SUM4Re

Creating materials banks from digital urban mining

D6.1 C-BIM Design

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EXECUTIVE SUMMARY

The European construction sector faces the critical challenge of high resource consumption and significant waste generation. The SUM4Re project aims to address this by enabling the creation of "materials banks" from the existing built environment through advanced digitalization. This report, Deliverable 6.1, presents the conceptual and foundational design for a Circular Building Information Model (C-BIM) capable of seamlessly integrating Digital Material Passports (DMPs). It serves as the high-level blueprint, outlining the strategic motivation, requirements, and architecture needed to bridge the gap between building design, deconstruction, and material reuse.

The proposed C-BIM framework moves beyond conventional BIM by adopting a lifecycle-centric approach built upon open standards, primarily the Industry Foundation Classes (IFC) . It is designed to integrate diverse data sources, including existing auxiliary data (drawings, reports), data from advanced scanning technologies (WP2), and standardized Pre-Demolition Audits. The model incorporates a new set of parameters specifically defined to support the 5R principles (Reduce, Reuse, Repair, Recycle, Renovate), capturing crucial information like material composition, connection types, condition, regulatory status, and dismantlability.

A core innovation is the integration of DMPs through a federated data ecosystem architecture. Instead of a monolithic database, the C-BIM acts as a central hub utilizing Universally Unique Identifiers (UUIDs) as immutable links between IFC objects and distributed external data sources, including DMPs, Digital Product Passports (DPPs), and specialized platforms like CIRDAX, CONCULAR, and GENIA. Real-time data exchange is facilitated by a conceptually defined Application Programming Interface (API), ensuring information remains current and accessible across the value chain.

The data model leverages IFC's Property Set (Pset) functionality, defining a custom Pset_Circularity to house key circularity attributes identified by the project, while acknowledging that a full DMP/DPP implementation might combine this with standard properties and other Psets. The structure is designed for interoperability, using IFC for the schema and the Information Delivery Specification (IDS) for data exchange protocols, and considers alignment with future standards like IFC5 and regulatory requirements like the CPR and DPP.

This report provides the strategic context and conceptual design that directly informs the accompanying detailed "SUM4Re C-BIM Schema: Technical Specification" document (Annex I), which is intended for software developers and implementers. The framework established herein forms the digital backbone for SUM4Re, enabling the data infrastructure required for creating material banks and supporting the subsequent economic and sustainability analyses crucial for advancing a circular economy in construction. Next steps involve finalizing the technical schema, developing the API, and implementing and testing the framework in the project's pilot sites.

GLOSSARY

Terms, Abbreviations, and Acronyms

- **API**: Application Programming Interface
- **BIM**: Building Information Model
- **C-BIM**: Circular Building Information Modeling
- **CDW**: Construction and Demolition Waste
- **CPR**: Construction Products Regulation
- **DBL**: Digital Building Logbook
- **DfD**: Design for Disassembly
- **DMP**: Digital Material Passport
- **DPP**: Digital Product Passport
- **EC**: European Commission
- **ECS**: Entity Component System
- **EoW**: End-of-Waste
- **EU**: European Union
- **GPR**: Ground Penetrating Radar
- **GWP**: Global Warming Potential
- **IDS**: Information Delivery Specification
- **IFC**: Industry Foundation Classes
- **JSON**: JavaScript Object Notation
- **LCA**: Life Cycle Assessment
- **PDA**: Pre-Demolition Audit
- **POPs**: Persistent Organic Pollutants
- **Pset**: Property Set
- **REACH**: Registration, Evaluation, Authorisation and Restriction of Chemicals
- **SUM4Re**: Creating materials banks from digital urban mining
- **UOI**: Unique Object Identifier
- **USD**: Universal Scene Description
- **UUID**: Universally Unique Identifier
- **WP**: Work Package
- **XRF**: X-ray Fluorescence

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Please note: "Annex" denotes a self-standing document bound with this deliverable. "Appendix" denotes author-produced supporting material directly tied to the main text.

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1. Introduction

1.1. Motivation and Objectives

The European construction sector is at a critical juncture. It is a cornerstone of the economy but also a major contributor to resource depletion, accounting for a significant portion of raw material consumption and generating the largest waste stream in the EU. The transition to a circular economy is therefore not just an environmental imperative but a strategic necessity to ensure long-term sustainability and competitiveness. The SUM4Re project directly addresses this challenge by aiming to create "materials banks" from the existing built environment. A key enabler for this vision is the digitalization of information regarding building materials and components. This report focuses on two critical digital tools: Circular Building Information Modelling (C-BIM) and Digital Material Passports (DMP). The primary objective of this task (Task 6.1) is to develop a robust conceptual and technical framework that provides the structure for implementing DMPs into C-BIM processes, thereby bridging the gap between design, deconstruction, and the reuse of materials in time. Since circularity also means the delivery of a current materials to a future usage, without using any new materials.

1.2. Scope and Delimitation

This document outlines the conceptual framework for the design and implementation of a C-BIM structure capable of integrating DMPs. The scope of this report is to define:

1. The necessary enhancements to standard BIM practices to meet the requirements of a circular construction model (the 5R principles: Reduce, Reuse, Repair, Recycle, Renovate).
2. A strategy for the seamless, real-time integration of DMP data into BIM software.
3. The interoperability requirements and protocols, adhering to open data standards like Industry Foundation Classes (IFC), to ensure compatibility with various software tools across the value chain.
4. The conceptual design and adaptation of an Application Programming Interface (API) to support circular economy use cases, such as material marketplaces and deconstruction planning. This report provides the foundational blueprint for the subsequent technical development. It delimits its focus to the conceptual design and technical structure, while the actual software programming and implementation will be covered in later project stages.

1.3. Methodological Approach

The development of this framework follows a collaborative, multi-stage methodology designed to ensure the resulting C-BIM structure is robust, stakeholder-aligned, and technically feasible. The approach leverages the interdisciplinary expertise within the SUM4Re consortium and consists of the following stages:

1. Data Foundation and Analysis: The process begins with a comprehensive analysis of all available information sources. Crucially, this involves a distinction between different data types. As detailed in Deliverable D1.6 "Connectivity with auxiliary data", a significant amount of auxiliary data often exists before any on-site scanning occurs (SUM4Re (THUAS, CONC, BLOCKM)). This includes legacy documents (2D drawings, demolition and pre-demolition reports, historical photos), data from municipal or national registries (e.g., land registers, building permits), and information from existing asset management systems. This auxiliary data provides an essential baseline that informs the subsequent data acquisition strategy. This initial data gathering is complemented by an analysis of the needs of key stakeholders (as

identified in WP1) to define the requirements for a circular construction process based on the 5R principles.
2. Conceptual Design: Based on the foundational analysis, a conceptual model for the enhanced C-BIM is designed. This includes the specification of new parameters and attributes required for circularity (e.g., dismantlability, reusability), the definition of the data hierarchy (Building -> Component -> Material), and the creation of visualized workflows that incorporate both auxiliary and newly acquired data.
3. Integration and Interoperability Strategy: A detailed strategy for the on-demand integration of DMP databases is developed. This framework is built upon open standards (IFC, IDS) to ensure broad usability and prevent vendor lock-in. It defines the data models, connection protocols, and the central role of the Universally Unique Identifier (UUID) as the immutable link between the physical asset and its distributed digital information.
4. Open API Specification: The requirements for a federated data architecture and a central API are specified. This API is designed to connect the C-BIM environment to external platforms like CIRDAX, GENIA, and CONCULAR, enabling a dynamic and service-oriented ecosystem for data exchange. This methodology ensures that the resulting framework is not only technically sound but also practically aligned with the complex data landscape of existing buildings.

1.4. Envisioning the Circular Object Lifecycle

To frame the objectives of this report, the following schema illustrates the envisioned lifecycle of a single building component (e.g., a steel beam) as it moves through a circular process. This entire journey is managed and tracked at every stage by the C-BIM and its connected digital ecosystem, using data derived from standardized Pre-Demolition Audit (PDA) processes, exemplified here by DIN SPEC 91484, which provide foundational data. (DIN SPEC 91484:2023-09)

- **Stage 1: In-Situ & Pre-Demolition Audit (First Life)**
  - **State:** The component is part of an existing building.
  - **Action:** A standardized Pre-Demolition Audit (PDA), such as one following the principles outlined in DIN SPEC 91484, is initiated. Stage 1 (Preliminary Assessment) involves gathering general information, and an object-oriented inspection identifies the component as having high potential for reuse. Stage 2 (Detailed Testing) involves a detailed, product-specific inspection.
  - **C-BIM Function:** The "Scan-to-C-BIM" process creates a digital twin. This object is populated with mandatory data gathered during the audit, including Year of Construction (e.g., *Baujahr* in DIN SPEC 91484), Connection Type (e.g., *Verbindungsart*), and an initial assessment of Condition (e.g., *Zustand*). Its Digital Material Passport (DMP) is created.
- **Stage 2: Deconstruction Planning**
  - **State:** A decision is made to deconstruct the building.
  - **Action:** Planners use the C-BIM, now enriched with the complete audit data, to finalize the reuse strategy.
  - **C-BIM Function:** The detailed data on Deconstructability from the audit allows for precise simulation of the deconstruction. This directly addresses barriers identified in D8.1 by providing standardized, reliable planning data.
- **Stage 3: Dismantling, Recovery & Verification**
  - **State:** The component is physically removed from the building.

- **Action:** A trained crew follows disassembly instructions linked to the C-BIM. The component's actual condition is verified against the audit findings.
- **C-BIM Function:** A site engineer updates the component's status. The DMP's Component_Condition is finalized. The Regulatory_Status is confirmed as "Product" for reuse, not "Waste" (as per D1.2 (SUM4Re (VTT, THUAS, SINTEF, TECN, BLOCKM))), supported by the formal audit documentation.

- **Stage 4: Logistics & Marketplace Listing**
  - **State:** The recovered component is transported to a material hub.
  - **Action:** The component is catalogued based on its verified audit data.
  - **C-BIM Function:** The component's DMP is updated with its new location. The C-BIM automatically pushes the component's verified data (condition, photos, technical specs from the audit) to digital materials databases like CIRDAX and CONCULAR and its connected marketplaces.
- **Stage 5: Design & Procurement (Second Life)**
  - **State:** An architect is designing a new building.
  - **Action:** The architect searches marketplaces for secondary materials. They find the steel beam, supported by its comprehensive and standardized audit report accessible via the DMP.
  - **C-BIM Function:** The API provides the architect with the beam's full DMP and associated audit data (as described in Section 4 of this report), instilling confidence in its quality and history. The purchase is made, and the component's status is updated to "Sold."
- **Stage 6: Reintegration & Digital Logbook Update**
  - **State:** The component is installed in its new building.
  - **Action:** The component begins its second life.
  - **C-BIM Function:** The component's DMP, including its original audit, is linked to the new building's Digital Building Logbook (DBL). The component's entire history is now part of the new asset's digital record.
- **Stage 7: End of Second Life & High-Quality Recycling**
  - **State:** The second building reaches its end-of-life.
  - **Action:** A future deconstruction team accesses the DBL and finds the component's complete history, including the initial PDA from its first life.
  - **C-BIM Function:** The DMP provides all necessary data for final processing. If no longer suitable for reuse, the detailed Material_Composition data ensures it is directed to the correct high-quality recycling stream, preventing downcycling. This property is more closely described in Section 3.3.

