technical & Structural)	Health & Safety Officer	Operational Phase			Hazardous Material	Hazardous Waste Code: "HP3 Flammable" (example).	Text (Enum)	Alphanumerical	IfcSlab → Pset_MaterialSource (Custom Property Set) → HazardousMaterial (Custom DOR bSDD Property)	DOR bSDD: https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2/prop/HazardousMaterial
Evaluate Suitability for Reuse (Technical & Structural)	Designer	Design Phase			Prefabrication Status	This element was not fabricated of site the value is "FALSE".	Boolean	Alphanumerical	IfcSlab → Pset_CustomPset (Custom Property Set) → PrefabricationStatus (Custom DOR bSDD Property) Or Use CastingMethod of IFC with a value "PRECAST"	Custom Property

			Condition & Lifecycle Data							
Assess Component Condition & Performance (Condition & Lifecycle)	Asset Manager	Operational Phase		ition Assessment (IFC Ps	*Assessment Date*	"2066-02-01"	Date	Alphanumeric al	IfcSlab → Pset_Condition → AssessmentDate	Standard IFC Property
Assess Component Condition & Performance (Condition & Lifecycle)	Asset Manager	Operational Phase			*Assessment Condition*	"Good"	Text (Enum)	Alphanumeric al	IfcSlab → Pset_Condition → AssessmentCondition	Standard IFC Property
Assess Component Condition & Performance (Condition & Lifecycle)	Asset Manager	Operational Phase			*Assessment Description*	"Minor hairline cracks (<0.1mm) in non-load-bearing areas. No visible signs of corrosion or spalling."	Text	Alphanumeric al	IfcSlab → Pset_Condition → AssessmentDescription	Standard IFC Property
Assess Component Condition & Performance (Condition & Lifecycle)	Asset Manager	Operational Phase			*Assessment Method*	"Visual inspection based on NEN 2767 guidelines."	Text	Alphanumeric al	IfcSlab → Pset_Condition → AssessmentMethod	Standard IFC Property
Assess Component Condition & Performance (Condition & Lifecycle)	Structural Engineer	Operational Phase			Actual (vs. Theoretical) Deflection Data	"As-designed max deflection: 15mm. As-Built Phase measured deflection at mid-span: 12mm."	Text	Geometrical	IfcSlab → Pset_ConditionAssessment (Custom Pset) → DeflectionData (Custom Property)	Custom Property
Assess Component Condition & Performance (Condition & Lifecycle)	Asset Manager	Operational Phase		Lifecycle Maintenance	*Maintenance Log*	"Specialist Contractor A; 2065-07-30: Surface coating reapplied in high-traffic area" Or Link to Maintenance Log: "https://cde.owner.com/docs/slab123/maintenance_log.pdf"	URL	Alphanumeric al	IfcSlab → Pset_ComponentReused (Custom Property Set) → ServiceHistory (WASTEie bSDD)	WASTEie bSDD: https://identifier.buildingsmart.org/uri/rcn/WASTEie/0.1.1/prop/ServiceHistory
Assess Component Condition & Performance (Condition & Lifecycle)	Asset Manager	Operational Phase			*Quality Check Reports*	"https://cde.owner.com/docs/slab123/qc_reports.zip"	URL	Documentatio n	IfcSlab → IfcRelAssociatesDocument → IfcDocumentReference	Custom Property
Assess Component Condition & Performance (Condition & Lifecycle)	Asset Manager	Operational Phase			*Last Maintenance Date*	"2060-05-20"	Date	Alphanumeric al	IfcSlab → Pset_Maintenance (Custom Pset) → LastMaintenanceDate (Custom Property)	Custom Property
Assess Component Condition & Performance (Condition & Lifecycle)	Quality Manager	As-Built Phase		-Built Phase Deviation Da	*Has Deviation*	FALSE	Boolean	Alphanumeric al	IfcSlab → Pset_AsBuiltDiscrepancyData (Custom Pset) → DeviationFlag (Custom Property)	Custom Property
Assess Component Condition & Performance (Condition & Lifecycle)	Quality Manager	As-Built Phase			*Deviation Description*	Here the description of the Discrepancy is given, such as "Slab was designed for 6.00 meters but is actually installed at 6.02 meters" or "N/A".	Text	Alphanumeric al	IfcSlab → Pset_AsBuiltDiscrepancyData (Custom Pset) → DeviationDescription (Custom Property)	Custom Property
Circularity Strategy Development (Condition & Lifecycle)	Designer	Design Phase			Design Life	"70"	Integer	Alphanumeric al	IfcSlab → Pset_CircularRequirement (DOR bSDD Pset) → DesignLife (DOR bSDD Property)	DOR bSDD: https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2/prop/DesignLife
Circularity Strategy Development (Condition & Lifecycle)	Asset Manager	Operational Phase			Economic Life	"60"	Integer	Alphanumeric al	IfcSlab → Pset_CircularRequirement (DOR bSDD Pset) → EconomicLife (DOR bSDD Property)	DOR bSDD: https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2/prop/EconomicLife
Circularity Strategy Development (Condition & Lifecycle)	Asset Manager	Operational Phase			Current Reuse Count	"0" (This is its first life cycle)	Integer	Alphanumeric al	IfcSlab → Pset_CircularRequirement (DOR bSDD Pset) → CurrentReuseCount (DOR bSDD Property)	DOR bSDD: https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2/prop/CurrentReuseCount
Circularity Strategy Development (Condition & Lifecycle)	Designer	Design Phase			Total Reuse Count	"2" (Can be reused for at least 2 times)	Integer	Alphanumeric al	IfcSlab → Pset_CircularRequirement (DOR bSDD Pset) → TotalReuseCount (DOR bSDD Property)	DOR bSDD: https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2/prop/TotalReuseCount
Assess Component Condition & Performance (Condition & Lifecycle)	Asset Manager	Operational Phase			Fire Exposure	"Has not been exposed to fire"	Boolean	Alphanumeric al	IfcSlab → Pset_Condition (Custom Pset) → FireExposure (Custom Property)	Custom Property

			Deconstruction & Disassembly							
Deconstruction & Disassembly	Structural Engineer	As-Built Phase			Connection Type	"CT_Direct" (The Direct Connection refers to a type of connection where two components are in direct physical contact with each other, with their surfaces touching)	Text (Enum)	Alphanumeric al	IfcSlab → Pset_CircularRequirement (DOR bSDD Pset) → ConnectionType (DOR bSDD Property)	DOR bSDD: https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2/prop/ConnectionType
Deconstruction & Disassembly	Structural Engineer	As-Built Phase			Connection Accessibility	"Concealed. Requires removal of floor and ceiling finishes to expose slab-beam interface."	Text (Enum)	Alphanumeric al	IfcSlab → Pset_CircularityPerComponent (Custom Pset) → ATC (Custom Property: Accessibility to Connection)	Circularity bSDD: https://identifier.buildingsmart.org/uri/Al-Qazzaz/Circularity/0.0.1/prop/ATC
Deconstruction & Disassembly	Structural Engineer	As-Built Phase		Disassembly Method	*Preferred Method*	"LiftingWithCrane" (For disassembly the preferred method is to life with crane)	Text (Enum)	Alphanumeric al	IfcSlab → Pset_Decommisioning (Custom Pset) → PreferredDisassemblyMethod (Custom Property)	Custom Property
Deconstruction & Disassembly	Structural Engineer	As-Built Phase			*Is Non-Destructive*	TRUE (Lifting With Crane will not be destructive)	Boolean	Alphanumeric al	IfcSlab → Pset_Pset_Decommisioning (Custom Pset) → IsNonDestructive (Custom Property)	Custom Property
Deconstruction & Disassembly	Structural Engineer	As-Built Phase		Disassembly Instructions	*Step-by-Step Guide Link*	"https://cde.owner.com/docs/slab123/decon_guide.pdf"	URL	Documentation	IfcSlab → IfcRelAssociatesDocument → IfcDocumentReference	Custom Property
Deconstruction & Disassembly	Demolition Contractor	As-Built Phase			*Specialized Knowledge Needed*	"Certified operator for diamond wire sawing equipment and heavy crane lifting."	Text	Alphanumeric al	IfcSlab → Pset_CircularRequirement (DOR bSDD Pset) → PersonnelRequirement (DOR bSDD Property)	DOR bSDD: https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2/prop/PersonnelRequirement
Deconstruction & Disassembly	Demolition Contractor	As-Built Phase			Required Disassembly Tools	"Diamond wire saw, 100-ton crane with spreader beam, core drill for lifting anchors." (example)	Text	Alphanumeric al	IfcSlab → Pset_CircularRequirement (Custom Pset) → RequiredDisassemblyTools (Custom Property)	Custom Property
Deconstruction & Disassembly	Deconstruction Planner	As-Built Phase		Disassembly Effort	*Disassembly Score*	"0.5" (Medium effort needed)	Decimal	Alphanumeric al	IfcSlab → Pset_Deconstruction (Custom Pset) → DisassemblyScore (Custom Property)	Custom Property
Deconstruction & Disassembly	Deconstruction Engineer	As-Built Phase			Disassembly Sequence	1. Remove non-structural finishes 2. Install temporary shoring 3. Saw-cut main slab into manageable sections. 4. Sequentially lift and remove sections ... Or attatch document	Text	Alphanumeric al	IfcSlab → Pset_Deconstruction (Custom Pset) → DisassemblySequence (Custom Property)	Custom Property
Deconstruction & Disassembly	Deconstruction Engineer	As-Built Phase			Physical Constraints	Motion Constraint +Z (Up): Slab-Upper-01 (The slab of the floor above it). Motion Constraint -Z (Down): Beam-S-01, Beam-E-01, Beam-W-01 (The beams supporting it). Motion Constraint +X: Slab-Adjacent-E01 (The adjacent slab to the east). ..... Or attatch document	Text	Geometrical	IfcSlab → Pset_Deconstruction (Custom Pset) → PhysicalConstraints (Custom Property)	Custom Property
Deconstruction & Disassembly	Designer	Design Phase			Predetermined Cut Lines	FALSE (No cut lines were predetermined in the original design) or "This element has a designed cutl line at 50cm from the ..."	Boolean	Geometrical	IfcSlab → Pset_Deconstruction (Custom Pset) → PredeterminedCutLines (Custom Property)	Custom Property
Deconstruction & Disassembly	Structural Engineer	As-Built Phase			Contribution to Overall Stability	"Acts as a rigid diaphragm for the floor. Temporary bracing required during removal to maintain building stability." Or give a scoring from 0 (low constribution to stability) to 1 (high stability to stability).	Text	Alphanumeric al	IfcSlab → Pset_Deconstruction (Custom Pset) → StabilityContribution (Custom Property)	Custom Property
Deconstruction & Disassembly	Logistics Coordinator	As-Built Phase			Hoisting Provision Locations	"No pre-installed provisions. Lifting points to be core-drilled as per disassembly plan."	Text	Geometrical	IfcSlab → Pset_Deconstruction (Custom Pset) → HoistingProvisions (Custom Property)	Custom Property
Deconstruction & Disassembly	Demolition Contractor	As-Built Phase		emolition Handling Instru	*Handling Guidelines*	"Use soft slings for lifting. Stack on level dunnage. Protect cut edges from chipping."	Text	Alphanumeric al	IfcSlab → Pset_Logistics (Custom Pset) → HandlingGuidelines (Custom Property) Or IfcSlab → Pset_Logistics (Custom Pset) → LogisticsRequirement (DOR bSDD Property)	Custom Property / DOR bSDD
Deconstruction & Disassembly	Logistics Coordinator	As-Built Phase			*Transport Method*	"Flatbed Truck"	Text	Alphanumeric al	IfcSlab → Pset_Logistics (Custom Pset) → TransportMethod (Custom Property) Or IfcSlab → Pset_Logistics (Custom Pset) → LogisticsRequirement (DOR bSDD Property)	Custom Property / DOR bSDD
Logistics (Deconstruction & Disassembly)	Logistics Coordinator	As-Built Phase			Storage Requirements	"Store in a dry, sheltered environment on level ground. Avoid exposure to freeze-thaw cycles."	Text	Alphanumeric al	IfcSlab → Pset_CircularRequirement (DOR bSDD Pset) → ExposureRequirement (DOR bSDD Property)	DOR bSDD: https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2/prop/ExposureRequirement
Deconstruction & Disassembly	Deconstruction Planner	As-Built Phase			Hosted Components	"Floor finishes, underfloor heating pipes." (Note: This is a descriptive summary; the actual relationships are in the IFC model structure).	Text	Alphanumeric al	IfcSlab → Pset_Deconstruction (Custom Pset) → HostedComponentsSummary (Custom Property)	Custom Property
Evaluate Suitability for Reuse (Deconstruction & Disassembly)	Designer	Design Phase			Embedded Services Information	"Contains PEX underfloor heating pipes and electrical conduits. See drawings for layout."	Text	Alphanumeric al	IfcSlab → Pset_Deconstruction (Custom Pset) → EmbeddedServices (Custom Property)	Custom Property
Deconstruction & Disassembly	Designer	As-Built Phase		ayer Decoupling Strategy	*Strategy Description*	"The tile finish is chemically bonded to the structural slab. Decoupling requires mechanical removal."	Text	Alphanumeric al	IfcSlab → Pset_Design (Custom Pset) → DecouplingStrategy (Custom Property)	Custom Property
Deconstruction & Disassembly	Designer	Design Phase			*Decoupling Ease Score*	"0.2"	Decimal	Alphanumeric al	IfcSlab → Pset_Design (Custom Pset) → DecouplingScore (Custom Property)	Custom Property

			Circularity Strategy & Impact							
Circularity Strategy Development (Circularity Strategy & Impact)	Circularity Specialist	As-Built Phase			Economic Data	"Estimated reuse cost savings: €50/m². Estimated value on secondary market: €80/m²."	Text	Alphanumeric al	IfcSlab → Pset_CircularityImpact (Custom Pset) → EconomicData (Custom Property)	Custom Property
Circularity Strategy Development (Circularity Strategy & Impact)	Designer	As-Built Phase			Circular Potential	"Reuse"	Text (Enum)	Alphanumeric al	IfcSlab → Pset_CircularRequirement (DOR bSDD Pset) → CircularPotential (DOR bSDD Property)	DOR bSDD: https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2/prop/CircularPotential
Circularity Strategy Development (Circularity Strategy & Impact)	Designer	As-Built Phase			Reusability Score	High potential so "0.7" (Scale 0-1)	Decimal	Alphanumeric al	IfcSlab → Pset_CircularityImpact (Custom Pset) → ReusabilityScore (Custom Property)	Custom Property
Circularity Strategy Development (Circularity Strategy & Impact)	Sustainability Consultant	As-Built Phase			Environmental Impact	Embodied Carbon (A1-A3): "250 kgCO2e/m²"	Text	Alphanumeric al	IfcSlab → Pset_EnvironmentalImpactIndicators → (e.g., ClimateChangePerUnit)	Standard IFC Property
Circularity Strategy Development (Circularity Strategy & Impact)	BIM Coordinator	As-Built Phase			Reference Documentation	"Material Passport Link: https://cde.owner.com/docs/slab123/passport.pdf"	URL	Documentatio n	IfcSlab → IfcRelAssociatesDocument → IfcDocumentReference	Standard IFC Property
Establish Legal & Contractual Framework (Circularity Strategy & Impact)	BIM Coordinator	As-Built Phase			Data Archiving Format	"IFC4.3; PDF/A for documents. Stored on owner's Common Data Environment."	Text	Alphanumeric al	For the entire building (model): → Pset_DataManagement (Custom Pset) → ArchivingFormat (Custom Property)	Custom Property
Establish Legal & Contractual Framework (Circularity Strategy & Impact)	Asset Manager	Operational Phase			Model Maintenance Plan	"https://cde.owner.com/docs/governance/maintenance_plan.pdf"	URL	Documentatio n	For the entire building (model): → Pset_DataManagement (Custom Pset) → ModelMaintenancePlan (Custom Property)	Custom Property
Establish Legal & Contractual Framework (Circularity Strategy & Impact)	Asset Manager	Operational Phase			Owner-Managed Model	"https://cde.owner.com/models/asbuilt_digital_twin.ifc"	URL	Documentatio n	For the entire building (model): → Pset_DataManagement (Custom Pset) → OwnerManagedModel (Custom Property)	Custom Property
Establish Legal & Contractual Framework (Circularity Strategy & Impact)	Manufacturer	As-Built Phase		Legal Requirement	*Guarantee Status for Reuse*	"Original manufacturer guarantee is void upon deconstruction."	Text	Alphanumeric al	IfcSlab → Pset_Legal (Custom Pset) → ReuseGuaranteeStatus (Custom Property)	Custom Property
Establish Legal & Contractual Framework (Circularity Strategy & Impact)	Project Manager	As-Built Phase			*Reuse Obligation Status*	TRUE (Legel oblication for an actor (contractor) to provide reuse data)	Boolean	Alphanumeric al	IfcSlab → Pset_Legal (Custom Pset) → ReuseObligationStatus (Custom Property)	Custom Property
Circularity Strategy Development (Circularity Strategy & Impact)	Asset Manager	Operational Phase			Availability Status	"Currently in use. Expected availability: Q1 2066."	Text	Alphanumeric al	IfcSlab → Pset_Logistics (Custom Pset) → AvailabilityStatus (Custom Property)	Custom Property
Circularity Strategy Development (Circularity Strategy & Impact)	Asset Manager	As-Built Phase			Post-Demolition Destination Readiness	FALSE (No destination project confirmed yet)	Boolean	Alphanumeric al	IfcSlab → Pset_Logistics (Custom Pset) → DestinationReadiness (Custom Property)	Custom Property
Evaluate Suitability for Reuse (Circularity Strategy & Impact)	Designer	Design Phase			Modularity Degree	"Low" (In-situ cast with irregular boundaries)	Text (Enum)	Alphanumeric al	IfcSlab → Pset_Design (Custom Pset) → ModularityDegree (Custom Property)	Custom Property
Establish Legal & Contractual Framework (Circularity Strategy & Impact)	Manufacturer	As-Built Phase			Return Guarantee by Manufacturers	"According to contract X, the manufacturer provides a return guarantee for the element after its first service life. The buy-back value is ...% of the original purchase price, contingent upon a formal condition assessment. For complete details, please refer to contract X."	Text	Alphanumeric al	IfcSlab → Pset_CircularAgreement (Custom Pset) → ReturnGuarantee (Custom Property)	Custom Property

Note: The Property set column lists the name of the relevant Property Set. To the right, the corresponding properties belonging to that Property set are shown. If a property does not have an associated Property Set, the Property set column remains empty and the cell is shaded grey.

4.4.1 The Structure of the EIR

To ensure clarity, consistency, and interoperability, the EIR is systematically structured according to the LOIN framework, as defined in ISO 19650 and ISO 7817. The following sections explain the logic used to define both the LOIN prerequisites (Purpose, Actor, Milestone) and the specific information requirements (the 'how'), based on the analysis of how information is created, exchanged, and used throughout the stages of a circular construction project.

Purpose (WHY)

The Purpose column explicitly defines the reason a specific piece of information is required. Each purpose is directly linked to a practical activity or decision within a circular workflow, ensuring that no unnecessary data is requested. To provide a clear and consistent structure, the main purpose of each property was also categorized according to the five thematic groups established in the literature review. In the EIR table, the main purpose (e.g., "Assess Reuse Potential") is listed first, followed by its corresponding thematic category in parentheses (e.g., "Condition & Lifecycle").

Actor (WHO)
The Actor column identifies the role or discipline responsible for creating, managing, or using a specific piece of information. The assignment of an actor was based on identifying the stakeholder most likely to possess or require that data at a given stage of the project. For example, the Designer is the logical actor for providing Design Choices, while the Concrete Supplier is responsible for the detailed Material Composition. During the building's life, the Asset Manager becomes the key actor for tracking Lifecycle Maintenance and Condition Assessment data.

Milestone (WHEN)
The Milestone defines the project phase when information must be complete and added to the model. The milestones for the case study were established in the methodology (Section 3.2). The As-Built milestone was chosen for entering the final values for many properties. This is a practical decision based on the changeable nature of the design process. During the Design Phase, building models are frequently updated, and adding final, detailed reuse information too early would be inefficient and require repeated corrections. This does not mean that circularity is ignored during the design process. On the contrary, strategic thinking about reuse is essential from the start. An property like Circular Potential, for example, is considered by the designer from the outset. However, the definitive value is formally entered into the model at the As-Built milestone. This is because a late-stage design change, such as altering a component's material or connection type, can significantly impact its reuse potential. The As-Built model represents the final, verified state of the building as it was constructed.

Defining the LOIN Information Requirements (The "How")
he primary achievement of the "how" columns is to ensure clarity and quality. This is done in two key ways:

1. Ensuring Data Quality and Consistency: The properties are first categorized according to the three LOIN dimensions. The EIR then specifies the precise data format for each property, including its Value Type (e.g., Text, Boolean, Integer) and provides an Example Value.
2. IFC Mapping and bSDD Links: The final columns of the EIR table, IFC Mapping and Property Source, are dedicated to mapping each property to the IFC schema and linking it to a bSDD (when possible). This shows how each piece of information connects to existing openBIM frameworks.

4.5 Case Study Application: Enriching BIM Model with Circular Properties

As detailed in the Methodology chapter, the CoBuilder Require platform was used to implement a practical subset of the EIR for the selected case study elements. This process translated the theoretical EIR into a structured set of digital requirements, ready for the enrichment of the BIM model. This section presents the key outcomes of that implementation.

4.5.1 Implementing the EIR in CoBuilder Require

The primary result of this phase is a structured set of machine-readable information requirements defined in CoBuilder Require for each selected structural element. The IfcSlab

(concrete floor) is used here as a representative example. Several properties connected to the DOR bSDD and IFC properties were successfully applied this element.

In CoBuilder Require, each information requirement is defined by a unique combination of Purpose, Actor, and Milestone (based on LOIN). This means that properties sharing identical prerequisites can be grouped in one entry, whereas any difference in prerequisites requires a separate entry. As a result, even though all properties applied to the same IfcSlab, multiple distinct entries had to be created. This outcome illustrates how the LOIN framework influences data structuring in practice, as shown in Figure 23.

The same enrichment process was applied to the other seven selected elements to verify that the defined properties could also be successfully added to different element types. This confirmed that the EIR's structure was broadly applicable across the case study's range of structural components, resulting in a complete, project-wide set of structured information requirements.

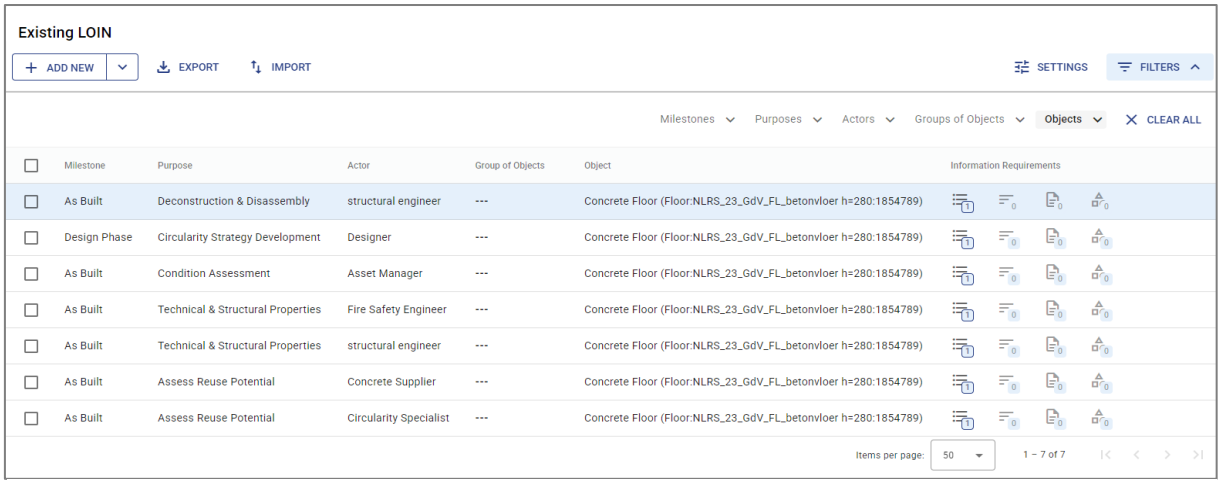


Figure 23 - Overview of the multiple LOIN entries for the IfcSlab in CoBuilder Require

The full "Project LOIN" overview and the Excel export of all entries are provided in Appendix VII as a human-readable reference. The Excel export reproduces the structure of the EIR table and includes columns for the LOIN prerequisites (Purpose, Actor, Milestone) alongside the specific information requirements and their definitions.

4.5.2 Model Enrichment and Technical Verification

The final step in the practical application was to embed the information requirements, previously defined in CoBuilder Require, directly into the case study's IFC model. This was achieved using the platform's "Enrich IFC" feature. The result of this automated process was an enriched IFC model in which the selected building components, such as the IfcSlab, now contain the specified circularity properties. Figure 24 illustrates this outcome, showing the IfcSlab element with the newly created CoBuilder_Requirements property set (automatically generated by the platform). This property set contains the defined properties, including Total Reuse Count, which is used in the following verification steps as a representative example. This final step confirms that the entire workflow is successful: from defining the properties and structuring them in an EIR, to practically adding them to a BIM model.

