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Creating materials banks  
from digital urban mining

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## **EXECUTIVE SUMMARY**

The construction industry is rapidly integrating circular economy principles to enhance resource efficiency, reduce waste, and support material reuse. Various classification systems and detailed digital models have been developed to ensure consistency and interoperability in construction data management. However, such systems often lack the flexibility required to support circularity-driven processes, highlighting the necessity for their adaptation and expansion. This research investigates how classification and digital frameworks can incorporate circular economy principles to improve sustainability, facilitate material reuse, and enhance lifecycle assessment practices. Additionally, it explores the role of digitalisation in transforming classification systems, with Building Information Modeling (BIM) and Digital Twins emerging as essential tools for enabling circular construction.

A scoping review of 2,649 abstracts highlights that the circular economy is the fastest-growing area, especially after 2015, driven by advancements in digitalisation, robotics, and the Internet of Things (IoT). A detailed review of 14 academic publications further investigates the role of BIM in managing and incorporating circularity-related data. Comprehensive digital sources of information, such as BIM, facilitate material reuse, support deconstruction planning, and enhance lifecycle assessment by providing structured and interoperable data. However, challenges remain in connecting technical material properties, disassembly factors, and high-level sustainability targets within existing frameworks.

In addition to scientific findings, this study reviews relevant national and international standards that guide circular construction practices. International policies like the EU Construction & Demolition Waste Management Protocol and technical standards such as DIN SPEC 91484 provide selective demolition, material reuse, and sustainability assessment guidelines. National frameworks like the DGNB Circularity Index, FutureBuilt Circularity, and Alba Concepts Circularity Indexes measure key parameters, including disassembly potential and material sustainability. Despite the increasing focus, differences in evaluation criteria and a lack of standardised assessment frameworks present barriers to effective implementation.

Additionally, digital records such as the Digital Material Passport (DMP), Digital Product Passport (DPP), and Digital Building Logbook (DBL) have recently been developed or are under development to facilitate transparency, traceability, and enhanced material lifecycle management. These digital solutions offer comprehensive data on material composition, carbon footprint, recyclability, and performance. However, barriers such as data standardisation issues, system integration challenges, data privacy concerns, and economic constraints hinder widespread adoption. Addressing these challenges is vital for advancing digital solutions in circular construction.

The absence of a unified digital framework that incorporates circularity-related parameters restricts consistency and information sharing. Establishing a standardised BIM structure focused on circularity is essential for effectively capturing data from existing buildings and integrating circular principles into design and demolition procedures. A crucial aspect of this research involves defining a list of properties related to circularity, derived from several reviews, that can be integrated into the BIM framework to enhance the development of C-BIM and its application in demolition processes. The study identifies and categorises additional parameters at the building or product level, including condition, hazardous substance identification, dismantling procedures, reuse potential and environmental impact, which are critical for effective BIM integration from a lifecycle perspective. However, the extensive data collection and evaluation of the identified properties can be resource-heavy. A streamlined approach featuring mandatory and optional properties can simplify data collection while enhancing efficiency. Moreover, technological advancements like laser scanning and computer vision tools offer promising solutions for automating circular-oriented BIM models. These technologies can enhance data collection accuracy and facilitate rapid assessments of material reuse potential.

In addition to the list of properties, this report introduces several frameworks for evaluating circularity properties that combine technical and economic assessment methods, as well as lifecycle assessment (LCA) and material flow analysis (MFA). Automation through BIM and digital records can further simplify evaluation assessment processes, boosting decision-making efficiency and promoting a more circular and resource-efficient construction industry.

This deliverable highlights the need for a comprehensive and standardised approach to circularity in construction. The industry can move towards more sustainable and resource-efficient practices by integrating digital tools, adapting classification systems, and leveraging technological advancements. The findings highlight opportunities for policymakers, industry professionals, and researchers to develop frameworks that facilitate material reuse, minimise waste, and support the transition to a circular built environment on an international scale.

## **GLOSSARY**

### **Terms, Abbreviations, and Acronyms**

API	Application Programming Interface
BCI	Building Circularity Indicator
BIM	Building Information Modelling
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
BRP	Building Resource Passport
BSA	Building Sustainability Assessment
BWPE	BIM-based Whole-Life Performance Estimator
C-BIM	Circular Building Information Modelling
CA	Connection Accessibility
CCI	Construction Classification International
CCIC	Construction Classification International Collaboration
CCS	Cuneco Classification System
CDW	Construction and Demolition Waste
CE	<i>Conformité Européenne</i> (European Conformity)
CEAP	Circular Economy Action Plan
CI	Construction Index
CirBIM	Circular BIM database framework
CMP	Circular Material Passport
CPX	Circularity Performance Index
CT	Connection type
DAS	Deconstructability Assessment Score
DBL	Digital Building Logbook
DfA	Design for Assembly
DfD	Design for Disassembly
DGBC	Dutch Green Building Council
DGNB	<i>Deutsche Gesellschaft für Nachhaltiges Bauen</i> (German Sustainable Building Council)
DGNB ZI	DGNB Zirkularitätsindex (DGNB Circularity Index)

DIM	Deconstruction Information Model
DIN	<i>Deutsches Institut für Normung</i> (German Institute for Standardization)
DMP	Digital Material Passport
DPP	Digital Product Passport
EC	European Commission
EN	European Norm / European Standard
EOL	End-of-Life
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EPD	Environmental Product Declaration
ESPR	Ecodesign for Sustainable Products Regulation
EU	European Union
EURAL	<i>Europese Afvalstoffenlijst</i> (European Waste List)
EWC	European Waste Catalogue
FYI	First-Year-Index
GHG	Greenhouse Gas
GPE	Geometry of Product Edge
GPR Gebouw	<i>Gemeentelijke Praktijk Richtlijn Gebouw</i> (Municipal Practice Guideline Buildings)
ICE	Inventory of Carbon and Energy
ID	Independency
IEQ	Indoor Environmental Quality
IFC	Industry Foundation Classes
IoT	Internet of Things
ISO	International Organization for Standardization
JRC	Joint Research Centre
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LEED	Leadership in Energy and Environmental Design
LoW	List of Wastes
MCI	Madaster Circularity Indicator
MEP	Mechanical, Electrical, and Plumbing

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MFA	Material Flow Analysis
MPG	Environmental Performance of Buildings
MVD	Model View Definition
NEN	<i>Nederlandse Norm</i> (Dutch Standard)
NS	<i>Norsk Standard</i> (Norwegian Standard)
NYI	Normalized-Year-Index
OmniClass	Comprehensive Construction Classification System
PCI	Product Circularity Indicator
PDT	Product Data Template
PED	Positive Energy District
PEF	Product Environmental Footprint
PROGRESS	Provisions for a Greater Reuse of Steel Structures
QR	Quick Response (code)
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RFID	Radio Frequency Identification
RIBA	Royal Institute of British Architects
RoHS	Restriction of Hazardous Substances
RQ	Research Question
SCI	System Circularity Indicator
SfB	Swedish Building Classification System
SUM4re	Creating materials banks from digital urban mining
UMI	Urban Mining Index
Uniclass	Unified Classification for the Construction Industry
UUID	Universally Unique Identifier
WELL	Building standard for health and wellness in buildings
WFD	Waste Framework Directive
ZEN	Zero Emission Neighborhood

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# 1. Introduction

## 1.1. Background

The construction industry has long been recognised as a major resource consumer, contributing substantially to global waste generation and environmental degradation<sup>1</sup>. Sustainable construction practices, including recycling, reclaiming, and reusing building materials, are gaining significance in combating these impacts<sup>2</sup>. These practices contribute to a circular economy, where materials from existing structures are reintegrated into the supply chain, reducing reliance on new resources and minimising waste. However, implementing these circular practices on a large scale presents significant logistical and technical challenges, particularly in identifying, categorising, and evaluating the quality and reusability of materials at the end of a building's lifecycle<sup>3</sup>.

Building Information Modelling (BIM) offers potential solutions to these challenges by digitally representing a building's components, systems, and materials. BIM's data-rich models allow for detailed analysis and tracking of materials throughout the lifecycle of a building. However, conventional BIM has traditionally focused on the design, construction, and maintenance phases, with limited emphasis on deconstruction or end-of-life (EOL) considerations. The Circular BIM (C-BIM) concept is emerging as an evolution of BIM focused on circular economy principles to address this limitation<sup>4</sup>. Although it is still a theoretical model, C-BIM envisions an advanced digital platform specifically designed to identify, catalogue, and track the lifecycle of materials, providing essential data for their potential reuse.

A C-BIM system could empower stakeholders involved in deconstruction, including demolition contractors, building owners, and engineers, by providing accurate data on the materials in existing structures. Such data could inform decisions about disassembly, reuse, or recycling, ultimately supporting more sustainable practices within the built environment. This report explores how a C-BIM system could address current barriers to material reuse by developing frameworks for material classification, labelling, and evaluation. The eventual implementation of C-BIM could streamline circular practices in construction, transforming how the industry approaches the lifecycle of building materials<sup>4,5</sup>.

## 1.2. Goal, scope and focus

The primary goal of this report is to establish a systematic approach for identifying and classifying reusable building materials within existing structures as part of Task 1.1, "Identification of Material-Products & Sustainability." The task focuses on creating a detailed classification framework for construction elements, such as materials, components, products, and modules, that can be reclaimed from deconstructed or renovated buildings and reintroduced into the supply chain. This framework will facilitate decision-making in demolition,

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<sup>1</sup> United Nations Environment Programme (2022). 2022 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector. Nairobi, Kenya.

<sup>2</sup> Hossain, Md.U. et al. (2020) 'Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction,' *Renewable and Sustainable Energy Reviews*, 130, p. 109948. <https://doi.org/10.1016/j.rser.2020.109948>.

<sup>3</sup> Arora, M. et al. (2019) 'Buildings and the circular economy: Estimating urban mining, recovery and reuse potential of building components,' *Resources Conservation and Recycling*, 154, p. 104581. <https://doi.org/10.1016/j.resconrec.2019.104581>.

<sup>4</sup> Aziminezhad, M. and Taherkhani, R. (2023) 'BIM for deconstruction: A review and bibliometric analysis,' *Journal of Building Engineering*, 73, p. 106683. <https://doi.org/10.1016/j.jobe.2023.106683>.

<sup>5</sup> Akbarieh, A. et al. (2020) 'BIM-Based End-of-Lifecycle Decision Making and Digital Deconstruction: Literature review,' *Sustainability*, 12(7), p. 2670. <https://doi.org/10.3390/su12072670>.

renovation, disassembly, or adaptation scenarios to support sustainable construction practices.

This report provides a foundation for developing a labelling system compatible with a future C-BIM system. The system aims to support various stakeholders, including demolition contractors, architects, engineers, and investors, by categorising materials and products based on their reuse potential. Additionally, a supply potential evaluation framework will be developed to assess the identified parameters of products available for reuse within typical built structures, aiding in accurate supply forecasting and resource planning.

A significant part of the report is dedicated to a state-of-the-art review. The review covers two main areas: (1) the overall field of material reuse, reclamation, urban mining, circularity etc., and (2) the specific application of BIM frameworks for deconstruction and material recovery through analysis of scientific articles, technical publications and digital tools. The report identifies knowledge gaps by analysing existing literature, expert insights, and case studies, laying the groundwork for future C-BIM research and development.

Research questions (RQ)

1. **How has the broader field of circularity, material reuse and recycling, waste management, urban mining and closed-loop approaches evolved, and what are applied technologies, the key trends and the dominant or niche topics?**

This question provides a comprehensive overview of the actual situation in circular economy practices related to buildings. By mapping historical development, key trends, and critical gaps, it seeks to identify dominant approaches, emerging innovations, applied technologies, and less-explored or niche areas within the industry.

2. **How can existing research, frameworks and digital tools be adapted or extended to assess the supply potential of construction products in existing structures under various deconstruction scenarios?**

This question examines how current frameworks, methodologies, and research can be leveraged or modified to evaluate the volume, quality, types of materials, and other relevant information that can be accurately reclaimed from buildings. It seeks to understand the applicability of circularity parameters within a BIM context, aiming to identify best practices and necessary adaptations for effective material redirection.

3. **What evaluation systems and criteria can be developed or adapted from existing frameworks to effectively identify and label construction materials, components, and products for reuse within a Circular BIM (C-BIM) system?**

Based on the answer to RQ 2, this question explores how construction elements can be systematically evaluated and what essential deconstruction and circular-based criteria should be included to create a comprehensive labelling system. This system would support C-BIM integration, enabling stakeholders to make informed decisions about material reuse based on properties such as composition, lifecycle stage, and reuse potential.

### 1.3. Methodology

A combination of research methods was employed to address the research questions outlined in this report, each tailored to the specific nature of the questions.

#### 1.3.1. Approach for answering RQ 1

RQ 1 focuses on the evolution and current trends in circular economy practices related to material reuse, reclamation, urban mining, and deconstruction. A scoping review approach, particularly appropriate given the rapid development of the literature and the breadth of the field, was used to answer the question. While scoping and systematic reviews share certain characteristics, a systematic review is designed to answer a specific research question,

focusing on empirical evidence and aiming to conclude a refined selection of high-quality studies<sup>6,7</sup>. On the other hand, a scoping review addresses broader questions with less emphasis on the quality assessment of included studies<sup>7</sup>. They are exploratory by nature and aim for a comprehensive overview of the available literature on a wide-ranging topic, highlighting key themes and prevalent issues<sup>6,8</sup>. As a result, a scoping review offers a preliminary analysis of the potential size and scope of available research literature<sup>9</sup>. Thus, in contrast to other review types, which generally aim for deeper analysis and definitive conclusions about a particular phenomenon, the scoping review is used to identify a topic area for the next step, i.e., a future systematic literature review<sup>8</sup>.

Consequently, this method identifies dominant, emerging, and niche topics, providing a comprehensive overview of the field. The scoping review involves a systematic search in one of the largest databases for scientific literature, followed by semi-automated text analysis, metadata extraction and thematic evaluation.

Section 3.1 provides a detailed overview of this approach, including the search syntax, workflow description, and applied tools.

### 1.3.2. Approach for answering RQ 2

Research Question 2 seeks to establish classification systems and criteria for building materials suitable for C-BIM integration. This question will be explored through a semi-systematic review approach, as it is ideal for mapping theoretical frameworks, identifying themes, and pinpointing knowledge gaps in existing literature<sup>10</sup>. In addition, a review of actual technical standards and reports as well as recent digital platforms, will be included in the assessment to answer the question.

A semi-systematic review is less strict in selecting and synthesising the literature than a full systematic review, e.g., regarding the exhaustiveness of literature identification, inclusion criteria, and study analysis. Unlike the strictly quantitative and exhaustive character of the fully systematic review, the semi-systematic review is more flexible regarding its methodology and allows for qualitative evaluations. Thus, a semi-systematic review provides an appropriate approach to identify the state of knowledge in classification systems for C-BIM integration.

Section 3.2 provides a detailed overview of the approach followed, including the search syntax, workflow description, and applied tools.

The various types of reviews assess current classification systems, relevant BIM frameworks, digital platforms and deconstruction and material labelling criteria. By analysing scholarly and industry publications and relevant standards, the review outlines the strengths and limitations of current approaches and highlights areas requiring further development for C-BIM compatibility.

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<sup>6</sup> DiCenso, A. et al. (2010) 'Advanced Practice Nursing in Canada: Overview of a decision support synthesis,' *Nursing Leadership*, 23(sp), pp. 15–34. <https://doi.org/10.12927/cjnl.2010.22267>.

<sup>7</sup> Arksey, H. and O'Malley, L. (2005) 'Scoping studies: towards a methodological framework,' *International Journal of Social Research Methodology*, 8(1), pp. 19–32. <https://doi.org/10.1080/1364557032000119616>.

<sup>8</sup> Munn, Z. et al. (2018) 'Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach,' *BMC Medical Research Methodology*, 18(1). <https://doi.org/10.1186/s12874-018-0611-x>.

<sup>9</sup> Grant, M.J. and Booth, A. (2009) 'A typology of reviews: an analysis of 14 review types and associated methodologies,' *Health Information & Libraries Journal*, 26(2), pp. 91–108. <https://doi.org/10.1111/j.1471-1842.2009.00848.x>.

<sup>10</sup> Snyder, H. (2019) 'Literature review as a research methodology: An overview and guidelines,' *Journal of Business Research*, 104, pp. 333–339. <https://doi.org/10.1016/j.ibusres.2019.07.039>.

1.3.3. Approach for answering RQ 3

Research Question 3 builds on the findings from RQ 2 and encompasses practical insights from actual evaluation systems, developed frameworks, and an expert workshop. The workshop includes direct stakeholders such as researchers, architects, engineers, and experts from governmental, financial and sustainability sectors. The purpose is to unify and validate the proposed classification frameworks, gather feedback, and refine criteria for a C-BIM-compatible labelling system. Combining existing categorisation and assessment platforms, literature findings, and expert input ensures a robust foundation for assessing the supply potential of reusable materials under various deconstruction scenarios.