1.5. Relationship Between the Report and the Technical Schema

This report (D6.1) and the accompanying "SUM4Re C-BIM Schema: Technical Specification" (Annex I) are two distinct, but interconnected documents designed for different purposes and audiences.

- **This Report (D6.1 Conceptual Framework):** This document serves as the high-level, narrative framework. It outlines the strategic motivation, analyses the requirements for a circular construction model (the 5R principles), and presents the conceptual design of the C-BIM architecture and its integration with Digital Material Passports (DMPs).

Its primary audience includes project stakeholders, partners, and reviewers who need to understand the project's goals, methodology, and overall structure. It explains the "why" and "what" of the C-BIM design.

- **The C-BIM Schema (Technical Specification):** The schema is a formal, detailed, and prescriptive technical document intended for implementation. It translates the concepts from this report into a precise, machine-relevant specification, detailing the exact IFC (Industry Foundation Classes) mappings, data hierarchies, and the custom Pset_Circularity with all its parameters, data types, and definitions. Its primary audience is software developers, BIM managers, and data specialists who will build, validate, and use the C-BIM data structure. It defines the "how" of the implementation.

In essence, this report provides the justification and context for the technical choices that are formalized and detailed in the C-BIM Schema document (Annex I). The schema is the direct, actionable output of the conceptual work described herein. Keeping them separate ensures that each document effectively serves its intended audience without overwhelming readers with unnecessary detail.

2. Analysis and Requirements for C-BIM

2.1. Fundamentals of 5R Construction

The transition to a circular economy in the built environment is guided by the 5R principles: Reduce, Reuse, Repair, Recycle, and Renovate. For a Building Information Model to effectively support this transition and evolve into a C-BIM, that support the future delivery and use of materials, it must provide specific functionalities tailored to each principle,

- **Reduce:** The C-BIM must facilitate design strategies that minimize material consumption from the project's inception. This requires tools for precise material quantity take-offs, waste prediction simulations, and the ability to compare design alternatives based on their material footprint.
- **Reuse:** To enable the reuse of components, the C-BIM must go beyond generic material data. It needs to store detailed, object-specific information, including dimensions, connection types, current condition, disassembly instructions, and remaining service life. This necessitates the creation of new, standardized parameters that are not typically found in conventional BIM.
- **Repair:** The model should function as a dynamic Digital Building Logbook (DBL), tracking the history of components, including maintenance and repairs. This allows asset managers to identify elements that can be repaired to extend their lifespan, rather than being prematurely replaced.
- **Recycle:** For effective recycling, the C-BIM must contain granular data on material composition, including purity levels, the presence of any contaminants, or hazardous substances (as will be identified by technologies in WP2 & WP3). This information is crucial for accurately assessing the recyclability potential and directing materials to the correct waste streams.
- **Renovate:** The C-BIM must be capable of accurately representing existing "as-is" conditions, integrating data from advanced scanning technologies (WP2). Furthermore, it must allow for the simulation of renovation scenarios that prioritize the use of salvaged materials and components sourced from other deconstruction projects.

2.2. Identification of Improvement Potential

Conventional BIM practices are primarily optimized for the design and construction phases of new buildings. Their utility diminishes significantly at the end-of-life stage, presenting several gaps that SUM4Re aims to address. A major limitation is the inefficient and often manual process of creating accurate as-built models of existing structures, a challenge that the automated data acquisition technologies in WP2 are designed to overcome. Furthermore, standard BIM lacks a standardized vocabulary and parameters for circularity; information regarding a component's potential for reuse, its disassembly sequence, or its residual value is typically not captured. This information gap decouples the design and deconstruction phases from materials markets, including both primary and secondary materials. Existing software for Construction and Demolition Waste (CDW) management often operates in isolation, without direct integration into the BIM environment, hindering holistic planning and a proper future delivery of materials currently available in buildings. The C-BIM framework developed in SUM4Re will address these shortcomings by creating an integrated, data-rich environment that spans the entire building lifecycle and makes it possible to include contracts with the future like term- and option contracts.

2.3. Stakeholder Requirements

A successful C-BIM must serve the diverse information needs of all actors across the construction value chain. Through workshops and interviews (as planned in WP1 and WP8), the specific requirements of each stakeholder group will be incorporated into the framework's design.

- **Architects & Engineers:** Require direct access to libraries of secondary materials and reusable components within their design software including their location for transport and estimated availability in case the donor building is not yet demolished. They need tools that support "Design for Disassembly" (DfD) and allow them to assess the circularity potential of their designs.
- **Deconstruction & Demolition Companies:** Need the C-BIM to function as a comprehensive pre-demolition audit, providing clear information on component connections, the location of hazardous materials, and the location and identification of high-value elements to enable selective and efficient deconstruction.
- **Investors & Building Owners:** Require data on the long-term economic benefits of circular strategies, including the residual value of materials and components, which should be quantifiable and traceable within the C-BIM.
- **Material Suppliers & Recyclers:** Need reliable, real-time data on the quantity, quality, and availability of materials from deconstruction projects to optimize their logistics, processing, and supply chain management. The C-BIM will act as a crucial source of this market intelligence.
- **Inventory or audit experts:** Need the C-BIM to effectively map, store and identify materials in a building to improve their productivity.

3. Conceptual Design of the C-BIM Structure

3.1. Design of the Enhanced C-BIM Model

The design of the enhanced C-BIM model is foundational to achieving the project's circularity goals. Unlike conventional BIM, which is primarily product-centric and focused on new builds, the C-BIM must be lifecycle-centric. It will be built upon an open standard (IFC), as recommended in Deliverable D1.3 (SUM4Re (VTT,CONC, THUAS, TECN)), to ensure maximum interoperability and prevent data silos. The model is designed to be a central repository that transforms an as-is building into a dynamic material bank. It must be capable of integrating data from pre-demolition audits (as outlined in D1.2 (SUM4Re (VTT, THUAS, SINTEF, TECN, BLOCKM))) and the advanced scanning technologies from WP2. The data structure will follow the hierarchical logic proposed in D1.3 (Building -> Kit -> Component -> Constituent -> Material) (SUM4Re (VTT,CONC, THUAS, TECN)), allowing for varying levels of detail necessary for different circularity strategies.

This enhanced C-BIM will serve as the digital twin of the physical asset, enriched with the specific data needed to plan, execute, and validate circular construction practices. It includes the integration of Unique Object Identifiers (UOI's) or Universally Unique Identifiers (UUID) to ensure that every material has an identity and an owner. Both can be generated by using Blockchain Technology to create identities and ownership according to the characteristics of Blockchain technology.

The C-BIM support the market integration in this way by organising future contracts due to its identities and ownership characteristics which make it possible to include elements of time, aggregation, etc. to organise the needed economies of scale and scope in a circular economy.

The data structure will follow the hierarchical logic proposed in D1.3 (Building -> Kit -> Component -> Constituent -> Material) (SUM4Re (VTT,CONC, THUAS, TECN)), allowing for varying levels of detail necessary for different circularity strategies. This hierarchical relationship, which connects physical assets and activities to the Material Passport, Product Passport, and the overall Building Logbook, is shown in Figure 1.

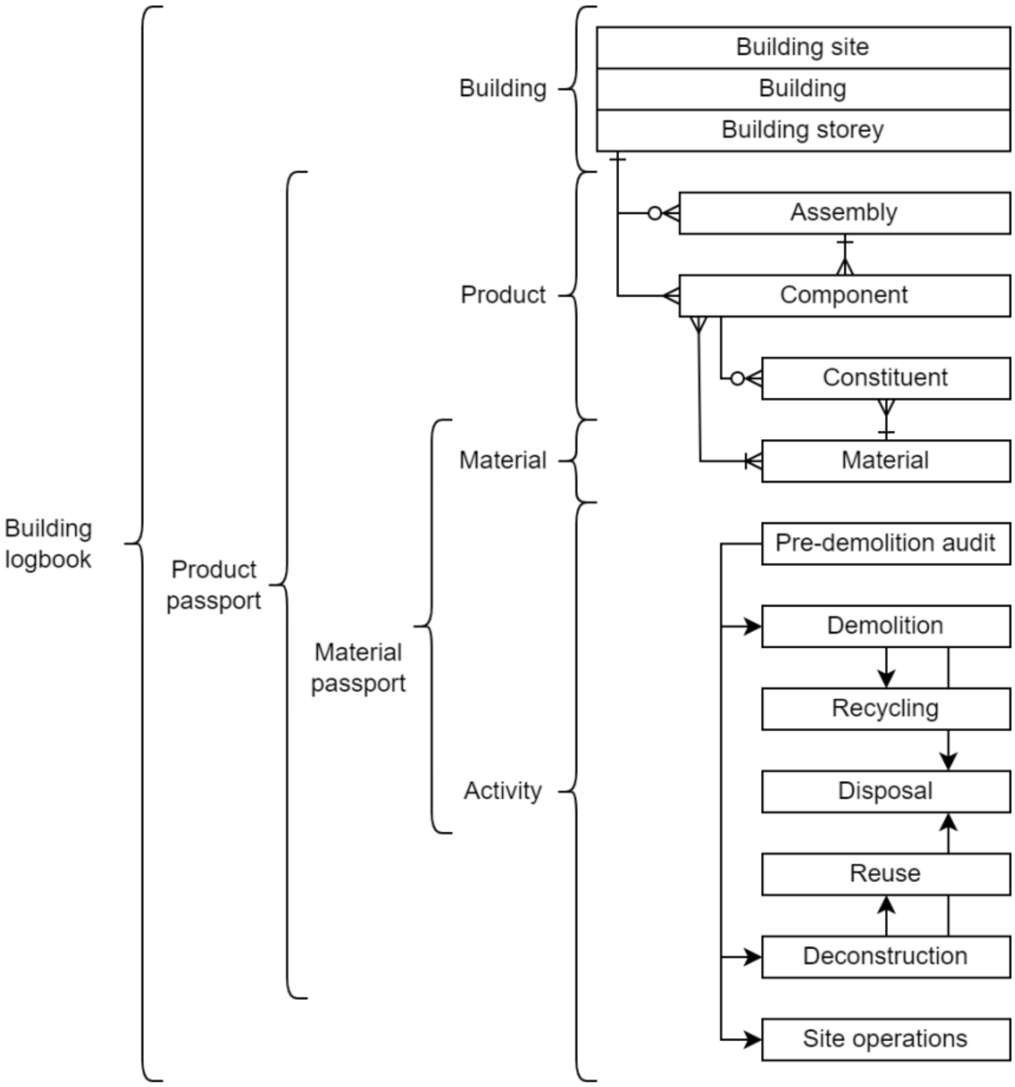

Figure 1 - Information domains of DMP, DPP and DBL

3.2. Information Domains: Material and Product Passports

As illustrated in Figure 1, the data is structured hierarchically to serve distinct purposes within the circular economy. The Material Passport (DMP) operates at the most fundamental level, containing data about the substance itself, such as its chemical composition, origin, and the presence of any hazardous materials. This information is crucial for end-of-life processes, ensuring materials can be safely and effectively directed to the correct high-quality recycling stream. In contrast, the Product Passport (DPP) describes a manufactured component, like a window or a steel beam. It aggregates one or more DMPs and adds product-specific information, including dimensions, performance data, connection types, and disassembly instructions. The DPP's purpose is to enable component reuse, repair, and efficient deconstruction by providing actionable data about the object as a whole. Finally, the Digital Building Logbook (DBL) sits at the top of this hierarchy, serving as a comprehensive record for the entire asset. It aggregates all the DPPs for the components within the building and includes dynamic, lifecycle information such as maintenance history, renovation records, and energy performance data. The DBL provides a holistic view of the building as a material bank, essential for long-term asset management and strategic deconstruction planning.