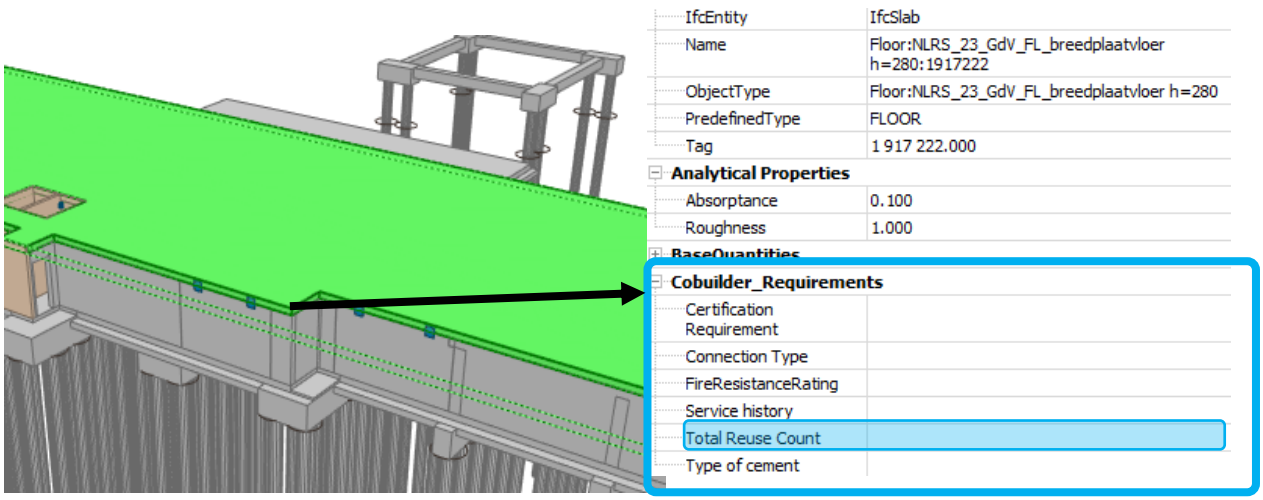


Figure 24 - Enriched IfcSlab element in BIMvision showing the automatically generated CoBuilder_Requirements property set, with Total Reuse Count property highlighted in blue.

Further technical verification of this successful enrichment for the Total Reuse Count property can be found by examining the source code of the IFC file itself. An IFC file is a text-based document where each line defines a part of the building model. The snippet below, taken from the enriched IFC file, illustrates how the Total Reuse Count property is embedded for the IfcSlab element with the Global Unique Identifier (GUID) 3udh7kMDH1Wx1qEAOM5f3J.

```
……

#1 = IFCORGANIZATION($, 'Autodesk Revit 2022 (ENU)', $, $, $);

#2 = IFCAPPLICATION(#1, '2022', 'Autodesk Revit 2022 (ENU)', 'Revit');

#3 = IFCCARTESIANPOINT((0., 0., 0.));

…….

#2751 = IFCSLAB('3udh7kMDH1Wx1qEAOM5f3J', #20, 'Floor:NLRS_23_GdV_FL_breedplaatvloer
h=280:1917222', $, 'Floor:NLRS_23_GdV_FL_breedplaatvloer h=280', #2269, #2750, '1917222',
.FLOOR.);

……
```

```
#65219 = IFCRELDEFINESBYPROPERTIES('0p4DZS_wnTDuZsZ5MmZeI9', #20, 'Object to Properties', $, (#2751), #65220);

……

#65220 = IFCPROPERTYSET('2fXrtcG9j0HgkUQe5PpQYN', #20, 'Cobuilder_Requirements', $, (#65221, #65222, #65223, #65224, #65225));

……

#65224 = IFCPROPERTYSINGLEVALUE('Total Reuse Count', 'https://identifier.buildingsmart.org/uri/cobuilder/requirements/TotalReuseCount', IFCINTEGER(), $);

……
```

The sequence of relationships is as follows:

1. IfcSlab element definition (#2751): This line defines the specific floor element in the model.
2. IfcRelDefinesByProperties (#65219): This relationship connects the IfcSlab element (#2751) to a property set (#65220).
3. IfcPropertySet "Cobuilder_Requirements" (#65220): This property set contains multiple properties, including TotalReuseCount (#65224).
4. IfcPropertySingleValue (#65224): This line defines the property Total Reuse Count and assigns it a URI: This URI is a bSDD link, specifically linking to the DOR bSDD.

In the snippet, the highlighted elements show:

- The connection from the IfcSlab to the Cobuilder_Requirements property set.
- The inclusion of the TotalReuseCount property within that set.
- The bSDD URI linking the property to its standardized definition.

4.5.3 Populating Property Values using usBIM

The enrichment process adds the properties themselves, but these properties do not yet contain any values. The next step in the workflow is to populate these empty fields with the correct data. As defined in the EIR, this responsibility lies with the designated Actor for each specific property. In a typical project workflow, this data would be entered within a native BIM authoring tool such as Autodesk Revit.

For this case study, the open-source platform usBIM was used to demonstrate how values can be added to the enriched IFC file. The example values were taken directly from the “Case Study Example” column of the EIR table. Figure 25 illustrates this process for the IfcSlab, again using Total Reuse Count as an example, where the added value “3” is visible in the property field.

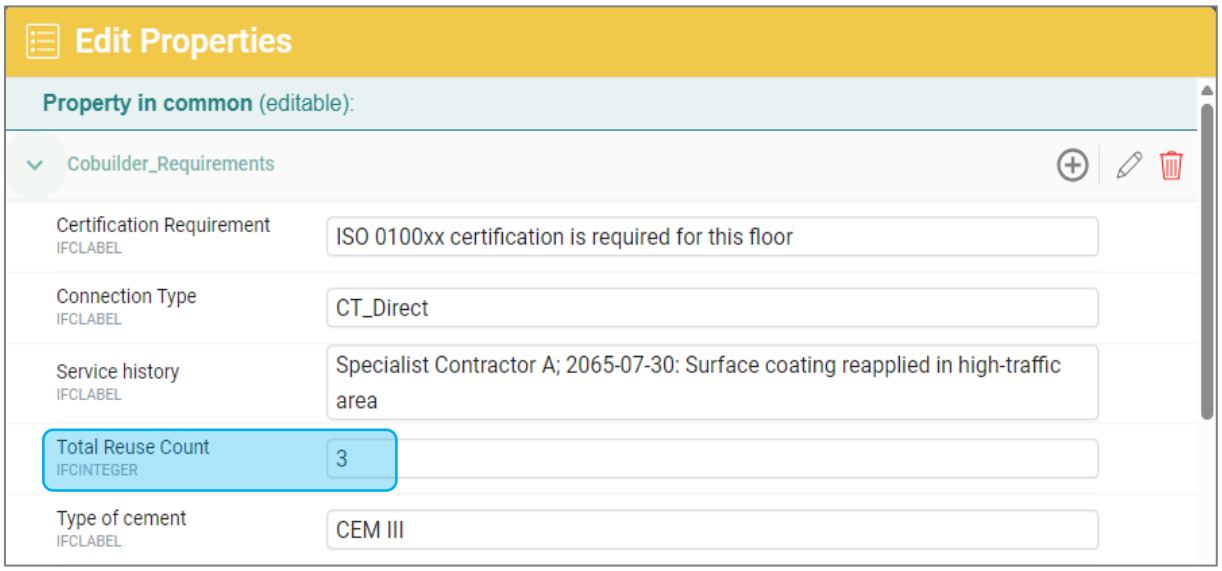


Figure 25 - Adding a value to the “Total Reuse Count” property of the IfcSlab in usBIM, using the case study example value from the EIR table (usBIM).

After completing the value population process in usBIM, the IfcSlab became a fully enriched component. Figure 26 shows its properties, now with the circular properties populated with their corresponding data. This confirms the full success of the workflow: from defining the properties and structuring them in an EIR, to adding both the properties and their values to a standard openBIM model.

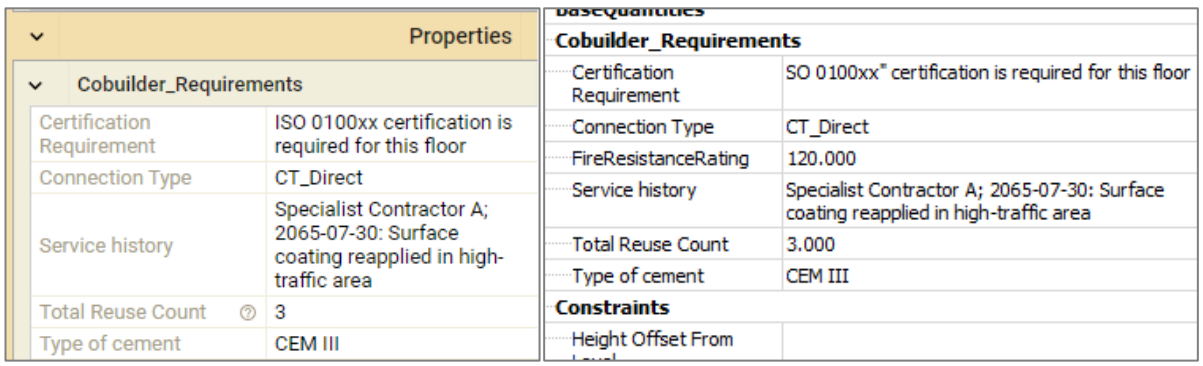


Figure 26 - The final result of the workflow: the properties of the IfcSlab with the circularity properties successfully populated with example values.

4.6 IDS-Based Validation

The final outcome of implementing the EIR in the CoBuilder Require platform is the automatic translation of this structured, LOIN-based requirement into a formal, machine-readable specification. The platform provides a function to export the defined requirements as a standardized IDS file. This step is crucial as it bridges the gap between the human-readable information plan (the EIR) and the technical validation of a BIM model.

A key aspect of how CoBuilder Require generates these files is that it creates a separate IDS file for each Actor defined in the LOIN prerequisites. For example, all information requirements assigned to the Designer are compiled into one IDS, while all requirements for the Structural Engineer are compiled into another. This is a logical approach, as it allows for targeted validation in a real-world project, where different parties are responsible for delivering different sets of information.

The generated IDS file is an XML-based specification that defines, for a specific actor, which properties must be present for which IFC elements. To illustrate this, the example below shows a snippet from an IDS file generated for the Designer, requiring the Total Reuse Count property to be present for IfcSlab.

```
.....
<ids:purpose>Circularity Strategy Development</ids:purpose>
  <ids:milestone>Design Phase</ids:milestone>
.....
<ids:property uri="https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2" dataType="IFCINTEGER">
 <ids:propertySet>
  <ids:simpleValue>Cobuilder_Requirements</ids:simpleValue>
 </ids:propertySet>
 <ids:baseName>
  <ids:simpleValue>Total Reuse Count</ids:simpleValue>
 </ids:baseName>
</ids:property>
```

This IDS snippet defines the Total Reuse Count requirement for the element type IfcSlab within the CoBuilder_Requirements property set.

- Purpose: *Circularity Strategy Development*
- Milestone: *Design Phase*
- Property: *Total Reuse Count* – linked to its standardized definition via the bSDD URI https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2.
- Data type: IFCINTEGER

Figure 27 provides an example of the IDS-based validation process, performed within an IDS-checker in usBIM. The checker has loaded both the enriched IFC model and the IDS file that was generated from the requirements defined in CoBuilder. In this specific example, a requirement for the IfcSlab (Concrete Floor) element is being verified. The IDS specifies that

this element must contain the property Total Reuse Count. The screenshot shows a successful validation, indicated by the checkmark, confirming that the property exists in the model with its correct value.

Figure 27 - An example of a successful IDS validation, showing the verification (checkmark) of the Total Reuse Count property for the highlighted IfcSlab element (in the usBIM platform).

4.7 Summary of the Enrichment and Validation Process

To briefly summarize the process, Figure 28 shows the step-by-step workflow for enriching and validating circular properties:

- Define EIR in CoBuilder Require: Circular properties are linked to IFC and bSDD properties, structured with LOIN prerequisites (Purpose, Actor, Milestone).
- Embed Properties in the IFC Model: The defined properties are automatically embedded into the model using the Enrich IFC file function in Cobuilder Require.
- Populate data: Property values (e.g., Total Reuse Count) are added to the enriched model in usBIM.
- Export IDS: CoBuilder generates IDS files per Actor for targeted validation.
- IDS validation: The usBIM IDS-checker verifies that required properties exist and contain the correct values, confirming the complete enrichment and validation workflow.

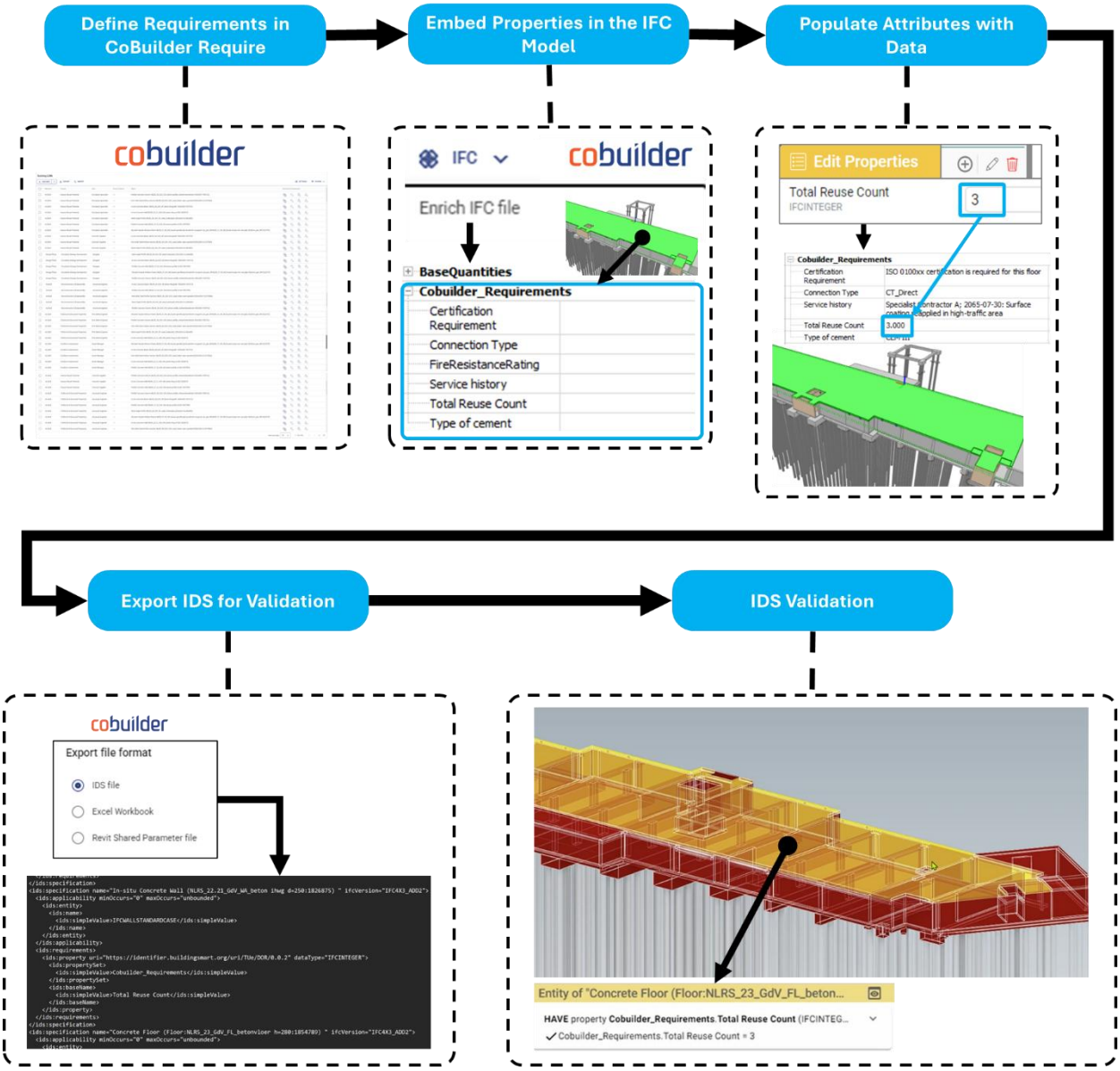


Figure 28 - Overview of Enrichment and Validation Process

[This page is left empty]

5. Discussion

Following the presentation of the results, this chapter evaluates and interprets their significance. The findings are considered in relation to the original research questions and positioned within the context of existing literature, highlighting their contribution to the field. It further reflects on the meaning of the results, addresses any unexpected outcomes, and examines the theoretical and practical implications of the workflow.

5.1 Interpretation of Findings

The central goal of this research was to answer the question: *How can information modeling for circular construction be aligned with the Level of Information Need (LOIN) using the Decommissioning and Reuse buildingSMART Data Dictionary (bSDD) through a controlled case study?* The results show that the alignment of circularity data with the LOIN framework is practically feasible using existing openBIM standards. Through the development of a structured EIR and its successful application to a case study model, the research illustrates a complete digital workflow; from defining the required data to enriching the model and validating its content.

5.1.1 Essential Information for Decommissioning and Reuse (SQ1)

The first sub-question asked what information is essential for supporting end-of-life scenarios for structural elements. This study answered this by first compiling a Foundational Property List from a systematic literature review (Table 2) of 27 properties. This initial set of information requirements was categorized into five thematic groups, including data categories such as Origin and Identification, and Technical and Structural Properties.

Second, expert interviews identified 55 additional practice-based properties, many of which are not prominently represented in current academic literature. These properties were compiled into the Practice-Based Property list (Appendix VI). These were then merged with the foundational property list from the literature to form the Consolidated Final Property list (Table 7), which consists of 82 properties. This final list provides a more comprehensive and definitive answer regarding the information required to support the decommissioning and reuse of structural elements. Since the final list is a consolidation of the foundational and practice-based property list, the definitions in this final property list were either derived from literature, experts, or both.

While the experts did not provide a formal ranking of properties, some were mentioned more frequently or were described as being critically important. This emphasis suggests they can be interpreted as essential circular data. These include:

- Material Type & Quality/Grade (Mentioned by ID1, ID5, ID7, ID8, ID9).
- Geometry / Dimensions (Mentioned by ID2, ID3, ID4, ID5, ID7).
- Reinforcement Details (Mentioned by ID1, ID2, ID3, ID5, ID6 ID8, ID9).
- Original Design Data / Standard (Mentioned by ID2, ID5, ID6, ID9).
- Proven Strength / Load-Bearing Capacity (Mentioned by ID1, ID2, ID9).
- Physical Condition Assessment (Mentioned by ID3, ID4, ID5, ID6, ID8).
- Lifecycle / Load History (Mentioned by ID1, DI2, ID4, ID5).

- Connection Type (Mentioned by ID1, ID2, ID5, ID7, ID8, ID9).
- Disassembly Method / Instructions (Mentioned by ID1, ID4, ID5, ID8, ID9).

These findings confirm the requirements identified in the literature. Both the literature and interviews emphasize the importance of technical and geometric data, connection types, traceability through a unique ID or material passport, and lifecycle history for assessing reuse potential. They also both highlight the need for deconstruction-related information, including method, sequence, and effort.

Based on a synthesis of the expert interviews and the literature review, the following properties were frequently mentioned by experts while also being a core part of the Foundational Property List:

- Material type and quality;
- Geometry and dimensions;
- Reinforcement details (for concrete);
- Connection type and accessibility;
- Lifecycle and load history;
- Physical condition assessment;
- Disassembly method;
- Unique ID (to link information over time).

In addition to confirming known properties, the expert interviews revealed several properties that are absent or only weakly represented in literature. For example, Actual vs. Theoretical Deflection Data addresses the gap between calculated and real-world performance. Expert ID3 explained that a floor might have a theoretical deflection of 11–12 mm, but may in practice only deflect 3–4 mm, revealing a hidden strength reserve that could enable safe and cost-effective reuse. Contribution to Overall Stability, emphasized by expert ID8, highlights the safety risks of removing components without understanding their role in the building's stability. Other practice-driven additions include Hoisting Provisions Locations (precise lifting points for safe maneuvering), Predetermined Cut Lines, and Return Guarantee by Manufacturers. These were all valued for reducing operational uncertainty and deconstruction costs, despite rarely being codified in taxonomies.

Some properties were identified as particularly difficult to collect reliably in practice. Experts highlighted the "as built reality" gap as a critical pain point, leading to the identification of properties such as As built Deviation Data, Original Design Data and Actual versus Theoretical Deflection Data. These properties enable practitioners to manage the frequent mismatch between design documentation and constructed reality, a challenge acknowledged in literature (Akbarieh, 2023). Reliable as-built information is rare, as few projects systematically track differences between the design model and actual construction; a challenge highlighted by experts who question if a building was constructed as designed. Expert ID8 went so far as to state, "My experience is that I have yet to come across the first good archive of a building". Lifecycle History is often lost over time, especially with changes in ownership. This data degradation destroys the economic value of reusable components, as one expert warned that

"If you lose that data... it costs you so much effort to retrieve that data that it is often not worth it".

Beyond property lists, the expert findings also aligned with key DOR bSDD concepts. While the experts did not refer to the bSDD by name, the information they repeatedly identified as critical aligns directly with the dictionary's key properties. Concepts that were strongly supported by the experts include:

- Connection Type: This was one of the most frequently mentioned topics, with experts consistently citing it as a primary driver of deconstruction cost and feasibility.
- Material Composition and Hazardous Material: The need to know exactly "what was in" a component, both for recycling and for health and safety, was a recurring theme that directly corresponds to these bSDD properties.
- Design Life: Experts discussed the importance of a component's intended lifespan or "best before" date, which aligns with this bSDD property for assessing degradation and planned longevity.
- Legal Requirement: The need for material certificates for legal and insurance purposes was highlighted, directly linking to this property's purpose of tracking compliance-related information.

However, some bSDD properties were notably absent from the expert discussions. For instance, while experts discussed different end-of-life scenarios, they did not refer to a formal, structured classification system like the Circular Potential property. Similarly, properties for tracking a component over multiple lifecycles, such as Current Reuse Count and Total Reuse Count, were not mentioned. This suggests that while these properties may be just as crucial for a fully realized CE, they are not the first things experts prioritize when defining the essential information needed for a reuse assessment today.

Finally, not all properties in the Consolidated and Final Property List apply directly to a single structural element. Some, such as Owner-Managed Model Link and Data Archiving Format, operate at the project or model level instead. These properties focus on keeping reuse-relevant information accessible, compatible, and reliable over time.

In summary, SQ1 shows that essential information for decommissioning and reuse is a combination of the standard technical data found in literature, and new practical properties from experts that deal with real-world site conditions, safety, and data reliability.

5.1.2 Structuring Information Requirements with LOIN (SQ2)

The second sub-question asked: *How can information requirements for decommissioning and reuse be structured according to the Level of Information Need (LOIN)?* While SQ1 established what information is essential, SQ2 examined how these properties can be structured so they are clear, verifiable, and actionable in BIM workflows. To address this, the consolidated list of 82 properties from SQ1 was organized within an EIR table using the LOIN framework defined in ISO 19650-1 and ISO 7817.

The LOIN approach requires that each information requirement is explicitly described across three dimensions; geometric, alphanumeric, and documentation, while also linking it to its

intended purpose (WHY), the responsible actor (WHO), and the relevant project milestone (WHEN). By doing so, the properties move from a theoretical list to actionable, verifiable requirements in a BIM environment.

For example, the property *Connection Type*, identified in SQ1 as one of the most critical for deconstruction, was structured in the EIR as follows:

- Purpose (WHY): To support deconstruction and disassembly decisions by identifying the nature of the physical connection between components.
- Actor (WHO): Structural engineer.
- Milestone (WHEN): As-built phase.
- Property Definition: A superclass describing the type of connection and its properties. Different connection types facilitate different end-of-life options, such as deconstruction, demounting, disassembly, or dismantling. The definition also allows for specifying precise technical details (e.g. reversible bolted connections with exact fastener details such as M20 hexagonal head).
- Case Study Example: "CT_Direct": a direct physical contact connection where surfaces touch.
- LOIN Dimension: Alphanumeric.

Applying this method to all case study properties initially involved creating EIR entries for each selected structural element type (e.g. walls, beams, and columns). The expectation was that different types of elements would require distinct sets of circularity properties. However, during the process of mapping the properties, it became apparent that there was a significant degree of overlap. The vast majority of essential properties were applicable across most structural elements. While there are some exceptions such as, Presence of Openings, which may not be relevant for a simple column, and a Reinforcement Geometry is not needed for a steel beam. The core set of properties for each element remained essentially identical.

Because of this significant repetition, a comprehensive EIR table with separate entries for every element would have been unnecessarily long and complex. Therefore, to improve clarity, the EIR was simplified to demonstrate the complete workflow using a single, representative element. The IfcSlab (Concrete Floor) was chosen for this purpose because it could accommodate the full range of properties identified in the research. It is important to note that this is a presentational choice to make the table more understandable. In the actual enrichment workflow, all selected elements (including beams, columns, and walls) are still enriched with the same relevant sets of properties as the concrete floor.

While the Consolidated and Final Property List from SQ1 defines what information is needed, the LOIN-based approach clarifies why it is needed, who is responsible, when it should be delivered, and how it should be represented. This additional context helps prevent misinterpretation, ensures that information delivery aligns with project workflows, and supports automated validation through IDS. This approach turns the properties from general ideas into clear, practical requirements. As a result, it is much easier for project teams to consistently gather, check, and share the information needed for reuse.

Translating properties into fully specified LOIN entries also revealed several challenges. One recurring difficulty was determining the most appropriate milestone for data delivery. In an

ideal DfD scenario, end-of-life considerations should be addressed from the earliest design stages. However, as pointed out in Section 4.4.1, this is not always practical. Many properties were therefore assigned to the As-Built milestone when the final verified state of the building is known. This decision was based on the changeable nature of design models; entering final reuse values too early can lead to repeated rework. For example, the Circular Potential of a component may be conceptually assessed in early design, but the definitive value can change significantly if the material specification is altered later in the process.

Another challenge was that some properties had multiple valid ways of fulfilling their LOIN dimensions. For instance, the Rebar Layout Diagram could be represented as an alphanumeric code (e.g., “RYD01” referring to a specific layout type) or as a document link pointing to a detailed drawing. The issue could be resolved if industry practice converges on a preferred representation method, whether as structured data (alphanumerical dimension), linked documentation, or a combination, supported by clear guidance in project EIRs.

Finally, not all properties identified in the Consolidated and Final Property List apply to individual components. Specific properties, such as Owner-Managed Model Link or Data Archiving Format, operate at the project or model level. These ensure that reuse-relevant information remains accessible, interoperable, and trustworthy over the long term, even after project completion. Their inclusion highlights an important point: the quality of the data is just as important as the quality of the digital system used to store and manage it over the building's entire lifecycle.