Figure 1 visualises the overall method and approaches to answer the research questions.

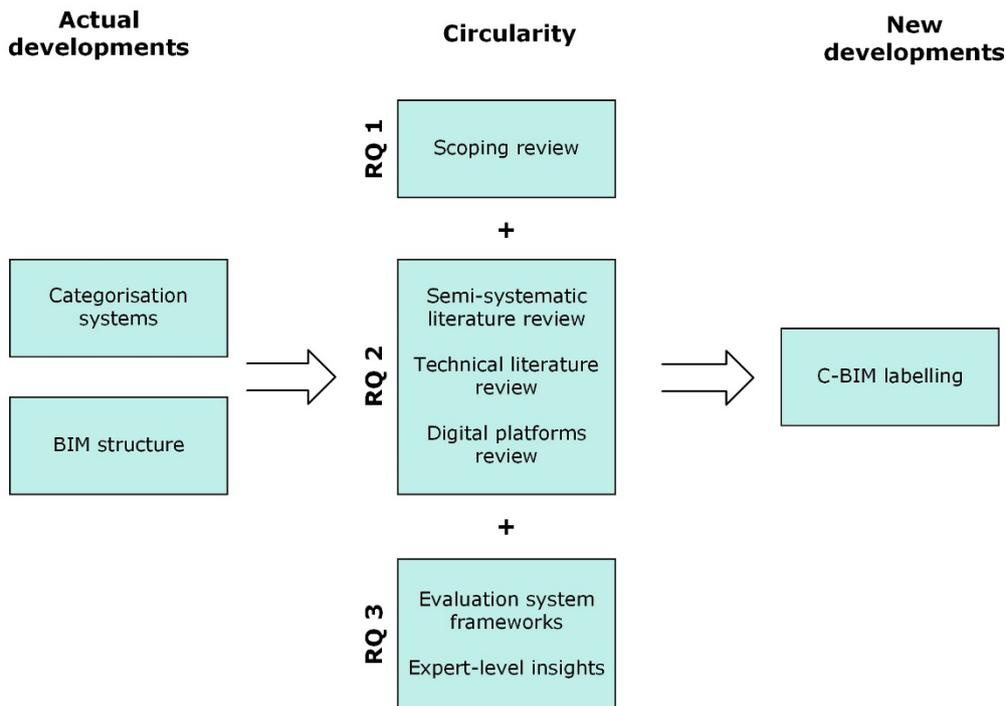


Figure 1: Schematic visualisation of overall methodologies and approaches.

## 2. Categorisation of the construction elements

Key messages:

- Various classification systems, such as SfB, OmniClass, Uniclass and CCI, have been developed based on regional standards, construction methods, and industry needs to ensure consistency and interoperability.
- Traditional classification systems, such as SfB, have limitations that newer frameworks like Uniclass and OmniClass aim to overcome.
- Digitalisation and BIM integration have driven the evolution of classification systems, with CCI representing a modern faceted approach.
- Challenges remain in applying these systems to existing buildings due to outdated records and the complexity of mapping historical data to newer frameworks.

The categorisation of constructions is crucial for structuring and standardising information within the built environment. Various classification systems have been developed to organise building types, areas, elements, and materials, each influenced by regional standards, construction methods, and linguistic differences.

During this research, it became evident that the existing classification frameworks vary significantly across countries and industries, highlighting the complexity and breadth of categorisation in construction. This diversity extends beyond the immediate scope of the SUM4re project, necessitating a focused approach to ensure relevant and applicable findings.

The research was centred on internationally recognised classification systems, including ISO, NS, and NEN, as well as OmniClass, Uniclass, SfB coding, and the ICE Database V4. These frameworks provided a structured basis for analysing the categorisation of construction elements and their applicability within a circular economy. Other classification systems, such as CoClass International (CCI), are included in the analysis. Such recent developments are dedicated to digitalisation within the construction industry and present a novelty compared to traditional classification systems.

Furthermore, the study aims to explore how these classifications can be expanded with circular-based parameters to develop a more comprehensive labelling system. A more holistic approach to material reuse and sustainable construction practices can be established by integrating circular principles into standardised classifications.

Table 1 summaries some internationally recognised classification systems and their main features.

**Table 1: The main aspects of the international classification systems**

Aspect	SfB Classification	OmniClass	Uniclass
Region	Scandinavia and Europe	North America (USA, Canada)	UK and Europe
Material Focus	Building components and materials	Full construction lifecycle (materials, elements, processes)	Full construction and asset lifecycle
BIM Integration	Limited (older system)	Widely used in BIM	Fully compatible with BIM
Material Examples	Concrete, timber, masonry, steel	All structural, mechanical, and finishing materials	All construction materials and systems

The built environment is categorised based on various criteria, such as building types, areas, elements and materials. An overview of the main international classification systems used for

categorising the building sector is given in the following paragraphs, while the main categories for each are presented in a tabular format in APPENDIX A.

## 2.1. SfB classification

The **SfB classification system** (Swedish Building Classification System) is a classification system from the 1950s, but it is still a relevant building classification system used in Scandinavian countries and the Netherlands (NL-SfB)<sup>11</sup>. The UK system was adapted as CI/SfB (Construction Indexing Manual), administered by the Royal Institute of British Architects (RIBA)<sup>12</sup>. This adaptation aimed to standardise the classification of work sections, enhancing consistency and efficiency in construction documentation.

The SfB organises buildings, materials, and components for architecture, engineering, and construction. However, the SfB system has limitations, including its rigidity and a failure to reflect modern construction practices. These shortcomings led to the development of alternative classification systems. Over time, more comprehensive and modern classification systems like Uniclass and OmniClass have emerged, prompting a shift in industry standards. Despite these challenges, the SfB classification system has significantly shaped information management within the construction sector, influencing the development of more advanced systems that continue to build upon its foundational principles.

## 2.2. Uniclass

Uniclass 2015 is a comprehensive classification system developed to standardise information organisation within the UK construction industry. Originating from the Construction Project Information Committee's efforts in 1997, it has evolved to meet modern construction practices and support BIM processes<sup>13</sup>. The system comprises a series of tables, each serving distinct roles in the classification hierarchy. These tables facilitate categorising various construction elements, ranging from entire systems like railways to individual components such as anchor plates or LED lamps.

Uniclass 2015's structured approach enhances interoperability among diverse stakeholders, including designers, constructors, and facilities managers. It streamlines various processes such as specification development, project information management, and asset record classification by providing a unified framework. Regular updates ensure that Uniclass remains aligned with evolving industry standards and practices. For instance, the January 2025 release introduced revisions across multiple tables, reflecting ongoing feedback and the integration of new construction methodologies<sup>14</sup>.

Incorporating Uniclass 2015 into project workflows standardises information management and supports the adoption of BIM processes. Its alignment with international standards, such as ISO 12006-2, underscores its global relevance and adaptability. Uniclass 2015 serves as an important tool for organising and managing construction information, promoting efficiency, clarity, and consistency throughout the lifecycle of built assets.

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<sup>11</sup> Classification of building elements; English version (2025). <http://nl-sfb.bk.tudelft.nl/eng.htm>.

<sup>12</sup> Ray-Jones, A. (1974) 'Classification by CI/SfB,' Building Research and Practice, 2(6), pp. 314–316. <https://doi.org/10.1080/09613217408550340>.

<sup>13</sup> Uniclass (2025). <https://www.thenbs.com/our-tools/uniclass>.

<sup>14</sup> Download | Uniclass (2025). <https://uniclass.thenbs.com/Download>.

### 2.3. OmniClass

OmniClass is a comprehensive system for organising and retrieving information in the construction industry. The system is widely used in BIM to structure data effectively throughout a project's lifecycle<sup>15</sup>. The system consists of 15 tables, each focusing on different aspects of construction information. These tables cover diverse areas such as construction entities, spaces, elements, work results, products, phases, services, disciplines, organisational roles, tools, information types, materials, and properties. Using these tables, OmniClass facilitates various applications, including organising reports, structuring object libraries, and supporting data retrieval in BIM environments.

The structured approach of OmniClass enhances collaboration among project stakeholders and streamlines information management throughout the project's lifespan. OmniClass's adaptability across different project types and its alignment with international standards make it a valuable tool for professionals seeking a standardised method to manage construction information effectively.

### 2.4. Construction Classification (CoClass) International (CCI)

The CCI (**CoClass** International) classification system, developed by the non-profit organisation Construction Classification International Collaboration (CCIC), is designed to enhance construction productivity through a collaborative **digital** information infrastructure, facilitating consistent data exchange across the built environment's lifecycle. It is based on international standards and developed for digital processes, covering buildings, infrastructure, and other civil engineering works<sup>16</sup>.

The system was first published in 2020 and was inspired by Denmark's Cuneco Classification System (CCS). It is based on international standards and developed for digital processes, covering buildings, infrastructure, and other civil engineering works<sup>17</sup>. Specific European countries, such as Denmark, Sweden, the Czech Republic, Estonia, etc., are considering implementing and adapting the CCI system to meet local requirements and practices<sup>18</sup>.

Unlike traditional and hierarchical classification systems above, CCI aims for a faceted approach that provides flexibility, enabling various construction professionals to operate within a unified framework while addressing their specific needs and promoting collaboration across different construction disciplines<sup>19,20</sup>.

CCI consists of six main tables—covering construction complexes, building entities, spaces, functional systems, technical systems, and components. In a digital environment, objects can be classified in multiple ways, allowing various construction disciplines to access relevant data while maintaining a unified classification framework. This adaptability makes CCI a powerful tool for digital construction, ensuring consistency and interoperability across different phases and facilitating effective integration with BIM.

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<sup>15</sup> About OmniClass™ - Construction Specifications Institute (2025). <https://www.csiresources.org/standards/omniclass/standards-omniclass-about>.

<sup>16</sup> CCIC (2025a). <https://cci-collaboration.org/>.

<sup>17</sup> Royano, V. et al. (2023b) 'Analysis of classification systems for the built environment: Historical perspective, comprehensive review and discussion,' Journal of Building Engineering, 67, p. 105911. <https://doi.org/10.1016/j.jobe.2023.105911>.

<sup>18</sup> Ehituse ühtne klassifitseerimissüsteem (CCI-EE) - e-ehitus (2024). <https://eehitus.ee/timeline-post/cci-ee/>.

<sup>19</sup> CCIC (2025b). <https://cci-collaboration.org/why-digital-work/>.

<sup>20</sup> Comparison of OmniClass, Uniclass, Cuneco and CoClass with reference to ISO 12006-2 and ISO 81346-12 (2018). [www.icis.org/wp-content/uploads/2018/07/2018\\_Classification-system-comparison.pdf](http://www.icis.org/wp-content/uploads/2018/07/2018_Classification-system-comparison.pdf).

While CCI can be relevant for new buildings, integrating the CCI classification system with existing buildings presents several challenges. Existing buildings often lack comprehensive digital records, making applying the CCI system difficult<sup>21</sup>. Existing buildings are documented using outdated or different classification systems, necessitating complex mapping and conversion to align with CCI standards. Additionally, the process can be time-consuming and resource-intensive, requiring significant time and cost investment in data collection, conversion, and system integration.

## 2.5. Norwegian Standards NS

NS 3457 comprises a collection of Norwegian standards designed to systematise and categorise buildings based on their function and use<sup>22</sup>. All the constituent standards of NS 3457 aim to establish a unified reference system for the Norwegian construction industry, thereby facilitating the comparison, recording, and analysis of building data. The standard parts contribute to a consistent understanding of buildings in Norway and are frequently used in public registers, property management, and BIM modelling.

The third part of the series, NS 3457-3:2013 – Classification of Buildings – Part 3: Building Types, was published in 2013 and specifies a system for classifying buildings based on their function<sup>23</sup>. The classification uses a code system and is organised into three levels: the main function of the building (the primary purpose of the building), the building group (a subcategory within the primary function that provides a more specific description), and the building type (a detailed classification that specifies the particular type of building within a building group).

The fourth part of the NS 3457 series, NS 3457-4:2015 Classification of Buildings – Part 4: Area Functions, was published in 2015 and specifies a system for classifying area/room functions in Norwegian constructions<sup>24</sup>. The standard defines spatial functions at three levels: main area, group of areas, and specific area functions. It does not include outdoor room functions, which are not directly associated with a building.

In addition to the NS 3457 series, NS 3451 is a Norwegian standard that provides a structured classification of building components and systems in buildings and their associated outdoor areas<sup>25</sup>. The standard aims to systematise and codify information about the physical parts of a building to facilitate construction projects and the management and maintenance of Norwegian buildings. NS 3451 operates mainly with a hierarchy of three levels, allowing for a detailed classification of building components. A fourth level was introduced in the 2022 update for some categories.

## 2.6. EU Construction and demolition waste

The above classification systems are focused on new or existing constructions, but in a circular approach, the classification must also be extended for the end-of-life stage and include products that can be redirected from existing buildings and back into the supply chain. The European Commission has established a unified list of wastes, the **European Waste Catalogue (EWC)**, integrating general and hazardous waste categories<sup>26</sup>. The EWC is a

<sup>21</sup> Volk, R., Stengel, J. and Schultmann, F. (2013) 'Building Information Modeling (BIM) for existing buildings — Literature review and future needs,' *Automation in Construction*, 38, pp. 109–127. <https://doi.org/10.1016/j.autcon.2013.10.023>.

<sup>22</sup> Klassifikasjon av byggverk – NS 3457 (2022). <https://standard.no/fagomrader/ns-3420-/klassifikasjon-av-byggverk---ns-3457/>.

<sup>23</sup> NS 3457-3:2013 (2013). <https://online.standard.no/nb/ns-3457-3-2013>.

<sup>24</sup> NS 3457-4:2015 (2015). <https://online.standard.no/nb/ns-3457-4-2015>.

<sup>25</sup> NS 3451:2022 (2022). <https://online.standard.no/nb/ns-3451-2022>.

<sup>26</sup> Decision - 2014/955 - EN - EUR-LEX (2014). <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014D0955>.

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standardised framework for waste classification across EU Member States, facilitating consistent waste management practices and regulatory compliance. The list is organised into categories based on the source and type of waste and is continuously updated. Each category is assigned a specific code to aid in identification and handling. The category of construction and demolition wastes (including excavated soil from contaminated sites) is assigned code 17, and the sub-classification of waste types is given in APPENDIX A.5:

### 3. Literature review

This chapter describes four different types of reviews from various bodies of information, discusses the emerging research related to circularity and BIM adaptation in the construction sector, and highlights the challenges of directing the ongoing work towards standardisation and digitalisation.

Key messages:

Scoping review

- A review of 2,649 abstracts reveals that research on circularity, material reuse, and waste management in construction has surged since the mid-1990s, with the circular economy emerging as the fastest-growing topic.
- Topics cluster into emerging (circularity-focused, post-2015), established (waste management, 2005–2010), and long-standing (material reuse, pre-2005) areas.
- Integrating BIM, Digital Twins, Robotics, and IoT with circular economy principles can enhance sustainability and reduce construction waste.

Detailed review

- A review of 14 articles highlights that BIM is crucial in managing, classifying, and integrating circular construction data, facilitating material reuse, deconstruction planning, and lifecycle assessment.
- Various classification systems, material passports, and performance estimation tools emphasise the need for structured, interoperable data to improve reusability and sustainability in construction.
- Challenges in connecting detailed technical parameters (e.g., material properties, disassembly factors) with high-level sustainability targets require better integration of digital platforms and standardised frameworks.

Standards and technical reports review

- National and international standards and technical reports are essential in guiding sustainable and circular construction practices to ensure safety, quality, and sustainability in construction.
- Protocols like the EU Construction & Demolition Waste Management Protocol and national standards (e.g., DIN SPEC 91484) are available to guide material reuse and selective demolition.
- Several tools, like the DGNB Circularity Index, measure material reuse, disassembly potential, and sustainability, but challenges exist due to the vast parameters and evaluation systems for each framework.