3.3. Definition of New Parameters and Attributes

To transition from a conventional BIM to a C-BIM, standard object parameters are insufficient. Based on the findings of previous deliverables, a new set of attributes is required to capture the information essential for a circular economy. The hierarchical organization of these parameters within Material Passports, Product Passports, and the overarching Building Logbook is illustrated in Figure 2. The connecting arrows in the diagram represent a one-to-many relationship flowing from the highest level of aggregation downwards. The Digital Building Logbook serves as the master container, aggregating the Product Passports for all components within the building. Each Product Passport, in turn, contains the Material Passports for all the constituent substances that make up that specific product. Furthermore, the Building Logbook is explicitly linked to the technical documentation, with the C-BIM file acting as the central model that provides the spatial and relational context for all the nested passport data. These parameters are categorized as follows:

- Material & Component Data (SUM4Re (SINTEF, BLOCKM, VTT)) (SUM4Re (VTT,CONC, THUAS, TECN)):
  - Material_Composition: Detailed breakdown of constituent materials.
  - Circularity_Classification: A tag (e.g., reusable, recyclable, downcyclable) based on the classification framework in D1.1 (SUM4Re (SINTEF, BLOCKM, VTT)).
  - Hazardous_Substances: A Boolean or text field indicating the presence of hazardous materials, as per the regulatory frameworks discussed in D1.2 (SUM4Re (VTT, THUAS, SINTEF, TECN, BLOCKM)) or if applicable a presence concentration of a certain substance with a threshold value.
  - Origin: Data on the source of the material or component. This includes specifying if it is virgin, its recycled content percentage, or if it is bio-based. Crucially, for components reused from previous structures, this parameter should indicate its status as 'Reused'. In such cases, if the component originated from a building with its own C-BIM or Digital Building Logbook (DBL), its original Universally Unique Identifier (UUID) should ideally be retained or referenced. This allows for linking back to its previous history and data (e.g., original Digital Material Passport (DMP), maintenance records) within the federated data ecosystem, rather than solely copying historical data into the new C-BIM. This maintains the full lifecycle traceability envisioned by the SUM4Re framework.
- **Deconstruction & Disassembly Data** (SUM4Re (SINTEF, RAFER))**:**
  - Connection_Type: Classification of connections (e.g., welded, bolted, glued) to assess disassembly ease.
  - Disassembly_Instructions: A link to external documentation or a text field with procedural steps.
  - Disassembly_Difficulty: A scored rating (e.g., 1-5) based on accessibility, required tools, and component dependencies.
  - Component_Condition: The current state of the component (e.g., as new, used, requires repair).
- **Lifecycle & Regulatory Data** (SUM4Re (VTT, THUAS, SINTEF, TECN, BLOCKM)) (SUM4Re (VTT,CONC, THUAS, TECN))
  - Remaining_Service_Life: An estimation of the component's remaining functional lifespan. Optimally derived from manufacturer documentation (EPD or other document).
  - Regulatory_Status: Classification regarding product vs. waste status, as explored in D1.2, to clarify legal handling requirements (SUM4Re (VTT, THUAS, SINTEF, TECN, BLOCKM)).

  - Certifications: Any relevant environmental or quality certifications.

- **Placeholders for Economic & Social Data (to be detailed in D6.2 & D6.3):** To avoid overlap with subsequent deliverables while ensuring the C-BIM is future-proof, the following placeholder attributes are included. The detailed methodologies for their calculation will be the focus of D6.2 (Economic Analysis) and D6.3 (Social-Environmental Analysis).
  - Residual_Value_Estimate: A field for an estimated monetary value.
  - Embodied_CO2_Impact: A field to store the lifecycle Global Warming Potential (GWP) data derived from Life Cycle Assessments (LCA). The calculation methodology must align with relevant standards (e.g., EN 15978, EN 15804) to ensure harmonization with the EPBD lifecycle GWP reported in energy certificates, avoiding data duplication.
  - Social_Impact_Score: A placeholder for metrics related to social value, such as local job creation through repair or remanufacturing.

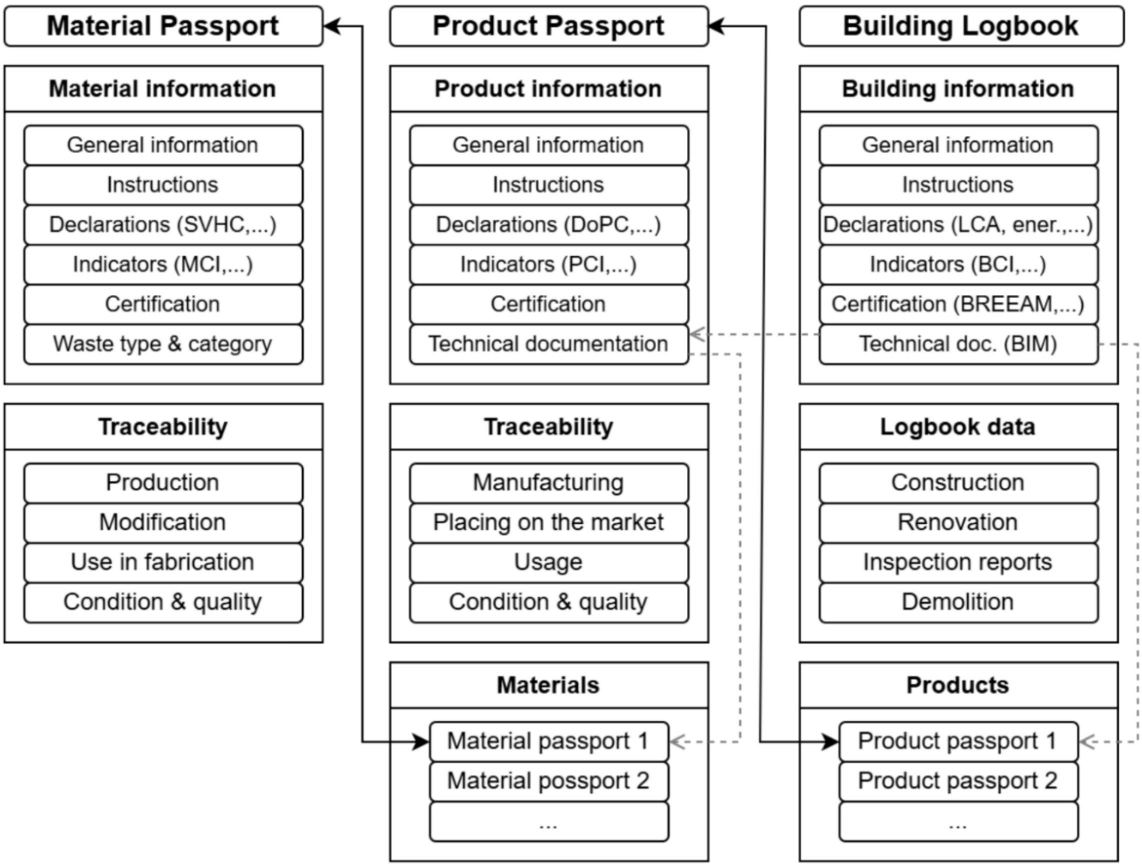

Figure 2 - Hierarchical data structure of Material Passport, Product Passport and Building Logbook. (SUM4Re (VTT,CONC, THUAS, TECN))

3.4. Process Schemas

To operationalize the C-BIM concept, a clear, standardized workflow is required that integrates data from all available sources. The following schema illustrates the enhanced process, beginning with the collection of auxiliary data (as highlighted in D1.6) and culminating in an enriched, actionable C-BIM (SUM4Re (THUAS, CONC, BLOCKM)). This workflow is visually represented in the comprehensive data flow diagram developed across the project (see Figure 4).

Phase 1: Data Aggregation & Baseline Creation

This initial phase occurs before any on-site scanning and focuses on creating a foundational understanding of the asset.

- Action: Collection and digitization of all available auxiliary data. As outlined in D1.6, this includes a wide range of sources (SUM4Re (THUAS, CONC, BLOCKM)):
  - Document Review: Analysis of existing plans (2D CAD or PDF drawings), historical reports, maintenance logs, and demolition plans.
  - External Database Query: Retrieval of structured data from municipal or national registries (e.g., land registers for ownership history, building permits for construction year) and existing asset management systems.
- Output: An initial, expected inventory is created. This baseline provides crucial context, informs the strategy for on-site data acquisition, and identifies potential data gaps or areas requiring special attention.

Phase 2: On-Site Data Acquisition & "As-Is" Model Creation

This phase focuses on capturing the current physical state of the building, guided by the insights from Phase 1.

- Action: Targeted on-site scanning using advanced acquisition technologies.
  - Data Capture: Use of iMMS, GPR, XRF, etc., to capture raw geometric and material data. The scanning strategy is optimized based on the auxiliary data to focus on unknown areas or verify outdated information.
- Data Processing & Output:
  - "As-Is" Model Creation: Raw data (point clouds, sensor readings) is processed into an initial geometric BIM ("Scan-to-BIM"). This model represents the current physical state of the building.

Phase 3: C-BIM Enrichment and Central Registration

In this phase, all data sources are consolidated into a single, enriched model.

- Action: The "As-Is" geometric model is enriched by integrating the auxiliary data from Phase 1 with the detailed data from the two-stage Pre-Demolition Audit (PDA) as per DIN SPEC 91484.
- C-BIM Function:
  - Data Integration: Information from drawings, reports, and the PDA (e.g., Connection_Type, Component_Condition, Regulatory_Status) is mapped to the corresponding geometric objects in the BIM.
  - Central Registration: Each relevant component and material is registered in the central UUID system. This assigns a persistent and unique identifier (UUID) that serves as the "golden thread" linking the object to all its associated data across different platforms. The Digital Material Passport (DMP) is initiated for each component, creating a trusted data foundation. This transparent record of

a material's properties and history is fundamental to overcoming the information asymmetry detailed in Deliverable T6.2, thereby enabling a reliable assessment of its economic value. Furthermore, the DMP serves as the repository for key sustainability metrics, capturing the data necessary for the lifecycle assessments (e.g., calculation of avoided "embodied CO2") that form the core of the sustainability analysis in Deliverable T6.3. (SUM4Re (BLOCKM, THUAS, CONC)) (SUM4Re (BLOCKM, THUAS, CONC))

Phase 4: C-BIM as a Central Data Hub

The fully enriched C-BIM is now ready for use as a dynamic tool for circularity planning.

- State: The enriched C-BIM is complete, with every key component linked via UUID to a rich dataset comprising auxiliary, scanned, and audited information.
- C-BIM Function:
  - Simulation & Planning: Enables deconstruction simulation, waste prediction, and reuse scenario planning.
  - API Connectivity: The C-BIM is ready to push and pull data via the central API to external platforms (e.g., material marketplaces like CIRDAX and CONCULAR), making the building's material stock visible and accessible. This data-rich connectivity is the technical enabler for the market strategies and economic models developed in T6.2, and it provides the transparency needed to realize the social and environmental value of materials as analysed in T6.3 (SUM4Re (BLOCKM, THUAS, CONC)) (SUM4Re (BLOCKM, THUAS, CONC)).
- Output: An actionable, data-rich digital twin that serves as the backbone for lifecycle management and the creation of a "material bank".