In summary, This structuring process shows both the practical potential of LOIN for operationalizing reuse-related properties in BIM and the areas where implementation challenges remain, particularly regarding milestones, representation formats, and project-level data handling.

5.1.3 Embedding and Validating Circularity Data in BIM (SQ3)

The third sub-question asked: *How can the identified information requirements be validated in an IFC model using an IDS?* To explore this, the case study applied the properties from the Consolidated and Final Property List to selected structural elements in a BIM model, mapped them where possible to IFC and bSDD properties, and then validated them using an IDS file.

As described in the previous section, the EIR was initially created for multiple elements, including walls, beams, and columns. However, due to the high degree of overlap in relevant properties across element types, the demonstration focused on a single representative element: the concrete floor (IfcSlab). All case study elements were enriched with the same property sets, and partial validation was possible by visually inspecting the enriched IFC model to confirm that the properties had been correctly added to each element. However, only the IfcSlab was fully validated using IDS. This is because IDS validation requires properties to be populated with complete values, and validating multiple elements would not have provided additional methodological insights beyond what was demonstrated with the IfcSlab. Focusing the full validation on a single representative element was therefore sufficient to confirm the feasibility of the workflow.

Mapping Properties to IFC and bSDD

efore validation, each property from the Consolidated Final Property List was mapped where possible to existing IFC or buildingSMART Data Dictionary (bSDD) properties. Of the 82 properties, 19 could be mapped to standard IFC properties and 13 to bSDD properties, leaving 50 properties as custom properties with no formal definition in current IFC or bSDD schemas. This distribution highlights a significant gap in schema coverage for circularity-related data and reinforces the need to expand both IFC and bSDD to better support deconstruction and reuse workflows.

The mapping process involved a detailed review of the IFC schema and available bSDD definitions via the buildingSMART Identifier platform (BuildingSMART, n.d.). While some properties aligned directly with the DOR bSDD, many could not be matched, even when alternative terminology was tested. Searches across other reuse-related dictionaries, including WASTEie, Circularity, and RecycleBIM, produced only limited matches, with a few additional connections made through ETIM (e.g., Cement Type). However, the overall coverage of reuse properties outside the DOR bSDD was minimal.

IDS Validation Findings

During the technical validation phase, an unexpected behavior was observed. After enriching the IFC model with the required properties through the CoBuilder platform and exporting the corresponding IDS file, the validation software flagged many properties as missing, even though they were visible in the IFC model. Investigation revealed that the IDS validation tool only passed the check after the properties were populated with values in usBIM. This outcome was unexpected, as the IDS file itself was correctly structured and, according to the standard, should have passed validation based solely on the presence of the specified properties. The issue appears to have arisen from the way the validation software interpreted the model, rather than from the IDS content itself. Two technical factors are likely to have contributed:

1. Data Type Requirements – Some IFC data types (e.g., *IFCINTEGER*, *IFCBOOLEAN*) may be treated as invalid if left empty, causing validation tools to flag them as errors even when no explicit value requirement exists.
2. IFC Version Inconsistencies – The case study used an IFC2x3 model, whereas IDS is designed with IFC4 alignment in mind. Schema mismatches between older models and modern validation tools may have influenced the results.

Once values were manually added, the IDS validation succeeded for all mapped properties in the IfcSlab, confirming that the enrichment–validation workflow is technically viable. This finding shifts the discussion from what information should be in the model to how it must be structured and populated to pass automated checks.

Examples of Validation Outcomes

The example property that validated successfully was Total Reuse Count. In contrast, properties such as Return Guarantee by Manufacturer, and Predetermined Cut Lines could not be validated because they exist only as custom properties without formal IFC or bSDD definitions. This limitation reinforces the need for standardization if such properties are to be reliably checked in future projects.

Implications
The case study demonstrates that while the IDS framework can technically validate reuse-related requirements, current standard schemas only cover a fraction of the properties needed for circular construction. Without the expansion of bSDD and IFC to include more reuse-specific data, many essential properties will remain outside automated compliance checks.

5.2 Theoretical and Practical Implications

This chapter discusses the theoretical and practical implications of the findings, integrating insights from all sub-questions. It positions the study within the existing body of knowledge on BIM–circularity integration and highlights how the developed methodology can be applied in practice.

5.2.1 Theoretical Implications

Positioning within existing theory
This research builds on and extends existing BIM frameworks, such as LOIN, and recognized openBIM standards by demonstrating a structured method to integrate circularity-related data into BIM models. It combines standardized properties from sources like the DOR bSDD with additional attributes identified through literature review and expert consultation. The approach is built around four key components:

- A structured EIR developed from literature and expert insights.
- Alignment with LOIN to define context and detail.
- Integration of bSDD-based property definitions with new attributes to address gaps.
- Validation using IDS to ensure compliance, interoperability, and quality in IFC workflows.

Emerging concepts
In addition to confirming properties frequently cited in literature, this study identified several novel, practice-based attributes not yet established in academic sources or standardized dictionaries. Examples include *Return Guarantee by Manufacturer* and *Predetermined Cut Lines*. These emerged from expert interviews, reflecting operational needs and barriers in circular construction. However, some could not be implemented in the case study due to the absence of corresponding IFC or bSDD definitions, underlining the need to expand existing ontologies such as the DOR bSDD.

The findings also highlight a practical challenge: while adding detailed properties can improve decision-making for reuse and recycling, excessive data requirements may slow processes and increase modelling workload.

Theoretical contribution
This research contributes on three interconnected levels:

- **Methodological**: Introduces a reproducible workflow linking EIR, LOIN, bSDD, and IDS from requirement definition to model verification.
- **Conceptual**: Demonstrates how standardized frameworks can be applied and extended for circularity.

- **Empirical**: Validates the workflow through a real IFC case study, showing both opportunities and current limitations in implementing circular properties.

5.2.2 Practical Implications

The findings of this research have direct implications for multiple stakeholder group. By demonstrating how circularity-related data can be systematically integrated into BIM models through a structured EIR aligned with the LOIN framework, the proposed methodology offers concrete benefits for different types of stakeholders such as contractors and asset owners.

Contractors and Demolition Contractors

For contractors, including those responsible for demolition, aligning data requirements with project milestones such as the As-Built stage helps ensure that essential circularity properties such as disassembly method, required disassembly tools, and reuse potential are accurately captured. This structured approach reduces the risk of missing or inconsistent data at end-of-life, minimizes uncertainty in deconstruction operations, and preserves component-specific knowledge for future planning. Over time, these benefits can contribute to cost reductions, improved risk management and safety during demolition, and higher recovery rates for reusable components.

Asset Owners

For asset owners, adding circularity properties to BIM models turns the As-Built model into a long-term digital asset that works like a material passport for the building. Having all reuse, refurbishment, and recycling information clearly stored makes it easier to recover value at the end of the building's life. Complete and validated data also supports better decisions during operation, such as planning maintenance and refurbishments.

Long-term lifecycle scenario

To illustrate the practical impact of the proposed methodology, consider the following scenario:

All relevant circularity properties, structured through the LOIN framework, specified in the EIR, and linked to an expanded bSDD, are accurately added to the BIM model at the As-Built stage. Fifty years later, when the building reaches the end of its lifecycle, the decommissioning team gains immediate access to a complete, standardized dataset containing disassembly methods, material specifications, certifications, and reuse potential for each component. Because this data was captured decades earlier by the original project team and maintained in an interoperable format, it remains fully accessible and usable across future software platforms. This future-proof dataset prevents the loss of important information and allows all stakeholders to benefit in their own way. For example, it can help plan dismantling in a safe and efficient order, avoid damage to reusable parts, accurately assess the value and condition of components for resale or remanufacturing, and reduce waste by directing materials to the most valuable reuse option.

The long-term scenario illustrates the potential value of a structured EIR, aligned with the LOIN framework for circular data.

6. Conclusion

This research set out to develop and demonstrate a practical, standards-based workflow for integrating circularity data into BIM models. By combining insights from literature, expert interviews, and a real-world case study, this study has shown that it is feasible to align circular information modeling with key industry frameworks like the LOIN and openBIM standards such as the bSDD. The findings provide clear answers to the research questions.

6.1 Addressing the Research Questions

SQ1: What information requirements are essential for building components and materials, particularly structural elements, in a BIM model to support decommissioning and reuse?
This study identified a comprehensive set of 82 properties essential for the decommissioning and reuse of structural elements. This "Consolidated Final Property List" was created by first identifying foundational properties from academic literature, and then enriching this list with additional practice-based properties derived from expert interviews.

While all properties are valuable, the research found a core set to be most critical. Both literature and experts consistently highlighted the importance of:

- Material type and quality
- Geometry and dimensions
- Reinforcement details (for concrete)
- Connection type and accessibility
- Lifecycle and load history
- Physical condition assessment
- Disassembly method
- A Unique ID to ensure traceability over time

The expert interviews also introduced several novel properties not yet established in literature, such as Actual vs. Theoretical Deflection Data, Predetermined Cut Lines, and Return Guarantee by Manufacturers, which address practical on-site challenges and economic barriers.

SQ2: How can information requirements for decommissioning and reuse be structured according to the Level of Information Need (LOIN)?
The research demonstrates that the LOIN framework provides an effective structure for transforming the identified properties from a simple list into clear, actionable requirements. By organizing the 82 properties into a formal EIR table, each piece of data was given a clear context. This was achieved by first defining the core LOIN prerequisites (Purpose, Actor, and Milestone) for each property. Then, the information itself was specified across LOIN's three core dimensions: geometrical, alphanumerical, and documentation requirements. This dual approach ensures that every piece of data is not only contextually relevant but also clearly defined in its required format and detail.

SQ3: How can structured information related to decommissioning and reuse be effectively embedded into a Building Information Modeling (BIM) model and subsequently validated against predefined information requirements?

This study successfully demonstrated a practical workflow for embedding and validating circularity data in a BIM model using open standards. The key steps were:

- Enrichment: The LOIN-structured EIR was implemented in the CoBuilder Require platform. This platform was then used to automatically embed the required properties into the correct structural elements of the case study's IFC model.
- Population: The open-source platform usBIM was used to populate the newly added properties with their correct values, simulating the process of data entry by the responsible actors in a real project.
- Validation: An IDS file was automatically generated from the requirements in CoBuilder. This machine-readable file was then used to automatically verify that the IFC model contained the correct properties with the correct values, confirming the workflow's success.

This process confirms that it is technically feasible to move from a human-readable requirement (the EIR) to a fully enriched and machine-validated BIM model.

SQ4: What challenges and limitations are encountered when applying Level of Information Need (LOIN) and buildingSMART Data Dictionary (bSDD) for circular information modeling in practice?

Applying the LOIN framework and the bSDD to model circularity in practice revealed several key limitations, highlighting a gap between the potential of these standards and their current practical readiness. A primary limitation was the lack of standardized definitions for essential circularity properties; of the 82 properties identified, more than half (50) could not be mapped to existing bSDD or IFC standards and had to be treated as custom properties . This gap is significant because custom properties cannot be reliably checked with automated validation tools like IDS. Furthermore, applying the LOIN framework itself presented practical challenges, particularly when determining the most appropriate milestones for delivering specific information. In some cases, information required for circularity assessments was not naturally generated at the identified project stage, making it difficult to meet the requirements without altering existing workflows. Finally, the case study showed that more information is not always better: excessive property requirements can increase workload, slow down modelling, and overwhelm stakeholders without adding real value.

Main Research Question: How can information modeling for circular construction be aligned with the Level of Information Need (LOIN) using the Decommissioning and Reuse buildingSMART Data Dictionary (bSDD) through a controlled case study?

The starting point for applying LOIN, bSDD, and IDS in circular information modelling is having clear and well-defined information requirements. In this study, these requirements were established by identifying relevant reuse-related properties through a combination of literature review and expert consultation, resulting in a structured list of properties. These properties formed the basis of an EIR, which was then structured according to LOIN principles to specify what information is needed, for which elements, by whom, and at what project stage. Where possible, the properties were mapped to standardized definitions in the bSDD to ensure interoperability and reusability across projects and software. For properties not yet available in existing standards, custom definitions were created, although these cannot yet be

fully validated using IDS. The structured EIR was then translated into machine-readable IDS rules, enabling automated checking of IFC models against the defined requirements. This workflow was applied to a real IFC case study model, demonstrating that circular data can be systematically embedded and validated within structural BIM elements. While technically feasible and beneficial for improving interoperability, the study also revealed practical challenges, including gaps in bSDD coverage, uncertainty in assigning information to the correct project milestones, and the potential inefficiencies caused by excessive property requirements. Overall, this research demonstrates a reproducible, standards-based methodology that connects theoretical BIM–circularity concepts to operational modelling practices. It shows how openBIM standards can be used together to structure and validate circular information for long-term reuse, while also highlighting areas where further development of standards and workflows is needed.

6.2 Limitations and Recommendations for Future Research

Focus on structural elements

The research focused exclusively on structural elements, which represent only a subset of the built environment. While these elements account for significant embodied carbon and reuse potential, they differ in their material composition, manufacturing processes, and decommissioning practices from other building components. As such, the results may not directly apply to other components such as mechanical, electrical, and plumbing systems or architectural finishes without further adaptation. These components may require distinct data properties, considerations, and reuse or recycling strategies. Applying the proposed workflow to these components would likely necessitate additional adjustments and validation.

Future research should therefore expand the methodology to include a broader range of building elements, such as mechanical, electrical, and plumbing systems or architectural finishes. Extending the scope beyond structural elements could reveal additional requirements, constraints, and property sets relevant to different construction disciplines, ensuring the workflow is applicable across different construction domains and project types.

Lack of formal property validation

As new properties originate from practice, their importance has not been formally validated through academic research and literature. However, throughout this research, properties were consistently emphasized as important by the interviewed industry experts because they address real-world barriers and opportunities in circular construction. This research provides a practical example of adding the identified circular properties to structural elements in a BIM model, rather than validating the properties themselves.

Additionally, while a large number of properties have been identified in this study, implementing all of them for every component in a large-scale project may be impractical. Although, in theory, more information can improve decision-making, in practice, excessive data requirements can lead to inefficiencies, increased modeling effort, and potential information overload.

Future research should address this by testing and validating the properties across multiple projects, regions, and building types, ideally through longitudinal studies covering the entire lifecycle from design to demolition . Such research would help identify which properties are truly useful for circular workflows and which ones could be left out without harming circularity goals.

Single case study

The research was conducted on a single case study model provided by one contractor (Heijmans). While this added depth and realism, it limits the generalizability of the findings and restricts variability across different BIM implementation practices. These practices can vary significantly between organizations, regions, and software ecosystems, which may influence the applicability of the proposed workflow. Such variations can include differences in modeling conventions, levels of detail, information structuring methods, and integration with openBIM standards such as IFC, bSDD, and IDS. As a result, the proposed approach may require adjustments to align with other organizational workflows or digital maturity levels.

Future research could replicate the workflow across multiple projects, regions, and software environments to assess its robustness and transferability. Testing the approach under different organizational contexts and BIM implementation practices would help determine its adaptability and identify potential adjustments needed for broader industry adoption.

Tool dependency

The current study approach is reliant on tools that support IDS and bSDD standards, such as CoBuilder. While CoBuilder proved effective in managing and applying the EIR and IDS, it may limit replicability for organizations using alternative platforms or tools without equivalent capabilities. Not all BIM software environments natively support the integration of bSDD classifications or automated IDS validation.

Future research should test the workflow in different software tools to see how well it adapts and what changes might be needed. This would help create guidelines that work across platforms, reducing reliance on specific tools and making the process more accessible.

Partial application of the LOIN framework

The application of the LOIN framework in this study primarily focused on alphanumerical information, as the identified reuse-related properties were mainly alphanumerical in nature. While geometric and documentation requirements, two other key dimensions of LOIN, were acknowledged, they were less prominent in the developed workflow due to the characteristics of the selected properties.

Future research could expand this approach by more explicitly integrating geometric and documentation requirements alongside alphanumerical data. Addressing all three dimensions would enable a more holistic specification of information needs and further strengthen the integration of circularity considerations in BIM workflows.

7. References

Adams, W. C. (2015). Conducting Semi-Structured interviews. ResearchGate, 492–505. https://doi.org/10.1002/9781119171386.ch19

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

Akbari, S., Sheikhkhoshkar, M., Rahimian, F. P., Haouzi, H. B. E., Najafi, M., & Talebi, S. (2024). Sustainability and building information modelling: Integration, research gaps, and future directions. Automation in Construction, 163, 105420. https://doi.org/10.1016/j.autcon.2024.105420

Akbarieh, A. (2023, December). Information Modelling for Circular Transformation of Built Assets' End-Of-Life. ResearchGate. https://doi.org/10.13140/RG.2.2.27124.26246

Akbarieh, A., F. N. Teferle, and J. O'Donnell. 2023. "Semantic Material Bank: A Web-Based Linked Data Approach for Building Decommissioning and Material Reuse." Pp. 69–76 in CRC Press eBooks.

Amudjie, Judith, Albert P. C. Chan, Amos Darko, Caleb Debrah, and Kofi Agyekum. 2025. "CircularBIM: Future Needs at the Convergence of Building Information Modelling and the Circular Economy." Automation in Construction 176:106250. doi: 10.1016/j.autcon.2025.106250.

Banihashemi, S., Meskin, S., Sheikhkhoshkar, M., Mohandes, S. R., Hajirasouli, A., & LeNguyen, K. (2023). Circular economy in construction: The digital transformation perspective. Cleaner Engineering and Technology, 18, 100715. https://doi.org/10.1016/j.clet.2023.100715

Basta, A., Serror, M. H., & Marzouk, M. (2019). A BIM-based Framework for Quantitative Assessment of Steel Structure Deconstructability. Automation in Construction, 111, 103064. https://doi.org/10.1016/j.autcon.2019.103064

Benachio, G. L. F., Freitas, M. D. C. D., & Tavares, S. F. (2020). Circular economy in the construction industry: A systematic literature review. Journal of Cleaner Production, 260, 121046. https://doi.org/10.1016/j.jclepro.2020.121046

Bhandari, P. (2025, January 14). What is Qualitative Research? | Methods & Examples. Scribbr. Retrieved June 23, 2025, from https://www.scribbr.com/methodology/qualitative-research/. (n.d.).

Bigai, S., & Santos, E. T. (2024). Implementing Information Delivery Specification (IDS) encoding for a BIM object standard based on model uses. ResearchGate. Retrieved from https://www.researchgate.net/publication/385099241_Implementing_Information_Delivery_Specification_IDS_encoding_for_a_BIM_object_standard_based_on_model_uses

Boote, D. N., & Beile, P. (2005). Scholars Before Researchers: On the Centrality of the Dissertation Literature Review in Research Preparation. Educational Researcher, 34(6), 3–15. https://doi.org/10.3102/0013189x034006003

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

BuildingSMART. (2020, April). Technical Roadmap buildingSMART. BuildingSMART International. Retrieved from https://www.buildingsmart.org/wp-content/uploads/2020/09/20200430_buildingSMART_Technical_Roadmap.pdf

BuildingSMART. (2024, August 29). openBIM®: what is it and why do we need it? – buildingSMART International. Retrieved from https://www.buildingsmart.org/openbim-what-is-it-and-why-do-we-need-it/

BuildingSMART. (n.d.). BSDD Identifier. Retrieved from https://identifier.buildingsmart.org/

Carrera-Rivera, A., Ochoa, W., Larrinaga, F., & Lasa, G. (2022). How-to conduct a systematic literature review: A quick guide for computer science research. MethodsX, 9, 101895. https://doi.org/10.1016/j.mex.2022.101895

Caulfield, J. (2023, June 22). How to do Thematic Analysis | Step-by-Step Guide & Examples. Scribbr. Retrieved June 20, 2025, from https://www.scribbr.com/methodology/thematic-analysis/. (n.d.).

Charef, R. (2016). BIM Through The Entire Life cycle Of An Asset A Focus On Construction and Demolition Waste in UK. ResearchGate. https://doi.org/10.13140/RG.2.2.28308.31362

Charef, R. (2024). A Digital Framework for the Implementation of the Circular Economy in the Construction Sector: Expert Opinions. Sustainability, 16(14), 5849. https://doi.org/10.3390/su16145849

Charef, R., Alaka, H., & Emmitt, S. (2018). Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views. Journal of Building Engineering, 19, 242–257. https://doi.org/10.1016/j.jobe.2018.04.028

CoBuilder. (2025, February 24). Cobuilder require - Digital solutions for the construction industry. Retrieved from https://cobuilder.com/en/cobuilder-require/

Crisan, A., Juravle, A., & Bancila, R. (2025). A BIM-Enabled workflow for the rehabilitation of heritage steel bridges. Applied Sciences, 15(2), 677. https://doi.org/10.3390/app15020677

Datta, S. D., Tayeh, B. A., Hakeem, I. Y., & Aisheh, Y. I. A. (2023). Benefits and Barriers of Implementing Building Information Modeling Techniques for Sustainable Practices in the Construction Industry—A Comprehensive Review. Sustainability, 15(16), 12466. https://doi.org/10.3390/su151612466

De Marco, G., Slongo, C., & Siegele, D. (2024). Enriching Building Information Modeling Models through Information Delivery Specification. Buildings, 14(7), 2206. https://doi.org/10.3390/buildings14072206

De Wolf, C., Byers, B. S., Raghu, D., Gordon, M., Schwarzkopf, V., & Triantafyllidis, E. (2024). D5 digital circular workflow: five digital steps towards matchmaking for material reuse in construction. Npj Materials Sustainability, 2(1). https://doi.org/10.1038/s44296-024-00034-8

Dervishaj, A., Fonsati, A., Vargas, J. H., & Gudmundsson, K. (2023). Modelling precast concrete for a circular economy in the built environment. eCAADe Proceedings. https://doi.org/10.52842/conf.ecaade.2023.2.177

Doan, D. T., Ghaffarianhoseini, A., Naismith, N., Zhang, T., Rehman, A. U., Tookey, J., & Ghaffarianhoseini, A. (2019). What is BIM? A Need for A Unique BIM Definition. MATEC Web of Conferences, 266, 05005. https://doi.org/10.1051/matecconf/201926605005

Elhegazy, H., Zhang, J., Amoudi, O., Zaki, J. N., Yahia, M., Eid, M., & Mahdi, I. (2022). An exploratory study on the impact of the construction industry on climate change. Journal of Industrial Integration and Management, 1–23. https://doi.org/10.1142/s2424862222500282

Filardo, M. M., Debus, P., Melzner, J., & Bargstädt, H. (2024). Enhancing Information Requirement Compliance Through Automated Integration in a Modelling Environment. ResearchGate. Retrieved from https://www.researchgate.net/publication/382077666_Enhancing_Information_Requirement_Compliance_Through_Automated_Integration_in_a_Modelling_Environment

Glaser, B. G., & Strauss, A. L. (2017). The discovery of grounded theory. Routledge eBooks. https://doi.org/10.4324/9780203793206

Godager, Bjoern, Knud Mohn, Christoph Merschbrock, Ole Jonny Klakegg, and Lizhen Huang. 2022. “Towards an Improved Framework for Enterprise BIM: The Role of ISO 19650.” Journal of Information Technology in Construction 27:1075–1103. doi: 10.36680/j.itcon.2022.053.

Gomes, F., Mendes, T., Freire, S., Spínola, R., & Mendonça, M. (2024). Investigating the use of Snowballing on Gray Literature Reviews. arXiv (Cornell University). https://doi.org/10.48550/arxiv.2407.14991

Gragnaniello, C., Mariniello, G., Pastore, T., & Asprone, D. (2023). BIM-based design and setup of structural health monitoring systems. Automation in Construction, 158, 105245. https://doi.org/10.1016/j.autcon.2023.105245

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

Hentour, Y., Elganadi, Y., & Bolpagni, M. (2024). Level of Information Need in Heritage Building Management: a case study in Morocco. Retrieved from https://itc.scix.net/paper/w78-2024-38

Hradil, P., Mäkeläinen, A., Vares, S., & Pimentel, R. (2020, April). Building Information Model (BIM) Implementation in Steel Reuse (747847). Steelconstruct. VTT Technical Research Centre of Finland & Steel Construction Institute. Retrieved from https://www.steelconstruct.com/wp-content/uploads/PROGRESS-D3.2-BIM-for-reuse.pdf

Illankoon, C., & Vithanage, S. C. (2023). Closing the loop in the construction industry: A systematic literature review on the development of circular economy. Journal of Building Engineering, 76, 107362. https://doi.org/10.1016/j.jobe.2023.107362

Kallio, H., Pietilä, A., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. Journal of Advanced Nursing, 72(12), 2954–2965. https://doi.org/10.1111/jan.13031

Khan, Hilal, Zamil Bin Zahid, Umair Jalil Malik, and Junaid Ahmad. 2025. “Performance Evaluation of Innovative Connection Systems for Structural and Seismic Challenges in High-Rise Modular Construction: A State-of-the-Art Review.” Journal of Building Engineering 108:112808. doi: 10.1016/j.jobe.2025.112808.