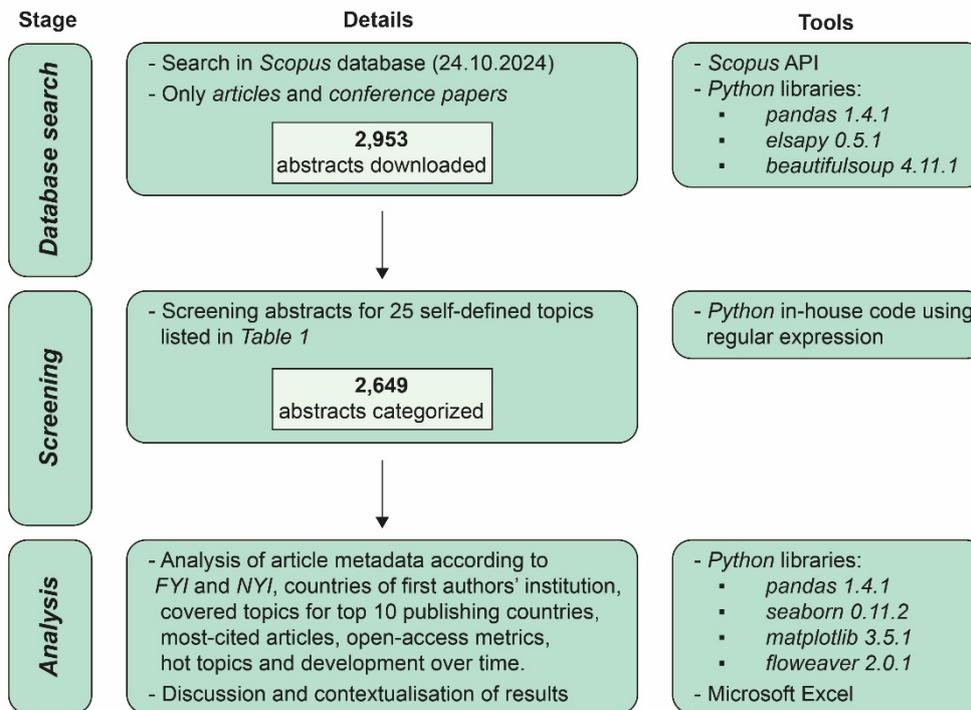
Digital platform review

- Digital representations, such as DMP, DPP, and DBL, have been developed to enhance the construction sector's transparency, traceability, and sustainability, supporting the circular economy movement.
- The digital records provide comprehensive data on materials and products, including their composition, carbon footprint, recyclability, and performance, which enables more efficient building management, material reuse, and improved environmental outcomes.
- The effectiveness of digital tools is hindered by challenges such as a lack of standardisation, integration issues with existing systems, data privacy concerns, and economic barriers. Addressing these challenges is critical for advancing circularity in construction.

### 3.1. Scoping review

#### 3.1.1. Overall approach

A scoping review approach was applied to identify and analyse topics and trends in the broader field of circularity, material reuse and recycling, waste minimisation and management, urban mining, and closed-loop economy in the construction sector. Figure 2 illustrates the applied workflow and methodology in this study.



**Figure 2: Schematic visualisation of applied methodology for screening review.**

The Python package *elsapy* was used to identify the body of literature considered as a basis for semi-automated text analysis, metadata extraction, and thematic evaluation. It allows connecting to the *Elsevier* Application Programming Interface (API) to access the *Scopus*<sup>27</sup> database, one of the largest abstract and citation databases with more than 97 million records. The advantage of using *Scopus* instead of other, more extensive databases is the possibility of a close to fully automated process of identifying, bulk-downloading, structuring, managing, and visualising vast amounts of metadata. This choice is also because almost all records contain English abstracts that are freely available, independent of access limitations due to missing institutional subscriptions to publishers or an article's language (abstracts are always available in English).

Applying a text-mining approach to identify keywords and patterns from the abstracts of research articles, in this case, allows for screening a vast body of literature in a relatively short time. The following search syntax was applied to identify the most comprehensive body of literature possible:

<sup>27</sup> Scopus | Abstract and citation database | Elsevier (2025). <https://www.elsevier.com/solutions/scopus>.

TITLE-ABS-KEY ( ((Circular\* PRE/3 (economy OR construction OR design OR building OR materials OR cities OR urbanism OR communities OR waste)) OR (material PRE/3 (reuse OR recycling OR upcycling OR mining OR recovery OR secondary OR reclaim\* OR "closed loop" OR "closed-loop")) OR ("construction waste" PRE/3 (minimiz\* OR reduc\* OR reuse OR recycling OR upcycling OR mining or reclaim\* OR recovery)) OR (("closed loop" OR "closed-loop") AND (reuse OR recycling OR upcycling OR mining OR recovery OR secondary OR reclaim\* OR "supply chain" OR "waste management" OR economy)) OR ("urban mining")) AND ("built environment" OR AEC OR "architecture engineering and construction" OR ((construction OR building) PRE/1 (sector OR industry))) AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "cp" ) ) )

Since *Scopus* applies word stemming, plural and possessive forms of words are covered in the search phrase. Only documents of types “article” and “conference paper” were included to avoid non-peer-reviewed publications like books, notes, short surveys, editorials, etc. Additionally, review articles are excluded as they might address multiple topics and thus bias the results. The proximity operator “PRE/*n*” indicates that the terms before and after this operator are searched for with at most *n* words in between.

### 3.1.2. Main categories

The search was performed on 24.10.2024 and resulted in 2,953 elements in total. After downloading the abstracts, an in-house *Python* code was used for parsing and grouping into a set of 25 self-defined categories (Table 2). In the search, both singular and plural forms and different notations of all words (American/British English) were considered. The categories are a combination of the “main category” and the “keyword combinations”. It was possible to allocate 2,649 out of the 2,953 abstracts (89.7 %) to at least one category, with an average of 2.1 categories per abstract.

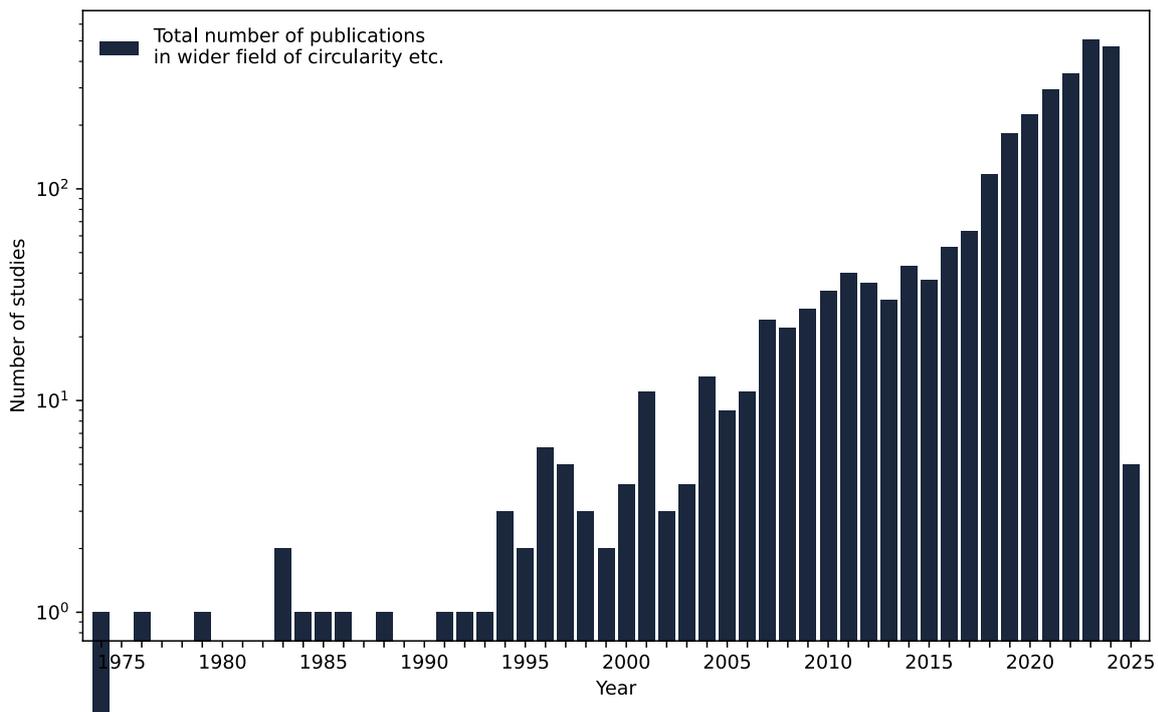
**Table 2: Main categories and keyword combinations used to categorise abstracts.**

Main category	Keyword combinations
Circular .../... circularity	... economy ... construction ... design ... building ... material ... city urban ... ... communities ... waste
Material .../... material	... reuse ... recycling ... upcycling ... mining ... recovery secondary ... reclaimed ...
Waste ...	... management

	... reduction/minimisation ... reuse ... recycling ... upcycling ... mining ... reclamation
<b>Urban mining</b>	-
<b>Closed loop</b>	-

### 3.1.3. Publication trend

Figure 3 shows the yearly publication trend of the documents obtained from the *Scopus* search. As noted, the first identified study was published in 1974. While for the next ca. 20 years, only 12 documents emerged in total, the development from about the mid-1990s shows a sharp increase in published studies per year (note the logarithmic y-axis of the figure), documenting the rising interest in the topic. There is a clear trend of an increase in the number of publications in recent years. Thus, the year with the most published studies is 2023, with 509 documents, followed by 2024 and 2022, with 470 and 351 studies, respectively.



**Figure 3: Total number of publications as identified by the document search in Scopus.**

This study uses two publication year indicators to facilitate an understanding of the overall field’s development over time. The first indicator is the *First-Year-Index* (FYI), corresponding to the earliest publication year for an article in a specific category, as shown in Figure 4. The second indicator is the Normalised-Year-Index (NYI)<sup>28</sup> and is calculated from equation (1),

<sup>28</sup> Brozovsky, J., Labonnote, N. and Vigren, O. (2023) 'Digital technologies in architecture, engineering, and construction,' *Automation in Construction*, 158, p. 105212. <https://doi.org/10.1016/j.autcon.2023.105212>.

where  $y$  represents a particular year,  $y_0$  the year of the earliest study in a certain category and  $y_n$  the year of the newest study investigated in this article.  $f_{w,y}$  is a weighting factor for a particular year  $y$ , calculated from  $f_{w,y} = n_{C,y}/n_{T,y}$ , where  $n_{C,y}$  is the number of publications in a specific category in that year, and  $n_{T,y}$  is the total number of publications across all categories in a particular year.

$$NYI = \frac{\sum_{y_0}^{y_n} y * f_{w,y}}{\sum_{y_0}^{y_n} f_{w,y}} \tag{1}$$

Figure 4 illustrates the FYI and NYI for each topic category, where the FYI indicates the earliest publication year of a study within a particular topic, and the NYI indicates its topicality. The figure also shows that there are three major clusters of main topics. Currently, circularity-related topics are more frequently studied than, e.g., waste- or material-related, as 7 of the 11 topics of cluster 1 (NYI > 2015) have the keyword *circularity* or *circular* in the topic name (*Circular waste*, *Circular materials*, *Circular economy*, *Urban circularity*, *Circular construction*, *Circular cities*, *Circular communities*). The second cluster of topics, with an NYI from 2005–2010, is dominated by waste-related topics (4 out of 7), such as *Waste reuse*, *Waste management*, *Waste reduction & minimisation*, and *Waste recycling*. Other topics in cluster 2 include *Circular building*, *Circular design*, and *Closed loop*. Cluster 3 contains the topics with an NYI < 2005. There are, first and foremost, material-related categories in this cluster (6 out of 7), such as *Reclaimed materials*, *Secondary materials*, *Material recycling*, *Material reuse*, *Material mining*, and *Material recovery*. The only material-unrelated topic in this cluster is *Waste reclaim*.

This scoping review effectively mapped the field’s progression, illustrating how research emphasis has evolved from material-centric approaches to waste management and recently towards comprehensive circularity concepts. This layered understanding aids researchers and stakeholders in identifying how the focus areas have shifted, where current research efforts are concentrated, and what potential future directions for exploration are.

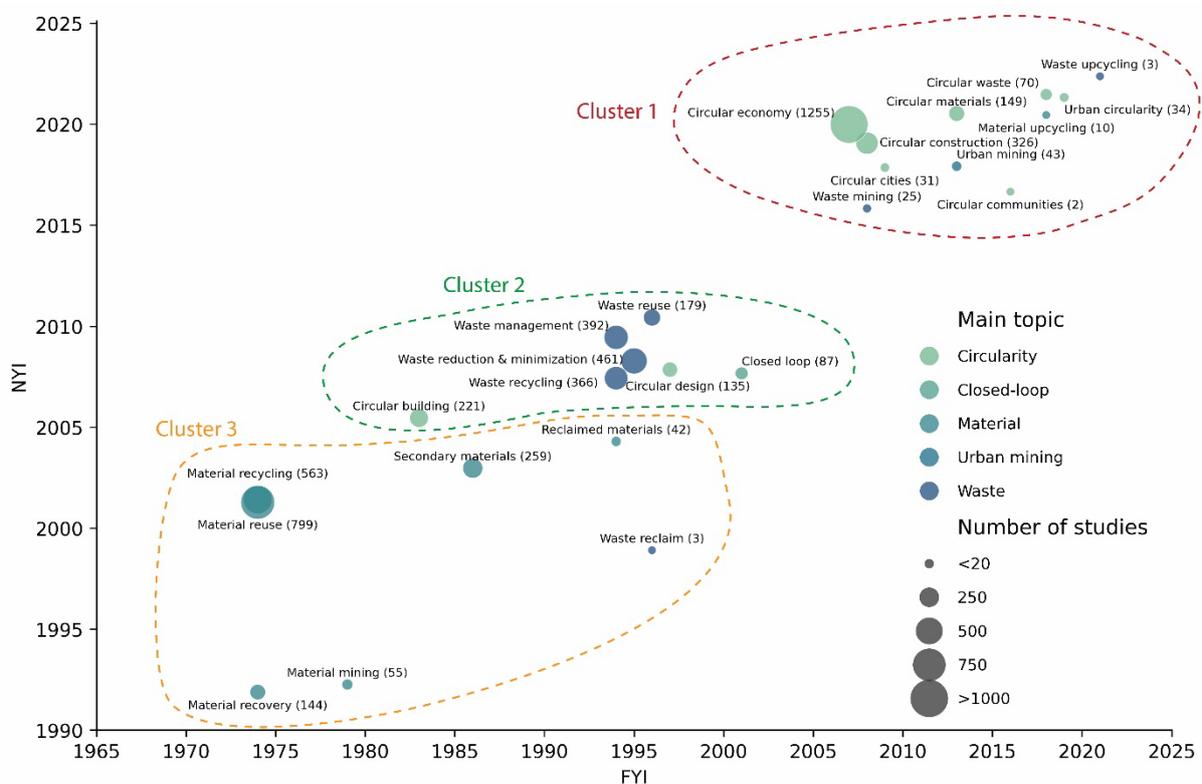


Figure 4: First-Year-Index (FYI) and Normalized-Year-Index (NYI) for all categories (number of studies in parentheses).

Additional results of the screening review are given in APPENDIX B.

### 3.1.4. Discussion of the scoping review

The screening review results indicate that the broader field of circular economy related to material reuse, reclamation, urban mining, and deconstruction is garnering increasing research attention on a global scale.

A comprehensive field analysis revealed various topics associated with circular economy practices in the construction sector. The temporal analysis highlighted that some topics have recently gained substantial research interest (emerging topics) while others have been well-established areas of study for decades (dominant topics). Additionally, there are niche topics that, possibly due to the unique choice of keywords and terminology, have received relatively limited attention.

Among the dominant topics, *Material reuse* and *Material recycling* have consistently been focal points of research since the early days of the field. Similarly, *Waste reduction and minimisation*, *Waste management*, and *Waste recycling* have been prominent since the early 1990s, representing a significant portion of the scientific literature in this domain.

Niche topics of particular interest include *Waste upcycling*, *Material upcycling*, *Waste mining*, *Circular cities*, and *Circular communities*. With an increasing focus on sustainability and low-energy/emission initiatives at the neighbourhood level<sup>29</sup> (e.g., Positive Energy Districts – PED<sup>30</sup>, or Zero Emission Neighbourhoods – ZEN<sup>31</sup>), it is anticipated that topics such as *Circular cities* and *Circular communities* will attract more research in the future.

*Circular economy* stands out as the “hottest” emerging topic due to the relatively short period it has been studied in academic literature, despite having the highest number of associated research articles. This trend suggests that it is well-positioned to become a dominant topic soon. Other notable emerging topics include *Circular construction*, *Circular materials*, *Circular waste*, and *Urban mining*.

Regarding technologies employed, *BIM* and *Prefabrication* are currently the most prevalent. However, recent years have seen a surge in interest in *Digital Twin* technology, *Robotics/Drones*, and the *Internet of Things*. The results highlight that while the combination of BIM and circular economy concepts in construction is not entirely new, the potential impact of integrating circularity with BIM is substantial. BIM is already utilised by approximately 70–80% of contractors<sup>32</sup> in the world’s foremost construction markets, and its usage continues to grow. Modifying or extending BIM to incorporate circular economy aspects offers the potential for significant scaling and widespread implementation, contributing to increased sustainability and transparency in the construction sector.