This entire multi-phase workflow—from initial data gathering to the creation of an actionable digital twin—is visually represented in the comprehensive data flow diagram in Figure 4. This diagram illustrates how auxiliary data, newly acquired scans, and enriched C-BIM information interact within a federated ecosystem of specialized platforms, a concept detailed further in section 4.2.

This process schema illustrates the journey from diverse data sources to a fully enriched, actionable C-BIM. Having established this workflow, the following chapters will delve into the specific technical mechanisms required to realize this vision. Chapter 4 will detail how the crucial Digital Material Passport (DMP) is seamlessly integrated within this structure, elaborating on the federated data ecosystem concept. Chapter 5 will address how interoperability is ensured through the rigorous application of open standards and protocols. Finally, Chapter 6 will focus on adapting the central Application Programming Interface (API) to enable dynamic data exchange and support the specific use cases vital for a functioning circular economy in construction.

4. Seamless Integration of the Digital Material Passport

4.1. Concept for Real-Time Integration

The integration of DMPs into the C-BIM environment is not a one-time data import but a dynamic, ongoing process. The concept for real-time integration relies on a service-oriented architecture where the C-BIM acts as a central hub that can query and exchange data with external DMP platforms and databases, like described in the figure below.

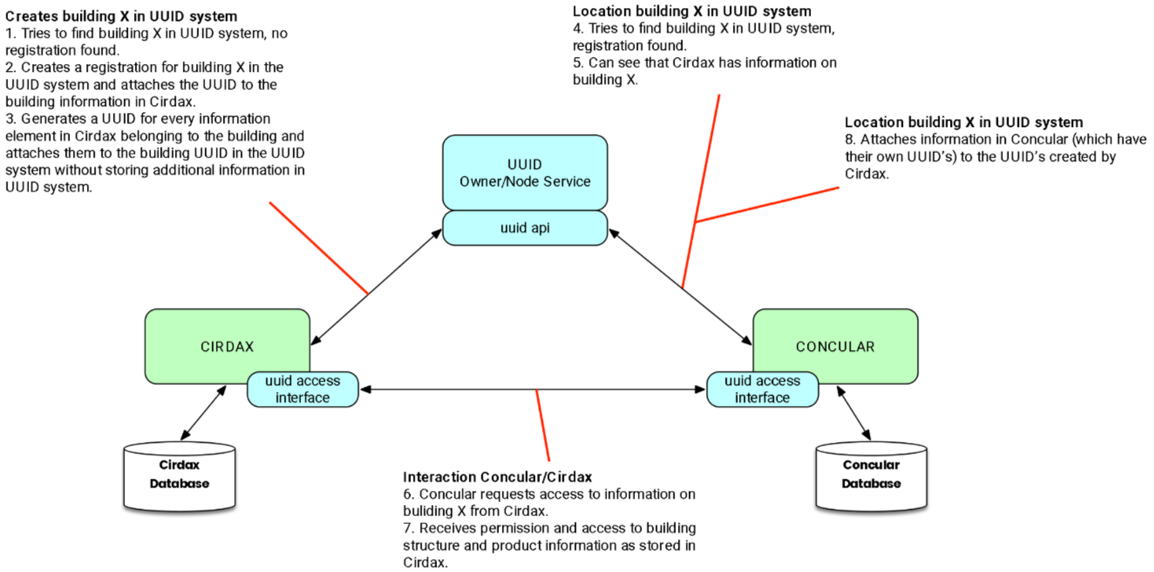

Figure 3 - Workflow for location and sharing of information between external platforms (CIRDAX, CONCULAR) and the central UUID service, enabling real-time data exchange.

This ensures that the information within the C-BIM remains current and reflects the real-world status of materials and components. For example, when a component is dismantled and its condition is assessed, its DMP can be updated, and this change should be immediately accessible within the C-BIM. This approach avoids data redundancy and ensures that all stakeholders are working with the most up-to-date information, a critical factor for logistics, market transactions, and compliance verification.

4.2. The Federated Data Ecosystem Architecture

While Section 4.1 introduced the concept of real-time integration, this section details the high-level technical architecture that makes it possible. The SUM4Re framework does not rely on a single, monolithic database. Instead, it operates as a federated ecosystem where specialized platforms interact through a central identification and API layer. This service-oriented approach ensures that each platform can focus on its core strengths while contributing to a holistic and comprehensive data profile for each building component.

The overall data and process flow is illustrated in Figure 4.

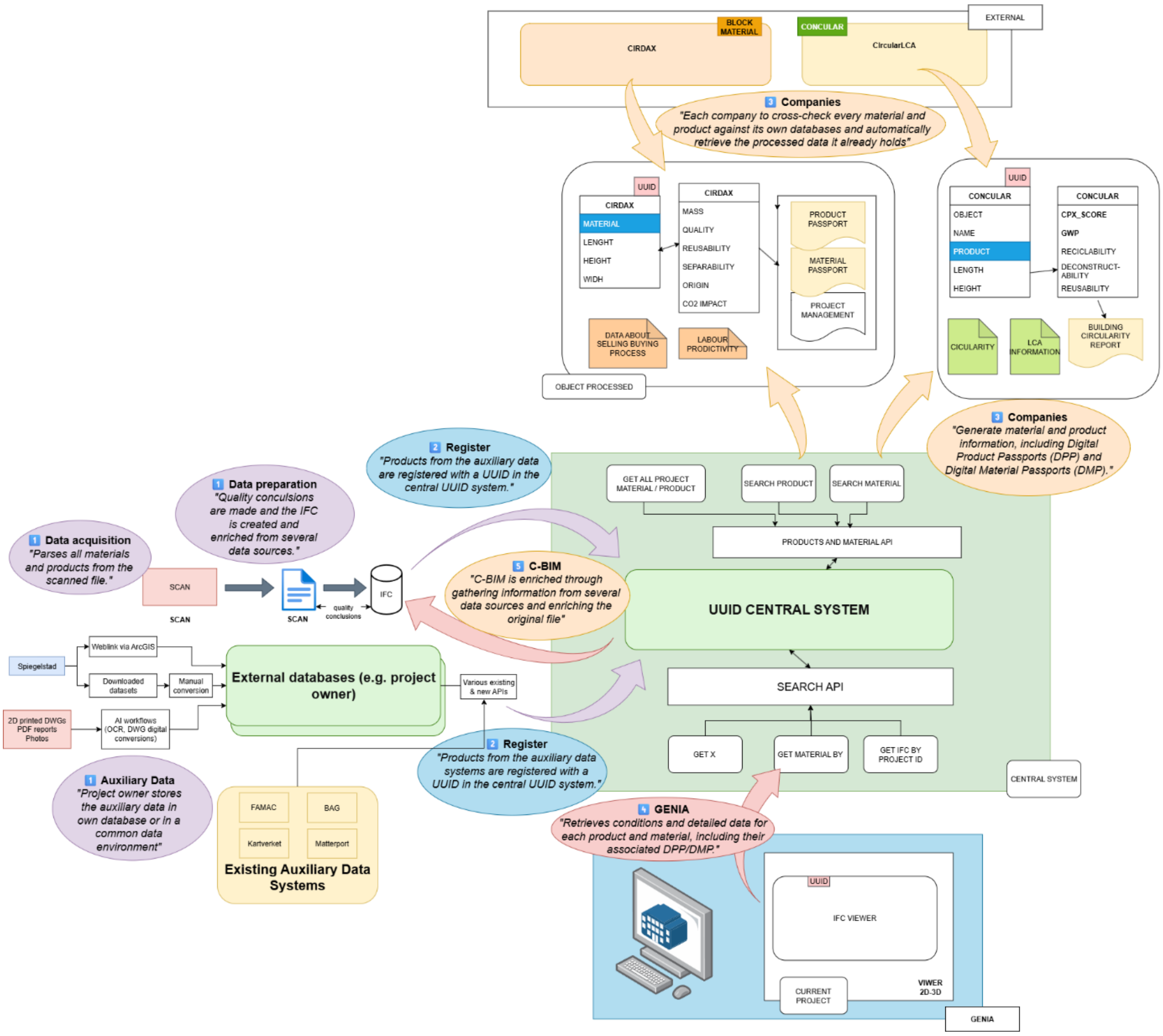

Figure 4 - High-Level Data and Process Flow for the SUM4Re C-BIM Ecosystem

The SUM4Re framework doesn't rely on a single, monolithic database but operates as a federated ecosystem where specialized platforms interact through a central identification and API layer. This service-oriented approach ensures each platform can focus on its core strengths while contributing to a holistic data profile for each building component. The overall data and process flow, illustrated in Figure 4, can be understood through the following stages:

1. Data Acquisition and Aggregation: The process begins with the project owner gathering all available asset information. This is a multi-source process that incorporates everything from modern 3D scans to legacy data like 2D drawings, PDFs, and photos. This information is aggregated into an external project owner database, creating a comprehensive initial dataset.
2. Central Registration and C-BIM Enrichment: The aggregated data is then processed into a C-BIM, which serves to enrich the original files by gathering information from multiple sources. Crucially, each identified product and material within the C-BIM is then registered in the UUID CENTRAL SYSTEM. This assigns a unique and persistent Universally Unique Identifier (UUID) to every component, creating a "golden thread" that links all subsequent information back to a single, unambiguous entity.
3. Data Enrichment by Specialized Platforms: With a unique identifier in place, specialized platforms retrieve, analyze, and enrich the data for each component. The ecosystem relies on the distinct capabilities of its partner platforms:

- CIRDAX acts as a deep repository for material-specific properties, holding detailed information on mass, quality, reusability, and CO2 impact. It is instrumental in generating the formal Digital Product Passports (DPPs) and Digital Material Passports (DMPs).
- CONCULAR functions as a circularity assessment engine, processing object information to generate high-level metrics like the CPX_SCORE and ultimately producing a comprehensive Building Circularity Report.

4. API-Driven Data Retrieval: The interaction between these platforms is managed through a Central System Search API. This allows authorized platforms like GENIA to programmatically query the system using a component's UUID. GENIA can then retrieve all associated data—including the C-BIM file, DPPs, and DMPs—to visualize and display a component's complete, enriched digital record for the end-user.

This federated architecture allows the C-BIM to be enriched with a wealth of information that goes far beyond simple geometry, creating a truly dynamic and actionable digital twin for the circular economy.

4.3. Data Model for the DMP within C-BIM

The DMP is not just a document; it is a structured dataset. Within the C-BIM, the data model for the DMP will directly correspond to the parameters and attributes defined in 3.2**.** This will be implemented using the property set (Pset) functionality within the IFC standard.

Acknowledging that a full Digital Material Passport encompasses a wide range of data, some of which may already be covered by standard IFC properties and existing Psets, the SUM4Re project defines a custom Pset_Circularity. This specific Pset is designed to house the key circularity-focused attributes identified as essential by this project and detailed in section 3.2 and APPENDIX A. While Pset_Circularity captures the core circularity aspects, a complete DMP implementation might leverage a combination of this custom Pset, standard IFC properties, and potentially additional dedicated Psets (such as a Pset_DMP linked to IfcMaterial or a Pset_DPP linked to IfcBuiltElement) to store supplementary data not already defined elsewhere in the IFC schema.

The specific parameters for this Pset are derived directly from the foundational analysis conducted in Deliverable D1.1 (SUM4Re (SINTEF, BLOCKM, VTT)), which provides a complete taxonomy of circularity properties for inclusion in BIM. This ensures consistency across project work packages.