Kirchherr, J., Yang, N. N., Schulze-Spüntrup, F., Heerink, M. J., & Hartley, K. (2023). Conceptualizing the Circular Economy (Revisited): An analysis of 221 definitions. Resources Conservation and Recycling, 194, 107001. https://doi.org/10.1016/j.resconrec.2023.107001

Kładź, M., & Borkowski, A. S. (2025). IDS Standard and bSDD Service as Tools for Automating Information Exchange and Verification in Projects Implemented in the BIM Methodology. Buildings, 15(3), 378. https://doi.org/10.3390/buildings15030378

Kuzminykh, A., Granja, J., Parente, M., & Azenha, M. (2024). Promoting circularity of construction materials through demolition digitalisation at the preparation stage: Information requirements and openBIM-based technological implementation. Advanced Engineering Informatics, 62, 102755. https://doi.org/10.1016/j.aei.2024.102755

Kuzminykh, A., Parente, M., Vieira, V., Granja, J., & Azenha, M. (2023). RecycleBIM Approach Towards Integrated Data Management for Circularity: Proof of Concept in a RC Building. In Rilem bookseries (pp. 252–262). https://doi.org/10.1007/978-3-031-33211-1_23

M. Marzouk, M., Elmaraghy, A., & Voordijk, H. (2019). Lean Deconstruction Approach for Buildings Demolition Processes using BIM. Retrieved from https://www.semanticscholar.org/paper/Lean-Deconstruction-Approach-for-Buildings-using-Marzouk-Elmaraghy/8be04967756edf21e90d4d44c76df57cd45882c9

M. Marzouk, Mohamed, & Elmaraghy, A. (2021, July). Design for Deconstruction Using Integrated Lean Principles and BIM Approach. ResearchGate. https://doi.org/10.3390/su13147856

Malla, V., Tummalapudi, M., & Delhi, V. S. K. (2023). Perceptions of Built-Environment Professionals on using ISO 19650 Standards for Information Management. Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 16(1). https://doi.org/10.1061/jladah.ladr-1076

Martin, H., Chebrolu, D., Chadee, A., & Brooks, T. (2024). Too good to waste: Examining circular economy opportunities, barriers, and indicators for sustainable construction and demolition waste management. Sustainable Production and Consumption, 48, 460–480. https://doi.org/10.1016/j.spc.2024.05.026

Mattaraia, L., Fabricio, M. M., & Codinhoto, R. (2021). Structure for the classification of disassembly applied to BIM models. Architectural Engineering and Design Management, 19(1), 56–73. https://doi.org/10.1080/17452007.2021.1956420

McGrath, C., Palmgren, P. J., & Liljedahl, M. (2018). Twelve tips for conducting qualitative research interviews. Medical Teacher, 41(9), 1002–1006. https://doi.org/10.1080/0142159x.2018.1497149

Mellenthin Filardo, M., Liu, L., Hagedorn, P., & Zentgraf, S. (2024). A standard-based ontology network for information requirements in digital construction projects. ResearchGate. Retrieved from https://www.researchgate.net/publication/381408124_A_standard-based_ontology_network_for_information_requirements_in_digital_construction_projects

Mercado Siles, C. & Universidade do Minho. (2020). BIM-based Framework for Deconstructability Assessment of Steel Structures. (M. I. Brito Valente), European Master in Building Information Modelling. Retrieved from https://bimaplus.org/wp-content/uploads/2020/10/2020-CamiloSiles-Dissertation.pdf

Mikulėnas, Manvydas, and Lina Šeduikytė. 2025. “Circularity and Decarbonization Synergies in the Construction Sector: Implications for Zero-Carbon Energy Policy.” Energies 18(5):1164. doi: 10.3390/en18051164.

Mitera-Kiełbasa, E., & Zima, K. (2024). Automated Classification of Exchange Information Requirements for Construction Projects Using Word2Vec and SVM. Infrastructures, 9(11), 194. https://doi.org/10.3390/infrastructures9110194

Morganti, C., & Bragadin, M. A. (2024). A Literature Review of H-BIM Strategy for Construction Maintenance. Lecture Notes in Civil Engineering, 556–568. https://doi.org/10.1007/978-3-031-71867-0_37

Naghibalsadati, F., Gitifar, A., Ray, S., Richter, A., & Ng, K. T. W. (2024). Temporal Evolution and Thematic Shifts in Sustainable Construction and Demolition Waste Management Through Building Information Modeling Technologies: A Text-mining Analysis. Journal of Environmental Management, 369, 122293. https://doi.org/10.1016/j.jenvman.2024.122293

Odenbreit, Christoph, Jie Yang, Alfredo Romero, and Andras Kozma. 2022. “A Reusable Structural System Fit for Geometrical Standardisation and Serial Production.” Ce/Papers 5(2):11–20. doi: 10.1002/cepa.1693.

Oliveira, A., Granja, J., Bolpagni, M., Motamedi, A., & Azenha, M. (2024). Development of standard-based information requirements for the facility management of a canteen. Journal of Information Technology in Construction, 29, 281–307. https://doi.org/10.36680/j.itcon.2024.014

Oliveira, Andressa, José Granja, Marzia Bolpagni, Ali Motamedi, and Miguel Azenha. 2024. “Development of Standard-Based Information Requirements for the Facility Management of a Canteen.” Journal of Information Technology in Construction 29:281–307. doi: 10.36680/j.itcon.2024.014.

Ortiz, O., Castells, F., & Sonnemann, G. (2008). Sustainability in the construction industry: A review of recent developments based on LCA. Construction and Building Materials, 23(1), 28–39. https://doi.org/10.1016/j.conbuildmat.2007.11.012

Pan, X., Khan, A. M., Eldin, S. M., Aslam, F., Rehman, S. K. U., & Jameel, M. (2023). BIM adoption in sustainability, energy modelling and implementing using ISO 19650: A review. Ain Shams Engineering Journal, 15(1), 102252. https://doi.org/10.1016/j.asej.2023.102252

Pauline, Jegen, Gast Lukas, and Faulstich Martin. 2025. “A Review of the Implementation of R-Imperatives in Circular Construction.” Cleaner Production Letters 100097. doi: 10.1016/j.clpl.2025.100097.

Pereiro, X., Cabaleiro, M., Conde, B., & Riveiro, B. (2023). BIM methodology for cost analysis, sustainability, and management of steel structures with reconfigurable joints for industrial structures. Journal of Building Engineering, 77, 107443. https://doi.org/10.1016/j.jobe.2023.107443

Piazzi, M. A., Feng, H., & Kassem, M. (2022). An investigation of concepts for the specification of graphical exchange information requirements in building information modelling. Journal of Information Technology in Construction, 27, 662–684. https://doi.org/10.36680/j.itcon.2022.033

Pomponi, F., & Moncaster, A. (2016). Circular economy for the built environment: A research framework. Journal of Cleaner Production, 143, 710–718. https://doi.org/10.1016/j.jclepro.2016.12.055

Qu, S., & Dumay, J. (2011, May 14). The Qualitative Research Interview. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2058515

Randolph, J. (2007). A Guide to Writing the Dissertation Literature Review. ResearchGate. Retrieved from https://www.researchgate.net/publication/251499995_A_Guide_to_Writing_the_Dissertation_Literature_Review

Rao, P. A., Rahman, M. M., & Duraman, S. B. (2025). Adopting Circular Economy in Construction: A Review. Frontiers in Built Environment, 11. https://doi.org/10.3389/fbuil.2025.1519219

Rasmussen, Fn, M. Birkved, and H. Birgisdóttir. 2019. “Upcycling and Design for Disassembly – LCA of Buildings Employing Circular Design Strategies.” IOP Conference Series Earth and Environmental Science 225:012040. doi: 10.1088/1755-1315/225/1/012040.

Rios, Fernanda Cruz, Wai K. Chong, and David Grau. 2015. “Design for Disassembly and Deconstruction - Challenges and Opportunities.” Procedia Engineering 118:1296–1304. doi: 10.1016/j.proeng.2015.08.485.

Ruslin, R., Mashuri, S., Sarib, M., & Syam, H. (2022). Semi-structured Interview: A Methodological Reflection on the Development of a Qualitative Research. . . ResearchGate. https://doi.org/10.9790/7388-1201052229

Safari, K., & AzariJafari, H. (2021). Challenges and Opportunities for Integrating BIM and LCA: Methodological choices and framework development. Sustainable Cities and Society, 67, 102728. https://doi.org/10.1016/j.scs.2021.102728

Sanchez, B., Honic, M., Leite, F., Herthogs, P., & Stouffs, R. (2024). Augmenting materials passports to support disassembly planning based on building information modelling standards. Journal of Building Engineering, 90, 109083. https://doi.org/10.1016/j.jobe.2024.109083

Sanchez, B., Rausch, C., Haas, C., & Hartmann, T. (2021). A Framework for BIM-based Disassembly Models to Support Reuse of Building Components. Resources Conservation and Recycling, 175, 105825. https://doi.org/10.1016/j.resconrec.2021.105825

Sibaii, Mohamad El, Jose Granja, and Miguel Azenha. 2025. “An Open and Standards-Compliant Platform for Product Data Templates in Digital Construction.” Journal of Information Technology in Construction 30:679–710. doi: 10.36680/j.itcon.2025.028.

Suchek, N., Fernandes, C. I., Kraus, S., Filser, M., & Sjögrén, H. (2021). Innovation and the circular economy: A systematic literature review. Business Strategy and the Environment, 30(8), 3686–3702. https://doi.org/10.1002/bse.2834

Sun, Y., Rameezdeen, R., Chow, C. W., & Gao, J. (2025). Information sharing barriers of construction projects toward circular economy: Review and framework development. Buildings, 15(15), 2744. https://doi.org/10.3390/buildings15152744

Theißen, S., Höper, J., Drzymalla, J., Wimmer, R., Markova, S., Meins-Becker, A., & Lambertz, M. (2020). Using Open BIM and IFC to Enable a Comprehensive Consideration of Building Services within a Whole-Building LCA. Sustainability, 12(14), 5644. https://doi.org/10.3390/su12145644

Theißen, Sebastian, Jannick Höper, Reinhard Wimmer, Anica Meins-Becker, and Michaela Lambertz. 2020. “Suggestions for the Technical Integration of Life Cycle Assessment Data Sets of ÖKOBAUDAT into Building Information Modeling and Industry Foundation Classes.” Pp. 113–28 in Sustainable production, life cycle engineering and management.

Ting, H., Memon, M. A., Thurasamy, R., & Cheah, J. (2025). Snowball Sampling: A review and guidelines for survey research. Asian Journal of Business Research, 15(1), 1–15. https://doi.org/10.14707/ajbr.250186

Tomczak, A., Benghi, C., Van Berlo, L., & Hjelseth, E. (2024). Requiring circularity data in BIM with information delivery specification. Circular Economy, 1(2). https://doi.org/10.55845/rejy5239

Tomczak, A., Berlo, L. V., Krijnen, T., Borrmann, A., & Bolpagni, M. (2022). A review of methods to specify information requirements in digital construction projects. IOP Conference Series Earth and Environmental Science, 1101(9), 092024. https://doi.org/10.1088/1755-1315/1101/9/092024

Topraklı, A. Y. (2024). Enabling circularity in Turkish construction: a case of BIM-based material management utilizing material passports. Smart and Sustainable Built Environment. https://doi.org/10.1108/sasbe-05-2024-0199

usBIM: The solution for construction and infrastructure project management. (n.d.). Retrieved from https://www.accasoftware.com/en/bim-management-system

Vullings, Marcel, Satu Huuhka, Simon Wijte, Thijs Lambrechts, Justin Houtman, Marijn Landman, Emmi Salmio, Aapo Räsänen, Paul Jonker-Hoffrén, Inari Weijo, Jukka Lahdensivu, Erik Stenberg, Caroline Wedelsbäck, Tina Appelqvist, Kjartan Gudmundsson, Arlind Dervishaj, Helena Westerlind, Hernández Vargas José, Christoph Henschel, Jakob Fischer, and Dietmar Gottschling. 2024. “Best Practice Guidelines and Recommendations for Reuse-Optimised Deconstruction.” Zenodo. doi: 10.5281/zenodo.13828738.

Wieringa, R. J. (2014). Design Science Methodology for information systems and software engineering. Springer eBooks. https://doi.org/10.1007/978-3-662-43839-8

Xing, K., Kim, K. P., & Ness, D. (2020). Cloud-BIM Enabled Cyber-Physical Data and Service Platforms for Building Component Reuse. Sustainability, 12(24), 10329. https://doi.org/10.3390/su122410329

Zhu, Shiyao, and Haibo Feng. 2025. “Construction and Demolition Waste Circulation and Its Sustainability Performance in the Building Sector: Current Trend and Future Directions.” Engineering Construction & Architectural Management. doi: 10.1108/ecam-05-2024-0678.

Zima, K., & Mitera-Kiełbasa, E. (2022). Level of information need for BIM models: Australia, New Zealand and ISO 19650. Civil and Environmental Engineering Reports, 32(4), 1–3. https://doi.org/10.2478/ceer-2022-0041

[This page is left empty]

Appendix I - Selected Cased Study Elements

Based on the selected IFC objects, a representative set of IFC elements from the Willemspoort Zuid project's BIM model was selected for detailed enrichment. The selected elements, with their unique identifiers and brief descriptions, are presented below, providing foundational context for property application.

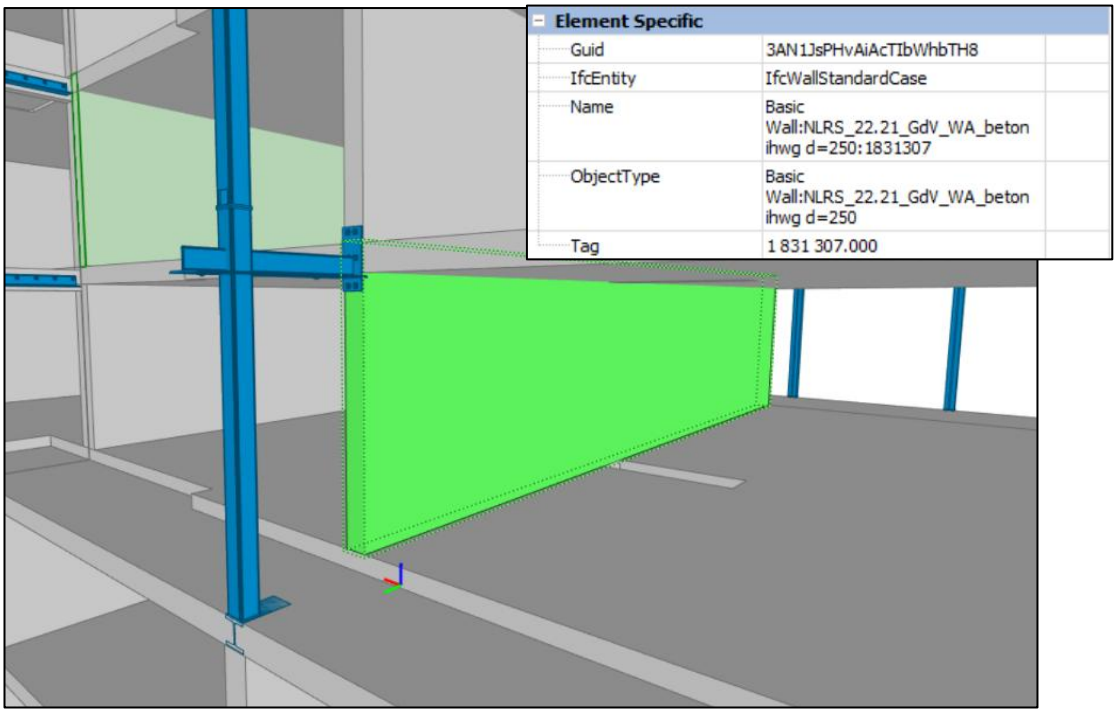


Figure 29 - IfcWallStandardCase - In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875)

In-situ Concrete Wall - This element is an in-situ cast concrete wall (250mm thick), with a C45/55 concrete class. This is a basic wall serving as an example. A steel element from the steel structure is linked to this specific wall.

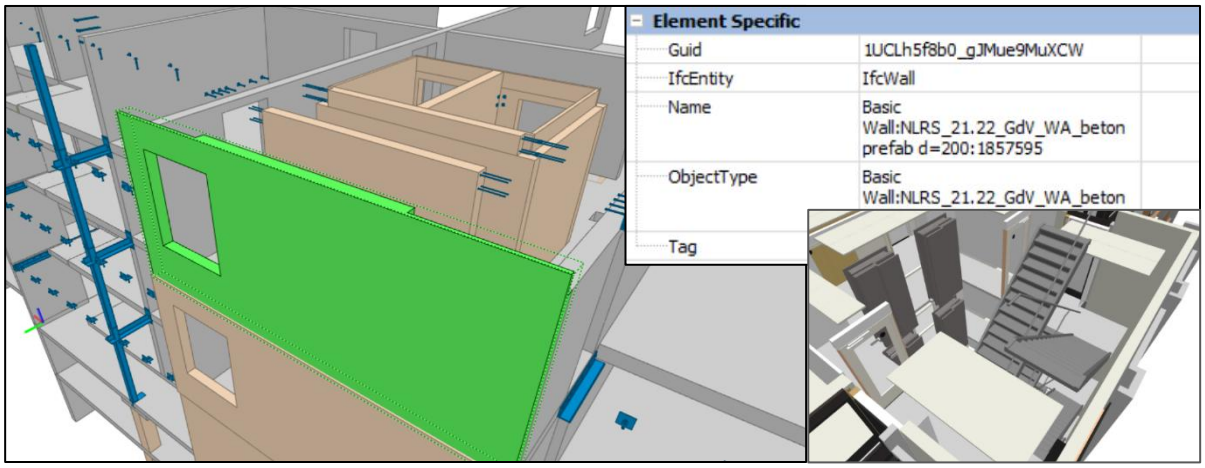


Figure 31 - IfcWall - Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)

Prefab Concrete Wall - This element represents a prefabricated concrete wall (200mm thick) with an integrated opening for a window frame. The wall is located on the facade side near the stairwell of the apartment complex. The choice of a prefabricated element is crucial to demonstrate properties related to standardization, modular disassembly, and the complexity of elements with built-in components (like a window opening).

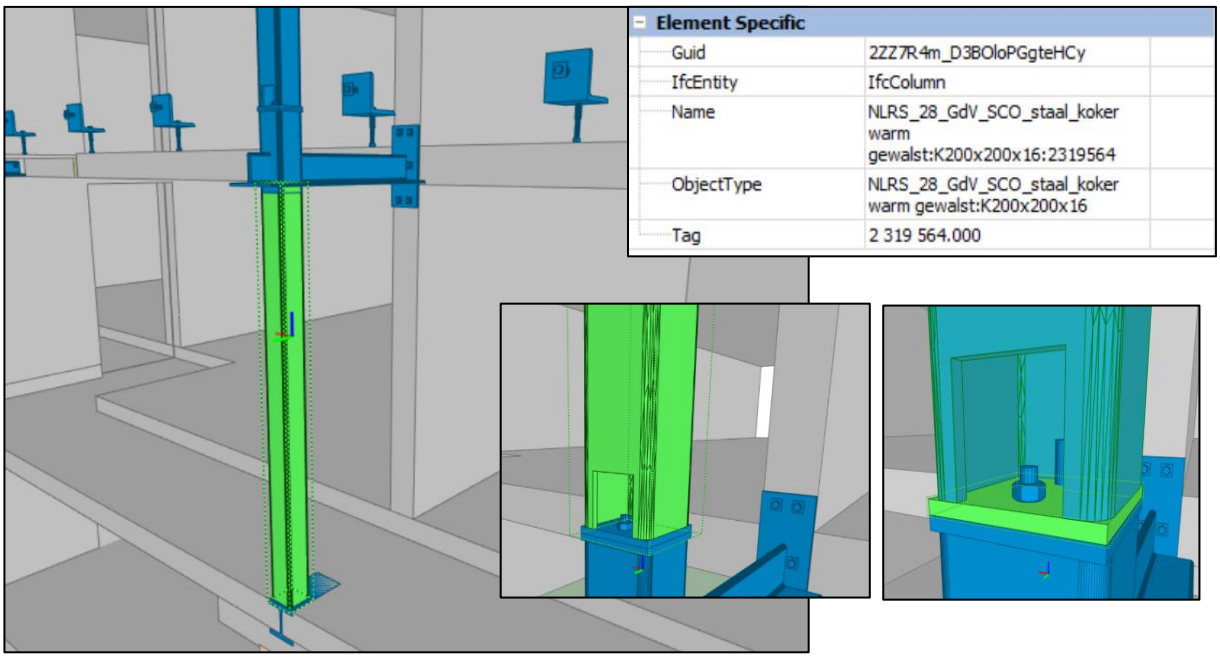


Figure 30 - IfcColumn - Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)

Hot-rolled Steel Hollow Section - This is steel hollow section column (K200x200x16) from the structural model. Steel columns are highly significant for circular construction due to their high reuse potential. This specific example was chosen because it is an element typically fastened with bolts, which directly relates to demonstrating 'Connection Type' properties and the ease of dismounting connections.

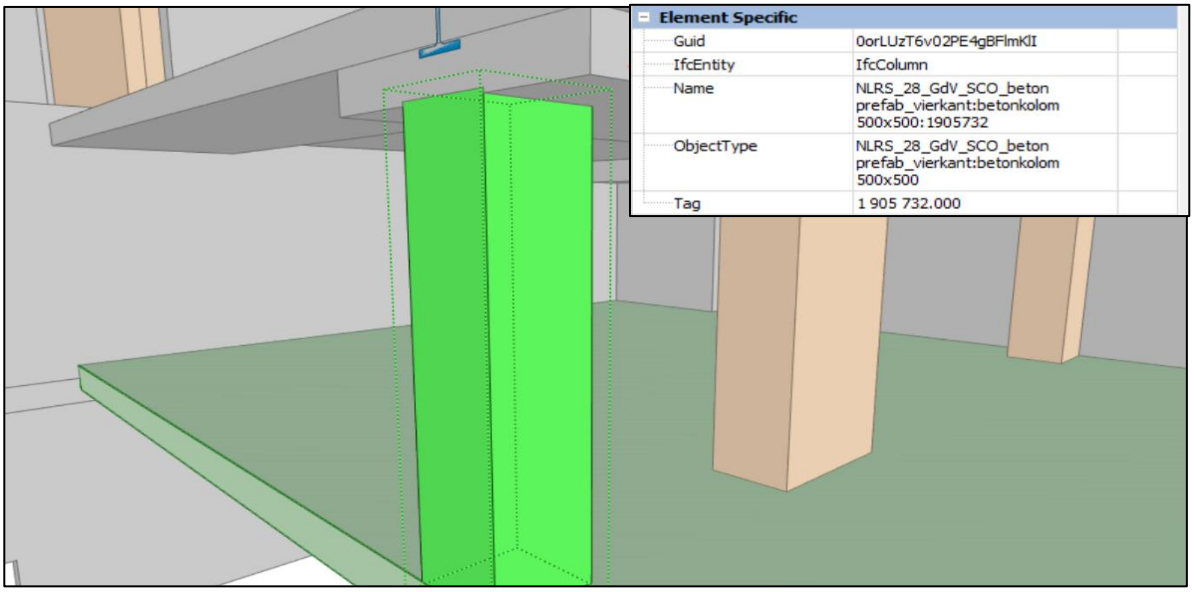


Figure 33 - IfcColumn - Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)

Prefab Concrete Column - This square prefabricated concrete column (500x500mm) is part of the main load-bearing structure and directly supports a concrete beam under a floor. As a prefabricated concrete element, it offers a contrast to the in-situ wall and the steel column, allowing for the exploration of properties related to fabrication, hoisting provisions, and the impact of connections with other concrete elements.

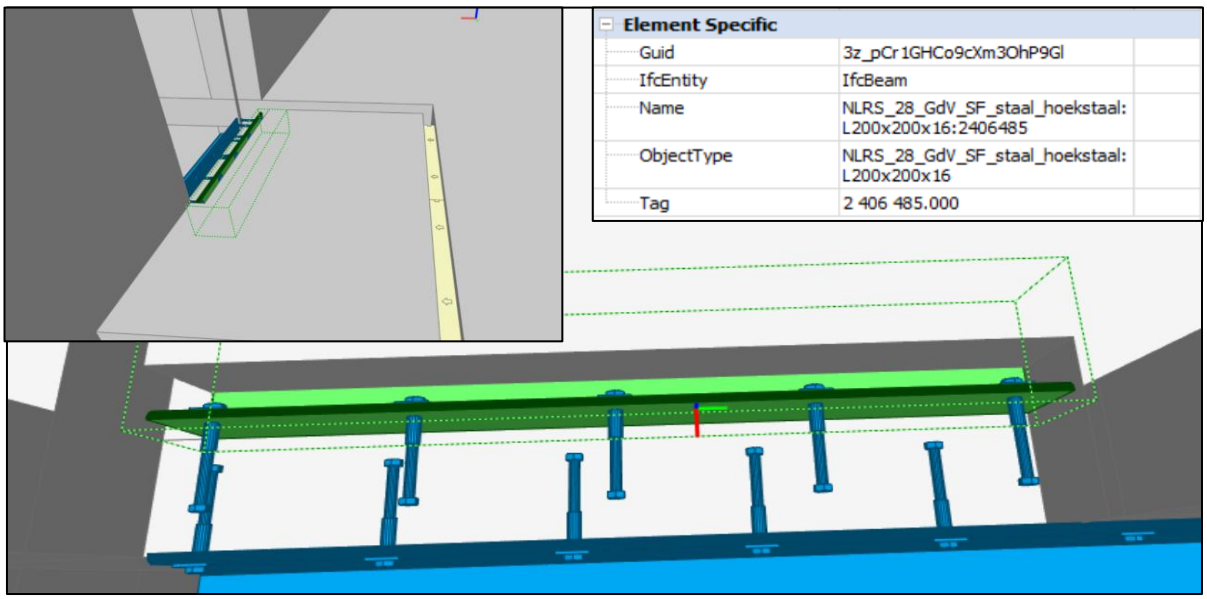


Figure 32 - IfcBeam - Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)

Steel Angel Profile - This is a steel angle profile (L200x200x16) functioning as a beam that supports a concrete floor. The profile is fastened using a DEMU through-coupling system. This system is specifically designed for mechanical connections of steel reinforcement bars in concrete structures, which introduces complex and specific disassembly properties.