Since the construction industry generates around 100 billion tons of waste annually<sup>33</sup>, incorporating circular economy principles has a substantial impact potential, underscoring the importance and urgency of integrating circularity within BIM systems.

<sup>29</sup> Brozovsky, J., Gustavsen, A. and Gaitani, N. (2021) 'Zero emission neighbourhoods and positive energy districts – A state-of-the-art review,' *Sustainable Cities and Society*, 72, p. 103013. <https://doi.org/10.1016/j.scs.2021.103013>.

<sup>30</sup> Derkenbaeva, E. et al. (2021) 'Positive energy districts: Mainstreaming energy transition in urban areas,' *Renewable and Sustainable Energy Reviews*, 153, p. 111782. <https://doi.org/10.1016/j.rser.2021.111782>.

<sup>31</sup> Wiik, M.R.K. et al. (2024) Zero Emission Neighbourhoods in Smart Cities Definition, key Performance Indicators and Assessment Criteria: Version 5.0. <https://sintef.brage.unit.no/sintef-xmlui/handle/11250/3135641>.

<sup>32</sup> McGraw Hill Construction. (2014) The Business Value of BIM for Construction in Major Global Markets: How Contractors Around the World Are Driving Innovation With Building Information Modeling. [https://icn.nl/pdf/bim\\_construction.pdf](https://icn.nl/pdf/bim_construction.pdf).

<sup>33</sup> United Nations Environment Programme (2022). 2022 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector. Nairobi, Kenya.

## 3.2. Detailed review

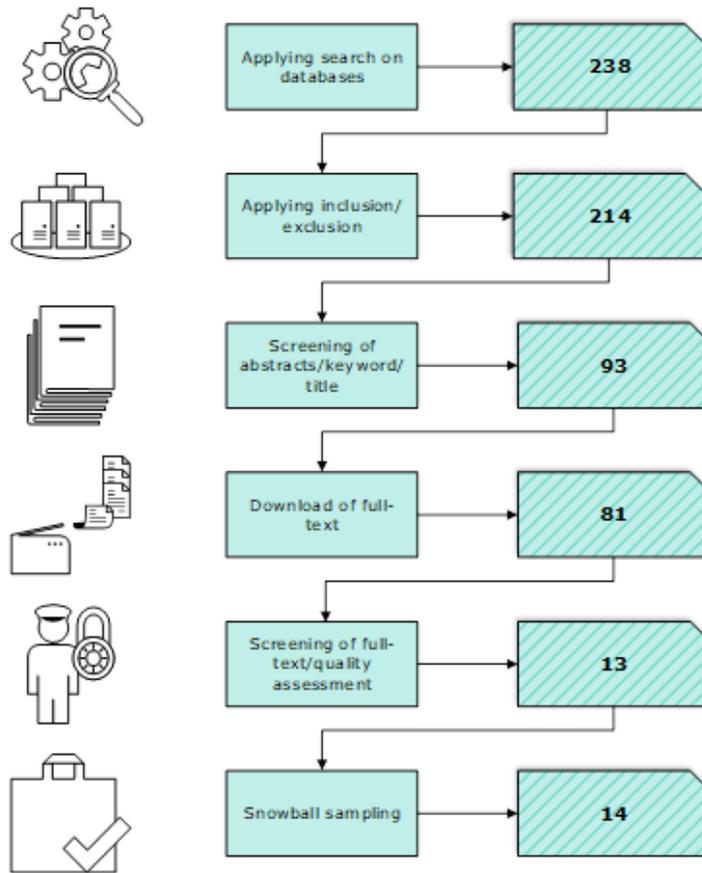
### 3.2.1. Overall approach

A systematic literature review was further conducted using the same database, *Scopus*. The scope of the review was to search the scientific literature for information classification regarding circular construction components/materials for inclusion in BIM. This enrichment in classification systems becomes the basis for the generation of circular-related BIM systems. The search methodology included the keywords related to 'bim,' 'deconstruction,' and 'circularity,' as well as their synonyms or associates combined with Boolean operators (AND/OR).

*Scopus* search is sensitive to word stemming; therefore, plural and other forms of words in the search bar were again covered by using the symbol of an asterisk (\*) after the root of each word. No publication limit was used for publication years to collect all available scientific information. Only documents of types "article", "conference paper", and "review" were included to avoid non-peer-reviewed sources. Additionally, the search was limited to documents written in English. The following search syntax was applied to identify the most comprehensive body of scientific literature possible related to the scope of the review:

```
TITLE-ABS-KEY(( bim OR "building information modeling" ) AND ( deconstruct* OR
disassemb* OR demoli* ) AND ( circular* OR reus* OR recla* OR waste*)) AND ( LIMIT-
TO ( DOCTYPE,"ar" ) OR LIMIT-TO ( DOCTYPE,"cp" ) OR LIMIT-TO ( DOCTYPE,"re" ) )
AND ( LIMIT-TO ( LANGUAGE,"English" ) )
```

The search was performed on 07.11.2024 and resulted in a total of 214 elements. Titles, keywords and abstracts from the search were initially screened by two researchers to find relevant articles, resulting in 93 documents. Out of that, full-text documents were searched for to conduct a full-text screening. It was possible to download 81 full-text documents, which were screened for data on classification systems for construction and materials from deconstruction. 13 documents were considered relevant for containing valuable categorisation information, and the results, mostly in table form, were extracted and synthesised to be further implemented in integrated circular BIM systems. In the end, snowballing, also known as citation chaining (i.e., searching the references and the citations of the identified articles), was applied to identify other relevant documents. A schematic visualisation of the literature review is presented in Figure 5.



**Figure 5: Schematic visualisation of applied methodology for detailed literature review.**

The complete list of the 14 articles considered for the review is given in APPENDIX C.

### 3.2.2. Categorisation approaches for circularity in BIM

The reviewed literature collectively emphasises the role of structured information systems and parameter taxonomies for enhancing the potential of building deconstruction, reuse, and recycling within the circular economy framework. A recurring theme is the centrality of BIM as a tool to host, manage, and transfer such information. The proposed systems can broadly be categorised into (1) salvage performance estimation tools, (2) material passports, (3) BIM-based disassembly models, and (4) data integration frameworks for circular assessment.

#### Structural Reusability and Salvage Estimation Tools

Akanbi et al.<sup>34</sup> (2018) developed a BIM-based Whole-Life Performance Estimator (BWPE) to forecast the reusability and recyclability of structural components using Weibull distribution to model degradation over time. Parameters identified include material type (with a focus on steel), connection type (dismountable vs fixed), prefabrication level, and structural role. This system is deeply quantitative but narrowly scoped to structural elements. The main parameters are presented in Table 3.

<sup>34</sup> Akanbi, L.A. et al. (2017) 'Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator,' Resources Conservation and Recycling, 129, pp. 175–186. <https://doi.org/10.1016/j.resconrec.2017.10.026>.

Mohammed et al.<sup>35</sup> (2024) propose a BIM-Deconstructability Assessment Score (BIM-DAS) for steel structures, integrating mathematical modelling and questionnaire-derived weights for parameters such as connection reversibility, prefabrication, assembly sequence, and material compatibility. Their system combines technical and operational dimensions, offering a more comprehensive model for deconstructability planning.

### Material Passports and Component-Centric Systems

Göswein et al. (2022a)<sup>36</sup> introduced a Circular Material Passport (CMP) aligned with EU Level(s) indicators and presented the CirBIM database framework in Göswein et al. (2022b)<sup>37</sup>. The CMP includes three layers of data: general (e.g., product name, supplier, certifications), contextual (e.g., location in the building, service life), and circularity potential (e.g., recyclability, reusability, disassembly ease). These passports are intended to facilitate component recovery, and inform renovation permits and procurement. The proposed parameters are presented in Table 4.

Sanchez et al. (2024)<sup>38</sup> and (2023)<sup>39</sup> contributed to disassembly data structuring by identifying key disassembly parameters in BIM environments. These include geometric location, fastener type, extraction direction, connection difficulty, hosted component dependencies, and modular sub-assemblies. These systems take cues from manufacturing disassembly literature but adapt them to architectural contexts.

Kim and Kim (2023)<sup>40</sup> designed a graph-based deconstructability support tool that builds connectivity maps between components to estimate CO<sub>2</sub> emissions and reuse value. Their parameters include component hierarchy, material embodied energy, joint types, and ease of removal. Their model advances the integration of performance metrics into early-stage design.

### BIM-Based Disassembly and Lifecycle Models

Mattaraia et al. (2023)<sup>41</sup> created a classification structure for Design for Disassembly (DfD), focused on Brazilian construction systems. It identifies building layers (structure, envelope, services) and ranks them by disassembly friendliness, using BIM to store classifications. Emphasis is placed on interface design, lifetime layers (per Brand), and changeability.

Sanchez et al. (2024) went further in proposing a BIM Model View Definition (MVD) for disassembly planning, integrating data into the IFC schema and proposing specific object properties for reuse and disassembly. Parameters include component geometry, interface characteristics, lifecycle stage, and energy consumption during removal.

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<sup>35</sup> Mohammed, A., Ghannam, M. and Elmasoudi, I. (2024) 'Design for steel structures deconstruction: an analytics system for construction waste minimization in a circular economy through BIM technology,' *Innovative Infrastructure Solutions*, 9(11). <https://doi.org/10.1007/s41062-024-01703-2>.

<sup>36</sup> Göswein, V. et al. (2022) 'Circular material passports for buildings – Providing a robust methodology for promoting circular buildings,' *IOP Conference Series Earth and Environmental Science*, 1122(1), p. 012049. <https://doi.org/10.1088/1755-1315/1122/1/012049>.

<sup>37</sup> Göswein, V., Carvalho, S., Lorena, A., et al. (2022) 'Bridging the gap – A database tool for BIM-based circularity assessment,' *IOP Conference Series Earth and Environmental Science*, 1078(1), p. 012099. <https://doi.org/10.1088/1755-1315/1078/1/012099>.

<sup>38</sup> Sanchez, B. et al. (2024) 'BIM Model View Definition (MVD) for disassembly planning of buildings,' *Proceedings of the 41st ISARC*. <https://doi.org/10.22260/isarc2024/0155>.

<sup>39</sup> Sanchez, B., Herthogs, P. and Stouffs, R. (2023) 'Identifying key parameters for BIM-based disassembly planning,' *Proceedings of the 40th ISARC*. <https://doi.org/10.22260/isarc2023/0007>.

<sup>40</sup> Kim, S. and Kim, S.-A. (2022) 'A design support tool based on building information modeling for design for deconstruction: A graph-based deconstructability assessment approach,' *Journal of Cleaner Production*, 383, p. 135343. <https://doi.org/10.1016/j.jclepro.2022.135343>.

<sup>41</sup> Mattaraia, L., Fabricio, M.M. and Codinoto, R. (2021) 'Structure for the classification of disassembly applied to BIM models,' *Architectural Engineering and Design Management*, 19(1), pp. 56–73. <https://doi.org/10.1080/17452007.2021.1956420>.

## Conceptual and Interoperability Frameworks

Schamne et al. (2024)<sup>42</sup> developed a conceptual information model for CDW management that aligns BIM with sustainability certifications (LEED, BREEAM). They propose collecting parameters on material quantities, types, lifecycle stages, and locations mapped into Industry Foundation Classes (IFC). The focus is on facilitating automated waste tracking and pre-demolition planning.

Kuzminykh et al. (2024)<sup>43</sup> demonstrated a BIM-driven demolition data pipeline for CDW marketplaces. Their framework specifies data requirements for digital demolition preparation, including material recoverability, contamination, demand-based recovery priorities, and marketplace integration metadata. Their use of openBIM supports low-entry digital solutions for circular supply chains.

Charef (2022)<sup>44</sup> introduced the concept of an 8D BIM dimension, proposing a dedicated model for deconstruction (Deconstruction Information Model – DIM). Parameters include contamination history, accessibility, insurance and warranty constraints, and regulatory requirements. The study emphasises stakeholder alignment and data lifecycle ownership.

Gupta et al. (2022)<sup>45</sup> proposed a BIM-based theoretical framework for CDW management, categorising waste sources across design, construction, and demolition. The system highlights the integration of logistics data, cost factors, and recovery potential using BIM. It identifies quality and safety parameters as key missing links in existing tools.

Royano et al. (2023)<sup>46</sup> reviewed international classification systems (Uniclass, OmniClass, CoClass) and identified the lack of consistent, standardised categorisation for building components at end-of-life. They stress the need for extensions of these systems to accommodate lifecycle-based reuse classification.

Jayasinghe et al. (2019)<sup>47</sup> bridged reverse logistics, information management, and quality management in a BIM-enabled context. Their synthesis highlights the need to track parameters like residual performance, client behaviour, and secondary market data to support circular flows. They advocate for integrated models to capture the quality of salvaged materials systematically.

## Synthesis of the literature review

The reviewed literature converges on the need for standardised, interoperable, and lifecycle-aware data systems embedded within BIM environments to promote circular outcomes. A shared emphasis is placed on parameters related to:

- Material characteristics (type, recyclability, toxicity)
- Component-level metadata (connection type, service life, modularity)

<sup>42</sup> Schamne, A.N. et al. (2024) 'BIM in construction waste management: A conceptual model based on the industry foundation classes standard,' *Automation in Construction*, 159, p. 105283. <https://doi.org/10.1016/j.autcon.2024.105283>.

<sup>43</sup> Kuzminykh, A. et al. (2024) 'Promoting circularity of construction materials through demolition digitalisation at the preparation stage: Information requirements and openBIM-based technological implementation,' *Advanced Engineering Informatics*, 62, p. 102755. <https://doi.org/10.1016/j.aei.2024.102755>.

<sup>44</sup> Charef, R. (2022) 'The use of Building Information Modelling in the circular economy context: Several models and a new dimension of BIM (8D),' *Cleaner Engineering and Technology*, 7, p. 100414. <https://doi.org/10.1016/j.clet.2022.100414>.

<sup>45</sup> Gupta, S., Jha, K.N. and Vyas, G. (2020) 'Proposing building information modeling-based theoretical framework for construction and demolition waste management: strategies and tools,' *International Journal of Construction Management*, 22(12), pp. 2345–2355. <https://doi.org/10.1080/15623599.2020.1786908>.

<sup>46</sup> Royano, V. et al. (2023) 'Analysis of classification systems for the built environment: Historical perspective, comprehensive review and discussion,' *Journal of Building Engineering*, 67, p. 105911. <https://doi.org/10.1016/j.jobe.2023.105911>.

<sup>47</sup> Jayasinghe, R.S., Chileshe, N. and Rameezdeen, R. (2019) 'Information-based quality management in reverse logistics supply chain,' *Benchmarking an International Journal*, 26(7), pp. 2146–2187. <https://doi.org/10.1108/bij-08-2018-0238>.

- Spatial and functional context (location in building, access, dependency)
- Lifecycle indicators (condition, maintenance, wear)
- Operational metrics (deconstruction time, effort, energy, emissions)
- Regulatory and market data (warranty, certifications, market value)

While some studies focus on structural reuse through performance modelling, others emphasise policy compliance and systems integration. A critical challenge remains in bridging granular technical data with high-level sustainability goals, especially in legacy buildings where data may be missing. The need for data normalisation shared ontologies, and plug-and-play compatibility with circular procurement systems and digital marketplaces is paramount. Cross-pollination between product-centric and system-level models could unlock a more scalable pathway for digital reuse planning in the built environment.

### 3.2.3. Tables of parameters from the literature review

The reviewed articles provide categorisation systems to quantify and evaluate the salvaged materials or products. This section summarises the main parameters from the most relevant documents.

Akanbi et al. (2018) proposed a BIM-based Whole-Life Performance Estimator (BWPE) designed to evaluate the salvage performance of structural components in buildings, particularly steel structures, over time. The system uses the Weibull reliability distribution to simulate material degradation and forecast recoverable quantities at the end of life. It draws data from the building's BIM model to extract structural information, including material type, quantity, and connection detail. Key influencing parameters include connection type (e.g., demountable or welded), prefabrication level, material durability, and structural role (Table 3). BWPE calculates the reusability and recyclability potential in terms of tonnage, integrating time as a core variable. It aims to inform architects and demolition engineers at both the design and end-of-life stages. The model emphasises objective, quantifiable assessment over subjective judgment. Its scope is limited to structural components, particularly steel-framed systems, and assumes detailed, structured BIM data availability. Ultimately, BWPE promotes proactive design choices that enhance material recovery in a circular economy.

**Table 3: Key influencing parameters of BWPE, Akanbi et al. (2018)**

Factor	Description
Material Type	Steel, concrete, wood, etc., with emphasis on steel structures.
Connection Type	Demountable vs permanent joints.
Prefabrication	Modular elements ease disassembly.
Time of Use	Weibull-based degradation over the lifespan.
Structural Role	Primary vs secondary load-bearing members.