Crucially, this data model is designed to be legally and regulatorily compliant. Two key parameters, Hazardous_Substances and Regulatory_Status, are directly informed by the legal analysis in Deliverable D1.2 (SUM4Re (VTT, THUAS, SINTEF, TECN, BLOCKM)). The Hazardous_Substances field will hold data necessary for compliance with chemical legislation such as REACH and POPs. The Regulatory_Status field will classify a component according to the critical legal distinction between "product" and "waste," including End-of-Waste (EoW) criteria, which determines how a component can be legally traded and reused.

Furthermore, while this report focuses on the integration of the DMP (material-level data), the overall C-BIM data structure must also accommodate the requirements of the upcoming EU Construction Products Regulation (CPR), which mandates a Digital Product Passport (DPP) for manufactured components. Figure 5 illustrates the typical content expected within such a DPP, including declarations, technical documentation, and unique identifier. The C-BIM framework, utilizing a combination of custom Psets (like Pset_Circularity), standard IFC properties, and potentially dedicated Psets (like Pset_DPP linked to IfcBuiltElement), is designed to be flexible enough to store or link to both the granular DMP data (material composition, origin, hazardous substances) and the broader DPP information (performance, conformity, manufacturer details) .This structured approach ensures that DMP data is an integral part of the BIM object, rather than an external, loosely linked file. This tight integration allows for powerful data filtering, visualization, and automated analysis directly within the BIM software.

This structured approach ensures that relevant passport data (both DMP and potentially DPP) becomes an integral part of the BIM object, rather than just an external, loosely linked file. This tight integration allows for powerful data filtering, visualization, and automated analysis directly within BIM software.

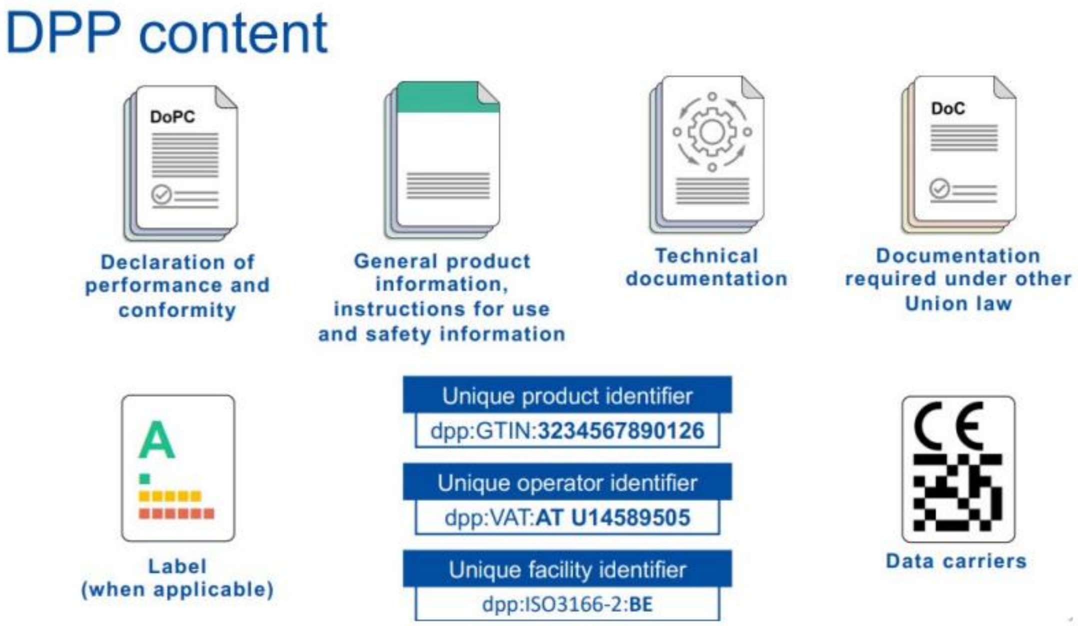

Figure 5 - Data to be included in DPP for construction products (Schulze)

This structured approach ensures that DPP data is an integral part of the BIM object, rather than an external, loosely linked file. This tight integration allows for powerful data filtering, visualization, and automated analysis directly within the BIM software.

4.4. Core Architectural Principle: IFC Structure and UUID Linking

The integration of this federated data relies on a central architectural principle. The entire information system is based on the IFC (Industry Foundation Classes) structure, even though not all information is stored directly in an IFC file. The system consistently adheres to the hierarchical logic of Building -> Object -> Material, with specific properties attached at each level (International Organization for Standardization).

The Universally Unique Identifier (UUID) for each building component serves as the crucial bridge in this architecture. It links the central, IFC-structured object to a rich ecosystem of additional data in various non-IFC formats (e.g., PDF reports, sensor data, images, platform-specific analyses). This is conceptually illustrated in the diagram below.

This architecture enables a powerful bidirectional information flow. Information from external platforms (e.g., circularity calculations from CIRDAX) can be attached as specific parameters to the BIM object. At the same time, the UUID maintains a persistent connection to the source systems, allowing users to access the original base data at any time for verification, deeper analysis, or auditing.

4.5. Interface with BIM

The integration of DMPs into the C-BIM environment is not a one-time data import but a dynamic, ongoing process. The concept for real-time integration relies on a service-oriented architecture where the C-BIM acts as a central hub that can query and exchange data with external DMP platforms and databases, as depicted in the figure below. At the core of this concept is the use of a Universally Unique Identifier (UUID) for each building component. This UUID acts as a crucial bridge between the geometric object within the IFC-based C-BIM and a rich ecosystem of external, non-IFC data.

This architecture enables a powerful bidirectional information flow. On one hand, processed information derived from external scans (e.g., quality assessments, photos) and platforms (e.g., circularity calculations from CIRDAX) can be directly attached as specific parameters to the BIM object, enriching the standard IFC data. On the other hand, the UUID maintains a persistent link back to the source systems. This is critically important, as it ensures that users can, at any time, retrieve the original base data (the raw scanning data) or detailed platform reports for verification, deeper analysis, or auditing. This dual capability ensures that the information within the C-BIM remains current and reflects the real-world status of materials. For instance, when a component is dismantled and its condition is verified, its DMP can be updated, and this change is immediately accessible within the C-BIM. This approach avoids data redundancy and guarantees that all stakeholders are working with the most up-to-date, verifiable information—a critical factor for logistics, market transactions, and compliance.

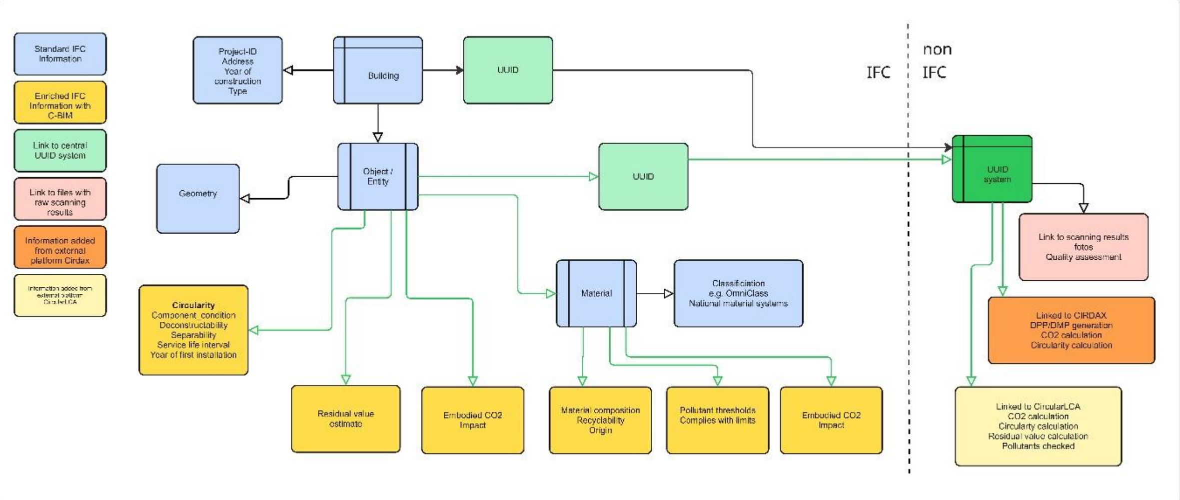

Figure 6 - Conceptual data structure of the C-BIM, illustrating the integration of circularity parameters and the connection to external systems via a Universally Unique Identifier (UUID).

4.6. Prototypical Connection

To demonstrate the feasibility of this integration, a prototypical connection will be conceptualized at the beginning of work package 7. This proof-of-concept will outline a workflow for linking a BIM authoring tool (e.g., Autodesk Revit) with two of the project's partner platforms (e.g., CircularLCA and CIRDAX). The workflow would be as follows:

1. An object in the Revit model is assigned a Universally Unique Identifier (UUID).
2. A custom plugin or script within Revit uses this UUID to make an API call to the CircularLCA and Cirdax platforms, requesting the DMP for that specific object.
3. The Cirdax platform returns the DMP data in a structured format (e.g., JSON).
4. The plugin then parses this data and populates the corresponding parameters within the Pset_Circularity of the Revit object. This demonstrates a clear, automatable pathway for enriching a BIM with live, external DMP data, forming the basis for the development in later work packages.

5. Ensuring Interoperability

5.1. Requirements for Open Data Standards

The long-term success and widespread adoption of the SUM4Re framework hinges on its commitment to interoperability as a way to improve the value of secondary materials and enhancing the labour productivity of making inventories of materials in buildings. Interoperability as such is an important way to make data about materials more transparent and is a means to improve the value of materials, because it closes the gap of information asymmetry, currently causing secondary materials to be used inefficiently. As strongly recommended in Deliverable D1.3, the entire data architecture will be built upon open standards, with the Industry Foundation Classes (IFC) serving as the core data schema (SUM4Re (VTT,CONC, THUAS, TECN)). The use of an open standard like IFC is non-negotiable as it prevents vendor lock-in, ensures that data remains accessible and usable for decades (spanning the entire lifecycle of a building), and facilitates seamless collaboration among the multitude of stakeholders and software platforms that characterize the fragmented construction industry. This approach guarantees that the circularity data captured within the C-BIM is not trapped in a proprietary format but can be freely exchanged and utilized by anyone, like described in 4.1.

To achieve this, the project's conceptual data hierarchy is mapped directly to the IFC standard, ensuring that every element—from physical components to process activities—is represented by a corresponding IFC entity. This mapping, detailed in Figure 7, provides a clear and standardized data structure. For instance, a building component is represented as an IfcBuiltElement, while a process like demolition is defined as an IfcTask of the type DEMOLITION. This direct implementation within the IFC schema is fundamental to ensuring seamless data exchange and interoperability across the entire project ecosystem.