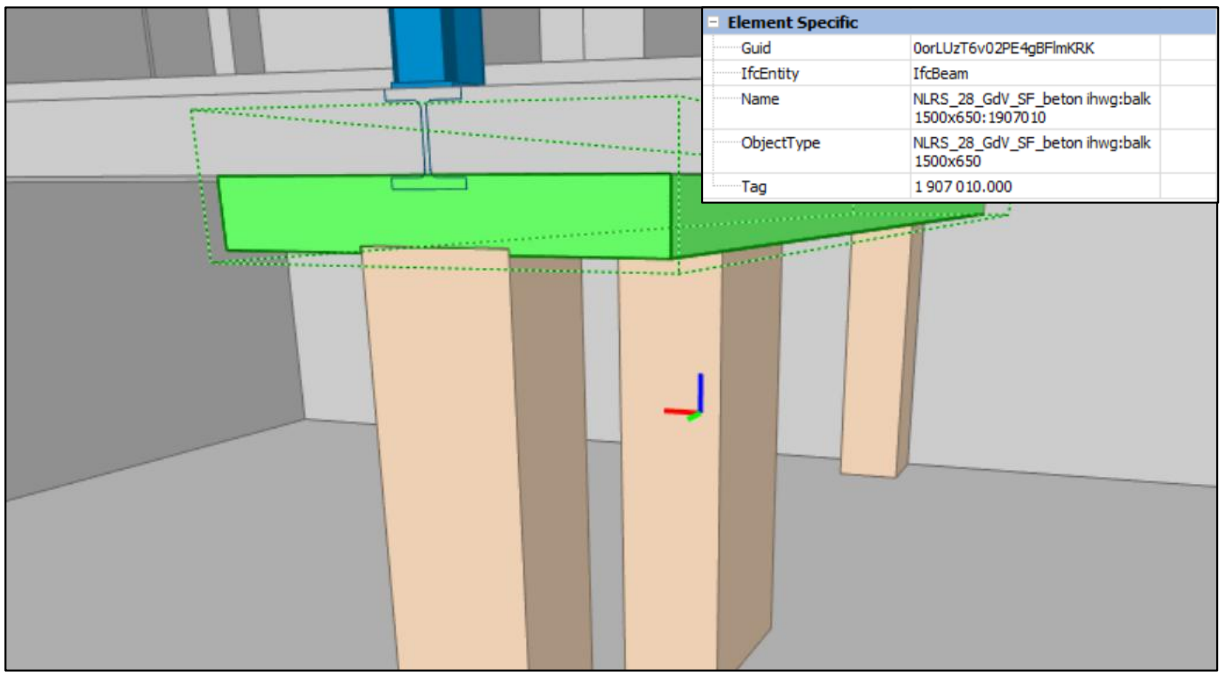


Figure 35 - IfcBeam - In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)

In Situ-Concrete Beam - This is an in-situ cast concrete beam (1500x650mm) directly supported by the prefabricated concrete column. The selection of this element allows for demonstrating properties relevant to large, massive concrete load-bearing elements, including their interaction with prefabricated components and considerations for their disassembly and reuse.

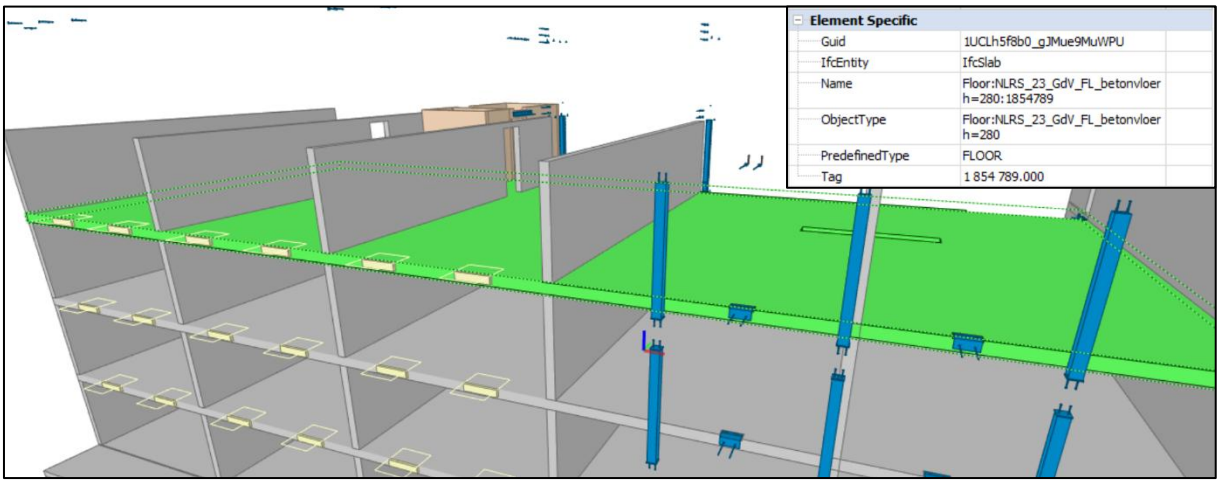


Figure 34 - IfcSlab - Concrete Floor (Floor: NLRS_23_GdV_FL_betonvloer h=280:1854789)

Concrete Floor - This element is a reinforced concrete floor slab (280mm thick). Floor slabs are extensive elements in a building and are representative for demonstrating properties related to their material condition, deflection (as an indicator of load history), and the challenges of their large-scale disassembly.

Appendix II - Semi-Structured Interview Guide Protocol

Phase / Section	Content / Script / Questions
1. Pre-Interview Preparation	Interviewer Checklist: ☐ Review research objectives and the "Foundational Property Set." ☐ Research the participant's professional background and expertise. ☐ Test all recording equipment (audio). ☐ Send a email to the participants with the five core questions and consent form.
2. Interview Introduction Script	(To be read at the start of each interview) "Good morning/afternoon, [Participant's Name]. Thank you for making time to speak with me today. This interview is part of my Master's thesis research at TU/e, which focuses on optimizing digital processes for the reuse of building components. The purpose of this interview is to gather your expert perspective on the data needed to make component reuse a practical reality. The interview should take about 30 minutes. It is confidential, and your personal information will be anonymized in the final report. To ensure I can accurately capture your insights, I would like to record the audio. Is that okay with you? Do you have any questions before we begin?"
3. Interview Questions	**Theme A: Introduction & Rapport Building (Approx. 5 mins)** 1. To begin, could you please briefly describe your current role and your experience with construction materials or digital workflows?

	Theme B: General Views on Circular Economy (Approx. 5 mins) 2. From your perspective, why is Circular Economy such a relevant topic? **Theme C: Core Data Requirements (Approx. 20 mins)** 3. In your experience, which properties of a structural component are most critical for determining if it can be reused? 4. When it comes to the physical disassembly of a building, which factors have the most impact on whether an element can be removed without damage? 5. If we want to include this reuse data in a BIM model, how would you suggest structuring it to be useful for someone like you? (Probes: A score, text, a link?) 6. In practice, what visible signs or characteristics do you look for to get a first impression of a component's suitability for reuse? (Probes: How reliable are these signs? When is formal testing needed?) 7. Looking beyond current practices, are there any new or unconventional types of data you believe should be tracked to better support reuse in the future? **Theme D: Closing Question (Approx. 5 mins)**

	8. Those are all the main questions I had. Do you have any more questions?
4. Closing Script	"Thank you again for your time and for sharing your valuable insights. This is really helpful for my research. Have a great day."
5. Post-Interview Actions	Interviewer Notes Template : Date & Time: ** Participant ID: ** Key Takeaways/Properties ** Surprising or Unexpected Insights: **

Appendix III - Interview Questions Justification

IQ	Aim of the Question	Justification / Relevance	Expected Responses (to reach the goal of the interview)
1.	To identify properties that are considered most relevant by experts when evaluating the reuse potential of (structural) building components.	This question is designed to explore which information professionals consider important for reuse assessments in practice. In addition, it helps validate findings from the literature and identify which properties (e.g. material type, damage, size) are commonly used in real-life engineering or demolition decisions. This contributes to RQ1 and RQ2 by providing input for improving/extending the properties list.	Mentions of common indicators/properties. Responses may confirm known properties or introduce new (overlooked) ones that may be relevant.
2.	To gain insight into physical or practical factors that influence disassembly feasibility and risk of damage.	This question focuses on real-world removal scenarios and helps identify what makes disassembly difficult or easy. It provides a practical perspective on reuse barriers that may not be available in the literature. The responses can lead to improvement or the addition of properties related to disassembly effort or risk. Supports RQ1 and RQ2.	Factors like dry vs. wet connections, embeddedness, weight, fragility, joint quality, or access limitations.
3.	To understand how reuse-related information should be formatted and structured to enable digital use and validation in BIM environments.	To explore expert opinions on how decommissioning and reuse-related information could be structured in a standardized, consistent way for use in BIM models. The aim is not only to gather suggestions for structuring properties (e.g. using enums, checklists, scales) but also to better understand how technical information can be made suitable for digital interpretation and validation (machine-readability). Insights from this question contribute to the thesis goal of developing EIRs that are practically usable in BIM workflows and compatible with tools such as IDS and bSDD.	Suggestions for standard options, structured value type. Reflections on what works best in practice or what causes confusion when using models.
4.	To understand how experts evaluate elements for reuse based on physical condition and observable characteristics.	Determining reuse suitability. It supports the development of new or improved properties that reflect condition assessment in practical settings. Supports RQ1.	Examples of visual checks like surface rust, hairline cracks, spalling, discoloration, and a discussion on the reliability of these signs versus the need for formal testing.
5.	To encourage open exploration of gaps in current standards and brainstorm..	This is an open-ended, exploratory question. It directly contributes to the innovative aspect of the thesis by seeking out new ideas not yet present in the literature.	New insights.

Appendix IV – Informed Consent Sheet for Expert Interviews

Information sheet for research project "[Thesis Case Study on Decommissioning and Reuse]"

1. Introduction

Eindhoven University of Technology (TU/e) invites you to take part in this research project which aim is to explore how structured data in Building Information Modeling (BIM) can support the reuse and decommissioning of structural building elements. The study seeks to identify which data attributes are essential for enabling decommissioning reuse. You receive this invitation because you are recognized as an expert in the field of structural engineering, materials science, or construction. For your participation, you will not be compensated.

Joining this research project is your choice. Your participation is completely voluntary and does not pose any physical, legal or economic risks. You are not obliged to answer questions you are uncomfortable with, and you can withdraw from the research at any time without explaining why. Declining or withdrawing will not have negative impact for you.

Before you decide, please read the following information to understand what the project is about, what we expect from you and how we handle your personal data. After reading, you can sign up by completing the attached form.

If you have questions, feel free to contact us (contact details below). You can also discuss this information with people you trust.

2. Who are we?

This research project is conducted by:

Technische Universiteit Eindhoven (TU/e) De Groene Loper 3 5612 AE Eindhoven	Data controller

How to contact us?

Personal TUe mail	j.c.e.m.v.d.eijnden@tue.nl
Privacy Operations	privacy@tue.nl
Data Protection Officer	dataprotectionofficer@tue.nl

3. What will taking part in the research project involve?

In the research project we will collect your personal data using the following methods:

- **Interview Recording:** With your consent, the interview will be recorded for accurate analysis.
- **Transcript Creation:** The recording will be transcribed, and your responses will be documented.
- **Pseudonymization:** Your name and any identifying details will be replaced with a code to ensure anonymity.
- **Storage:** The recordings and transcripts will be securely stored on a password-protected online cloud.
- **Data Usage:** Your insights will be used for academic research purposes in my thesis on BIM and reuse of structural elements.

4. What personal data from you do we gather and process?

We collect and process the following personal data which is necessary for the project purpose:

Category and type	Personal data	Purpose	Retention period
Contact data (regular personal data)	*Name, e-mail*	*To communicate with you and invite you to events*	*6 months after data collection*
Job profile (regular personal data)	*Job title, years of experience, name and location of employer*	*Analyze data concerning your experience*	*10 years after research is complete*

Your data is retained only for the time period as specified in the table. Keeping your data for this period helps us to comply with scientific principles, such as producibility and verification.

After this period, your personal data will be deleted or anonymized to ensure it can no longer be linked to you. Unless you explicitly agree to the use of your identifiable information in publications (for example your quotes or your name).

5. Stopping your participation and your rights

If you end your participation in the research we will not use your data anymore from that moment on.

For questions, ending your participation or complaints, please contact the researcher via the contact details as provided in the table under section 2.

For concerns or questions about the handling of personal data, you can e-mail the data protection officer as indicated in the table under section 2. You can also file a complaint with the Dutch data protection authority: the Autoriteit Persoonsgegevens.

You have the right to request access, rectification, objection, erasure or adaptation of your data. Submit your request through team Privacy Operations via the contact details as provided in the table under section 2.

6. Legal basis for processing your personal data

The TU/e processes your personal data to conduct scientific research, which is the university's public task as stated in article 1.3 of the Dutch Wet Hoger onderwijs en Wetenschappelijk onderzoek. The TU/e always follows the applicable codes of conduct for research integrity and the scientific standards when conducting research.

7. Who has access to your personal data?

Only authorized employees involved in the research have access to your personal data if this is necessary for their tasks. The authorized employees will keep your personal data confidential.

Other parties/processors that have access to the data are listed in the table below:

Party/processor	Why access?	Category	Processing within the European Economic Area?
Microsoft (Netherlands)	*Storage solution /* Recording of the interviews	*All Data*	*Yes*

TU/e has a suitable agreement with these parties to protect your personal data. We will not share your personal data with any other party, unless we are required to do so by law.

TU/e will process your personal data within the European Economic Area (EEA) by storing your data on a server inside the EEA. In addition, TU/e has implemented appropriate technical and organizational

measures to protect your personal data. These measures include using centrally managed and verified research- and storage tools.

8. Future research

During the research project, your personal data may also prove useful for new, socially important research. In such case, we would like to reuse your data for the new research. This will only happen if (1) your personal data is truly necessary, (2) the recognized ethical standards for scientific research are followed, and (3) the new research objectives align with the current research objectives. If your personal data is used in future research, we will take all reasonable steps to inform you about this. You can object to the use of your personal data for new research.

This research has been assessed and approved by the ethical committee of Eindhoven University of Technology.

***** Scroll down for the form *****

Consent form for participation by an adult

By signing this form, I confirm:

1. I have enough information about the research project from the separate information sheet. I have read it and I had the chance to ask questions, which have been answered to my satisfaction.

2. I take part in this research project voluntarily. There is no explicit or implicit pressure for me to take part in this research project and I understand I can stop my participation at any moment, without explaining why. I do not have to answer any question I do not want to answer.

3. I know my personal data will be collected and used for the research, as explained to me in the information sheet.

Furthermore, I consent to the following parts of the research project:

4. I consent to my personal data, answers or quotes I gave during the research, to be used by the researcher in publications and/or in presentations – without including my name.

   YES ☐ NO ☐

Name of Participant:	Name of researcher:
Signature:	Signature:
Date:	Date:

Consent form LR – Version 2.3 – August 2024

Appendix V - Detailed Thematic Analysis Results from Semi-Structured Interviews

Table 10 - Thematic Analysis Results

Interview ID	Code	Sub-Theme	Theme	Quote
ID1	[Insight] Need for Machine-Readable Data	Data Management	Challenges & Enablers	"I would suggest to use machine-readable, fixed options instead of free text."
ID1	[Insight] Prioritize renovation over disassembly	Assessment & Strategy	Challenges & Enablers	"Try to look at renovation first instead of full recycling or disassembly"
ID1	[Insight] Need for case studies to define categories	Assessment & Strategy	Challenges & Enablers	"Do case studies... Then you can see which categories you can make."
ID1	Need for initial data before testing	Assessment & Strategy	Challenges & Enablers	"If you have no info to start with, it's not worth doing tests..."
ID1	[Insight] Challenge of high-effort individual checks	Assessment & Strategy	Challenges & Enablers	"You don't want to have to check every single beam…it has to be efficient to avoid the high effort"
ID1	[Insight] Certainty for reuse drives information needs	Assessment & Strategy	Challenges & Enablers	"You want the highest possible certainty for reuse... And for that you want as much information as possible."
ID1	Material Type & Quality	Foundational Properties	Component-Specific Information Requirements	"The type and quality of the materials used in a component are important for determining its reuse potential."
ID1	Reinforcement Details	Foundational Properties	Component-Specific Information Requirements	"For concrete elements, the details of the internal reinforcement are essential information."
ID1	Presence of Openings	Foundational Properties	Component-Specific Information Requirements	"Any openings within an element need to be documented."
ID1	Geometric Tolerances	Foundational Properties	Component-Specific Information Requirements	"The tolerances of the original element are important for assessing its fit in a new structure."
ID1	Record of Modifications	Performance & History	Component-Specific Information Requirements	"If modifications are made, then how to guarantee or track changes?"
ID1	Change in Loading History	Performance & History	Component-Specific Information Requirements	"Any change in the building's function should be recorded, as this implies a change in the loading history of the components"
ID1	Load History (Proven vs. Design)	Performance & History	Component-Specific Information Requirements	"Proven load is different from the design load."
ID1	Manufacturer data for quality/warranty	Documentation & Provenance	Component-Specific Information Requirements	"It is important to identify who made it. This is because of quality controls and warrenty"
ID1	Connection Properties (Material, Strength)	Connection	Deconstruction Process and Strategy	"The demountability of a component is largely determined by its connections."
ID1	[Insight] Disassembly cost is driven by connections	Connection	Deconstruction Process and Strategy	"Most money is often from disassembling connections"
ID1	Connection Demountability	Connection	Deconstruction Process and Strategy	"It is important to know the properties of the connections, including the material type and strength."

ID1	Disassembly Score / Rating	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"A score or code of disassembly could be used to rate the ease of disassembly. Also the type disassembly and then giving a score from 1-100, for example."
ID1	Recommended Disassembly Technique	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"A recommendation for the specific technique that should be used for disassembly is valuable information."
ID2	Need for Original Production/Design Data	Documentation & Provenance	Component-Specific Information Requirements	"Everything from production must be added. Calculations, standards, stability systems, design choices ect."
ID2	Need to Identify Key Properties	Foundational Properties	Component-Specific Information Requirements	"Looking at a document and seeing which properties are important, like Concrete Quality."
ID2	Data Responsibility by Originator /supplier	Circular Economy & Business Models	Challenges & Enablers	"Imagine you have a prefab element, than the prefab supplier creates the detail and adds information. It is important that the correct party adds the correct information."
ID2	Importance of Geometry	Foundational Properties	Component-Specific Information Requirements	"The geometry of a component is important to know."
ID2	Importance of Material Properties	Foundational Properties	Component-Specific Information Requirements	"Material properties are important."
ID2	Need for Reinforcement Info	Foundational Properties	Component-Specific Information Requirements	"Reinforcement info is important for concrete elements. Mostly this is done by creating details, but there are companies that only add reinforcement to 3D-models. If this is done correctly you don't have to create details, as you can see it in the model."
ID2	Need for Detailed Connection Information	Connection	Deconstruction Process and Strategy	"Information about the connections themselves."
ID2	[Insight] Challenge: Modeling Multi-Material Connections	Connection	Deconstruction Process and Strategy	"In practice, you often have to look at two different models to understand the connections. Typically, there is a concrete model and a steel model. In many cases, the connections aren't modeled at all."
ID2	Need for Usage History	Performance & History	Component-Specific Information Requirements	"Also for reuse, what the life of an element was like during previous use."
ID2	[Insight] Testing is not currently viable without initial data	Assessment & Strategy	Challenges & Enablers	"It's not profitable now to perform tests when no information is available, since too many tests would have to be performed. In the future, tests might be performed in a way that is much cheaper and better."
ID2	Using Class Designations to infer properties	Foundational Properties	Component-Specific Information Requirements	"Concrete has a class designation (with compressive strength you immediately know many other properties)."
ID2	Using Material Standards to infer properties	Foundational Properties	Component-Specific Information Requirements	"The same case with reinforcing steel."
ID2	[Insight] Potential of AI for document interpretation	Data Management	Challenges & Enablers	"AI that can understand documents?"

ID2	[Insight] Challenge: Non-standard materials with standard classifications	Foundational Properties	Component-Specific Information Requirements	"A challenge exists with non-standard materials, like cement-free concrete instead of normal concrete, that may have the same classification but different properties."
ID2	Need for Classification and Standard (with year)	Documentation & Provenance	Component-Specific Information Requirements	"The classification and the specific standard, including the year, need to be documented."
ID2	Linking element history across projects (via IFC/Blockchain)	Documentation & Provenance	Component-Specific Information Requirements	"To track the history of a reused element, the IFC model of its original building should be linked to it, potentially using Blockchain for example."
ID2	Need for Proven Strength Data	Performance & History	Component-Specific Information Requirements	"The proven strength of an element must be known for reuse."
ID2	[Insight] Need for a long-term (50-year) building vision	Assessment & Strategy	Challenges & Enablers	"Focus on where we need to go. It must become standard that we think about what we will do with this building in 50 years."
ID2	[Insight] Value of linking PDFs for future-proofing	Documentation & Provenance	Component-Specific Information Requirements	"Linking a PDF document is valuable for future-proofing, as it may become machine-readable in the future even if it isn't now."
ID2	[Insight] Challenge: Data vs. Reality verification	Performance & History	Component-Specific Information Requirements	"Does the linked information also correspond with reality?"
ID2	[Insight] Challenge: Reusing composite prefab elements with embedded services	Design for Disassembly (DfD)	Deconstruction Process and Strategy	"In prefab, parts like insulation/water pipes/heating/installations are cast-in. This is a challenge for reusing the entire composite element."
ID3	[Insight] Value of long-term data archiving	Data Management	Challenges & Enablers	"And the archive that our IT department is now saying 'I want to get rid of it, we're going to throw everything away'. And then I said, 'oh, wait, stop.' I think there is a lot of valuable information in it that will be worth gold in about 30 years."
ID3	[Insight] Component guarantees limit reuse	Circular Economy & Business Models	Challenges & Enablers	"But the supplier of the hoisting anchors said, 'Yes, it's nice that you want to do that, but I actually only guarantee hoisting once. So during assembly and disassembly, I don't guarantee the strength of those hoisting anchors'."
ID3	[Insight] Proposal for a "data for reuse obligation"	Circular Economy & Business Models	Challenges & Enablers	"If you now have a warranty obligation, you should also have a data for reuse obligation, in one way or another, that you are going to arrange that."
ID3	[Insight] Lack of data leads to costly testing	Assessment & Strategy	Challenges & Enablers	"...otherwise they would have had to test each element individually... Yes, then the investment to do that becomes, especially at this moment, far too large."
ID3	Need for Strength Class	Foundational Properties	Component-Specific Information Requirements	"apart from what you already know, right? Shape and such from your 3D model, you need strength class, environmental class, and where your hoisting provisions are. And a bit about reinforcement?"
ID3	Need for Environmental Class	Foundational Properties	Component-Specific	"apart from what you already know, right? Shape and such from your 3D

			Information Requirements	model, you need strength class, environmental class, and where your hoisting provisions are. And a bit about reinforcement?"
ID3	Need for Reinforcement Geometry (not just quantity)	Foundational Properties	Component-Specific Information Requirements	"And not the reinforcement itself, like how many kilos per cubic meter are in it, but where which bar is located."
ID3	Need for Material Composition (including additives)	Foundational Properties	Component-Specific Information Requirements	"Then you also really want to know, if I am going to modify it or reuse it in a building, you also want to know what was in it."
ID3	Need for as-built performance data	Performance & History	Component-Specific Information Requirements	"what is often missing, and this is the information we do have in our archives, is what the actual functionality is. There is often a difference between what was requested and what we deliver..."
ID3	Need for Visual Condition Assessment (e.g., Cracks)	Performance & History	Component-Specific Information Requirements	"With concrete, it's especially important to look at what your reinforcement looks like. Is the reinforcement visible or not, you especially don't want that. Then you see, is there any cracking or not?"
ID3	Need for actual vs. theoretical deflection data	Performance & History	Component-Specific Information Requirements	"with the first use, the first construction, you have a theoretical deflection and a practical deflection. ... And in practice, that is 3-4 mm."
ID3	[Insight] Gap between specified requirements and actual performance	Performance & History	Component-Specific Information Requirements	"And what is functionally required versus what it functionally performs. And, I think there is a very big gap there."
ID3	Need for Hoisting Provision Locations	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"apart from what you already know, right? Shape and such from your 3D model, you need strength class, environmental class, and where your hoisting provisions are. And a bit about reinforcement?"
ID3	Use of a Detachability Score/Index	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"Are you familiar with the "Losmaakbaarheids Index" (Detachability Index)? ... It's a kind of grading where connections are assessed and they get a score from 0 to 1."
ID3	[Insight] Detailed data enables future modifications	Design for Disassembly (DfD)	Deconstruction Process and Strategy	"the moment you know where which reinforcement is located and what the strength class of your element is, you can also make an assessment of whether you can, for example, make your opening a bit larger."
ID3	Need for hazardous materials data	Foundational Properties	Component-Specific Information Requirements	"Asbestos is the best example... you want to know what was inside it."
ID4	[Insight] Demolition is driven by functional obsolescence, not structural failure	Circular Economy & Business Models	Challenges & Enablers	"The reason why we demolish them is that we don't want that building there anymore."
ID4	[Insight] CE addresses material waste from functional obsolescence	Circular Economy & Business Models	Challenges & Enablers	"All buildings are temporary... residential buildings last around 50 years, office buildings 20-30 years... We do not demolish them because of structural damage, but because we don't want that building there anymore. It's a huge waste of materials."