Göswein et al. (2022a) proposed a Circular Material Passport (CMP) system to support material traceability and circular decision-making throughout the building lifecycle. The CMP is structured into three core sections: General Data (e.g., material name, supplier, certifications), Product Context (e.g., location, service life, function), and Circularity Potential (e.g., disassembly rating, reusability, recyclability). The main parameters for each section are given in Table 4. PCM is aligned with the EU Level(s) framework, ensuring compatibility with sustainability indicators and public procurement criteria. The passport is intended to be BIM-integrated, enabling component-level data storage and visualisation. CMPs serve as digital identities for building products, enhancing recovery, reuse, and recycling at end-of-life. The system supports both new and existing buildings, although it assumes access to high-quality

metadata. It is designed to be policy-compliant and applicable in public permitting, tendering, and audits. By assigning value to materials in situ, CMPs enable market-based circularity incentives. The framework also allows the aggregation of CMPs into building-level passports to support whole-asset analysis.

**Table 4: Input parameters of the Circular Material Passport, Göswein et al. (2022a)**

Section	Parameter
General data	Passport ID
	Name
	Category
	Function
	Manufacturer
	Data source
Product context	Building identification
	Installation date
	Location
	Service lifespan
	Maintenance
	End-of-life
Circularity potential	Design for disassembly
	Disassembly instructions
	Quantity
	Material composition
	Material input source
	Waste scenarios

Göswein et al. (2022b) presented the CirBIM database framework, designed to equip BIM users with reliable data to enhance circularity throughout a building's life cycle—from the design phase through renovations to the end-of-life stage. The paper introduces a novel workflow for assessing building circularity, explains the architecture of the proposed database tool, and identifies key data sources and information models to optimise data mining processes. The framework is demonstrated through its application to a case study building, highlighting the importance of diverse metrics and the integration of end-of-life scenarios in the early design phase. The database stores information on construction products to facilitate the analysis of circularity indicators. This data is structured within a product data template (PDT), as illustrated in Table 5, which enables the systematic and organised collection of new data.

**Table 5: Product data template for CirBIM, Gösswein et al. (2022b)**

Macro Objective		Parameter/Indicator
<b>Classification</b>	Product Info	Product Name Manufacturer Reference Flow (UUID)
	Uniclass	Uniclass Product (Pr) Code
	Building Aspect	Tier 2 Name
	Building Layer	Brand Layer
	Functional Unit	Declared Unit Density Expected Lifespan
<b>Metadata</b>	Info about environmental indicator data	Type of Data Life Cycle Impact Assessment (LCIA) Method Data Source
<b>Environmental Impacts</b>	Per LC Stage/Module (source: EPD)	Environmental impact indicators Resource impact indicators End of life – Waste indicators End of life – Output flow indicators
<b>Cost</b>		Initial marketplace
<b>Material Composition of the Product</b>	Type of Material	Material 1, 2, n
	Biomaterial (If Relevant)	Material 1, 2, n
	Quantity per Material	Material 1, 2, n

Sanchez et al. (2023) proposed a BIM-based disassembly planning framework focused on identifying the key parameters required to model and plan building disassembly at the component level. The system is structured around three stages: preprocessing, analytical disassembly modelling, and performance evaluation. Core parameters include disassembly part identification, connection type and difficulty, hosted component relationships, extraction direction, and physical interface characterisation (Table 6). These are used to build structured disassembly graphs within the BIM environment, facilitating logical sequencing and simulation. The framework also incorporates performance metrics such as disassembly time, cost, energy consumption, and recovery value. The model is based on established disassembly principles from manufacturing and adapted to building systems. It emphasises using BIM as a central data platform for visualisation, coordination, and automation of disassembly tasks. The system supports component reuse by making disassembly feasibility measurable and computable. It can be integrated into pre-demolition audits, offering a data-driven basis for reuse and recycling decisions. The model enables more efficient, optimised, and circular disassembly planning.

**Table 6: A summary of BIM disassembly parameters, Sanchez et al. (2023)**

Stage	Parameter	Purpose / Description
<b>Preprocessing</b>	Global Disassembly Model Identifier	Unique ID to group components under the same disassembly model.
	Disassembly Part Type	Classification as component or connection (e.g., c1, f1).
	Disassembly Part Identification	Unique identifier for each disassembly element.
	Hosted Components and Connections	Defines component dependency hierarchy and nesting.
	Connection Disassembly Difficulty	Rating of disassembly effort required for connections.
	Fastener Constraint Type	Specifies directionality and constraints of fastener removal.
	Physical Interface Characterization	Geometric and mechanical specs of joints and fasteners.
<b>Analytical disassembly model</b>	Graph Data Structure	Logical network linking components and disassembly sequences.
	Extraction Direction	Required direction or path for safe component removal.
	Object Geometry	2D/3D model information needed for disassembly planning.
	Working Space	Clearances and maneuvering room required for removal.
	Disassembly Tool and Method	Tools and techniques required per component type.
	Environmental impacts	LCA
	Disassembly Time	Estimated time needed for component removal.
<b>Performance</b>	Disassembly Cost	Associated costs including labor, tools, and overhead.
	Disassembly Revenue	Estimated resale or reuse value of components.
	Disassembly Energy Consumption	Energy use forecast for deconstruction operations.
	Disassembly Distance	Transport distance to reuse or recycling facilities.

Schamne et al. (2024) proposed a conceptual information model for construction and demolition waste (CDW) management integrated into BIM using the Industry Foundation Classes (IFC) standard. The system tracks and assesses material flows, quantities, and

sustainability indicators across a building's lifecycle, particularly at the end-of-life phase. The model introduces a CDW information structure that maps data to support LEED, BREEAM, and other sustainability certifications. Key indicators include material type, quantity, source location, lifecycle stage, and recovery potential, all embedded in IFC-compliant schemas (Table 7). The approach emphasises interoperability, automation, and flexibility, enabling stakeholders to optimise reuse and recycling during demolition planning. The model is developed using Design Science Research (DSR) and validated through expert input and application examples. It also links BIM to building sustainability assessment (BSA) frameworks and introduces exchange requirements for CDW data in digital workflows. The system is adaptable across different project phases and supports data-driven decision-making for circular construction practices.

**Table 7: CDW indicators for the BIM-CDW model, Schamne et al. (2024)**

Indicator	Description
CDW diagnostic	Quantification of types of waste
	Classification of CDW according to List of Wastes (LoW)
	Relationship between elements and types of waste
	Calculation of CDW according to the construction area
CDW valuation	Reuse of materials from other works
	Reuse of materials
	Recycling of materials
	Destination of waste
CDW management	Calculation of gains from recycling materials
	Calculation of gains from the reuse of materials

### 3.3. Standards and technical reports review

Scientific literature is crucial for identifying recent advancements in knowledge and technology. While it is essential for researching and exploring new ideas, standards and technical reports provide the practical and mandatory frameworks necessary for consistently and safely applying this knowledge in everyday applications. Consequently, a review of standards and technical reports focused on deconstruction and circularity was carried out.

Standards and technical reports for the construction sector provide established guidelines and specifications to ensure safety, quality, and sustainability throughout the lifecycle of a building. However, search databases that retrieve relevant standards based on titles, abstracts, keywords, or content are not fully established. Furthermore, standardisation is a process developed at national levels and is typically offered as a paid service or in the national language, complicating the inclusion of all essential information from diverse countries.

The list of standards and technical reports included in the review is derived from the expert's input and research on existing standards, technical literature, and relevant projects that focus on the potential for the disassembly and reuse of construction products from current buildings.

### 3.3.1. EU protocols and guidelines (2016-2024)

Conducting pre-demolition or pre-renovation audits facilitates selective demolition, enhances waste sorting, and improves the quality of recycled materials. The first **EU Construction & Demolition Waste Management Protocol**<sup>48</sup>, published in 2016, aimed to assess buildings designated for demolition or renovation, identify materials suitable for reuse or recycling, and detect hazardous substances. The proposed actions pointed to achieving the Waste Framework Directive target of recycling 70 % of C&D waste and closing the loop of product lifecycles through enhanced recycling and reuse, thus providing benefits for both the environment and the economy.

Emphasis was placed on efficient waste collection, transportation, and processing systems to ensure the quality and traceability of recycled materials throughout the supply chain. Implementing quality assurance mechanisms is crucial for confidence in reusing recycled materials and encouraging their integration into new construction projects. The Protocol consisted of 5 components, all contributing to the overall aim to increase confidence in the C&D waste management process and trust in the quality of C&D recycled material:

- Waste identification, source separation and collection
- Waste logistics
- Waste processing
- Quality management
- Policy and framework conditions.

The first three points are part of the C&D waste management chain, while the last two are horizontal. Quality management and quality assurance become crucial when using recycled construction materials, and they must be assessed and documented during each component of the waste management chain (Table 8).

**Table 8: Quality management steps for each C&D waste management chain stage.**

Waste identification, source separation and collection	Waste transportation	Waste processing and treatment
Pre-demolition audit (account of asbestos detection) Selective demolition Identification and separation of hazardous waste	Safe transport Special provisions/declaration for hazardous waste Identification form Registered or approved transporter/carrier	Waste acceptance (at recycling/landfilling site) Input control (e.g., asbestos protocol) Factory production control (addressing essential characteristics of products) Acceptance criteria (such as for raw materials used for waste-derived products manufacturing) Frequency of the sampling Identification of the recycled aggregates used in a specific product (tests of the waste-derived products documented)

<sup>48</sup> European Commission (2016). EU Construction and Demolition Waste Management Protocol. <https://ec.europa.eu/docsroom/documents/20509/>.

In addition, the report **Guidelines for the Waste Audits Before Demolition and Renovation Works of Buildings**, published by the European Commission in 2018, provided a comprehensive methodology for conducting waste audits before demolition or renovation projects<sup>49</sup>. These guidelines aimed to enhance the management of Construction and Demolition Waste (CDW) throughout the EU, promoting recycling and reuse to achieve a 70% recycling target as outlined in the Waste Framework Directive 2008/98/EC.

The guidelines emphasise the importance of conducting a waste audit before demolishing or renovating buildings and infrastructure as a specific task within project planning. The process has to include any relevant legislation, particularly regarding hazardous waste. The outcomes of this task are to ascertain the type and quantity of elements and materials that will be deconstructed and/or demolished and to recommend further handling options. The data, including waste management recommendations, are collected at the material and element levels. Table 9 gives the main information required for building materials and elements during a waste audit process.

**Table 9: Waste audit information for the inventory of materials or building elements.**

Material level category	Info
Type of material	Non-hazardous waste (Inert; Non-inert waste); Hazardous waste
Material identification	
Waste code (EWC and EURAL)	
Location	
Quantity	
Possible outlets	Reuse; recycle; backfill; energy recovery; elimination
Recommended outlet	Reuse; recycle; backfill; energy recovery; elimination
Possible markets	
Precautions to take during the deconstruction phase	
Handling precautions	
Storage, transport, and treatment conditions	
Pictures, notes, etc.	

The EU Construction and Demolition Waste Management Protocol and the EU Construction and Demolition Waste Management (in the paragraphs above) were updated in 2024 in a merged report to foster trust in recycled materials and promote a circular economy within the construction sector. The audit protocol, named **'EU Construction & Demolition Waste Management Protocol, including guidelines for pre-demolition and pre-renovation**

<sup>49</sup> European Commission (2018). Guidelines for the Waste Audits Before Demolition and Renovation Works of Buildings. <https://ec.europa.eu/docsroom/documents/31521/>.

**audits of construction works,**' provided comprehensive information on various aspects of the CDW management chain and guidance for the involved stakeholders<sup>50</sup>. The revised version incorporated the audit guidelines before the demolition and renovation of buildings and aligns with recent policy and technological developments.

The Protocol establishes several rules and provides examples of EU best practices, technologies, and tools. By adhering to this Protocol, stakeholders can significantly reduce environmental impacts, conserve resources, and support the EU's sustainability objectives within the construction industry. The Protocol is expected to assist practitioners in Member States in implementing the measures introduced by the Waste Framework Directive (WFD). Moreover, it aims to help practitioners in the Member States achieve the goals outlined in the European strategy for eliminating all asbestos and safeguarding workers and citizens from health risks associated with asbestos exposure. Additionally, the Protocol supports the reduction of intentional and unintentional microplastic releases into the environment.

The Protocol is referenced in the Climate Delegated Act and the Environmental Delegated Act of the EU Taxonomy Regulation. Apart from the achievements of the forerunners, the report presents an overview of available treatment options for typical construction CDW based on the results of the European Commission's JRC<sup>51,52</sup>. While the primary aim was about confidence in the CDW management process and trust in the quality of CDW recycled materials, the recent EU reports highlight the environmental aspect and the need to perform life cycle assessment and costing for construction and demolition waste (CDW) management.

### 3.3.2. DIN SPEC 91484 (2023)

The German standard DIN SPEC 91484:2023-09 - **Procedure to record building materials as a base to evaluate the potential for a high-quality reutilization prior to demolition and renovation work (pre-demolition audit)**<sup>53</sup> aims to regularise the potential of individual building products for high-quality reutilisation. It establishes a procedure for recording building materials to assess their potential for high-quality reuse before demolition and renovation work. This process, known as a pre-demolition audit, aims to provide all market participants with sufficient and consistent data throughout the value chain. The standard delineates requirements for information gathering, documentation, processes, involved stakeholders, and tools. It also serves as a guideline for developing pre-demolition audits and encourages using a standardised data format to ensure compatibility with other systems. The standard categorises building products that are potential targets for reuse into two stages. The first stage, known as preliminary assessment, records basic information and prepares for the second stage. The second stage details the information partially documented in the first stage. Further information is added to facilitate subsequent high-quality re-utilisation.

Data to be included in the detailed audit and their obligation are given in Table 10.

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<sup>50</sup> Publications Office of the European Union (2024) EU construction & demolition waste management protocol including guidelines for pre-demolition and pre-renovation audits of construction works: updated edition 2024. <https://op.europa.eu/en/publication-detail/-/publication/d63d5a8f-64e8-11ef-a8ba-01aa75ed71a1>.

<sup>51</sup> Damgaard, A. et al. (2022) 'Background data collection and life cycle assessment for construction and demolition waste (CDW) management,' JRC Publications Repository. <https://doi.org/10.2760/772724>.

<sup>52</sup> Cristobal, G.J. et al. (2024) 'Techno-economic and environmental assessment of construction and demolition waste management in the European Union,' JRC Publications Repository. <https://doi.org/10.2760/721895>.

<sup>53</sup> DIN SPEC 91484 - 2023-09 - DIN Media (2023). <https://www.dinmedia.de/en/technical-rule/din-spec-91484/371235753>.

**Table 10: Data to be included per building product based on DIN SPEC 91484.**

Data field	Data	Obligation
Year of construction	Year or period if not available	should
Year of production	Year or period if not available	should
Existing documentation	e.g.: <ul style="list-style-type: none"> <li>- CE marking,</li> <li>- Ü markings, for building products that do not fall under EN standards</li> <li>- Plate types,</li> <li>- Data sheets,</li> <li>- Declaration of performance/conformity.</li> </ul>	should
Specific attributes of the building product	e.g., data sheets, product standards or samples, etc.	should
Expert reports (building material analysis, material analysis, pollutant report)	Based on destructive or non-destructive methods: e.g., through existing data (e.g., data sheets) or core drilling and tests such as load-bearing capacity tests or determination of deformation behaviour.	should
Connection type	according to the DGNB Building Resource Passport	should
Dismantlability	according to the DGNB Building Resource Passport	should
Pollutant Report	if suspected and not yet clarified in stage1, then clarification with pollutant assessor	should
Potential reutilization possibility	Depending on further investigations and according to the DGNB Building Resource Passport	can
Further information	continuous text	can

### 3.3.3. DGNB Quality Standard for Circularity Indices for Buildings (2024)

The **DGNB Quality Standard for Circularity Indices for Buildings**<sup>54</sup>, developed in 2024 by the German Sustainable Building Council (DGNB) in cooperation with the DGNB Committee for Life Cycle and Circular Building, aims to provide a comprehensive framework for assessing and enhancing the circularity of buildings. It presents a calculation methodology that evaluates several sub-indicators, including material compatibility, detachability, material separability, material recycling potential, and tolerances in applying the quality standard. This framework allows for evaluating a building's role in the circular economy, considering both current and future impacts. The standard focuses on assessing and evaluating building materials through the development of the DGNB Circularity Index. The process initially requires a set of sub-indicators to allow a weighting factor for each. The sub-indicators cover material origin, construction and demolition waste, pollutant load, material compatibility, detachability, material separability and material recycling (if applicable). The list of sub-indicators for existing and future contributions is given in Table 11.