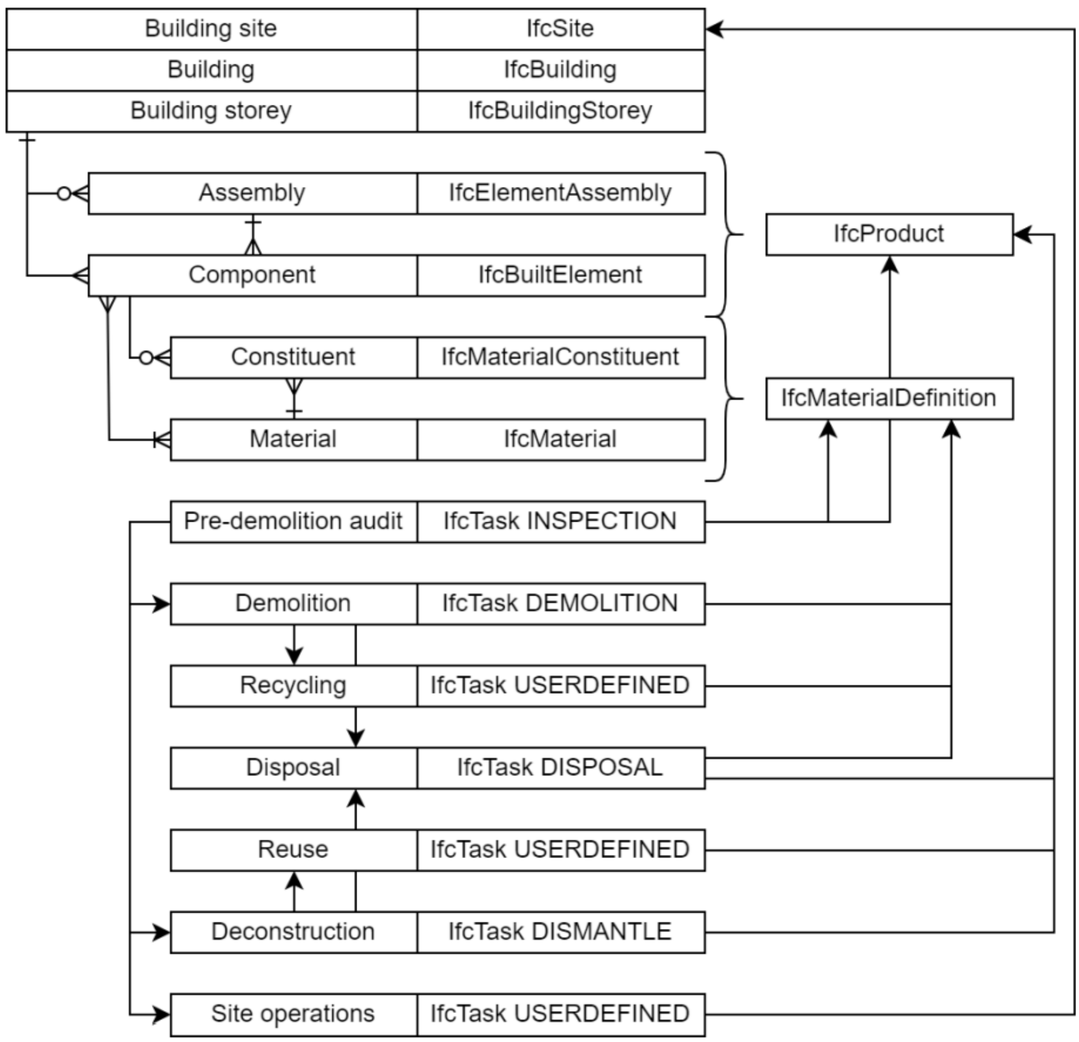

Figure 7 - Mapping of SUM4Re Data Concepts to the IFC Standard (SUM4Re (VTT,CONC, THUAS, TECN))

5.2. Protocols for Data Exchange

While IFC defines the "what" (the data schema), clear protocols are needed to define the "how" of data exchange. For this, the SUM4Re framework will adopt the Information Delivery Specification (IDS), another buildingSMART standard highlighted in D1.3. IDS is a computer-interpretable format that allows project stakeholders to define precisely what data is required, from whom, and at what stage of the project. For example, an IDS file can specify that for all structural steel elements, the Component_Condition and Residual_Value_Estimate parameters must be provided by the deconstruction contractor before a demolition permit is issued. This creates a formal, verifiable contract for data delivery, ensuring that the C-BIM is populated with the necessary information at the right time and significantly improving the quality and reliability of the circularity data.

5.2.1. Opportunities in the implementation of IFC5

As established in the comprehensive review of data standards in Deliverable D1.3 (SUM4Re (VTT,CONC, THUAS, TECN)), the evolution towards IFC5 presents significant opportunities for the circular economy. The limitations of the current IFC4 standard, which were analysed in D1.3, serve as the primary motivation for this next-generation schema.

The IFC schema up to version IFC4 was primarily developed for the STEP format. As D1.3 outlines, this file-based approach has become increasingly obsolete and creates several challenges. In the context of the circular economy, the most fundamental drawback is the complicated breakdown of a project into sub-assemblies and the difficulty of tracking separate objects that are recovered, recycled, or reused. This often requires re-creating components in a new model. Furthermore, linking external data from different formats (e.g., scanning, monitoring, and imaging data) to the IFC model remains a significant challenge.

To address these issues, buildingSMART International's development of IFC5, as detailed in D1.3, focuses on several key advancements (SUM4Re (VTT,CONC, THUAS, TECN)). The future schema will be language-independent, enabling data to be represented in multiple formats like XML, JSON, and RDF. This shift is validated by concepts tested in 2020, such as the Entity Component System (ECS), which offers greater flexibility and granularity for distributed collaboration. Another promising technology explored for IFC5 is Universal Scene Description (USD), which uses triangular meshes for geometry. This allows for better performance and optimization of geometric data, which is highly convenient for processing the point clouds generated during pre-demolition inspections.

Building on the analysis from D1.3, it can be concluded that IFC5 brings many opportunities for circular economy applications in buildings, namely (SUM4Re (VTT,CONC, THUAS, TECN)):

1. Distributed datasets across different platforms.
2. Integration of scanning, monitoring, and imaging binary data.
3. Better granularity and efficient decomposition of existing models.
4. Optimized performance of point-cloud-based geometry.

The federated data architecture and component-centric approach developed within the SUM4Re project (as detailed in 4.2) serve as a practical validation for this future direction. The project's API-driven ecosystem, which connects specialized platforms via a central UUID system, is a real-world implementation of the flexible, web-based principles that IFC5 aims to standardize, proving the viability and necessity of this evolution for the construction industry.

5.3. Interface Definition (API)

To enable the dynamic, real-time data exchange described in Chapter 4, a well-defined Application Programming Interface (API) is essential. The conceptual design of this API will serve as a bridge between the C-BIM environment and external platforms like CIRDAX, GENIA, and CONCULAR. The API will be designed based on RESTful principles, using standard web protocols to ensure easy implementation and integration. Key functionalities of the API will include:

- **Querying Data:** Allowing an application to GET the Digital Material Passport for a specific component using its unique ID.
- **Updating Status:** Enabling a user to POST or PUT updates to a component's status (e.g., changing Component_Condition from "in-situ" to "dismantled").
- **Publishing to Marketplaces:** Providing a mechanism to POST information about newly available secondary materials from the C-BIM directly to a marketplace platform. This API transforms the C-BIM from a static model into a dynamic hub for the circular construction ecosystem.

6. Adaptation of the API for Circular Economy Use Cases

6.1. Identification of Relevant Use Cases

The defined API is not an abstract concept, but a tool designed to serve specific, practical needs within the circular construction workflow. Key use cases that the API must support include:

- **On-Site Pre-Demolition Audit:** An auditor on-site uses a tablet application. They scan a QR code on a component, and the app uses the API to fetch and display its full DMP from the central C-BIM or a connected database, allowing for immediate verification and data entry.
- **Dynamic Inventory for Marketplaces:** As components are dismantled and their condition is verified, the API is used to automatically update their status in the C-BIM and push their availability, including images and condition reports, to the CIRDAX and CONCULAR marketplace platforms.
- **Design with Secondary Materials:** An architect using their BIM software can have a plugin that uses the API to query these marketplaces in real-time for available secondary components that meet specific design criteria (e.g., a steel beam of a certain length and profile).

6.2. Technical Specification of API Adaptations

The conceptual technical specification for the API will ensure it is robust, secure, and scalable. Key specifications include:

- **Architecture:** A RESTful architecture using standard HTTP methods.
- **Data Format:** JSON (JavaScript Object Notation) will be the standard format for all data exchange due to its lightweight nature and widespread support.
- **Authentication:** Secure authentication mechanisms (e.g., OAuth 2.0) will be required to ensure that only authorized users and applications can access or modify data.
- **Key Endpoints:** Conceptual endpoints will be defined, such as:
  - GET /api/v1/component/{uuid}/dmp to retrieve a component's Digital Material Passport.
  - POST /api/v1/marketplace/listing to create a new listing on a marketplace platform from a C-BIM object.
  - PUT /api/v1/component/{uuid}/status to update the status of a component.

7. Summary and Outlook

7.1. Key Findings

This report has laid out a comprehensive conceptual framework for a Circular Building Information Model (C-BIM) designed to operationalize the principles of the circular economy in the construction sector. The key findings are the definition of a lifecycle-centric model that begins with the integration of existing **auxiliary data** (as detailed in D1.6) to establish a comprehensive data foundation. This model is built on open standards (IFC and IDS), enriched with a specific set of new circularity parameters, and designed to seamlessly integrate with Digital Material Passports (DMPs) through a conceptually defined API. This transforms the BIM from a static design tool into a dynamic hub for managing material information from construction to deconstruction and beyond.

7.2. Outlook on Implementation

The framework detailed in this report serves as the strategic blueprint for the technical development work in subsequent work packages of the SUM4Re project. The immediate next steps will involve the detailed technical specification of the Pset_Circularity and the development of the API. Following this, the framework will be implemented and rigorously tested within the three pilot projects in Spain, the Netherlands, and Norway. This real-world application will provide invaluable feedback for refining the parameters, workflows, and tools, ensuring that the final solutions are robust, practical, and truly meet the needs of the industry.

7.3. Contribution to Overall Project Goal

This C-BIM and DMP integration framework is the digital backbone of the SUM4Re project. It provides the essential data infrastructure required to create functioning "materials banks" from our existing buildings. By establishing a trusted and transparent data record for each material, this framework serves as the technical prerequisite for the economic analyses in T6.2, which aim to overcome market barriers like information asymmetry, and for the sustainability assessments in T6.3, which quantify the environmental benefits of material reuse (SUM4Re (BLOCKM, THUAS, CONC)) (SUM4Re (BLOCKM, THUAS, CONC)). By enabling the accurate identification, detailed characterization, and efficient tracking of building components, this framework makes it possible to connect the supply of secondary materials from deconstruction sites with the demand from new projects. Ultimately, this work is a critical step towards closing the loop in the construction industry, reducing waste, conserving resources, and building a more sustainable and circular built environment for the future.