ID4	[Insight] CE as a strategy for resource efficiency and carbon reduction	Circular Economy & Business Models	Challenges & Enablers	"It's like you build something from Lego, and afterwards, if you want to build something else, you just throw it away and buy a completely new set. This is about waste reduction, more efficient use of resources, and carbon reduction."
ID4	Need for Storage Requirements	Design for Disassembly (DfD)	Challenges & Enablers	"If there is any specific requirement for storage, let's say it can be stored in a outside the stockyard, or it has to be internally stored."
ID4	Need for Dimensions and Weight for transport	Foundational Properties	Component-Specific Information Requirements	"before transportation, I think the most important thing that the dimensions... Also, the weight of element... this also has a direct impact on transportation."
ID4	Need for Component Age (re: concrete carbonation)	Foundational Properties	Component-Specific Information Requirements	"it would be good to know the age of the elements... The concrete chemically... protects them from corrosion, but this effect is gradually decreasing throughout the time."
ID4	Need for Physical State Assessment	Performance & History	Component-Specific Information Requirements	"The physical state of the element, whether it is damaged or not... if the element is damaged then how much it is damaged? Is it just a scratch or or bad practically kind of an assessment of of of the state of the Element."
ID4	Need for Load History (especially for fatigue)	Performance & History	Component-Specific Information Requirements	"if there was fatigue loading like in bridges. Then it is also important to know the the load history."
ID4	Need for Visual Damage Assessment (Cracks, Corrosion)	Performance & History	Component-Specific Information Requirements	"I would look for visible damages, cracks, corrosion, this kind of stuff."
ID4	Need for Original Shape / Initial Imperfections data	Performance & History	Component-Specific Information Requirements	"we will not know that this was the original shape or this is some kind of permanent deformation that occurred. During its lifetime."
ID4	Need for Material Certificates (for legal/insurance purposes)	Documentation & Provenance	Component-Specific Information Requirements	"what is not included for example is. Material certificates... These certificates are. Important from a legal point. Point of view. Because. Often with the reuse structures the the question of insurance comes up, and usually the insurers require this kind of certificate."
ID4	Need for Connection Accessibility	Connection	Deconstruction Process and Strategy	"We should provide accessibility that all these connections can be easily accessible."
ID4	Need for Ease of Retrieval Data	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"I would say the ease of retrieval and the and the damage that is kind of important."
ID4	[Insight] Importance of post-demolition handling	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"there are also effects during afterwards which are imposed on the elements like during lifting manipulation, the transportation stockage."
ID4	Need for required disassembly tools	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"if we could. Somehow include what kind of tools required for this assembly."
ID4	Need for Disassembly Sequence	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"in which order. The elements should be disassembled because... We not we do not necessarily know in which order these were built."

ID4	Need for Predetermined Cut Lines	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"If it has to be cut somewhere. Would be good to know where. Maybe already in the design process. Some predetermined cut lines could be included."
ID4	[Insight] Disassembly time/effort is a key factor	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"timber structures... sometimes they have thousands of screws and it just takes too much time to take them all all the way."
ID4	Need for data on replaceability of vulnerable parts	Design for Disassembly (DfD)	Deconstruction Process and Strategy	"If we foresee already in the design that some elements might be damaged... Then. These elements should be easily replaceable."
ID4	[Insight] Value of Design for Disassembly	Design for Disassembly (DfD)	Deconstruction Process and Strategy	"the best. If it was already designed for disassembly."
ID5	[Insight] Data loss destroys the economic value of reusable elements	Data Management	Challenges & Enablers	"The moment you have the data of the elements. That makes those elements valuable. If you lose that data... it costs you so much effort to retrieve that data that it is often not worth it."
ID5	[Insight] Storing calculated capacity is less useful than raw properties	Assessment & Strategy	Challenges & Enablers	"it... doesn't make direct sense to write down what the resistance is, the force capacity of an element."
ID5	Need for Geometry and Material Properties	Foundational Properties	Component-Specific Information Requirements	"Ja ja, eigenlijk...., Het is heel simpel. Geometrie de materialen eigenschappen." (Yes, yes, actually Jurgen, it's very simple. Geometry, the material properties.)
ID5	Need for Reinforcement Description	Foundational Properties	Component-Specific Information Requirements	"bij beton is eigenlijk ook de wapening heel belangrijk. Als ik niet weet wat voor wapen in een element zit, dat heb ik er niks aan." (with concrete, the reinforcement is also very important. If I don't know what kind of reinforcement is in an element, I have nothing.)
ID5	[Insight] Foundational data (geometry, materials) is the most critical	Foundational Properties	Component-Specific Information Requirements	"Het begint altijd bij de de getalletjes die je invoeren. En, Dat is de afmetingen en de materialen eigenschappen." (It always starts with the numbers you enter. And that is the dimensions and the material properties.)
ID5	[Insight] Load history data is likely superfluous for buildings	Performance & History	Component-Specific Information Requirements	"voor een gebouw vind ik het eigenlijk overbodige data. En, Dat is, je gaat heel veel data creëren. Bij vervolgens niks meer mee doet." (for a building I actually find it superfluous data. And, that is, you are going to create a lot of data that you subsequently do nothing with.)
ID5	Need for post-demolition damage/crack screening	Performance & History	Component-Specific Information Requirements	"Je moet toch wel even een een scan doen op schade of scheurvorming en dergelijke dingen?" (You still have to do a scan for damage or crack formation and such things, right?)
ID5	[Insight] Not all cracks are critical	Performance & History	Component-Specific Information Requirements	"Soms zijn scheur totaal geen probleem en soms zijn scheuren zodanig, zegt Van ja, Het is niet meer te te gebruiken op een verantwoorde manier." (Sometimes cracks are no problem at all and sometimes cracks are such that you say, 'Yes, it can no longer be used in a responsible manner'.)

ID5	Need for Manufacturing Date and Original Specifications	Documentation & Provenance	Component-Specific Information Requirements	"Als je weet wanneer iets van maakt is en welke specificatie daaraan toegekend is, kun je dan vervolgens normatief voldoende halen?" (If you know when something was made and which specification was assigned to it, you can then subsequently achieve normative sufficiency.)
ID5	Need for Connection Details	Connection	Deconstruction Process and Strategy	"Als je dan toch gaat opslaan bent, kun je ook gewoon de details opslaan van de verbindingen waaruit blijkt hoe het gedemonteerd kan worden." (If you are going to store it anyway, you can also just store the details of the connections which show how it can be dismantled.)
ID6	[Insight] BIM limitation: properties apply to the whole element, not specific faces/parts	Data Management	Challenges & Enablers	"in BIM, at least in the current BIM, you can assign a value to the whole element, but not to one side, top side, bottom side? That's not possible."
ID6	Need for a maintained database including engineering, delivery, and assembly data	Data Management	Challenges & Enablers	"I think that especially the engineering part and the delivery/assembly part, you really have to make that part of that database. Yes, everyone will be happy about that, and also keeping it updated."
ID6	[Insight] The data/model must be maintained throughout the building's life (living digital twin)	Data Management	Challenges & Enablers	"the moment you go and look in reality and you see, for example, crack formation. Yes, that is an indication."
ID6	[Insight] The concept of a maintenance/management model that is updated by the owner	Data Management	Challenges & Enablers	"We actually call it the maintenance and management model, right? So that means that the owner takes over a model after construction and actually mutates it."
ID6	[Insight] The market is still searching for a standard approach	Circular Economy & Business Models	Challenges & Enablers	"you just notice that the whole market is still very much searching, right? Some claim to have an answer."
ID6	[Insight] Business models (private ownership, short-term investors) hinder long-term data maintenance	Circular Economy & Business Models	Challenges & Enablers	"In residential construction it is very different with private buyers... Large investors neither, because they hold it for 10 years and sell it again, so it is less common there."
ID6	[Insight] CE is necessary due to finite resources	Circular Economy & Business Models	Challenges & Enablers	"Everything is finite, right? I think we need to be very careful with our resources... reuse is much more interesting. It will run out one day."
ID6	[Insight] CE requires a cultural shift away from the preference for 'new'	Circular Economy & Business Models	Challenges & Enablers	"I think people are still very attached to new things being good, but used things can be just as good... It's a real shift in mindset."
ID6	[Insight] Reuse starts with a 'shopping list' of required properties	Assessment & Strategy	Challenges & Enablers	"You have to make a kind of shopping list. And it's not just about geometry, but also about... it also has to do something acoustically, or not at all."
ID6	[Insight] Provide raw data/tools for future assessment, not just final answers	Assessment & Strategy	Challenges & Enablers	"actually you should provide the tools, so that the person at that time can assess it themselves. I think that is the most convenient."
ID6	Need for all design parameters (structural, building physics, etc.)	Foundational Properties	Component-Specific Information Requirements	"I think that actually all design parameters, whether they are structural or non-structural, building physics or whatever, should actually be in that model to make it reusable."

ID6	Need for 'best before' date / design life data	Foundational Properties	Component-Specific Information Requirements	"the only thing that I think is important is a kind of 'best before' date, right? You also have construction that is calculated for a reference period of normally 50 years."
ID6	Need for modeled reinforcement, especially at connections	Foundational Properties	Component-Specific Information Requirements	"reinforcement is actually not modeled, sometimes by a supplier at the element level, yes, but the connections are then in principle never modeled... that is actually very useful information."
ID6	Need for as-built vs. as-designed data	Performance & History	Component-Specific Information Requirements	"There are requirements. For a structure, these are structural requirements, and then of course there is also a difference between what you calculate... and what you ultimately put in... where, of course, in principle what you put in is more interesting for reuse than the calculation."
ID6	[Insight] Design life is a reference, not an absolute expiry date	Performance & History	Component-Specific Information Requirements	"you actually calculate everything with a reference period of 50 years, but it's not that it no longer complies after 50 years and one day."
ID6	Need for original design assumptions (e.g., loads)	Performance & History	Component-Specific Information Requirements	"suppose I have calculated a floor and it is used in 15 years, then I think it is important to know what my starting points were for that floor calculation, right? So what fire load can it handle?"
ID6	Need for visual inspection for damage indicators (e.g., cracks)	Performance & History	Component-Specific Information Requirements	"the moment you go and look in reality and you see, for example, crack formation. Yes, that is an indication."
ID6	Need to link as-built/production data to the model	Documentation & Provenance	Component-Specific Information Requirements	"make sure that they are added or linked to the BIM. I think that is super important... make sure that the final production data... is linked in one way or another."
ID6	[Insight] A standardized coding system for connection types is needed	Connection	Deconstruction Process and Strategy	"if someone ever maps that out and attaches a code to it... Can you code it? Look, it's about... How you detach it depends on how it's attached. Right?"
ID6	[Insight] On-site modifications (like cutting) are practical but hard to pre-define	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"what you can also do is just put a saw in it during the day, then that hollow core slab becomes a bit shorter than it once was. But you see it's still usable, it's much easier. This kind of thing cannot be recorded, of course."
ID7	[Insight] Long-term data accessibility and file format obsolescence is a risk	Data Management	Challenges & Enablers	"The question is, of course, what happens to all those BIM models... can you still open those models in 30 years? Is it all still supported?"
ID7	[Insight] CE is a key strategy for climate change mitigation	Circular Economy & Business Models	Challenges & Enablers	"Production is not good for the climate... I think construction accounts for 40% of CO2 emissions. That is a very important aspect."
ID7	[Insight] CE prevents the destruction of capital value in existing buildings	Circular Economy & Business Models	Challenges & Enablers	"It is also a lot of capital loss. Ultimately, we build something and tear it down 30 years later, while many buildings still have a lot of quality and life from a technical perspective."
ID7	[Insight] CE can enhance the aesthetic character of buildings	Circular Economy & Business Models	Challenges & Enablers	"I think it can also bring a lot of character to buildings when you reuse materials, that you start to think very differently about how you design with those materials."

ID7	Need for Location Data (for local sourcing)	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"indeed the location where it is, because you can get it from the other side of the country... you would actually want to have a kind of range so you can also search... within a range of 50 kilometers"
ID7	[Insight] Logistics and availability information are major bottlenecks	Circular Economy & Business Models	Challenges & Enablers	"I think logistics might be the biggest bottleneck... how do you ensure that everyone knows what is available?"
ID7	[Insight] Need for a central, government-facilitated platform	Circular Economy & Business Models	Challenges & Enablers	"what is mainly missing now is a central tool and actually, you want the government to facilitate that."
ID7	[Insight] Storage is a problem; reuse requires a destination project	Assessment & Strategy	Challenges & Enablers	"then there should actually already be a project where it can be reused, because storage is often also a problem."
ID7	Need for Dimensions, Strength Class, and Material Type	Foundational Properties	Component-Specific Information Requirements	"But yes, in the end, it's of course dimensions, strength class, what kind of material is it, material type, what else?"
ID7	Need for designated reuse scenario	Foundational Properties	Component-Specific Information Requirements	"you can ask yourself, can you reuse everything? With steel too, isn't it better to melt it down and reuse it in a new profile? Yes, also the, maybe the type of reuse or the way of reusing."
ID7	[Insight] Deviation between as-designed and as-built is a key challenge	Performance & History	Component-Specific Information Requirements	"And then the big question remains, did they do the same thing on the construction site as what we have drawn?"
ID7	Need for a unique ID / Material Passport	Documentation & Provenance	Component-Specific Information Requirements	"you can't just assume it's good. So in the end you get a kind of ID passport for every building material."
ID7	Need for Quality Control / Assurance	Documentation & Provenance	Component-Specific Information Requirements	"you can't just assume it's good... That it also has that strength class, for example... that you at least do a kind of quality control."
ID7	Need for Connection Type and Fastener Information	Connection	Deconstruction Process and Strategy	"Connections, connections. And also the fasteners. If you look at wooden beams... if there are all kinds of nails in them, then you can't saw them well again."
ID7	Need for Disassembly Labor/Effort data	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"So I think that in the end, factors that are very decisive are how labor-intensive it is and what kind of connections you make."
ID7	Need for Information about Handling	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"it's also about how you can pick up and move elements again."
ID7	[Insight] Modularity increases reusability	Design for Disassembly (DfD)	Deconstruction Process and Strategy	"if they are all single, unique elements, so not very modular, how easy is it then to make something with them again?"
ID8	[Insight] Lack of reliable as-built archives	Data Management	Challenges & Enablers	"My experience is that I have yet to come across the first good archive of a building, right? So if you are going to work with existing buildings, you first want to have as much good information as possible about that building."
ID8	[Insight] Data degrades over the building lifecycle	Data Management	Challenges & Enablers	"you have that original design information, but it is partly outdated."

ID8	[Insight] Cost of data management vs. cost of investigation	Data Management	Challenges & Enablers	"the question is whether, so to speak, that effort outweighs the investigations you have to do... at the moment you start working with the building again."
ID8	[Insight] Economic viability is a major barrier (cost of new vs. reuse)	Circular Economy & Business Models	Challenges & Enablers	"New materials are still too cheap, actually, to make reuse and circular use very interesting and clients therefore always find it... a hassle, you know."
ID8	[Insight] Prioritize high-impact (environmental/economic) materials	Assessment & Strategy	Challenges & Enablers	"I think you mainly look at where the environmental impact is, but also where the money is, right?"
ID8	Need for on-site verification (e.g., cover measurements)	Assessment & Strategy	Challenges & Enablers	"they then say yes, but I really want us to do some cover measurements and that I know how much cover is on the reinforcement"
ID8	Material-Specific Requirements	Foundational Properties	Component-Specific Information Requirements	"Look, you have a... If I think about a timber structure, then that is different again than for a concrete structure, right?"
ID8	Need for Strength Class	Foundational Properties	Component-Specific Information Requirements	"what strength, as for example with a timber structure, what strength class. Does the wood have..."
ID8	Need for Concrete Quality	Foundational Properties	Component-Specific Information Requirements	"...or what is the concrete quality?"
ID8	Need for Reinforcement Info	Foundational Properties	Component-Specific Information Requirements	"How much reinforcement has been applied?"
ID8	Need for Reinforcement Cover	Foundational Properties	Component-Specific Information Requirements	"What is the cover on the reinforcement?"
ID8	Degree of Assembly (system vs. mono-product)	Foundational Properties	Component-Specific Information Requirements	"is it an integrated product or is it a system or is it just a mono-product?... the degree of assembly is then actually... of importance."
ID8	Need for Condition and Performance Data	Performance & History	Component-Specific Information Requirements	"Ultimately, condition and performance are therefore important, right?"
ID8	Need for a Formal Condition Assessment (NEN 2767)	Performance & History	Component-Specific Information Requirements	"the condition is actually... about whether there are defects... defined in the NEN2767."
ID8	Need for Fire Resistance Data	Performance & History	Component-Specific Information Requirements	"If I then think further about fire resistance, then you would actually also want to know something about... the fire resistance of the material"
ID8	[Insight] As-designed vs. As-built Data is Crucial	Performance & History	Component-Specific Information Requirements	"Is it something that was designed, but it is also always the question if it was made as it was designed, right? So the question is also, is this information... derived from design information or... based on execution information?"
ID8	Visual Condition triggers further investigation	Performance & History	Component-Specific Information Requirements	"based on... the defects you see in a building... the moment you see many defects in the condition... then you have to become suspicious and then you have to start investigating"

ID8	Need for Detachability Information	Connection	Deconstruction Process and Strategy	"And the detachability of components itself is of course also an important factor"
ID8	Connection Type (wet vs. dry)	Connection	Deconstruction Process and Strategy	"Yes, dry connection, wet right? Yes yes yes, certainly that is of course also important."
ID8	Contribution to overall stability	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"then you might want to know to what extent this component contributes to stability, to overall stability"
ID8	Need for Disassembly Sequence	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"then there is a sort of sequence in the dismantling of your elements."
ID8	Need for Disassembly Instructions	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"And if you also know how to dismantle it, where you can grab it, that is also of importance again."
ID8	[Insight] Need for product-specific knowledge/equipment for disassembly	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"Because that particular party simply had too little knowledge of how that product and that system works."
ID8	[Insight] Decoupling of building layers	Design for Disassembly (DfD)	Deconstruction Process and Strategy	"to distinguish between the different layers you have, right? So that is actually, the decoupling of layers is of course a nice aspect, so to speak."
ID9	Need for Material Quality (Steel)	Foundational Properties	Component-Specific Information Requirements	"For a steel column, you would want to know the material quality, so the steel strength class."
ID9	Need for Concrete Quality	Foundational Properties	Component-Specific Information Requirements	"You would want to know the strength class of the concrete."
ID9	Need for Reinforcement Quantity	Foundational Properties	Component-Specific Information Requirements	"You would also want to know how much steel has been poured in [the concrete]."
ID9	Need for Finished Surface Specification	Foundational Properties	Component-Specific Information Requirements	"What kind of finishes have been applied? In the past, much steel was treated with a coating containing chromium 6... that is quite interesting."
ID9	Need for Material Properties Documentation	Foundational Properties	Component-Specific Information Requirements	"You would want to know the material qualities, the quality of the steel applied or the concrete."
ID9	Need for Original Production Drawings	Documentation & Provenance	Component-Specific Information Requirements	"You would actually like to have the calculation and the drawing, and then the certificate of that element."
ID9	Need for Technical Specifications (from tenders)	Documentation & Provenance	Component-Specific Information Requirements	"All those technical requirements that used to be described in the specifications, you would actually want to have in the BIM model now."
ID9	Need for As-Built Documentation (Current State)	Documentation & Provenance	Component-Specific Information Requirements	"You would actually want to model as much as possible 'as-built'."
ID9	Need for Material Certificates	Documentation & Provenance	Component-Specific Information Requirements	"You would actually like to have the calculation and the drawing, and then the certificate of that element."
ID9	Need for Detailed Connection Information	Connection	Deconstruction Process and Strategy	"Often, connections are not always so detailed in a BIM model."
ID9	Need for Specific Disassembly Details	Connection	Deconstruction Process and Strategy	"You would want to know the way it's fastened, so you can see how to take it apart this way or a certain order."

ID9	[Insight] Design for Demountability as a Trend	Connection	Deconstruction Process and Strategy	"You see that it's also a trend that buildings are increasingly designed as demountable buildings."
ID9	[Insight] Cost of Detailed Modeling (Time/Money)	Connection	Deconstruction Process and Strategy	"It could be a recommendation to model more detailed, but that also costs a lot of time and money."
ID9	[Insight] BIM as Central Hub for Information	Data Management	Challenges & Enablers	"This model should at least be the central place where everything is linked, where you can find all information through that BIM model."
ID9	[Insight] Market Lacks Standardized Modeling for Reuse	Data Management	Challenges & Enablers	"You see that it often doesn't happen, and what you also see in steel construction is, then a Tekla model is very often made... it stops at some point with 3D modeling where the producers no longer need it for a product."
ID9	[Insight] Digital Archive Improvement	Data Management	Challenges & Enablers	"You would then do it to, for example, have your archive drawings better digitally organized."
ID9	[Insight] Archive Quality Determines Research Effort	Data Management	Challenges & Enablers	"The quality of the archive information is quite decisive for how much work we still have to do on research."
ID9	[Insight] Digitalization of Legacy Data	Data Management	Challenges & Enablers	"You would actually want to digitalize that [old technical descriptions]."
ID9	[Insight] Information Layers with Zero Thickness	Data Management	Challenges & Enablers	"We sometimes use objects with zero thickness, so actually just a kind of information layer on, for example, walls or floors, to indicate the fire resistance between spaces."
ID9	[Insight] Need for Interface Information (0mm thick elements)	Data Management	Challenges & Enablers	"You could, for example, make a zero-millimeter-thick digital sheet between them, and that sheet then actually describes how those two connecting elements are attached to each other, good or bad?"
ID9	[Insight] Disassembly Labeling/Scoring	Disassembly Logistics & Planning	Deconstruction Process and Strategy	"You could label them as detachable or not detachable, or semi-detachable. You could give them a certain value or an object code or a color, so you can easily recognize that."
ID9	[Insight] Need for Client Commitment for Reuse	Circular Economy & Business Models	Challenges & Enablers	"It is very important that the initiator of the building... really wants reuse. They have to support it."
ID9	[Insight] Stricter Regulations Drive Reuse	Circular Economy & Business Models	Challenges & Enablers	"Regulations regarding material use are becoming stricter, and that also stimulates reuse... You are almost forced as a market to reuse more."
ID9	[Insight] Financial Viability Hinders Reuse (Costs vs. New)	Circular Economy & Business Models	Challenges & Enablers	"Processing costs are substantial, and because of that, the financial business case might not look as good... then it's too expensive."
ID9	[Insight] Warranty Issues with Reused Components	Circular Economy & Business Models	Challenges & Enablers	"The warranty that is currently in the chain is also a point of attention... a main contractor is often responsible for a certain period for the quality of the building... and if that supplier then says, yes, I'm going to hoist it myself... but if someone messes with it afterwards, then I don't have full control, so my warranty expires."
ID9	Need for Material Quantities	Foundational Properties	Component-Specific Information Requirements	"How much steel has been poured in [the concrete], because you can't see that from the outside."

ID9	Need for Load-Bearing Capacity Information	Technical & Structural Properties	Component-Specific Information Requirements	"What kind of floor load such an element has, that is very valuable information. If you don't have that, you immediately have to start a test program."
ID9	Need for Surface Finishes Information	Foundational Properties	Component-Specific Information Requirements	"What kind of finishes have been applied... I think that is interesting."
ID9	[Insight] Standardized Modeling for Archives/Reuse	Data Management	Challenges & Enablers	"It doesn't have to cost much more time, but you would do it to, for example, have your archive drawings better digitally organized."
ID9	[Insight] Return Guarantee by Manufacturers	Circular Economy & Business Models	Challenges & Enablers	"It might be interesting when producers, for example, have to give a return guarantee, so they will have to take back their own goods 30 years later. Because then they suddenly want to know what they are picking up again, because then they want to sell it again."
ID9	[Insight] Building as Temporary Storage	Circular Economy & Business Models	Challenges & Enablers	"You could also see a structure like that. It's a temporary storage place. It's a building, but yeah, that structure has a lifespan of about 50 years or so, whether it's in one or four buildings during that time or in one building. That doesn't really matter."

Appendix VI – Practice-Based Properties and Validation Against Literature

*Note on "Existing in Literature?":

- **Yes:** The interview-derived property is directly and clearly covered by an property in the Foundational Property Set.
- **Partial Match:** The interview-derived property is a more specific instance or a practical application of a broader concept found in the Foundational Property Set.
- **No:** The interview-derived property is not explicitly identified in the Foundational Property Set.
- **New:** New interview-derived property that is not covered in the literature.