<sup>54</sup> German Sustainable Building Council. (2024) DGNB quality standard for circularity indices for buildings: Fundamental understanding of quality and the DGNB Circularity Index, Version 1.0. <https://www.dgnb.de/en/sustainable-building/circular-building/circularity-indices>.

**Table 11: The sub-indicators for assessing the circularity index based on DGNB.**

Building level	Sub-indicator
Current contribution	Material Origin Construction and demolition waste Pollutant load
Use phase	Flexibility
Future contribution	Material compatibility Detachability Material separability Material recycling

A set of assessment factors by circularity class (as numerical factor 0-1) and their corresponding weighting factors (in %) are assigned for each sub-indicator in the table. The circularity index is then calculated as the sum of circularity indexes for current and future contributions according to the building mass.

The standard emphasises the significance of a Building Resource Passport (BRP) as an essential tool for data collection. A BRP provides transparent documentation and aggregated data at the building level, facilitating comprehensive circularity assessments. By adopting this quality standard, stakeholders can systematically evaluate and improve the circularity performance of buildings following sustainable construction practices.

#### 3.3.4. Circular Buildings - a measurement method for disassembly potential 2.0 (2022)

A consortium of Alba Concepts, the Dutch Green Building Council (DGBC), and other partners published in 2022 the report **Circular Buildings - a measurement method for disassembly potential 2.0** that outlines a framework for the disassembly potential of buildings<sup>55</sup>. The work, part of the DGBC circularity program, introduces a standardised methodology to assess the disassembly potential of buildings, which is crucial for promoting circularity in the construction industry and aims to include disassembly considerations into existing assessment tools like BREEAM-NL and GPR Gebouw.

The disassembly potential is a combination of technical, financial and process-related aspects, which influence the extent to which an object can be disassembled. In total, 25 factors have been identified, which have been further reduced to the 14 most important factors, 7 of which are of a technical nature (Table 12).

**Table 12: Technical, process and financial-related factors of disassembly potential.**

Technical factors	Process factors	Financial factors
Independency Number of connections Order of (dis)assembly Geometry of product edge Method of manufacture Connection type Connection accessibility	Safety Disassembly instructions Number of actions Experience	Disassembly time Disassembly costs Residual value

<sup>55</sup> Dutch Green Building Council (2025) Circular Buildings - een meetmethodiek voor losmaakbaarheid v2.0 - DGBC. <https://www.dgbc.nl/whitepapers/circular-buildings-een-meetmethodiek-voor-losmaakbaarheid-v2-0/>.

This report focuses on determining the potential for technical disassembly and elaborates further on the technical factors. Scores for the technical factor are set depending on the technical conditions for each component, as shown in Table 13.

**Table 13: Variations of technical-related factors for assessing disassembly potential.**

Connection type (CT)	Connection accessibility (CA)	Independency (ID)	Geometry of product edge (GPE)
Dry connection	Freely accessible without additional actions	No independency - modular zoning of products or elements from different layers	Open, no obstacle to the (interim) removal of products or elements
Connection with added elements	Accessible with additional actions that do not cause damage	Occasional independency of products or elements from different layers	Overlapping, partial obstruction to the (interim) removal of products or elements
Direct integral connection	Accessible with additional actions with fully repairable damage	Full integration of products or elements from different layers	Closed, complete obstruction to the (interim) removal of products or elements
Soft chemical connection	Accessible with additional actions with partially repairable damage		
Hard chemical connection	Not accessible - irreparable damage to the product or surrounding products		

Scoring values (0-1) on *Connection type (CT)* and *Connection accessibility (CA)* are used to estimate the potential for disassembly of the connection, while scoring on *Independency (ID)* and *Geometry of product edge (GPE)* is used to assess the potential for disassembly of the composition through well-defined mathematical formulas. Both disassembly potentials of connection and composition are needed to define the disassembly potential of the product or element. Hierarchically, the disassembly potential of products or elements is utilised to estimate the disassembly potential on a higher level, depending on their function in the building (Structure, Skin, Services and Space plan). The categorisation in this step utilises the Layers of Brand, which distinguishes various building layers based on their specific functions. In the end, based on the disassembly potential of the constituent layers, the disassembly potential of the whole building is defined.

### 3.4. Digital records review

Digitisation is transforming the construction industry, offering greater efficiency and reduced error rates. BIM is central to this shift, enabling digital management of building data. In addition to scientific and technical literature, the EU and other institutions have recently designed digital platforms and frameworks to enhance transparency, sustainability, and traceability across various sectors, particularly in the big wave of circular economy and sustainable practices.

Efficiency is achieved through functional classification systems tailored to digital workflows. These advancements target different levels, such as material, product, and building, and serve as key enablers of a circular economy, ensuring transparency and efficiency across the industries engaged in the significant movement towards circularity. Below is a short description of the digital repository information for each development, focusing on the construction sector, along with a comparison between them and their implementation challenges.

#### 3.4.1. Digital Material Passport (DMP)

A **Digital Material Passport (DMP)** is a digital record that contains detailed information about the materials used in a product or component, aiming for transparency, traceability, and

sustainability throughout the product lifecycle<sup>56</sup>. The DPM was proposed by various EU research projects and sustainability initiatives with strong industry and academic backing. It is not a formal EU regulation, but is closely linked to the Digital Product Passport (DPP) and building sustainability initiatives. Its implementation supports the transition towards a circular economy, where resources are managed responsibly, and environmental impacts are minimised<sup>57</sup>. The DPM represents a transformative approach to construction materials, electronics, and industrial components, promoting sustainability and efficiency by providing comprehensive information about building materials. The key parameters of a DMP are given in Table 14.

**Table 14: Key parameters in a Digital Material Passport (DMP).**

Parameter	Sub-parameter
<b>Material origin and composition</b>	Material type (e.g., steel, aluminium, concrete, plastics, rare earth metals) Material source (virgin, recycled, bio-based, secondary raw materials) Chemical and hazardous substance content (REACH, RoHS compliance) Manufacturing & Processing Information
<b>Environmental and carbon footprint</b>	Embodied carbon (CO <sub>2</sub> emissions) – LCA-based values (Modules A1–A3) Energy and water use in production Toxicity and environmental Impact (waste generation, pollution)
<b>Durability and performance</b>	Expected Service Life (years before degradation or replacement) Mechanical, fire, and chemical resistance Repairability and maintenance requirements
<b>Circularity and end-of-life data</b>	Recyclability and reuse potential (closed-loop vs. open-loop recycling) Disassembly and recovery guidelines Waste classification and disposal methods
<b>Compliance and certifications</b>	EU and international standards (EN 15804, REACH, RoHS, ISO 14040) Environmental Product Declarations (EPDs) Third-party certifications (Cradle to Cradle, FSC for wood, etc.)
<b>Digital integration and traceability</b>	QR code or RFID tag for real-time tracking Blockchain or cloud-based data storage for secure access Integration with DPP & DBL for building and product transparency

### 3.4.2. Digital Product Passport (DPP)

The **Digital Product Passport** is a comprehensive digital record of a product's lifecycle, aiming to enhance transparency and sustainability<sup>58</sup>. It encompasses more than just the

<sup>56</sup> Van Capelleveen, G. et al. (2023) 'The anatomy of a passport for the circular economy: a conceptual definition, vision and structured literature review,' Resources Conservation & Recycling Advances, 17, p. 200131. <https://doi.org/10.1016/j.rcradv.2023.200131>.

<sup>57</sup> Honic, M., Kovacic, I. and Rechberger, H. (2019) 'Concept for a BIM-based Material Passport for buildings,' IOP Conference Series Earth and Environmental Science, 225, p. 012073. <https://doi.org/10.1088/1755-1315/225/1/012073>.

<sup>58</sup> Data.Europa.EU (2024) 'EU's Digital Product Passport: Advancing transparency and sustainability'. <https://data.europa.eu/en/news-events/news/eus-digital-product-passport-advancing-transparency-and-sustainability>.

material passport and focuses on the entire product rather than solely on the materials. The framework was proposed by the EC under the Ecodesign for Sustainable Products Regulation (ESPR)<sup>59</sup>, and aligns with the EU Circular Economy Action Plan (CEAP) 2020<sup>60</sup> and the European Green Deal<sup>61</sup>. The DPP provides product lifecycle data (materials, emissions, recyclability) to support the circular economy and sustainable supply chains. The introduction of the Digital Product Passport covers a wide array of products, but construction products are not among the first and are expected to be completed no earlier than 2027<sup>62</sup>. It is initially intended for electronics, textiles, batteries, and other regulated products. Primary construction materials, such as cement and steel, are expected to be the first candidates for early DPP adoption since they are integral to construction and have significant environmental impacts.

The key parameters of a DPP are given in Table 15.

**Table 15: Key parameters in a Digital Product Passport (DPP).**

Parameter	Sub-parameter
<b>Product identification and composition</b>	Product name, type and model Unique Identifier (QR code, RFID, blockchain tracking) Material composition (e.g., virgin vs. recycled, hazardous substances) Country of origin, manufacturing process
<b>Environmental and carbon footprint</b>	Embodied carbon and energy use (LCA-based) Water and resource consumption during production Emissions and pollution impact (air, water, soil) Sustainability ratings and Circularity Index
<b>Durability, repairability and maintenance</b>	Expected Product Lifespan Repairability score (availability of spare parts, modular design) Maintenance and upgrade instructions Manufacturer support and warranty information
<b>Circularity and end-of-life data</b>	Recyclability and reuse potential Disassembly and material recovery instructions Waste classification and disposal guidelines Second-life and refurbishment options
<b>Compliance and certifications</b>	EU and International Standards (Ecodesign, EN 15804, CE marking) Environmental Product Declarations (EPDs) Third-party certifications (Cradle to Cradle, Fair Trade, FSC, Energy Star)

<sup>59</sup> Ecodesign for sustainable products Regulation (2024). [https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/ecodesign-sustainable-products-regulation\\_en](https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/ecodesign-sustainable-products-regulation_en).

<sup>60</sup> Circular economy action plan (2020). [https://environment.ec.europa.eu/strategy/circular-economy-action-plan\\_en](https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en).

<sup>61</sup> The European Green Deal (2021). [https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal\\_en](https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en).

<sup>62</sup> Digital Product Passport (DPP): a great opportunity for sustainability. (2025) <https://www.milgro.eu/en/blog/digital-product-passport>.

Parameter	Sub-parameter
<b>Digital integration and traceability</b>	QR Code, RFID, or Blockchain tracking for real-time access Cloud-based and Interoperable Data Storage Integration with DMP & DBL

### 3.4.3. Digital Building Logbook (DBL)

The **Digital Building Logbook** is a digital repository of information concerning a building, encompassing its design, construction, maintenance, and operational history<sup>63</sup>. The EC proposed the DBL under the EU Renovation Wave Strategy and Energy Performance of Buildings Directive (EPBD) to unify a building’s lifecycle data, including construction materials, energy performance, maintenance, and renovation history. The logbook is intended to enhance building management and sustainability for all buildings by supporting energy efficiency, circularity, and emissions reduction. The DBL aims to foster data management, increase transparency, and facilitate the transition towards more sustainable and well-managed building practices.

The key parameters of a DBL are given in Table 16.

**Table 16: Key parameters in a Digital Building Logbook (DBL).**

Parameter	Sub-parameter
<b>General building information</b>	Building name and address Unique Identifier (e.g., QR Code, RFID, Blockchain Tracking) Year of construction and renovation history Building type and usage (residential, commercial, industrial, etc.)
<b>Structural and material composition</b>	List of building materials and products (linked to DMP and DPP) Embodied carbon and LCA data (Modules A1–A3, A4–A5, C, D) Hazardous material inventory (e.g., asbestos, lead) Circularity and recyclability of materials
<b>Energy performance and consumption</b>	Energy Performance Certificate (EPC) rating Operational energy consumption (heating, cooling, lighting, ventilation) Renewable energy Integration (solar, wind, geothermal) Carbon footprint and GHG emissions (Module B)
<b>Maintenance, repair and renovation history</b>	Records of past maintenance and upgrades Expected Service Life of building systems Smart monitoring and IoT integration (real-time data from sensors) Scheduled inspections and performance assessments
<b>Indoor Environmental Quality (IEQ)</b>	Air quality, ventilation and thermal comfort Acoustic and lighting conditions

<sup>63</sup> Development of a harmonised EU model for a Digital Building Logbook | Digitalisation of Construction SMEs (2022). <https://digital-construction.ec.europa.eu/news/6/development-of-a-harmonised-eu-model-for-a-digital-building-logbook>.

Parameter	Sub-parameter
	Health and safety compliance
<b>Compliance, certifications and legal documentation</b>	EU and National Building Regulations (EPBD, Green Deal, etc.) Environmental Certifications (BREEAM, LEED, DGNB, WELL, etc.) Fire safety and structural integrity reports
<b>Digital integration and traceability</b>	Cloud-based and Blockchain-enabled storage QR Code or RFID for Quick Access Integration with DPP & DMP

#### 3.4.4. Digital records analysis

Digital Material Passports (DMPs), Digital Product Passports (DPPs), and Digital Building Logbooks (DBLs) play a crucial role in promoting the reuse of building materials by offering detailed information about materials and products throughout their lifecycle. However, various gaps and challenges impede their effectiveness in facilitating material reuse<sup>64</sup>.

Below is a summary of the main challenges in the construction industry that must be addressed to encourage the shift towards a circular economy.

- **Lack of standardisation:** The absence of standardised data formats and protocols across these digital tools results in inconsistencies, complicating information sharing and interpretation among stakeholders. This lack of uniformity can hinder the efficient tracking and reuse of materials.
- **Data collection and traceability:** Collecting accurate and comprehensive data throughout a building's lifecycle is complex. Challenges in tracing materials and components from production to end-of-life can lead to incomplete, subjective, or unreliable information, hindering efforts to evaluate and promote material reuse.
- **Integration issues:** Integrating DMPs, DPPs, and DBLs into existing Building Information Modelling (BIM) systems and other digital platforms poses a challenge. This lack of seamless integration may result in data silos, where information is confined within specific systems, thereby reducing accessibility and usability for stakeholders seeking to identify reusable materials.
- **Data privacy and ownership:** Sharing detailed information about building materials and products raises concerns about data privacy and ownership. Stakeholders may be hesitant to share proprietary information, which limits the availability of data necessary to assess the potential for material reuse.
- **Economic and market barriers:** Current market dynamics often do not favour material reuse due to economic factors such as cost competitiveness, a lack of demand for reused materials, and inadequate incentives. These economic barriers can restrict the practical application of information provided by DMPs, DPPs, and DBLs to promote material reuse.

Addressing these gaps requires collaborative initiatives focused on standardising data protocols, refining data collection and traceability techniques, improving system integration, establishing clear data-sharing guidelines, and creating economic incentives to promote the

<sup>64</sup> Honic, M., Magalhães, P.M. and Van Den Bosch, P. (2024) 'From data templates to material passports and digital product passports,' in Springer eBooks, pp. 79–94. [https://doi.org/10.1007/978-3-031-39675-5\\_5](https://doi.org/10.1007/978-3-031-39675-5_5).

reuse of building materials. Standardising data templates and implementing technological advancements such as geographic information systems, laser scanning, and computer vision can enhance the practical effectiveness of these passport instruments.

## 4. Circularity properties for inclusion in BIM

This section discusses the standard BIM structure for constructions, the need for additional parameters to support material reuse from demolished buildings, and the challenges and opportunities in applying BIM for demolition activities.

Key messages:

- Demolition-focused BIM requires additional parameters (e.g., material condition, ease of dismantling, environmental impact, etc.), which are grouped and presented in this chapter.
- The extensive data collection for evaluating all parameters is time-consuming and resource-intensive. A tiered approach by defining mandatory and optional parameters in collaboration with stakeholders can streamline the process while maintaining effectiveness.
- The absence of a standardised international framework for classifying and evaluating circularity-related parameters limits consistency and interoperability. A unified BIM structure is necessary to capture data from existing structures efficiently.
- Apart from a standardised framework, advanced tools like laser scanning and computer vision can help create circular-oriented BIM models quickly and reliably. Such a process requires research and experience for proper calibration and accuracy.

### 4.1. Standard BIM structure

The standard BIM structure organises and manages building components within 3D models by embedding essential data directly into objects<sup>65</sup>. The standardised structure of constructive elements in BIM makes it easier to share, integrate, and manage information between different teams, resulting in more efficient construction process management. It ensures that all stakeholders in a building project (architects, engineers, contractors, facility managers) view the project similarly, reducing the chance of errors and improving collaboration.

The standard BIM structures for constructive elements are essential for organising and managing data throughout a building project, from planning and design to construction and operations. They ensure consistency, collaboration, interoperability, and efficient data management, and clarity throughout the process, ultimately benefiting the efficiency and quality of the building.