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APPENDICES

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LIST OF APPENDICES

APPENDIX A Expanded dataset for integration of circularity parameters in BIM

Main category	Sub-category	Parameter	Comment	Level
General Building Information	Building Identification	Building name	Provides the basic identity of the building.	Building
		Building Address	Specifies the physical location of the building.	Building
		Year of Construction	Defines the year the building was constructed.	Building
		Building Type	Helps categorise the building by its intended use (e.g., residential, commercial, industrial).	Building
		Unique Identifier	Ensures digital traceability and access to building-specific data.	Building
	Maintenance, Repair, and Renovation History	Maintenance Records	Tracks the history of maintenance and renovation actions performed on the building.	Building
		Service Life of Components and Building	Defines how long each building component is expected to last before requiring replacement or maintenance.	Building
		State of Usage	Identifies the type of ownership and state of use of the building.	Building
Building Performance Indicators	Energy Performance	Operational Energy Consumption	Assesses the ongoing energy use of the building.	Building
		Energy Performance Certificates (EPC)	Certifies the energy efficiency of the building and its systems.	Building
		Renewable Energy Integration (e.g. Solar, Wind, Geothermal)	Tracks how much energy comes from renewable sources.	Building
	Indoor Environmental Quality (IEQ)	Air Quality	Monitors air quality for occupant health and safety.	Building
		Thermal Comfort	Ensures proper temperature regulation for occupant comfort.	Building
		Lighting Conditions	Monitors lighting for both energy efficiency and occupant comfort.	Building

Main category	Sub-category	Parameter	Comment	Level
		Acoustic Conditions	Tracks noise levels and ensures acceptable acoustics within the building.	Building
Product and Material Information	Product and Material Identification	Primary Material Type (e.g., Steel, Concrete, Wood)	Identifies the primary material composition of a product or building element.	Product
		Product Composition	Specifies the detailed breakdown of materials used, including the percentage of recycled and virgin materials.	Product
		Product Name	The name or model of the product being tracked.	Product
		Product Type	Specifies the category or class of the product (e.g., wall panel, beam).	Product
		Product Model	The specific model number or identifier for the product to ensure digital traceability.	Product
		Manufacturer	Company or entity responsible for the production of the product.	Product
		Country of Origin	The country where the product or material is sourced or manufactured.	Product
		Manufacturing Process	Describes the process through which the product is made (e.g., casting, welding, molding).	Product
Lifecycle Impact Data	Environmental and Carbon Footprint	Embodied carbon (LCA-based)	Total carbon footprint for a product across its entire lifecycle	Both
		Other Environmental Impacts (LCA-based)	Impact of product or building material on the environment across its entire lifecycle	Both
	Water and Energy Use	Water Usage During Production	Water consumed during the manufacturing process of the product.	Product
		Energy Consumption During Production	Energy consumed during the manufacturing process of the product.	Product
Circularity and Disassembly Data	Disassembly Planning	Modularity	Defines the type of structural system and the connection of elements.	Building
		Product Type (Component, Connection)	Classifies each product as either a standalone component or part of a connection.	Product
		Connection type	Defines the type of connection or fastener of the product in the building	Product

Main category	Sub-category	Parameter	Comment	Level
		Product Identification	Unique identifier for every part that requires disassembly.	Product
		Global Disassembly Model	Unique identifier used to group components that share similar disassembly requirements.	Product
		Dependency Hierarchy	Defines which products rely on others for support or functionality.	Product
		Detachability	Describes how easy it is to remove a product or material during the disassembly phase.	Product
	Disassembly Process	Disassembly and Recovery Guidelines	Provides instructions and directions for disassembling the product or building	Both
		Accessibility	Defines the difficulty of reaching the product and the connection	Product
		Tools and Methods	Identifies the tools required to disassemble the product or material.	Product
		Physical Interface (Geometric and Mechanical Specs)	Describes the physical attributes (geometry, force) to disassemble the product or material.	Product
	Salvageability and Circularity Data	Condition	Identifies the condition of a product or building.	Both
		Reuse/Recycling Opportunities	Tracks the potential for a material or product to be reintegrated into the supply chain.	Both
		Reusability	Specifies the potential for a material or product to be reused.	Both
		Recyclability	Specifies the potential for a material or product to be recycled after use.	Both
		Sustainability and Circularity Score	Specifies the circularity index calculated from various frameworks.	Both
	Disassembly Performance	Disassembly Time	Time required to disassemble a product or component.	Both
		Disassembly Cost	Estimates the cost involved in disassembling a product or material.	Both
		Disassembly Revenue	Anticipated financial return from recycling or reselling parts post-disassembly.	Both
		Disassembly Energy Consumption	Energy consumption required to dismantle products or materials.	Both

Main category	Sub-category	Parameter	Comment	Level
		Disassembly Distance (Transport to Recycling Sites)	Measures the travel distance required for materials to be recycled or disposed of.	Both
Waste and Recycling Management	Waste Management and Recycling	CDW Diagnosis and Classification	Classification and quantification of CDW	Both
		Waste Destination	Specifies where the waste will be sent, focusing on recycling or disposal pathways.	Both
		Waste Output Flow (Recycling, Reuse, Backfill, Elimination)	Guides the proper handling of waste materials, considering their impact and disposal methods.	Both
		Recycling and Waste Treatment Methods	Specifies the processes for recycling or treating waste materials.	Both
	Hazardous Waste Data	Hazardous Material Identification (Asbestos, Lead, etc.)	Identifies hazardous substances present in materials, ensuring safe handling during demolition.	Both
		Toxicity data (EPD and LCA-based)	Impact of product or building material on the environment, focusing on hazardous substances and waste.	Both
		Waste Scenarios for Hazardous and Toxic Waste	Tracks potential outcomes for waste materials, focusing on removal and disposal.	Both
Compliance, Certifications, and Digital Integration	Regulatory Compliance	Compliance with EU and International Standards	Ensures compliance with relevant building and product standards to guarantee sustainability and safety.	Both
		Environmental Product Declarations (EPDs)	Promotes transparency regarding environmental impacts and sustainability attributes.	Product
		Third-Party Certifications	Validates sustainability and quality claims through certifications (LEED, BREEAM, etc.).	Both
	Digital Integration and Traceability	QR Code, RFID Tracking, Blockchain Storage	Tracks products and materials digitally for transparency and real-time data access.	Product
		Documentations and Reports	Various documentations and drawings relevant during the disassembly.	Both

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Annex I

SUM4Re C-BIM Schema:

Technical Specification v1.0

VERSION 1.0

30 October 2025

PUBLIC

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GLOSSARY

- **API:** Application Programming Interface
- **BIM:** Building Information Model
- **C-BIM:** Circular Building Information Modeling
- **CDW:** Construction and Demolition Waste
- **CPR:** Construction Products Regulation
- **DBL:** Digital Building Logbook
- **DfD:** Design for Disassembly
- **DMP:** Digital Material Passport
- **DPP:** Digital Product Passport
- **EC:** European Commission
- **ECS:** Entity Component System
- **EoW:** End-of-Waste
- **EU:** European Union
- **GPR:** Ground Penetrating Radar
- **GWP:** Global Warming Potential
- **IDS:** Information Delivery Specification
- **IFC:** Industry Foundation Classes
- **JSON:** JavaScript Object Notation
- **LCA:** Life Cycle Assessment
- **PDA:** Pre-Demolition Audit
- **POPS:** Persistent Organic Pollutants
- **Pset:** Property Set
- **REACH:** Registration, Evaluation, Authorisation and Restriction of Chemicals
- **SUM4Re:** Creating materials banks from digital urban mining
- **UOI:** Unique Object Identifier
- **USD:** Universal Scene Description
- **UUID:** Universally Unique Identifier
- **WP:** Work Package
- **XRF:** X-ray Fluorescence

1. Introduction and Purpose

This document provides the formal technical specification for the SUM4Re Circular Building Information Model (C-BIM) Schema. It operationalizes the conceptual framework detailed in deliverable report D6.1 "C-BIM Design and DMP Implementation".

The purpose of this schema is to provide a standardized, interoperable, and machine-readable data structure for enriching Building Information Models with the information required to support a circular economy in the construction sector. It serves as the definitive blueprint for software developers, project managers, and data specialists implementing the SUM4Re digital ecosystem.

For all background information, justifications, stakeholder requirements, and references to source materials (including previous deliverables and external standards), readers should refer to the D6.1 report. This schema is intended to be the direct, technical implementation of the concepts established therein.

2. Core Architectural Principles

The C-BIM Schema is built upon three foundational principles to ensure robustness, interoperability, and longevity.

2.1. Foundation on Open Standards (IFC)

To prevent vendor lock-in and ensure data remains accessible across the entire lifecycle of a built asset, the C-BIM schema is fundamentally based on the **Industry Foundation Classes (IFC)** standard (ISO 16739). All conceptual entities for physical objects and processes defined within SUM4Re are mapped directly to their corresponding IFC classes.

2.2. The Universally Unique Identifier (UUID) as the Core Link

Every building component, from a structural beam to a window assembly, shall be assigned a persistent **Universally Unique Identifier (UUID)**. This UUID acts as the immutable digital anchor, linking the geometric object within the IFC model to its dynamic, external data sets, including its Digital Material Passport (DMP) and information held on federated platforms (CIRDAX, GENIA, CONCULAR).

2.3. Federated Data Ecosystem

The schema is designed to operate within a federated data ecosystem. The C-BIM does not store all information but acts as a central hub. The UUID is used to query external databases in real-time via the project's API, ensuring that all data (e.g., condition, market availability, regulatory status) remains current and authoritative.

3. Data Hierarchy and IFC Mapping

The schema follows a logical hierarchy to represent a built asset, from the overall structure down to its constituent materials.

3.1. Object Hierarchy Mapping

The conceptual hierarchy is mapped to the IFC standard as follows:

SUM4Re Concept	IFC Class Mapping	Description
Building Site	`IfcSite`	The physical site where the building is located.
Building	`IfcBuilding`	The building as a whole entity.
Building Storey	`IfcBuildingStorey`	A level or floor within the building.
Assembly (Kit)	`IfcElementAssembly`	A collection of components forming a larger unit (e.g., a curtain wall).
Product	`IfcBuiltElement`	The primary unit of interest; a distinct building product (e.g., a beam, door, window).
Constituent	`IfcMaterialConstituent`	A specific material making up part of a component.
Material	`IfcMaterial`	The fundamental substance a component is made from.

3.2. Activity & Process Mapping

Circular economy activities are mapped to IFC task types to enable process modeling and planning.

SUM4Re Activity	IFC Class Mapping	Description
Pre-demolition audit	`IfcTask` (Type: `INSPECTION`)	The process of auditing a building before deconstruction.

Deconstruction	`IfcTask` (Type: `DISMANTLE`)	The planned and careful disassembly of components for reuse.
Demolition	`IfcTask` (Type: `DEMOLITION`)	The tearing-down of a structure.
Reuse	`IfcTask` (Type: `USERDEFINED`)	The process of reintegrating a component into a new structure.
Recycling	`IfcTask` (Type: `USERDEFINED`)	The process of converting waste material into new substances
Disposal	`IfcTask` (Type: `DISPOSAL`)	The final discarding of waste material.

3.3. Visual Schema Overview

For clarity, the most important conceptual diagrams from the D6.1 report are included below as a visual reference for this technical specification.

Conceptual Data Structure: The following Figure 1 illustrates the core principle of linking IFC and non-IFC data via the Universally Unique Identifier (UUID).