Table 11 - Practice-Based Properties

Interview-Derived property	Description (Based on Expert Input)	Relevant Interview Codes (Examples)	Existing in Literature?	Corresponding Literature Property (if applicable)
Unique ID / Material Passport	A unique identifier for the component, often linked to a digital material passport, for traceability and life-cycle tracking.	"Need for a unique ID / Material Passport"	**Yes** (Banihashemi et al., 2024; De Wolf et al., 2024; Kuzminykh et al., 2023; Xing et al., 2020; Mercado Siles, 2020; Hradil et al., 2020)	Unique Component ID
Manufacturer Details	Name, contact information, and other relevant details of the original manufacturer of the component or material.	"Manufacturer data for quality/warranty"	**Yes** (Tomczak et al., 2024; Hradil et al., 2020)	Manufacturer Details
Material Type & Quality	Details on the type and specific quality (e.g., concrete strength class) of the component's material, crucial for its structural re-evaluation and reuse potential.	"Material Type & Quality" , "Concrete Quality" , "Material Properties" , "Need to Identify Key Properties" , "Material-Specific Requirements" , "Need for Strength Class"	**Yes** (Akanbi et al., 2019; Rao et al., 2025; Topraklı, 2024; Hradil et al., 2020; Charef, 2016)	Material Type , Material Properties , Structural Integrity / Grade
Material Composition (including additives)	A detailed breakdown of all materials and substances, including any additives, used in a product or composite. For concrete, this includes specific types of cement, aggregates, water, and chemical admixtures and their proportions.	"Need for Material Composition (including additives)"	**Partial Match** (Akbarieh, 2023; Tomczak et al., 2024; Kładź & Borkowski, 2025; buildingSMART, 2020)	Material Composition
Original Shape / Initial Imperfections	Data describing the original, as-manufactured shape and any initial imperfections of an element, to distinguish from deformations occurring during its lifetime.	"Need for Original Shape / Initial Imperfections data"	**Yes** (Mercado Siles, 2020; Rao et al., 2025; Xing et al., 2020)	(None directly comparable in Foundational Set)
Component Age (re: concrete carbonation)	The date of original manufacturing or installation, specifically noted for its relevance to material degradation processes like concrete carbonation.	"Need for Component Age (re: concrete carbonation)"	**Yes** (Topraklı, 2024; Tomczak et al., 2024; Akbarieh, 2023)	Age / Construction Date
Classification and Standard (with year)	The official classification system (e.g., concrete class designation) and the specific standard (including its year of publication) to which the material or component adheres. This information provides immediate insight into inherent properties, ensuring compliance with original design and manufacturing regulations.	"Need for Classification and Standard (with year)" , "Using Class Designations to infer properties" , "Using Material Standards to infer properties"	**Partial Match**	Standardized Terminology (more specific implementation)
Location Data (for local sourcing)	Location Data (for local sourcing) refers to geographic information indicating a component's origin or current placement. This is crucial not only for understanding where raw materials come from but also for identifying existing building elements in proximity to new	"Need for Location Data (for local sourcing)"	**Partial Match** (Topraklı, 2024; Hradil et al., 2020; Rao et al., 2025)	(None directly comparable in Foundational Set) Part of Location property

	projects that could benefit from reclaimed materials, thus supporting a local Circular Economy by minimizing transport impacts.			
Reinforcement Details / Geometry	Precise details on the location, diameter, and arrangement of reinforcement bars within concrete elements, essential for structural assessment and potential modifications. Clear and precise geometry is vital for assessing reuse potential, determining how a component fits into new designs, and understanding if it requires modifications like cutting. Modeled geometry is optimal for this purpose.	"Reinforcement Details" , "Need for Reinforcement Info" , "Need for Reinforcement Geometry (not just quantity)" , "Need for modeled reinforcement, especially at connections" , "Need for Reinforcement Cover"	**Partial Match** (Xing et al., 2020; Hradil et al., 2020; Sanchez et al. 2024; Piazzi et al., 2022)	Reinforcement Info (literature often less specific on geometry/cover)
Geometric Tolerances	The permissible variations or deviations from the ideal dimensions, shape, or position of a component, established during its original manufacturing or design. These tolerances are crucial for assessing a component's fit and compatibility for reuse in new structures, especially in contexts of modularity and standardization. For example, understanding a beam's length tolerance determines if it can be directly reused in a different building with slightly varying column sizes without costly re-manufacturing, thanks to adaptive connections.	"Geometric Tolerances"	**Partial Match** (Xing et al., 2020; Hradil et al., 2020; Sanchez et al. 2024; Piazzi et al., 2022)	Geometrical Specs / Dimensions (more specific aspect)
Presence of Openings	Documentation of any openings (e.g., holes, cutouts) within an element, crucial for assessing its remaining structural capacity and fit in new designs.	"Presence of Openings"	**Yes**	(None directly comparable in Foundational Set) Part of Geometry
Record of Modifications	Documented information about any changes, repairs, or alterations made to the component after its initial installation.	"Record of Modifications"	**Yes** (Morganti & Bragadin, 2025; Xing et al., 2020; Tomczak et al., 2024)	Maintenance History (broader category)
Change in Loading History	Records of significant changes in the loads applied to a component due to altered building functions or usage patterns throughout its life.	"Change in Loading History" , "Load History (especially for fatigue)" , "Need for original design assumptions (e.g., loads)"	**Partial Match** (Topraklı, 2024; De Wolf et al., 2024; Xing et al., 2020; Akbarieh, 2023; Theißen et al., 2020; Tomczak et al., 2024; Charef, 2016)	Product History (broader category), Service Life
Proven Strength Data	Actual performance data or verified load-bearing capacity of a component, obtained through real-world observation or specific load tests conducted on the installed element. This data is crucial because it reflects the actual strength demonstrated by the component after being subjected to real-world loads during its service life, offering empirical evidence that may confirm or deviate from its original design calculations or theoretical material quality/grade.	"Load History (Proven vs. Design)" , "Need for Proven Strength Data" , "Need for as-built performance data"	**Yes** (Hradil et al., 2020; Tomczak et al., 2024)	Structural Integrity / Grade (more specific aspect)
Original Production/Design Data	Comprehensive data from the initial manufacturing and design stages, including calculations, applied standards, and specific design choices and underlying principles made by the designer. This may also encompass any sustainability considerations or intentions for future circularity that guided the original design.	"Need for Original Production/Design Data" , "Everything from production must be added: Calculations, standards, stability systems, design choices ect."	**Yes** (Oliveira et al., 2024; Charef, 2024; Tomczak et al., 2024)	Reference Documentation (broader category)

All Design Parameters	Comprehensive data encompassing all original design parameters for an element, including structural, building physics, and other relevant specifications.	"Need for all design parameters (structural, building physics, etc.)"	**Partial Match** (Oliveira et al., 2024; Mellenthin Filardo et al., 2024)	Reference Documentation (broader concept)
Fire Resistance Data	Specific information about the component's ability to withstand fire and its fireproofing properties.	"Need for Fire Resistance Data"	**Yes** (Basta et al., 2020; Hradil et al., 2020)	Fire Resistance / Fireproofing
Best Before' Date / Design Life Data	Information indicating the expected or calculated service life or design life of a component across potential multiple uses.	"Need for 'best before' date / design life data"	**Yes** (Theißen et al., 2020; Tomczak et al., 2024; Charef, 2016; Akbarieh, 2023)	Service Life
Usage History	Information about the component's previous life cycles, including its uses, locations, and exposure conditions.	"Need for Usage History" , "Also for reuse, what the life of an element was like during previous use"	**Yes** (Topraklı, 2024; De Wolf et al., 2024; Xing et al., 2020; Akbarieh, 2023)	Product History
Physical State Assessment	A general assessment of the physical condition of the component, including observed damages or defects.	"Need for Physical State Assessment"	**Yes** (Hradil et al., 2020; Akbarieh, 2023)	Condition Assessment (broader category)
Visual Damage Assessment (Cracks, Corrosion)	Observation of visible signs of damage such as cracks or corrosion on the component's surface.	"Need for Visual Damage Assessment (Cracks, Corrosion)" , "Need for Visual Condition Assessment"	**Yes** (Rao et al., 2025; Xing et al., 2020)	Corrosion Level , Condition Assessment , Deformation
Material Certificates	Documentation (e.g., digital certificates) certifying the properties and quality of delivered materials, crucial for legal and insurance purposes in reuse.	"Need for Material Certificates (for legal/insurance purposes)"	**Partial Match**	Reference Documentation (more specific type of document)
Designated Reuse Scenario	The planned or assessed potential End-of-Life (EOL) pathway for the component after deconstruction (e.g., reuse as is, remanufacture, recycle).	"Need for designated reuse scenario"	**Yes** (Akbarieh, 2023; Mercado Siles, 2020; Basta et al., 2020; Charef, 2016)	Circular Potential / EOL Scenario
Original Design Assumptions	Data related to the original design assumptions, such as applied loads or environmental conditions, for which the component was calculated.	"Need for original design assumptions (e.g., loads)"	**Partial Match** (Oliveira et al., 2024; Mellenthin Filardo et al., 2024)	Reference Documentation (broader concept)
As-built Deviation Data (As-built vs. As-designed Data)	Explicitly documents any observed differences between planned design specifications and actual constructed conditions (which may include deviations if exceeding original manufacturing characteristics or tolerances). This includes variations that might exceed original manufacturing characteristics or acceptable tolerances (e.g. pre-fabricated concrete beam designed for 6.00 meters is actually installed at 6.02 meters). This data is crucial for assessing a component's precise characteristics for potential reuse	"Need for as-built vs. as-designed data" , "Deviation between as-designed and as-built is a key challenge"	**Partial Match** (Topraklı, 2024; De Wolf et al., 2024; Xing et al., 2020; Akbarieh, 2023)	Product History (broader category)
Quality Control / Assurance	Records of all checks, inspections, and formal verifications performed on a component during its manufacturing, installation, and use. This shows it met quality standards at different points, helping assess its reliability for reuse.	"Need for Quality Control / Assurance"	**New**	(None directly comparable in Foundational Set)
Actual vs. Theoretical Deflection Data	This property provides measurements of a floor or structural component's real-world deflection (bending or displacement under load), which are then compared against its theoretically calculated deflection values from the original design. This comparison is important because it shows the component's true performance over time, helping engineers understand its current strength and decide if it's suitable for reuse in a new building.	"Need for actual vs. theoretical deflection data"	**New**	(None directly comparable in Foundational Set)

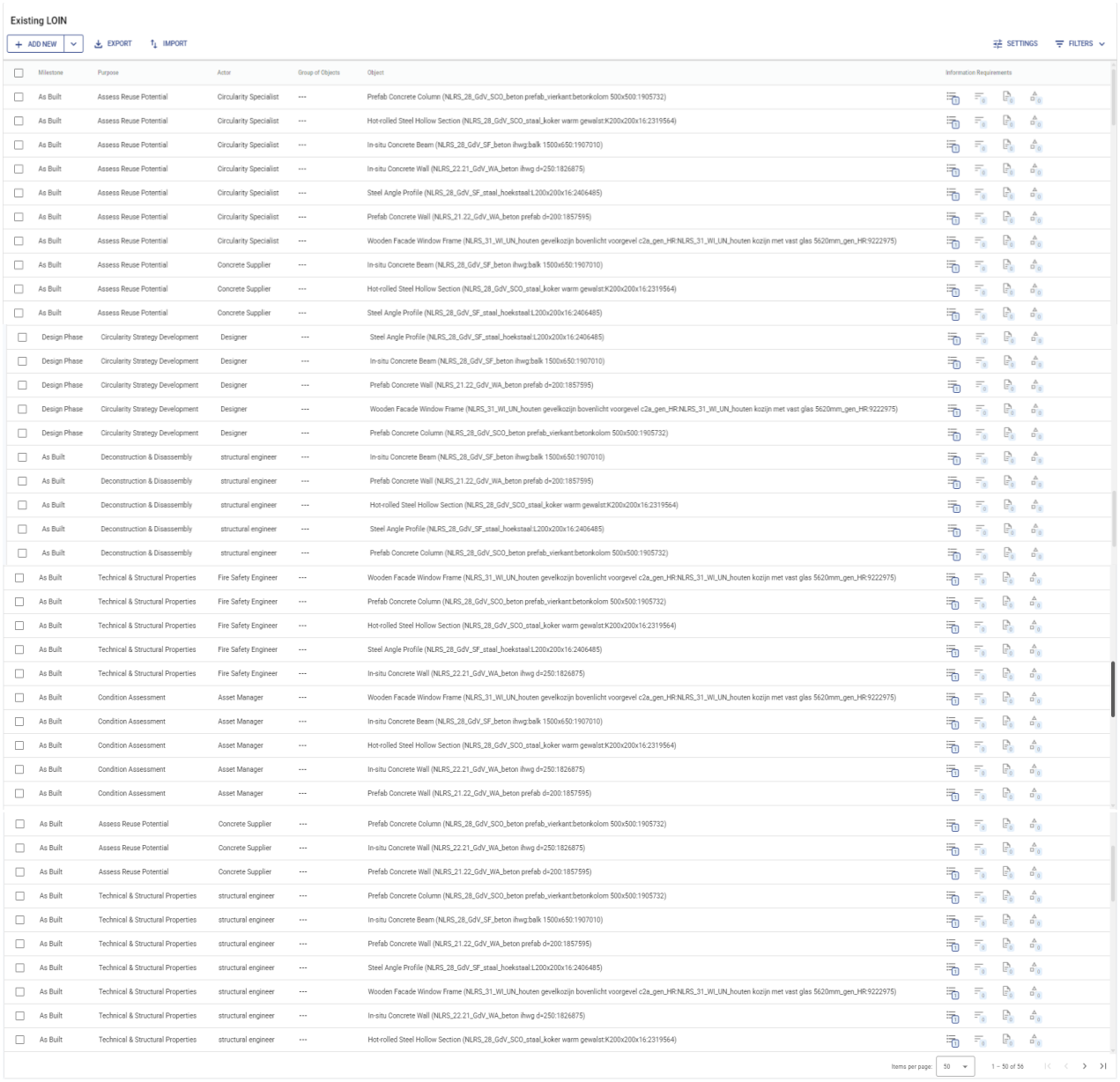
Connection Properties (Material, Strength)	Details about the properties of the connection itself. It provides specific information beyond the general connection type, such as the material, strength, and whether it's a wet (e.g., cast-in-place concrete) or dry (e.g., bolted steel) connection. It includes precise fastener details, such as the exact type of bolt (e.g., M20, hexagonal head), its material grade (e.g., 8.8), and quantity for reversible bolted connections. (This property becomes less necessary if the connection is already fully and correctly modeled in the BIM model with all its corresponding information embedded)	"Connection Properties (Material, Strength)"	**Yes** (Pereiro et al., 2023; Sanchez et al., 2021; Basta et al., 2020; Akbarieh, 2023)	Connection Type (more detailed aspect)
Connection Type	A superclass that allows to describe the type of the connections. Different connection types faciliate different circular and End-of-Life possibilities, including: (1) Deconstruction, i.e., a building is taken apart into products; (2) Demounting, i.e., a product is taken out of a building; (3) Disassembling, i.e., a product is separated into components or sub-parts; (4) Dismantling, i.e., a product is separated into individual materials.	"Connection Type (wet vs. dry)" , "Connection Type and Fastener Information" , "Connection Demountability"	**Yes** (Pereiro et al., 2023; Sanchez et al., 2021; Basta et al., 2020; Akbarieh, 2023)	Connection Type (more specific types)
Connection Accessibility	This property indicates the ease with which a component's connections can be physically reached and manipulated for various purposes, including routine inspection, maintenance (like tightening bolts or replacing parts), or ultimately, disassembly for reuse. It considers factors such as whether the connection is exposed, concealed within another element, requires specialized tools for access, or necessitates the removal of other components to reach it.	"Need for Connection Accessibility"	**Yes** (Tomczak et al., 2024; Sanchez et al., 2024)	Disassembly Instructions (implies accessibility)
Detachability Information	Information specifically detailing how a component can be detached or separated from the structure.	"Need for Detachability Information"	**Yes** (Tomczak et al., 2024; Sanchez et al., 2024)	Disassembly Instructions
Recommended Disassembly Technique	A suggestion for the most suitable method for removing a component to ensure safety and preserve reusability.	"Recommended Disassembly Technique"	**Yes** (Sanchez et al., 2024)	Disassembly Method
Disassembly Sequence	Outlines the preferred, ordered series of operations for removing multiple components from a structure. This property ensures safety (e.g., preventing structural collapse during removal), maintains structural integrity of the remaining parts, and enables efficient material recovery. It dictates what comes out when, and can preferably include machine-readable sequences to facilitate automated planning and execution.	"Need for Disassembly Sequence"	**Yes** (Marzouk & Elmaraghy, 2021; Sanchez et al., 2021; Tomczak et al., 2024)	Disassembly Sequence
Predetermined Cut Lines	These are specific lines or areas pre-planned in the design of a building part where controlled cuts can be made. This makes it easier to remove or change that part in the future. For example, a large concrete floor might have these lines to help cut it into smaller pieces that can be reused. This planning makes taking buildings apart more efficient, reduces waste, and helps save parts for new projects.	"Need for Predetermined Cut Lines"	**New**	(None directly comparable in Foundational Set)

Required Disassembly Tools	Information on the specific tools or equipment needed for the safe and efficient disassembly of a component.	"Need for required disassembly tools"	**New**	(None directly comparable in Foundational Set)
Information about Handling	Details on how to safely handle, lift, and move elements during and after disassembly to prevent damage.	"Need for Information about Handling"	**Partial Match** (Sanchez et al., 2024; Marzouk & Elmaraghy, 2021; Piazzi et al., 2022)	Physical Constraints (Motion) (more specific)
Contribution to Overall Stability	Data indicating the extent to which a component contributes to the overall structural stability of the building.	"Contribution to overall stability"	**New**	(None directly comparable in Foundational Set)
Hoisting Provision Locations	Maps the precise locations of hoisting anchors, lifting points, or other provisions on the component for safe lifting and maneuvering. For example, this could specify the exact coordinates or a clear diagram showing pre-installed lifting anchors in a prefabricated concrete column, or designated pick-up points on a steel beam.	"Need for Hoisting Provision Locations"	**New**	(None directly comparable in Foundational Set)
Storage Requirements	This property specifies the precise conditions and environmental parameters necessary for storing a component after its removal from the building to maintain its quality, integrity, and suitability for future reuse. This goes beyond general handling and addresses long-term preservation. Examples include requirements for a dry, sheltered environment to prevent corrosion or moisture damage, protection from direct sunlight to avoid material degradation (e.g., UV exposure for plastics or wood), specific temperature and humidity ranges, or proper ventilation to prevent mold or rot.	"Need for Storage Requirements"	**Yes** (M. Marzouk, M., & Elmaraghy, A., 2021)	Storage Requirements
Disassembly Labor/Effort data	An estimation of the time or human effort required to dismantle the component, relevant for planning and economic assessment.	"Need for Disassembly Labor/Effort data"	**Yes** (Marzouk et al., 2019)	Disassembly Time / Effort
Linking element history across projects	The ability to track a component's history across different projects, potentially using technologies like Blockchain.	"Linking element history across projects (via IFC/Blockchain)"	**Partial Match** (Topraklı, 2024; De Wolf et al., 2024; Xing et al., 2020; Akbarieh, 2023)	Product History (broader concept)
Data Archiving Format	Specifies the long-term format and accessibility strategy for digital building and component data to mitigate file format obsolescence risk.	"[Insight] Long-term data accessibility and file format obsolescence is a risk"	**New**	(None directly comparable in Foundational Set)
Model Maintenance Plan Link	Link to a plan or protocol detailing how the BIM model and its associated data should be updated and maintained throughout the building's lifecycle.	"[Insight] The data/model must be maintained throughout the building's life (living digital twin)"	**New**	(None directly comparable in Foundational Set)
Owner-Managed Model Link	Link to information indicating if the BIM model is managed and updated by the building owner for maintenance and management purposes.	"[Insight] The concept of a maintenance/management model that is updated by the owner"	**New**	(None directly comparable in Foundational Set)
Guarantee Status for Reuse	This property documents whether existing product guarantees (e.g., from original manufacturers or installers) extend to a component's reuse in a new context, or if these guarantees become void after its initial installation or decommissioning.	"[Insight] Component guarantees limit reuse"	**New**	(None directly comparable in Foundational Set)
Data for Reuse Obligation Status	Indicates if there is a formal obligation (e.g., contractual, regulatory) for parties to provide and maintain data specifically for the future reuse of components.	"[Insight] Proposal for a "data for reuse obligation""	**New**	(None directly comparable in Foundational Set)
Availability Status (Component)	Indicates the current readiness or status of a component for reuse, including its accessibility and	"[Insight] Logistics and availability information are major bottlenecks"	**New**	(None directly comparable in Foundational Set)

	logistical availability in a reuse market.			
Post-Demolition Destination Readiness	Information on whether a suitable next project or storage facility is identified/secured for the component immediately after demolition.	"[Insight] Storage is a problem; reuse requires a destination project"	**New**	(None directly comparable in Foundational Set)
As-built Deviation Flag	A simple indicator (e.g., boolean or status) signaling that documented discrepancies exist between the as-designed and as-built conditions of the component.	"[Insight] Challenge: Data vs. Reality verification"	**New**	(None directly comparable in Foundational Set)
Embedded Services Information	Details about any services (e.g., insulation, water pipes, heating installations) that are cast-in or otherwise permanently integrated into composite prefabricated elements.	"[Insight] Challenge: Reusing composite prefab elements with embedded services"	**New**	(None directly comparable in Foundational Set)
Post-Demolition Handling Instructions	SThis property provides specific, actionable guidelines or requirements for the safe handling, lifting, and initial transportation of a component immediately after its removal from the structure. These instructions are crucial to prevent damage to the component during its transfer from the demolition site to either a temporary storage area or its next destination.	"[Insight] Importance of post-demolition handling"	**Partial Match** (Sanchez et al., 2024; Marzouk & Elmaraghy, 2021; Piazzi et al., 2022)	Physical Constraints (Motion) (more specific)
Specialized Disassembly Knowledge/Equipment	Information about specific knowledge, skills, or unique equipment required for the safe and efficient disassembly of complex or specialized components.	"[Insight] Need for product-specific knowledge/equipment for disassembly"	**New**	(None directly comparable in Foundational Set)
Modularity Degree	This property offers a quantifiable indication of how modular or standardized a specific element is. A high degree of modularity means the component is designed with standard dimensions, interfaces, and connections, which significantly influences the ease and cost-effectiveness of its re-integration into new designs.	"[Insight] Modularity increases reusability"	**New**	(None directly comparable in Foundational Set)
Layer Decoupling Strategy	This property documents the design strategies implemented to facilitate the separation of different building layers (e.g., the structural frame from the facade, or services from partitions). This strategic design approach enables easier selective deconstruction, allowing individual layers or components to be removed independently and non-destructively.	"[Insight] Decoupling of building layers"	**New**	(None directly comparable in Foundational Set)
Return Guarantee by Manufacturers	Guarantee from the original manufacturer of a component to take back the product at the end of its initial service life for reuse, refurbishment, or recycling. This guarantee may include specific conditions regarding the returned product's condition, return logistics, and any financial compensation or credit	[Insight] Return Guarantee by Manufacturers	**New**	(None directly comparable in Foundational Set)

Appendix VII – Project LOIN in CoBuilder Require

Project LOIN in CoBuilder, showing all information requirements



Milestone	Purpose	Actor	Group of Objects	Object	Information Requirements
As Built	Assess Reuse Potential	Circularity Specialist	---	Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)	
As Built	Assess Reuse Potential	Circularity Specialist	---	Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)	
As Built	Assess Reuse Potential	Circularity Specialist	---	In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)	
As Built	Assess Reuse Potential	Circularity Specialist	---	In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875)	
As Built	Assess Reuse Potential	Circularity Specialist	---	Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)	
As Built	Assess Reuse Potential	Circularity Specialist	---	Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)	
As Built	Assess Reuse Potential	Circularity Specialist	---	Wooden Facade Window Frame (NLRS_31_WI_UN_houten gevelkozijn bovenlicht voorgevel c2a_gen_HR:NLRS_31_WI_UN_houten kozijn met vast glas 5620mm_gen_HR:9222975)	
As Built	Assess Reuse Potential	Concrete Supplier	---	In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)	
As Built	Assess Reuse Potential	Concrete Supplier	---	Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)	
As Built	Assess Reuse Potential	Concrete Supplier	---	Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)	
Design Phase	Circularity Strategy Development	Designer	---	Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)	
Design Phase	Circularity Strategy Development	Designer	---	In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)	
Design Phase	Circularity Strategy Development	Designer	---	Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)	
Design Phase	Circularity Strategy Development	Designer	---	Wooden Facade Window Frame (NLRS_31_WI_UN_houten gevelkozijn bovenlicht voorgevel c2a_gen_HR:NLRS_31_WI_UN_houten kozijn met vast glas 5620mm_gen_HR:9222975)	
Design Phase	Circularity Strategy Development	Designer	---	Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)	
As Built	Deconstruction & Disassembly	structural engineer	---	In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)	
As Built	Deconstruction & Disassembly	structural engineer	---	Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)	
As Built	Deconstruction & Disassembly	structural engineer	---	Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)	
As Built	Deconstruction & Disassembly	structural engineer	---	Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)	
As Built	Deconstruction & Disassembly	structural engineer	---	Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)	
As Built	Technical & Structural Properties	Fire Safety Engineer	---	Wooden Facade Window Frame (NLRS_31_WI_UN_houten gevelkozijn bovenlicht voorgevel c2a_gen_HR:NLRS_31_WI_UN_houten kozijn met vast glas 5620mm_gen_HR:9222975)	
As Built	Technical & Structural Properties	Fire Safety Engineer	---	Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)	
As Built	Technical & Structural Properties	Fire Safety Engineer	---	Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)	
As Built	Technical & Structural Properties	Fire Safety Engineer	---	Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)	
As Built	Technical & Structural Properties	Fire Safety Engineer	---	In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875)	
As Built	Condition Assessment	Asset Manager	---	Wooden Facade Window Frame (NLRS_31_WI_UN_houten gevelkozijn bovenlicht voorgevel c2a_gen_HR:NLRS_31_WI_UN_houten kozijn met vast glas 5620mm_gen_HR:9222975)	
As Built	Condition Assessment	Asset Manager	---	In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)	
As Built	Condition Assessment	Asset Manager	---	Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)	
As Built	Condition Assessment	Asset Manager	---	In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875)	
As Built	Condition Assessment	Asset Manager	---	Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)	
As Built	Assess Reuse Potential	Concrete Supplier	---	Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)	
As Built	Assess Reuse Potential	Concrete Supplier	---	In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875)	
As Built	Assess Reuse Potential	Concrete Supplier	---	Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)	
As Built	Technical & Structural Properties	structural engineer	---	Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)	
As Built	Technical & Structural Properties	structural engineer	---	In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)	
As Built	Technical & Structural Properties	structural engineer	---	Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)	
As Built	Technical & Structural Properties	structural engineer	---	Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)	
As Built	Technical & Structural Properties	structural engineer	---	Wooden Facade Window Frame (NLRS_31_WI_UN_houten gevelkozijn bovenlicht voorgevel c2a_gen_HR:NLRS_31_WI_UN_houten kozijn met vast glas 5620mm_gen_HR:9222975)	
As Built	Technical & Structural Properties	structural engineer	---	In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875)	
As Built	Technical & Structural Properties	structural engineer	---	Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)	

Items per page: 50 1 – 50 of 56

Figure 36 - LOIN in CoBuilder

CoBuilder Information Requirements Excel Export

The Excel file exported from CoBuilder Require contains all information requirements defined in the EIR, structured according to the LOIN principles.