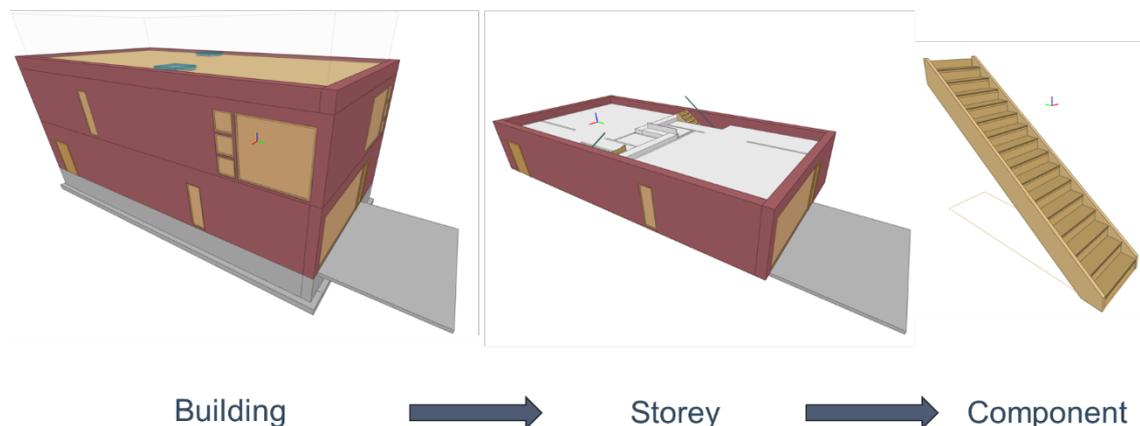
In BIM software like Revit, constructions are structured through:

- **Object-Based Hierarchy:** Elements (e.g., walls, floors, doors) are grouped into families with predefined parameters.
- **Parameter Fields:** Each object contains metadata such as material, dimensions, fire rating, thermal properties, and lifecycle data.
- **Geometric & Spatial Data:** 3D models define object placement, structural relationships, and system integrations (e.g., MEP systems).
- **Classification Codes:** Elements are assigned NL-SfB, OmniClass, or Uniclass codes for structured data exchange.
- **Phasing & Lifecycle Integration:** Objects are linked to specific construction phases (e.g., design, execution, maintenance).

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<sup>65</sup> What is building information modeling (BIM)? (2024). Autodesk. <https://www.autodesk.com/design-make/articles/bim-building-information-modeling>.

A typical hierarchy in the BIM structure and presentation of the BIM labelling is shown respectively in Figure 6 and Figure 7.



**Figure 6: Visualisation of a typical hierarchy in the BIM structure.**

Active	Type	Name	Description
✓	Project	1001	
✓	Site	Default	
✓	Building		
✓	Building Storey	T/FDN	
✓	Building Storey	Level 1	
✓	Walls		
✓	Slabs		
✓	Windows		
✓	Doors		
✓	Stairs		
✓	Stair	Stair:Residential - 200mm Max Riser ...	
✓	Stair Flight	Stair:Residential - 200mm Max Riser ...	
✓	Member	Stair:Residential - 200mm Max Riser ...	
✓	Member	Stair:Residential - 200mm Max Riser ...	
✓	Railing	Railing:900mm Handrail Only: 151162	
✓	Railinn	Railinn:1100mm Guard Rail: 151166	

Properties	Location	Classification	Relations	Name	Value	Unit
<b>Element Specific</b>						
				Guid	1oQpBvg6vCl9qOoQVIXCn	
				IfcEntity	IfcStairFlight	
				Name	Stair:Residential - 200mm Max Riser 250mm Tread: 151086:1	
				NumberOfRiser	16	
				NumberOfTreads	15	
				ObjectType	Stair:Residential - 200mm Max Riser 250mm Tread	
				RiserHeight	0.635663	m
				Tag	151086	
				TreadLength	0.82021	m
<b>Pset_StairFlightCommon</b>						
				NosingLength	0.01	m
				NumberOfRiser	16	
				NumberOfTreads	15	
				Reference	Reference	
				RiserHeight	0.19375	m
				TreadLength	0.25	m
				TreadLengthAtInnerSide	0.01	m
				TreadLengthAtOffset	0.25	m
				WalkingLineOffset	0.4572	m

**Figure 7: Visualisation of a component's BIM labelling and IFC structure.**

## 4.2. Additional properties for reintegrating products from existing buildings into the supply chain

BIM contains several important data points that enable the creation of detailed digital representations of buildings; however, the actual models lack end-of-life data in the structure that can be utilised to simulate and plan demolition activities. Including such information in the BIM labelling is necessary to quantify and categorise the demolition waste, aiding in demolition activities that optimise material reuse and recycling from the early conceptual stage.

The previous chapter highlighted significant efforts by industry partners, governmental bodies, and research institutions in this field. However, it also underscored the lack of standardised

BIM protocols for demolition-related properties, which impacts the consistency and efficiency of the process. Some information is related to the building level, while some is related to specific products. Additionally, the terminology is spread among different bodies of information.

Table 17 categorises and summarises the parameters extracted from these reviews, which focus on circularity in the construction sector. Integrating these parameters into the standard BIM structure would enhance comprehensive analysis and transparency in decision-making.

**Table 17: Expanded dataset for integration of circularity parameters in BIM**

Main category	Sub-category	Parameter	Comment	Level
<b>General Building Information</b>	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
	<b>Building Performance Indicators</b>	Energy Performance	Operational Energy Consumption	Assesses the ongoing energy use of the 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
<b>Product and Material Information</b>	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
<b>Lifecycle Impact Data</b>	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
<b>Circularity and Disassembly Data</b>	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
<b>Waste and Recycling Management</b>	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
<b>Compliance, Certifications, and Digital Integration</b>	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

### 4.3. Challenges and opportunities

Despite its advantages and broad use in new constructions, the application of BIM in demolition purposes faces challenges. Most existing buildings, especially the ones subject to demolition, were built in an era where digitalisation was not widespread, and there was a lack

of digital records. This technological gap hinders data collection and accuracy in correctly reflecting existing structures into BIM models. Creating BIM models for existing buildings without digital records requires significant time and resources, which may be a barrier for some projects. **The application of technological developments, such as laser scanning and other computer vision tools, can facilitate the process of creating BIM models for the actual built environment.** Such tools need to be calibrated to get accurate data efficiently and quickly.

Apart from the computational challenges, the BIM configuration for existing buildings subject to demolition must include additional parameters not incorporated in the classical BIM structure for new constructions. As reflected in the diverse reviews, there is a lack of standardised protocols for BIM parameters in demolition activities, which hampers consistency and information exchange across projects. **A unified list of parameters at an international level and a demolition-oriented BIM data structure would expand the reliability and interoperability in the construction sector and maximise the potential of demolition activities.** The parameters should cover all the topics which arise during the demolition and are not included in the actual BIM configuration, such as actual properties and state of the element, ease of retrieval and dismantling, environmental and health impact, economic viability, and potential for reuse or recycling.

**A comprehensive list of parameters linked to demolition is important to build a BIM model with effective and reliable data for existing structures.** A set of parameters is given in Table 17, but the list is not to be considered exhaustive, and it can constantly be improved and extended through experience and research.

Due to the large scale of added parameters, the data collection process requires additional manual work and human interaction, apart from computer vision tools. This complexity increases the time and cost to complete information for all added parameters, becoming a barrier for professionals. Therefore, **the list can be simplified into parameters which are considered mandatory during the demolition process and additional ones that are an added value if included.** Such grouping can be done through strong collaboration with involved stakeholders to define the categories that need to be included and are easy to assess without complicating the process.

The assessment of parameters, along with time and cost, presents challenges in data collection due to inadequate documentation for older structures. Additionally, the range of evaluation scores for specific parameters can differ across various assessment methods, highlighting the need for a generalised framework. Multiple assessment methods at the national or broader levels create challenges for consistently comparing projects. The process is also influenced by subjectivity, which primarily relates to the qualifications of evaluators and accessibility to such data. **Therefore, standardising the classification and evaluation scoring process, along with implementing technological advancements for circular building components, can enhance the effectiveness of creating BIM models for existing buildings.**

## 5. Supply and demand evaluation framework

This section introduces several possibilities for establishing a supply potential evaluation framework in the SUM4Re project and explores how to combine the supply potential with the demand.

Key messages:

- The supply potential evaluation framework can be based on one of the existing technical evaluation methods presented in Section 5.2
- It can be used to define scenarios for the Life Cycle Assessment (LCA) or Material Flows Analysis (MFA) modelling.
- It can be combined with evaluating economic prospects introduced in Section 5.3 within the same models or using simpler and direct scoring.
- It is possible to automate most of the assessment with the help of Building Information Modelling (BIM).

### 5.1. Introduction

The circularity-related parameters must be assessed and quantified to create detailed digital representations of buildings. The assessment process involves broad expertise in technical, economic, environmental, and management fields, as well as the combination of computational tools and human resources to quantify the properties. The assessment of components and materials from demolished or deconstructed buildings has received much attention worldwide in recent decades, with many commercial companies already exploiting the ability of construction elements and systems to be offered for further use. Their focus is either on a variety of structural and architectural elements, whole building systems or specific products and materials.

Unlike in automotive or aerospace industries, where many components are modular and designed for assembly and disassembly (DfA/DfD), facilitating remanufacturing, the existing building products are usually designed for cost and performance and are mainly disposed of after use. Recovering components and materials not designed for separation or reuse requires specific measures such as extensive testing, reinforcing and re-fabrication. The assessment of the degree of component reusability was developed in the PROGRESS project to estimate the extent of needed interventions and their marketing potential, focused explicitly on structural steelwork from single-storey halls<sup>66</sup>. A generalised version of this framework is presented in this report, extended to different building types, materials, and components.

The framework consists of technical and economic evaluations. The technical part assesses the feasibility of separating materials or components from the existing building and offering them for further use. Such an assessment is essential to have the whole picture of the supply potential of the components or materials still embedded in the building. Apart from the PROGRESS methodology, several other existing methods for the assessment of deconstruction can be used for the technical part of the evaluation. The economic part explores the potential demand for such material or component in a given time and location. At the same time, environmental assessment methods have been well-established in recent decades and can be applied to existing buildings or products, applying the same frameworks as new ones.

The goal is to propose a qualitative evaluation framework that fulfils the following criteria:

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<sup>66</sup> Kuhnhenne, M., et al. (2018) Report on the reuse potential of single-storey steel buildings, Deliverable D1.2 of PROGRESS project. <https://www.steelconstruct.com/wp-content/uploads/PROGRESS-D1.2-Reuse-potential.pdf>.

- The method is suitable for the assessment of existing and new buildings
- The method provides scoring for individual materials, components, component groups, sub-structures and the whole building.
- The assessment process is simple and requires minimal effort and tools.
- Different end-of-life scenarios can be compared.
- The economic feasibility of the future reuse (supply potential) can be assessed.

## 5.2. Technical assessment

The technical assessment methodologies described in this section aim to evaluate the specific project's supply potential. The evaluation methods are focused mainly on the deconstruction, separability and readiness of the products to be recycled or reused. Several existing methods that may apply to the SUM4Re project are listed in this paragraph. Some of these methods are already integrated into the platforms used in the project.

### 5.2.1. DGNB Circularity Index

The German market for circularity in construction projects has developed several scores over the last few years. One of the first metrics was the Urban Mining Index (UMI)<sup>67</sup>, which was followed by the introduction of the Dutch Madaster Circularity Indicator (MCI) into the German market. Based on these two existing scores, Concular and several partners developed the Circularity Performance Index (CPX)<sup>68</sup>.

The above-mentioned circularity measuring tools were considered when the DGNB was developing the Zirkularitätsindex (DGNB ZI) (engl. DGNB Circularity Index, as described in Section 3.3.3)<sup>69</sup>. The DGNB ZI is the most recent introduction to the different circularity scores, with an official score from the German government announced. Having several assessment scores at the national or broader level raises the issue of comparability between several projects. The mentioned scores all look at similar indicators but are not strictly comparable with each other.

An educated forecast can see the DGNB ZI and the upcoming state circularity index becoming the indicators with the widest adaptation. This outcome also leads to better comparability when using either one of those.

### 5.2.2. DGNB assessment of deconstruction and disassembly

A similar assessment method used in the DGNB certification scheme is called "Rückbau- und Recyclingfreundlichkeit/Deconstruction and Recycling Friendliness" and is integrated into the technical quality topic areas as criteria<sup>70</sup>. It evaluates all new construction typologies, including educational buildings, offices, healthcare buildings, hotels, industrial buildings, etc. The weighting for the criteria is between 3 and 3.5% for the overall score of the building, depending on the function of the building. It is possible to achieve up to 100 checklist points in the evaluation. The method considers three criteria (indicators), and the building components are divided into four groups. The scoring of each criterion is individual. The effort for disassembly has five effort levels, contributing up to 38 points; the scope of disassembly has three levels, contributing up to 38 points; and the recycling and disposal plan can contribute an additional

<sup>67</sup> Urban Mining Index (2021) Home | Urban Mining Index. <https://urban-mining-index.de/en/>.

<sup>68</sup> Concular (2024) Circularity Performance Index - concular - zirkuläres bauen. <https://concular.de/circularity-performance-index/>.

<sup>69</sup> German Sustainable Building Council. (2024) DGNB quality standard for circularity indices for buildings: Fundamental understanding of quality and the DGNB Circularity Index, Version 1.0. <https://www.dgnb.de/en/sustainable-building/circular-building/circularity-indices>.

<sup>70</sup> German Sustainable Building Council. (2023) Important facts about DGNB Certification. [http://www.dgnb-system.de/en/system/certification\\_system/](http://www.dgnb-system.de/en/system/certification_system/).

24 points if it exists. The calculation for the two sub-criteria, “ease of disassembly” and “scope of disassembly”, can be done manually or with the tool.

The following observations were made concerning the possible adaptation of the DGNB assessment method:

- Pre-defined component groups can be used in the assessment of the buildings.
- Similarly to the BRE methodology, the weighting factors based on the environmental footprint are unnecessary if the component groups are assessed separately. The volumes or weights might be sufficient and easily obtainable.

### 5.2.3. Disassembly Potential Indexes and Madaster Circularity Indicator

The Measurement Method for Disassembly Potential, explained in Section 3.3.4, provided a methodology to assess the detachability and reusability of building compositions, products, layers and structures in general. By evaluating criteria such as connection types, accessibility, modularity, and material separation, the weight of potential for disassembly offers insights into how easily materials can be dismantled and reused without damage.

Another metric developed in the Netherlands to assess and quantify the circularity of buildings is the Madaster Circularity Indicator (MCI), developed by Madaster<sup>71</sup>. The method assigns a score ranging from 0% to 100%, where 0% represents a fully linear building—constructed entirely from new materials and destined for landfill at the end of its life—and 100% denotes a fully circular building—comprising entirely recycled or reused materials, all of which can be reused or recycled in the future. The evaluation is done for the construction phase by assessing the proportion of secondary (recycled or reused) materials utilised in the building's construction, and the end-of-life phase by examining how materials and products are managed during renovation or demolition, focusing on the potential for reuse and recycling versus disposal as waste.

The evaluation processes play a key role in circular construction projects, and the scores can be integrated into digital building and product passports, as well as sustainability assessments like BREEAM-NL and the Environmental Performance of Buildings (MPG). By applying such measurement methods, material waste is reduced, environmental impact is minimised, and the lifecycle of building materials is extended.

### 5.2.4. FutureBuilt Circularity Index

FutureBuilt is a Norwegian initiative that promotes climate-friendly urban development and high-quality architecture<sup>72</sup>. Since its inception in 2010, the programme has collaborated with several large municipalities in the country to demonstrate that climate-neutral urban areas are attainable through innovative design and construction practices. The application of the FutureBuilt framework has become popular among new, ambitious projects and is playing a pivotal role in transforming the Norwegian construction industry by promoting sustainable design, construction, and operational practices.

A key component of FutureBuilt's strategy is the development of the Circularity Index, a tool designed to assess and promote circular practices in building projects<sup>73</sup>. This index evaluates a building's circularity performance on a scale from 0% to 100%, considering factors such as the use of recycled materials, design for disassembly, and adaptability. The methodology distinguishes between materials utilised during construction and those available at the

<sup>71</sup> Madaster Circularity Indicator - Madaster Global (2024). <https://madaster.com/inspiration/madaster-circularity-indicator/>.

<sup>72</sup> What is FutureBuilt (2025). <https://www.futurebuilt.no/English>.