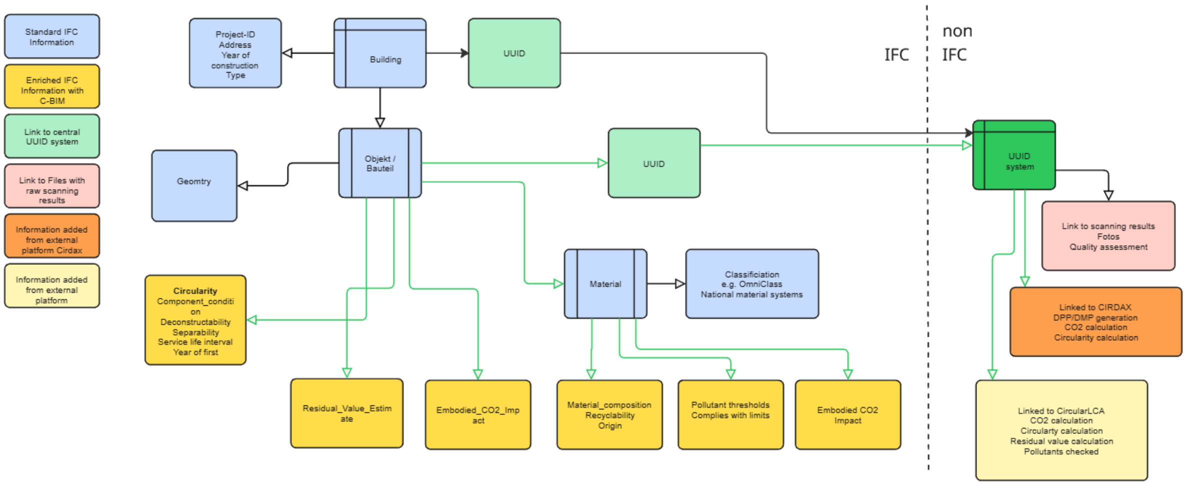

Figure 1 - Conceptual data structure of the C-BIM, illustrating the integration of circularity parameters and the connection to external systems via a Universally Unique Identifier (UUID).

IFC Mapping Diagram: The following Figure 2 shows how SUM4Re's conceptual entities are mapped directly to IFC standard classes. This is the foundation for interoperability.

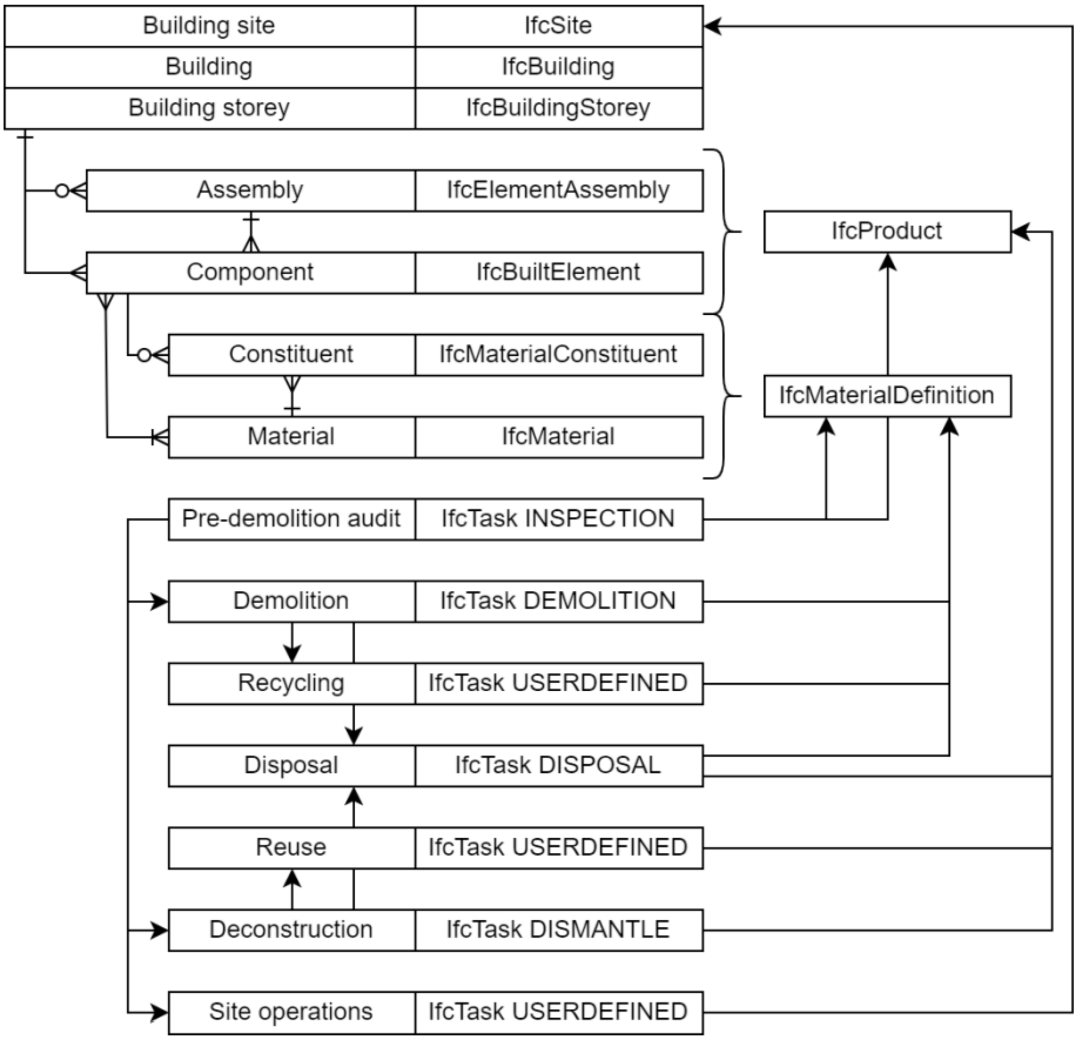

Figure 2 - Mapping of SUM4Re Data Concepts to the IFC Standard

4. Property Set Definition: `Pset_Circularity`

To enrich BIM objects with circularity data, a custom IFC Property Set named `Pset_Circularity` is defined. This Pset shall be attached to relevant objects, primarily instances of `IfcBuiltElement` and `IfcElementAssembly`.

The parameters within this Pset are detailed below, categorized according to their function as outlined in D6.1 Appendix A.

4.1. General Building Information

Parameter Name	IFC Data Type	Description	Level
BuildingName	IfcLabel	Provides the basic identity of the building.	Building
BuildingAddress	IfcText	Specifies the physical location of the building.	Building
YearOfConstruction	IfcInteger	Defines the year the building was constructed.	Building
BuildingType	IfcLabel	Categorises the building by its intended use (e.g., residential, commercial, industrial).	Building
UniqueIdentifier	IfcIdentifier	The UUID for the building itself. Ensures digital traceability and access.	Building
MaintenanceRecords	IfcText	Tracks the history of maintenance and renovation actions performed. This can include textual summaries and/or hyperlinks (URLs) to external documents like reports, images, or certificates.	Building
ServiceLifeOfComponents	IfcInteger	Defines the expected service life in whole years. Defines how long each building component is expected to last before requiring replacement or maintenance. If a range is needed due to uncertainty (e.g., 15-20), consider using the lower bound here and providing details in a separate notes field if available, or represent the range	Building

		textually if an IfcText type is used alternatively.	

4.2. Product and Material Identification

Parameter Name	IFC Data Type	Description	Level
PrimaryMaterialType	IfcLabel	Identifies the primary material of a product (e.g., Steel, Concrete, Wood).	Product
MaterialComposition	IfcText	Detailed breakdown of materials, including percentages of recycled and virgin content.	Product
ProductName	IfcLabel	The name or model of the product being tracked.	Product
ProductType	IfcLabel	Specifies the category or class of the product (e.g., wall panel, beam).	Product
ProductModel	IfcLabel	The specific model number or identifier for the product.	Product
Manufacturer	IfcLabel	Company or entity responsible for the production of the product.	Product
CountryOfOrigin	IfcLabel	The country where the product or material is sourced or manufactured.	Product

4.3. Lifecycle Impact Data

Parameter Name	IFC Data Type	Description	Level
EmbodiedCarbon	IfcReal	Total carbon footprint (LCA-based) for a product across its entire lifecycle (Unit: kgCO2e).	Both
OtherEnvironmentalImpacts	IfcText	Other key environmental impacts from an LCA (e.g., GWP, ODP).	Both

WaterUsageDuringProduction	IfcReal	Water consumed during the manufacturing process of the product (Unit: Liters).	Product
EnergyConsumptionDuringProduction	IfcReal	Energy consumed during the manufacturing process of the product (Unit: kWh).	Product

4.4. Circularity and Disassembly Data

Parameter Name	IFC Data Type	Description	Level
Modularity	IfcLabel	Defines the type of structural system and the connection of elements.	Building
ConnectionType	IfcLabel	Defines the type of connection or fastener of the product (e.g., Welded, Bolted, Glued).	Product
DependencyHierarchy	IfcText	Defines which products rely on others for support or functionality.	Product
Detachability	IfcLabel	Describes how easy it is to remove a product during disassembly (e.g., Easy, Moderate, Difficult).	Product
DisassemblyInstructions	IfcText	Provides instructions for disassembling the product. Can be a text field or a link to external documentation.	Both
DisassemblyDifficulty	IfcInteger	A scored rating (e.g., 1-5, with 1 being easiest) based on accessibility, tools, and dependencies.	Product
Accessibility	IfcLabel	Defines the difficulty of reaching the product and its connections (e.g., Direct, Obstructed).	Product
ToolsAndMethods	IfcText	Identifies the specific tools required to disassemble the product or material.	Product

Condition	IfcLabel	Identifies the current physical condition of a product (e.g., As New, Used, Requires Repair).	Both
ReuseRecyclingNotes	IfcText	Tracks the potential for a material or product to be reintegrated into the supply chain.	Both
Reusability	IfcBoolean	Specifies if the product has potential to be reused as-is. (TRUE/FALSE)	Both
Recyclability	IfcBoolean	Specifies if the material has potential to be recycled after use. (TRUE/FALSE)	Both
CircularityScore	IfcReal	Specifies a calculated circularity index based on established frameworks (e.g., a value from 0 to 1).	Both
DisassemblyTime	IfcTimeMeasure	Estimated time required to disassemble a product or component (e.g., in hours).	Both
DisassemblyCost	IfcMonetaryMeasure	Estimates the cost involved in disassembling a product or material.	Both

4.5. Waste and Regulatory Management

Parameter Name	IFC Data Type	Description	Level
CDWQuantity	IfcQuantityWeight	Quantification of Construction and Demolition Waste.	Both
CDWClassification	IfcLabel	Construction and Demolition Waste classified by European List of Waste [1]	
WasteDestination	IfcLabel	Specifies where the waste will be sent (e.g., Reuse Hub, Recycling Facility, Landfill).	Both

HazardousMaterialIdentification	IfcText	Identifies hazardous substances present (e.g., Asbestos, Lead), ensuring safe handling.	Both
ToxicityData	IfcText	Impact of product on the environment, focusing on hazardous substances (from EPD and LCA).	Both
RegulatoryStatus	IfcLabel	Classification regarding product vs. waste status, as per D1.2 (e.g., Product, Waste, End-of-Waste).	Product

4.6. Compliance, Certifications, and Digital Integration

Parameter Name	IFC Data Type	Description	Level
ComplianceWithStandards	IfcText	Ensures compliance with relevant building and product standards.	Both
EPDs	IfcText	Link to or summary of Environmental Product Declarations.	Product
ThirdPartyCertifications	IfcText	Validates sustainability and quality claims (e.g., LEED, BREEAM).	Both
DigitalTracking	IfcText	Stores digital tracking identifiers like QR Code data, RFID tags, or Blockchain hashes.	Product

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5. Data Exchange Protocol

The exchange of data based on this schema shall be governed by the **Information Delivery Specification (IDS)**, a buildingSMART standard. An IDS file will be provided to formalize data delivery requirements for project stakeholders, ensuring that the C-BIM is populated with the correct information at the required stages of a project lifecycle. This allows for automated validation of IFC files against the `Pset_Circularity` requirements.

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SOLAR SOLUTIONS | GSCAN | EBC CONSTRUCTION SMEs EUROPE | SCREENING EAGLE | proceq

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