Table 12 - EIR Excel Export from CoBuilder Require

Milestone	Purpose	Actor	Object	Property	Property set	Technical definition	Measure data type	Values
As Built	Technical & Structural Properties	Fire Safety Engineer	In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875)	Fire Resistance Rating		Measure of the fire resistance rating in hours (e.g., 1.5 hours, 2 hours, etc.).	String	
As Built	Condition Assessment	Asset Manager	Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)	Service history		information about building renovation history, and maintenance activities carried out on the building during service life.	String	
As Built	Assess Reuse Potential	Circularity Specialist	Wooden Facade Window Frame (NLRS_31_WI_UN_houten gevelkozijn bovenlicht voorgevel c2a_gen_HR:NLRS_31_WI_UN_houten kozijn met vast glas 5620mm_gen_HR:9222975)	Certification Requirement		Certification requirements refer to the specific criteria or standards that need to be met in order to obtain certification for certain products, processes, or components within the context of circular economy practices. Not all circular potentials may require certification, but certification can be necessary for certain reusable structural parts or components. A certificate serves as a validation or endorsement that the product or component meets specific - or minimum - standards or specifications related to safety, quality, environmental impact, or other relevant criteria that makes it eligible to be re-introduced to the market.	String	
As Built	Technical & Structural Properties	Fire Safety Engineer	Concrete Floor (Floor:NLRS_23_GdV_FL_betonvloer h=280:1854789)	Fire Resistance Rating		Measure of the fire resistance rating in hours (e.g., 1.5 hours, 2 hours, etc.).	String	
As Built	Deconstruction & Disassembly	structural engineer	Wooden Facade Window Frame (NLRS_31_WI_UN_houten gevelkozijn bovenlicht voorgevel c2a_gen_HR:NLRS_31_WI_UN_houten kozijn met vast glas 5620mm_gen_HR:9222975)	Connection Type		A superclass that allows to describe the type of the connections. Different connection types faciliate different circular and End-of-Life possibilities, including: (1) Deconstruction, i.e., a building is taken apart into products; (2) Demounting, i.e., a product is taken out of a building; (3) Disassembling, i.e., a product is separated into components or sub-parts; (4) Dismantling, i.e., a product is separated into individual materials.	String	Chemical Connection Indirect Connection Reversible Connection Gravitational Connection Irreversible Connection Component Connection Mechanical Connection Direct Connection
As Built	Technical & Structural Properties	Fire Safety Engineer	Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)	Fire Resistance Rating		Measure of the fire resistance rating in hours (e.g., 1.5 hours, 2 hours, etc.).	String	

As Built	Assess Reuse Potential	Circularity Specialist	Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)	Certification Requirement		Certification requirements refer to the specific criteria or standards that need to be met in order to obtain certification for certain products, processes, or components within the context of circular economy practices. Not all circular potentials may require certification, but certification can be necessary for certain reusable structural parts or components. A certificate serves as a validation or endorsement that the product or component meets specific - or minimum - standards or specifications related to safety, quality, environmental impact, or other relevant criteria that makes it eligible to be re-introduced to the market.	String	
As Built	Assess Reuse Potential	Concrete Supplier	Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)	Type of cement			String	
As Built	Technical & Structural Properties	structural engineer	Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)	Strength Class	Pset_ConcreteElement General	Classification of the concrete strength in accordance with the concrete design code which is applied in the project.	String	
As Built	Deconstruction & Disassembly	structural engineer	In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875)	Connection Type		A superclass that allows to describe the type of the connections. Different connection types faciliate different circular and End-of-Life possibilities, including: (1) Deconstruction, i.e., a building is taken apart into products; (2) Demounting, i.e., a product is taken out of a building; (3) Disassembling, i.e., a product is separated into components or sub-parts; (4) Dismantling, i.e., a product is separated into individual materials.	String	Direct Connection Mechanical Connection Component Connection Irreversible Connection Gravitational Connection Reversible Connection Indirect Connection Chemical Connection
As Built	Technical & Structural Properties	Fire Safety Engineer	Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)	Fire Resistance Rating		Measure of the fire resistance rating in hours (e.g., 1.5 hours, 2 hours, etc.).	String	
As Built	Condition Assessment	Asset Manager	Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)	Service history		information about building renovation history, and maintenance activities carried out on the building during service life.	String	
As Built	Assess Reuse Potential	Circularity Specialist	Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)	Certification Requirement		Certification requirements refer to the specific criteria or standards that need to be met in order to obtain certification for certain products, processes, or components within the context of circular economy practices. Not all circular potentials may require certification, but certification can be necessary for certain reusable structural parts or components. A certificate serves as a validation or endorsement that the product or component meets specific - or minimum - standards or specifications related to safety, quality, environmental impact, or other relevant criteria that makes it eligible to be re-introduced to the market.	String	
As Built	Technical & Structural Properties	structural engineer	In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875)	Strength Class	Pset_ConcreteElement General	Classification of the concrete strength in accordance with the concrete design code which is applied in the project.	String	

As Built	Deconstruction & Disassembly	structural engineer	Concrete Floor (Floor:NLRS_23_GdV_FL_betonvloer h=280:1854789)	Connection Type		A superclass that allows to describe the type of the connections. Different connection types faciliate different circular and End-of-Life possibilities, including: (1) Deconstruction, i.e., a building is taken apart into products; (2) Demounting, i.e., a product is taken out of a building; (3) Disassembling, i.e., a product is separated into components or sub-parts; (4) Dismantling, i.e., a product is separated into individual materials.	String	Chemical Connection Indirect Connection Reversible Connection Gravitational Connection Irreversible Connection Component Connection Mechanical Connection Direct Connection
As Built	Assess Reuse Potential	Concrete Supplier	In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875)	Type of cement			String	
As Built	Technical & Structural Properties	structural engineer	Wooden Facade Window Frame (NLRS_31_WI_UN_houten gevelkozijn bovenlicht voorgevel c2a_gen_HR:NLRS_31_WI_UN_houten kozijn met vast glas 5620mm_gen_HR:9222975)	Strength Class	Pset_ConcreteElementGeneral	Classification of the concrete strength in accordance with the concrete design code which is applied in the project.	String	
As Built	Condition Assessment	Asset Manager	Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)	Service history		information about building renovation history, and maintenance activities carried out on the building during service life.	String	
As Built	Assess Reuse Potential	Concrete Supplier	Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)	Type of cement			String	
Design Phase	Circularity Strategy Development	Designer	Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)	Total Reuse Count		Total Reuse Count indicates the total number of reuses, i.e., reuse counts, that a product is designed for. The total reuse count reflects the maximum number of times a product is designed to be (re)used. Each (re)use cycle corresponds to the expected service life length, while the (re)use count corresponds to the number of cycles. In other words, total reuse counts correspond to the design life length divided by the expected life length.	Integer	
As Built	Condition Assessment	Asset Manager	In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875)	Service history		information about building renovation history, and maintenance activities carried out on the building during service life.	String	
As Built	Technical & Structural Properties	structural engineer	Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)	Strength Class	Pset_ConcreteElementGeneral	Classification of the concrete strength in accordance with the concrete design code which is applied in the project.	String	
As Built	Technical & Structural Properties	structural engineer	Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)	Strength Class	Pset_ConcreteElementGeneral	Classification of the concrete strength in accordance with the concrete design code which is applied in the project.	String	

As Built	Deconstruction & Disassembly	structural engineer	Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)	Connection Type		A superclass that allows to describe the type of the connections. Different connection types faciliate different circular and End-of-Life possibilities, including: (1) Deconstruction, i.e., a building is taken apart into products; (2) Demounting, i.e., a product is taken out of a building; (3) Disassembling, i.e., a product is separated into components or sub-parts; (4) Dismantling, i.e., a product is separated into individual materials.	String	Chemical Connection Indirect Connection Reversible Connection Gravitational Connection Irreversible Connection Component Connection Mechanical Connection Direct Connection
As Built	Assess Reuse Potential	Circularity Specialist	Concrete Floor (Floor:NLRS_23_GdV_FL_betonvloer h=280:1854789)	Certification Requirement		Certification requirements refer to the specific criteria or standards that need to be met in order to obtain certification for certain products, processes, or components within the context of circular economy practices. Not all circular potentials may require certification, but certification can be necessary for certain reusable structural parts or components. A certificate serves as a validation or endorsement that the product or component meets specific - or minimum - standards or specifications related to safety, quality, environmental impact, or other relevant criteria that makes it eligible to be re-introduced to the market.	String	
As Built	Technical & Structural Properties	Fire Safety Engineer	Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)	Fire Resistance Rating		Measure of the fire resistance rating in hours (e.g., 1.5 hours, 2 hours, etc.).	String	
As Built	Technical & Structural Properties	Fire Safety Engineer	Wooden Facade Window Frame (NLRS_31_WI_UN_houten gevelkozijn bovenlicht voorgevel c2a_gen_HR:NLRS_31_WI_UN_houten kozijn met vast glas 5620mm_gen_HR:9222975)	Fire Resistance Rating		Measure of the fire resistance rating in hours (e.g., 1.5 hours, 2 hours, etc.).	String	
As Built	Assess Reuse Potential	Circularity Specialist	In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875)	Certification Requirement		Certification requirements refer to the specific criteria or standards that need to be met in order to obtain certification for certain products, processes, or components within the context of circular economy practices. Not all circular potentials may require certification, but certification can be necessary for certain reusable structural parts or components. A certificate serves as a validation or endorsement that the product or component meets specific - or minimum - standards or specifications related to safety, quality, environmental impact, or other relevant criteria that makes it eligible to be re-introduced to the market.	String	
As Built	Assess Reuse Potential	Concrete Supplier	Wooden Facade Window Frame (NLRS_31_WI_UN_houten gevelkozijn bovenlicht voorgevel c2a_gen_HR:NLRS_31_WI_UN_houten kozijn met vast glas 5620mm_gen_HR:9222975)	Type of cement			String	

As Built	Assess Reuse Potential	Concrete Supplier	Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)	Type of cement			String	
As Built	Technical & Structural Properties	Fire Safety Engineer	In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)	Fire Resistance Rating		Measure of the fire resistance rating in hours (e.g., 1.5 hours, 2 hours, etc.).	String	
As Built	Assess Reuse Potential	Concrete Supplier	Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)	Type of cement			String	
Design Phase	Circularity Strategy Development	Designer	Wooden Facade Window Frame (NLRS_31_WI_UN_houten gevelkozijn bovenlicht voorgevel c2a_gen_HR:NLRS_31_WI_UN_houten kozijn met vast glas 5620mm_gen_HR:9222975)	Total Reuse Count		Total Reuse Count indicates the total number of reuses, i.e., reuse counts, that a product is designed for. The total reuse count reflects the maximum number of times a product is designed to be (re)used. Each (re)use cycle corresponds to the expected service life length, while the (re)use count corresponds to the number of cycles. In other words, total reuse counts correspond to the design life length divided by the expected life length.	Integer	
As Built	Deconstruction & Disassembly	structural engineer	Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)	Connection Type		A superclass that allows to describe the type of the connections. Different connection types faciliate different circular and End-of-Life possibilities, including: (1) Deconstruction, i.e., a building is taken apart into products; (2) Demounting, i.e., a product is taken out of a building; (3) Disassembling, i.e., a product is separated into components or sub-parts; (4) Dismantling, i.e., a product is separated into individual materials.	String	Chemical Connection Indirect Connection Reversible Connection Gravitational Connection Irreversible Connection Component Connection Mechanical Connection Direct Connection
As Built	Technical & Structural Properties	structural engineer	Concrete Floor (Floor:NLRS_23_GdV_FL_betonvloer h=280:1854789)	Strength Class	Pset_ConcreteElementGeneral	Classification of the concrete strength in accordance with the concrete design code which is applied in the project.	String	
As Built	Condition Assessment	Asset Manager	Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)	Service history		information about building renovation history, and maintenance activities carried out on the building during service life.	String	
As Built	Deconstruction & Disassembly	structural engineer	Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)	Connection Type		A superclass that allows to describe the type of the connections. Different connection types faciliate different circular and End-of-Life possibilities, including: (1) Deconstruction, i.e., a building is taken apart into products; (2) Demounting, i.e., a product is taken out of a building; (3) Disassembling, i.e., a product is separated into components or sub-parts; (4) Dismantling, i.e., a product is separated into individual materials.	String	Chemical Connection Indirect Connection Reversible Connection Gravitational Connection Irreversible Connection Component Connection Mechanical Connection Direct Connection

Design Phase	Circularity Strategy Development	Designer	Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)	Total Reuse Count		Total Reuse Count indicates the total number of reuses, i.e., reuse counts, that a product is designed for. The total reuse count reflects the maximum number of times a product is designed to be (re)used. Each (re)use cycle corresponds to the expected service life length, while the (re)use count corresponds to the number of cycles. In other words, total reuse counts correspond to the design life length divided by the expected life length.	Integer	
As Built	Condition Assessment	Asset Manager	Concrete Floor (Floor:NLRS_23_GdV_FL_betonvloer h=280:1854789)	Service history		information about building renovation history, and maintenance activities carried out on the building during service life.	String	
As Built	Technical & Structural Properties	structural engineer	In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)	Strength Class	Pset_ConcreteElement General	Classification of the concrete strength in accordance with the concrete design code which is applied in the project.	String	
As Built	Deconstruction & Disassembly	structural engineer	Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)	Connection Type		A superclass that allows to describe the type of the connections. Different connection types faciliate different circular and End-of-Life possibilities, including: (1) Deconstruction, i.e., a building is taken apart into products; (2) Demounting, i.e., a product is taken out of a building; (3) Disassembling, i.e., a product is separated into components or sub-parts; (4) Dismantling, i.e., a product is separated into individual materials.	String	Chemical Connection Indirect Connection Reversible Connection Gravitational Connection Irreversible Connection Component Connection Mechanical Connection Direct Connection
Design Phase	Circularity Strategy Development	Designer	In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)	Total Reuse Count		Total Reuse Count indicates the total number of reuses, i.e., reuse counts, that a product is designed for. The total reuse count reflects the maximum number of times a product is designed to be (re)used. Each (re)use cycle corresponds to the expected service life length, while the (re)use count corresponds to the number of cycles. In other words, total reuse counts correspond to the design life length divided by the expected life length.	Integer	
As Built	Assess Reuse Potential	Circularity Specialist	In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)	Certification Requirement		Certification requirements refer to the specific criteria or standards that need to be met in order to obtain certification for certain products, processes, or components within the context of circular economy practices. Not all circular potentials may require certification, but certification can be necessary for certain reusable structural parts or components. A certificate serves as a validation or endorsement that the product or component meets specific - or minimum - standards or specifications related to safety, quality, environmental impact, or other relevant criteria that makes it eligible to be re-introduced to the market.	String	
As Built	Technical & Structural Properties	Fire Safety Engineer	Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595)	Fire Resistance Rating		Measure of the fire resistance rating in hours (e.g., 1.5 hours, 2 hours, etc.).	String	

Design Phase	Circularity Strategy Development	Designer	Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)	Total Reuse Count		Total Reuse Count indicates the total number of reuses, i.e., reuse counts, that a product is designed for. The total reuse count reflects the maximum number of times a product is designed to be (re)used. Each (re)use cycle corresponds to the expected service life length, while the (re)use count corresponds to the number of cycles. In other words, total reuse counts correspond to the design life length divided by the expected life length.	Integer	
Design Phase	Circularity Strategy Development	Designer	Concrete Floor (Floor:NLRS_23_GdV_FL_betonvloer h=280:1854789)	Total Reuse Count		Total Reuse Count indicates the total number of reuses, i.e., reuse counts, that a product is designed for. The total reuse count reflects the maximum number of times a product is designed to be (re)used. Each (re)use cycle corresponds to the expected service life length, while the (re)use count corresponds to the number of cycles. In other words, total reuse counts correspond to the design life length divided by the expected life length.	Integer	
As Built	Assess Reuse Potential	Concrete Supplier	In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)	Type of cement			String	
As Built	Assess Reuse Potential	Circularity Specialist	Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)	Certification Requirement		Certification requirements refer to the specific criteria or standards that need to be met in order to obtain certification for certain products, processes, or components within the context of circular economy practices. Not all circular potentials may require certification, but certification can be necessary for certain reusable structural parts or components. A certificate serves as a validation or endorsement that the product or component meets specific - or minimum - standards or specifications related to safety, quality, environmental impact, or other relevant criteria that makes it eligible to be re-introduced to the market.	String	
Design Phase	Circularity Strategy Development	Designer	In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875)	Total Reuse Count		Total Reuse Count indicates the total number of reuses, i.e., reuse counts, that a product is designed for. The total reuse count reflects the maximum number of times a product is designed to be (re)used. Each (re)use cycle corresponds to the expected service life length, while the (re)use count corresponds to the number of cycles. In other words, total reuse counts correspond to the design life length divided by the expected life length.	Integer	
As Built	Assess Reuse Potential	Circularity Specialist	Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)	Certification Requirement		Certification requirements refer to the specific criteria or standards that need to be met in order to obtain certification for certain products, processes, or components within the context of circular economy practices. Not all circular potentials may require certification, but certification can be necessary for certain reusable structural parts or components. A certificate serves as a validation or endorsement that the product or component meets specific - or minimum - standards or specifications related to safety, quality, environmental impact, or other relevant criteria that makes it eligible to be re-introduced to the market.	String	

As Built	Condition Assessment	Asset Manager	In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)	Service history		information about building renovation history, and maintenance activities carried out on the building during service life.	String	
As Built	Technical & Structural Properties	structural engineer	Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)	Strength Class	Pset_ConcreteElement General	Classification of the concrete strength in accordance with the concrete design code which is applied in the project.	String	
As Built	Deconstruction & Disassembly	structural engineer	In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)	Connection Type		A superclass that allows to describe the type of the connections. Different connection types faciliate different circular and End-of-Life possibilities, including: (1) Deconstruction, i.e., a building is taken apart into products; (2) Demounting, i.e., a product is taken out of a building; (3) Disassembling, i.e., a product is separated into components or sub-parts; (4) Dismantling, i.e., a product is separated into individual materials.	String	Direct Connection Mechanical Connection Component Connection Irreversible Connection Gravitational Connection Reversible Connection Indirect Connection Chemical Connection
As Built	Assess Reuse Potential	Concrete Supplier	Concrete Floor (Floor:NLRS_23_GdV_FL_betonvloer h=280:1854789)	Type of cement			String	
Design Phase	Circularity Strategy Development	Designer	Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)	Total Reuse Count		Total Reuse Count indicates the total number of reuses, i.e., reuse counts, that a product is designed for. The total reuse count reflects the maximum number of times a product is designed to be (re)used. Each (re)use cycle corresponds to the expected service life length, while the (re)use count corresponds to the number of cycles. In other words, total reuse counts correspond to the design life length divided by the expected life length.	Integer	
As Built	Condition Assessment	Asset Manager	Wooden Facade Window Frame (NLRS_31_WI_UN_houten gevelkozijn bovenlicht voorgevel c2a_gen_HR:NLRS_31_WI_UN_houten kozijn met vast glas 5620mm_gen_HR:9222975)	Service history		information about building renovation history, and maintenance activities carried out on the building during service life.	String	

Appendix VIII – IDS Validation- XLM Format

The XML snippet below shows part of the IDS file generated in CoBuilder Require for the *Designer* role. It defines the specific information requirements assigned to this actor, including the applicable IFC elements and the properties that must be present in the BIM model.

```
<?xml version="1.0" encoding="utf-8"?>
<ids:ids xmlns:xs="http://www.w3.org/2001/XMLSchema" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:schemaLocation="http://standards.buildingsmart.org/IDS http://standards.buildingsmart.org/IDS/1.0/ids.xsd" xmlns:ids="http://standards.buildingsmart.org/IDS">
 <ids:info>
  <ids:title>Case Study Decommissioning and Reuse</ids:title>
  <ids:copyright>Cobuilder</ids:copyright>
  <ids:version>1.0</ids:version>
  <ids:description>Requirements for the project IDS : Case Study Decommissioning and Reuse</ids:description>
  <ids:author>j.c.e.m.v.d.eijnden@student.tue.nl</ids:author>
  <ids:date>2025-08-04</ids:date>
  <ids:purpose>Circularity Strategy Development</ids:purpose>
  <ids:milestone>Design Phase</ids:milestone>
 </ids:info>
 <ids:specifications>
  <ids:specification name="Steel Angle Profile (NLRS_28_GdV_SF_staal_hoekstaal:L200x200x16:2406485)" ifcVersion="IFC4X3_ADD2">
   <ids:applicability minOccurs="0" maxOccurs="unbounded">
    <ids:entity>
     <ids:name>
      <ids:simpleValue>IFCBEAM</ids:simpleValue>
     </ids:name>
    </ids:entity>
   </ids:applicability>
   <ids:requirements>
    <ids:property uri="https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2" dataType="IFCINTEGER">
     <ids:propertySet>
      <ids:simpleValue>Cobuilder_Requirements</ids:simpleValue>
     </ids:propertySet>
     <ids:baseName>
      <ids:simpleValue>Total Reuse Count</ids:simpleValue>
     </ids:baseName>
    </ids:property>
   </ids:requirements>
  </ids:specification>
  <ids:specification name="In-situ Concrete Beam (NLRS_28_GdV_SF_beton ihwg:balk 1500x650:1907010)" ifcVersion="IFC4X3_ADD2">
   <ids:applicability minOccurs="0" maxOccurs="unbounded">
    <ids:entity>
     <ids:name>
      <ids:simpleValue>IFCBEAM</ids:simpleValue>
     </ids:name>
    </ids:entity>
   </ids:applicability>
   <ids:requirements>
    <ids:property uri="https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2" dataType="IFCINTEGER">
     <ids:propertySet>
```

```
        <ids:simpleValue>Cobuilder_Requirements</ids:simpleValue>
       </ids:propertySet>
       <ids:baseName>
        <ids:simpleValue>Total Reuse Count</ids:simpleValue>
       </ids:baseName>
      </ids:property>
    </ids:requirements>
  </ids:specification>
  <ids:specification name="Prefab Concrete Wall (NLRS_21.22_GdV_WA_beton prefab d=200:1857595) " ifcVersion="IFC4X3_ADD2">
    <ids:applicability minOccurs="0" maxOccurs="unbounded">
     <ids:entity>
      <ids:name>
       <ids:simpleValue>IFCWALL</ids:simpleValue>
      </ids:name>
     </ids:entity>
    </ids:applicability>
    <ids:requirements>
     <ids:property uri="https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2" dataType="IFCINTEGER">
      <ids:propertySet>
       <ids:simpleValue>Cobuilder_Requirements</ids:simpleValue>
      </ids:propertySet>
      <ids:baseName>
       <ids:simpleValue>Total Reuse Count</ids:simpleValue>
      </ids:baseName>
     </ids:property>
    </ids:requirements>
  </ids:specification>
  <ids:specification name="Wooden Facade Window Frame (NLRS_31_WI_UN_houten gevelkozijn bovenlicht voorgevel c2a_gen_HR:NLRS_31_WI_UN_houten kozijn met vast glas 5620mm_gen_HR:9222975) " ifcVersion="IFC4X3_ADD2">
    <ids:applicability minOccurs="0" maxOccurs="unbounded">
     <ids:entity>
      <ids:name>
       <ids:simpleValue>IFCWINDOW</ids:simpleValue>
      </ids:name>
     </ids:entity>
    </ids:applicability>
    <ids:requirements>
     <ids:property uri="https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2" dataType="IFCINTEGER">
      <ids:propertySet>
       <ids:simpleValue>Cobuilder_Requirements</ids:simpleValue>
      </ids:propertySet>
      <ids:baseName>
       <ids:simpleValue>Total Reuse Count</ids:simpleValue>
      </ids:baseName>
     </ids:property>
    </ids:requirements>
  </ids:specification>
  <ids:specification name="Prefab Concrete Column (NLRS_28_GdV_SCO_beton prefab_vierkant:betonkolom 500x500:1905732)" ifcVersion="IFC4X3_ADD2">
    <ids:applicability minOccurs="0" maxOccurs="unbounded">
     <ids:entity>
```

```
      <ids:name>
        <ids:simpleValue>IFCCOLUMN</ids:simpleValue>
      </ids:name>
    </ids:entity>
  </ids:applicability>
  <ids:requirements>
    <ids:property uri="https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2" dataType="IFCINTEGER">
      <ids:propertySet>
        <ids:simpleValue>Cobuilder_Requirements</ids:simpleValue>
      </ids:propertySet>
      <ids:baseName>
        <ids:simpleValue>Total Reuse Count</ids:simpleValue>
      </ids:baseName>
    </ids:property>
  </ids:requirements>
 </ids:specification>
 <ids:specification name="Hot-rolled Steel Hollow Section (NLRS_28_GdV_SCO_staal_koker warm gewalst:K200x200x16:2319564)" ifcVersion="IFC4X3_ADD2">
  <ids:applicability minOccurs="0" maxOccurs="unbounded">
    <ids:entity>
      <ids:name>
        <ids:simpleValue>IFCCOLUMN</ids:simpleValue>
      </ids:name>
    </ids:entity>
  </ids:applicability>
  <ids:requirements>
    <ids:property uri="https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2" dataType="IFCINTEGER">
      <ids:propertySet>
        <ids:simpleValue>Cobuilder_Requirements</ids:simpleValue>
      </ids:propertySet>
      <ids:baseName>
        <ids:simpleValue>Total Reuse Count</ids:simpleValue>
      </ids:baseName>
    </ids:property>
  </ids:requirements>
 </ids:specification>
 <ids:specification name="In-situ Concrete Wall (NLRS_22.21_GdV_WA_beton ihwg d=250:1826875) " ifcVersion="IFC4X3_ADD2">
  <ids:applicability minOccurs="0" maxOccurs="unbounded">
    <ids:entity>
      <ids:name>
        <ids:simpleValue>IFCWALLSTANDARDCASE</ids:simpleValue>
      </ids:name>
    </ids:entity>
  </ids:applicability>
  <ids:requirements>
    <ids:property uri="https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2" dataType="IFCINTEGER">
      <ids:propertySet>
        <ids:simpleValue>Cobuilder_Requirements</ids:simpleValue>
      </ids:propertySet>
      <ids:baseName>
        <ids:simpleValue>Total Reuse Count</ids:simpleValue>
      </ids:baseName>
```

```
      </ids:property>
    </ids:requirements>
  </ids:specification>
  <ids:specification name="Concrete Floor (Floor:NLRS_23_GdV_FL_betonvloer h=280:1854789) "
ifcVersion="IFC4X3_ADD2">
    <ids:applicability minOccurs="0" maxOccurs="unbounded">
      <ids:entity>
        <ids:name>
          <ids:simpleValue>IFCSLAB</ids:simpleValue>
        </ids:name>
      </ids:entity>
    </ids:applicability>
    <ids:requirements>
      <ids:property uri="https://identifier.buildingsmart.org/uri/TUe/DOR/0.0.2" dataType="IFCINTEGER">
        <ids:propertySet>
          <ids:simpleValue>Cobuilder_Requirements</ids:simpleValue>
        </ids:propertySet>
        <ids:baseName>
          <ids:simpleValue>Total Reuse Count</ids:simpleValue>
        </ids:baseName>
      </ids:property>
    </ids:requirements>
  </ids:specification>
 </ids:specifications>
</ids:ids>
```