<sup>73</sup> Wiik, M.K. et al. (2025) 'Circularity Index and Benchmarks for Buildings: A novel and transferable approach to evaluating the circularity performance tested in a Norwegian context,' in Lecture notes in civil engineering, pp. 955–965. [https://doi.org/10.1007/978-3-031-69626-8\\_80](https://doi.org/10.1007/978-3-031-69626-8_80).

building's end-of-life, emphasising the importance of reusing materials at the highest functional quality. FutureBuilt's Circularity Index provides a measurable framework for assessing circularity and encourages stakeholders to adopt sustainable practices throughout the building lifecycle. The Circularity Index is determined using the FutureBuilt Circularity Index calculation tool. The objective is to achieve a minimum of 50% circularity, with a progressively increasing level of circularity in the future. This index is intended for new or rehabilitation projects and encompasses current and future applications of primary building components and fill materials adjacent to the building.

#### 5.2.5. BRE design for deconstruction (DfD) methodology

The methodology developed by the Building Research Establishment (BRE) in the UK, with the support of BRE Trust, provides criteria for assessing the deconstruction potential of new residential building designs<sup>74</sup>. Besides residential construction, the method was used for office buildings and other structures. The method considers four criteria (performance categories) and nine groups of components. The scoring for each element/component and criteria is (not considered), (partially considered) or (fully considered in the design) and the elements are weighted according to their embodied CO<sub>2</sub> to achieve the overall score.

The following observations were made concerning the possible adaptation of the BRE assessment method:

- The choice of element groups limits the methodology to residential and similar buildings with clearly distinguishable roofs and external walls.
- Weighting according to the embodied CO<sub>2</sub> is appropriate for buildings with many building materials but requires additional effort for the evaluator to obtain these values. In the case of a single material assessment, it would be sufficient to use the masses of the components as the weighting factors.

#### 5.2.6. PROGRESS technical reusability index

The reusability index proposed in the PROGRESS project<sup>66</sup> was developed for single-storey steel buildings as a part of the broader assessment of the supply-demand potential of the reuse of the components. Its technical part is similar to the BRE and DGNB methods and yields a single score based on the specific criteria and weighting factors for the steelwork and the envelope, calculated according to the equation (2),

$$r = \sum \rho_i w_i \quad (2)$$

where  $\rho_i$  is the result of the assessment of the individual performance category  $i$  (performance category from 0% (impossible) to 100% (very easy)), and  $w_i$  is the weighting factor reflecting the average effort of this performance category. The sum of the weighting factors has to be 1 to obtain the reusability index  $r$  between 0 and 1.

The combined evaluation  $R$  of the product system or the whole building is the weighted average of the components' particular indexes, where  $m_i$  denotes the mass of the individual component  $i$  (see equation (3)).

$$R = \frac{\sum m_i r_i}{\sum m_i} \quad (3)$$

Scoring checklists have to be developed to assess particular building systems of typologies. The method is more flexible than BRE and DGNB because it can be used on the whole

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<sup>74</sup> Adams, K. (2015). Design for deconstruction – helping construction unlock the benefits of the circular economy. [https://www.designingbuildings.co.uk/wiki/Design\\_for\\_deconstruction,\\_BRE\\_modular\\_show\\_house](https://www.designingbuildings.co.uk/wiki/Design_for_deconstruction,_BRE_modular_show_house).

building, a particular system of components and subsystems. It is also not restricted to the existing buildings but can evaluate the reusability of the new designs.

The following observations were made concerning the possible adaptation of the PROGRESS technical reusability:

- The scoring system is simpler and, therefore, more flexible than BRE and DGNB
- The development of specific checklists and calibration of weighting factors is needed.

### 5.3. Economic assessment

Similarly, as in the case of technical assessment, the market demand for the recovered materials and components can be described as a number ranging from 0 to 1.

#### 5.3.1. Product Environmental Footprint (PEF) economic allocation factor

The Product Environmental Footprint (PEF) formula produces a combined environmental footprint of the product and part of the environmental impacts resulting from the recovery, recycling and reuse of the product (or its parts), depending on the economic allocation factor  $A$ <sup>75</sup>. This factor is the reverse of the circulation potential (i.e.  $A = 0$  means that all material can be circulated, and  $A = 1$  means that there is no demand for such material). The value is typically recommended by the industry and is based on the demand for recycled or reused material. For instance, Eurometaux recommends  $A = 0.2$  for metal products, and the World Steel Association uses a 1:100 allocation in their methodology<sup>76</sup> equivalent to  $A = 0$ .

The following observations were made concerning the possible adaptation of PEF economic allocation:

- The allocation factor is meant to calculate the environmental footprint and should not be combined with other scoring.
- It is defined by the industries for different material and product groups and is not specific to a particular project, location or time frame. Therefore, it does not need to be repeatedly calculated.

#### 5.3.2. PROGRESS economic prospect

The index proposed by the PROGRESS project<sup>66</sup> evaluates the likelihood that the specific material or product with specific dimensions and properties will be required for new buildings or renovation within a certain period. It is based on probabilistic modelling based on the data from the national buildings register about the materials, products and systems used in buildings. It was developed to be combined with the PROGRESS technical reusability described in the previous sections, but it can generally be used with different technical assessment methods.

The index for economic prospect  $e$  is calculated as the number of new buildings  $n$  in the defined geographical area per given period of time, multiplied by the probability  $P$  that each criterion ( $c_1, c_2, c_3 \dots$ ) will be satisfied (see equation (4)). Each target criterion has to be specified as a range because the absolute probability of an exact match is zero.

$$e = P(c_1 \cap c_2 \cap c_3 \dots) \times n \quad \text{where } e \leq 1 \quad (4)$$

<sup>75</sup> Environmental footprint methods (2024). [https://green-business.ec.europa.eu/environmental-footprint-methods\\_en](https://green-business.ec.europa.eu/environmental-footprint-methods_en).

<sup>76</sup> World Steel Association. (2017) Life cycle assessment methodology report. <https://worldsteel.org/wp-content/uploads/Life-cycle-inventory-methodology-report.pdf>.

The combined prospect  $E$  of the product system or the whole building is the weighted average of the components' particular indexes, where  $m_i$  denotes the mass of the individual component  $i$  (see equation (5)).

$$E = \frac{\sum m_i e_i}{\sum m_i} \quad (5)$$

The following observations were made concerning the possible adaptation of the PROGRESS economic prospect:

- The PROGRESS index is tailored to a specific recovery, recycling and reuse scenario and can give more reliable information than the general PEF index.
- It needs to be calculated from the statistical data that may not be available.

## 5.4. Integration of the technical and economic assessment

### 5.4.1. Life cycle assessment

Life cycle assessment (LCA) can accommodate the outcomes of the technical and economic evaluation in the following way:

- Technical evaluation can define a specific end-of-life scenario in Module C of the building according to EN 15978 or Module C of the product according to EN 15804 or in the PEF formula. However, this is not yet a common practice, and end-of-life scenarios are typically defined in a simple way without a particular methodology.
- Economic evaluation can be used to aggregate part (or all) loads and benefits beyond the system boundary to the environmental footprint of the current building or product. These loads and benefits are called Module D1 in EN 15978 and EN 15804, but aggregating these impacts is not recommended there. On the other hand, PEF methodology and some industry-specific approaches use the aggregation of the environmental footprint and these potential effects, as described in the previous sections.

### 5.4.2. Material flow analysis

Different existing assessment methods, such as Ellen MacArthur's Material Circularity Indicator (MCI)<sup>77</sup> and its derivations (e.g. Product Circularity Indicator PCI, System Circularity Indicator SCI or Building Circularity Indicator BCI), are based on the analysis of material flows without consideration of their environmental impacts. These methods also use end-of-life allocation; therefore, the end-of-life scenarios can be defined from the technical assessment, and the outcomes of the economic assessment can be integrated similarly to the LCA approach. For example, the MCI method uses a fixed value of 50:50 end-of-life allocation as the default for all materials and products.

### 5.4.3. PROGRESS reusability index

The PROGRESS project proposed a simple scoring that can be used without modelling material flows or life cycle systems (see equation (6)). It takes the technical assessment  $R$  (expressed as a number from 0 to 1 from the equation (3)) and multiplies it with the economic prospect  $E$  (expressed as a number from 0 to 1 from the equation (5)). The result will be again a number from 0 to 1. Such scoring has no physical meaning but can help compare different projects or processes.

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<sup>77</sup> The Ellen MacArthur Foundation, Towards the Circular Economy. Economic and business rationale for an accelerated transition. (2013) <https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf>.

$$reusability = R \times E \tag{6}$$

The PROGRESS project also recommends the integration of this scoring into the Building Information Modelling (BIM). BIM can provide information about the individual components, such as their size, volume, material, and sometimes connection methods. The specific data about component layout (such as orientation, height above the ground, etc.) can also be extracted from the model. If the BIM model is unavailable, an inventory of components can be used directly. As can be seen from Figure 8, most of the evaluation process can be automated.

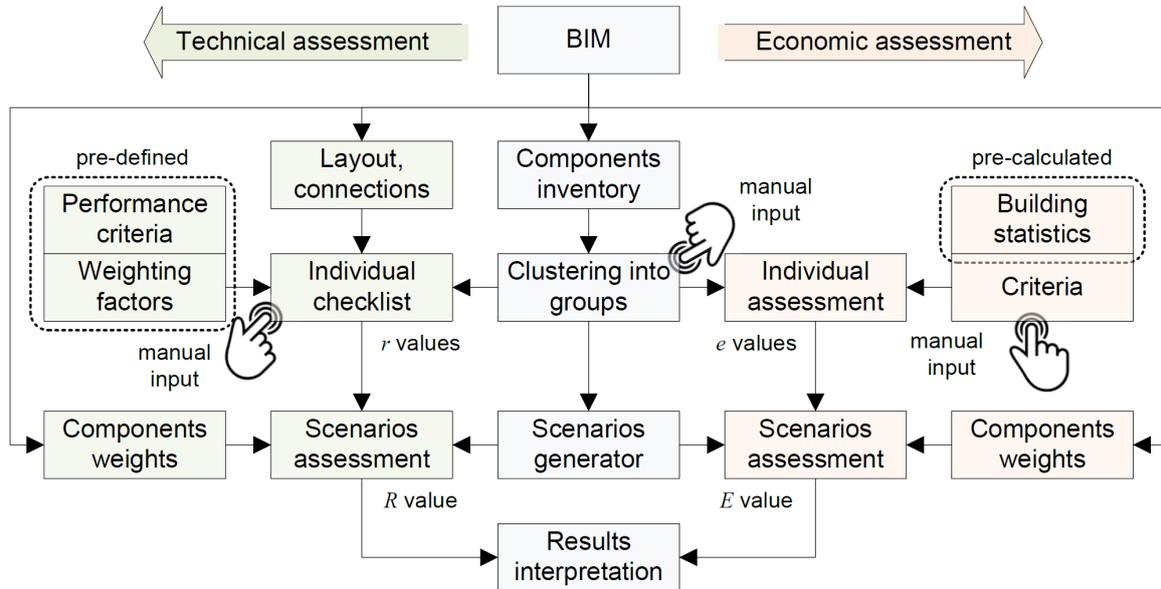


Figure 8. Implementation of BIM and reusability assessment<sup>66</sup>

## 6. Conclusions

Integrating circular economy principles, computational tools and vision equipment in the construction sector offers a transformative opportunity to enhance material reuse, improve resource efficiency, and promote sustainability. Various classification systems and digital platforms have been developed to provide structured, interoperable frameworks that increase efficiency and facilitate information exchange. However, challenges remain in aligning these systems with circular economy principles, particularly for existing buildings, where outdated records and the lack of circularity properties in digital models hinder their integration with modern models.

A comprehensive scoping review revealed a growing body of research on circularity in the construction industry in recent years. Widespread digital tools, such as BIM, hold immense potential for supporting circular construction by enhancing data traceability, deconstruction planning, and lifecycle assessment. However, a review of academic articles linking BIM to circularity indicated that the diversity of required information and integration issues limit its effectiveness. Addressing these challenges through standardisation, comprehensive data, and improved interoperability is essential for maximising the impact.

Further analysis of the technical literature highlights ongoing efforts at both national and international levels to develop demolition guidelines, protocols, and circularity indexes for the existing built environment. Despite the availability of various sustainability assessment tools, inconsistencies in parameters and evaluation methods present significant challenges to extensive adoption. Additionally, digital products are created to provide comprehensive data from a lifecycle perspective. However, such tools are initially intended for regulated products, and various gaps and challenges obstruct their effectiveness in construction material reuse. Tackling these barriers is essential for advancing digital solutions in circular construction.

BIM integration for demolition activities requires additional parameters to assess circularity for existing buildings or products that can be redirected into the supply chain, such as condition, dismantling feasibility, reusability potential, and environmental impact. This research contributes to this effort by defining a list of circularity-related properties, based on several reviews, that can be integrated into BIM to facilitate demolition processes. The extensive list of properties is grouped into categories and sub-categories, and provided at both building and product levels. Advanced developments that combine urban mining and technologies for automated on-site data acquisition and building materials identification could streamline the quantification process, provided that proper calibration and accuracy are achieved.

The defined list of properties necessitates evaluations and quantifications to facilitate decision-making and enhance transparency. The presented potential evaluation frameworks offer promising opportunities for assessing circularity properties. BIM can automate the evaluation and scoring processes by utilising consolidated technical assessment methods and integrating economic evaluations, lifecycle assessments, and material flow analysis. Multi-disciplinary approaches and collaborative efforts among stakeholders, researchers, and policymakers are crucial in developing a robust, comprehensive framework that effectively promotes circularity in construction.

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Creating materials banks  
from digital urban mining

## APPENDICES

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## APPENDIX A Tables of various classification systems

### A.1. Building type

#### A.1.1. SfB Classification

Unlike Uniclass and OmniClass, **SfB Classification** does not have a strict “building type” classification but provides a framework for categorising buildings based on function and structure<sup>78</sup>. SfB typically categorises buildings based on function and purpose rather than detailed classifications<sup>79</sup>.

*Table 1-A. Types of building categories following SfB classification*

Code	Main Category	Code	Subcategory
-	Residential Building	-	Single-family houses
		-	Apartment buildings
		-	Student housing
		-	Senior living homes
-	Commercial & Office Buildings	-	Office buildings
		-	Retail shops & shopping malls
		-	Hotels & Restaurants
-	Industrial & Warehouse Buildings	-	Factories & Production facilities
		-	Warehouses & Storage buildings
-	Educational Buildings	-	Schools (Primary & Secondary)
		-	Universities & Research facilities
		-	Libraries
-	Healthcare Buildings	-	Hospitals & Clinics
		-	Laboratories
		-	Nursing homes
-	Cultural & Public Buildings	-	Museums & Theaters
		-	Religious buildings (Churches, Mosques, Temples)
		-	Community centers
-		-	Sports halls & Gyms

<sup>78</sup> Ketenstandaard Bouw en Techniek (2024) NL-SfB is zoveel meer dan Tabel 1 - Ketenstandaard Bouw en Techniek. <https://ketenstandaard.nl/nieuws/nl-sfb-is-zoveel-meer-dan-tabel-1/>.

<sup>79</sup> Classifications (2025). <https://docs.madaster.com/nl/en/knowledge-base/classifications.html>.

Code	Main Category	Code	Subcategory
		-	Swimming pools & Stadiums
-	Transport & Infrastructure Buildings	-	Airports & Terminals
		-	Train & Metro stations
		-	Parking garages
-	Government & Civic Buildings	-	City halls & Government offices
		-	Courthouses & Embassies
		-	Police & Fire stations
-	Agricultural Buildings	-	Barns & Silos
		-	Greenhouses
		-	Livestock farms

### A.1.2. Uniclass

In **Uniclass**, building types are classified under the Complexes and Entities tables, specifically Table V1.33, Entities<sup>80</sup>. It was introduced in 1997 by the Construction Project Information Committee and then updated by the National Building Specification. The classification covers various building and infrastructure types used in the European construction and BIM sector. The building type is classified under the table SL – Space/location and aligned with ISO 12006-2. This classification is primarily in the United Kingdom but is also relevant in international BIM applications.

*Table 2-A. Types of building categories following Uniclass*

Code	Main Category	Code	Subcategory
20	Administrative, commercial and protective service complexes	10	Legislative complexes
		15	Administrative complexes
		20	Secular representative complexes
		45	Motor vehicle maintenance and fuelling complexes
		50	Commercial complexes
		55	Postal complexes
		60	Military complexes

<sup>80</sup> Uniclass 2015 Classification tables in CSV format (2025). <https://buildiq.com/uniclass-2015/>.

Code	Main Category	Code	Subcategory
		65	Law enforcement complexes
		70	Judicial complexes
		75	Detention complexes
		80	Weapons training complexes
		90	Incident support complexes
25	Cultural, educational, scientific and information complexes	5	Commemorative complexes
		10	Educational complexes
		30	Scientific complexes
		50	Exhibition complexes
		70	Information complexes
		90	Worship complexes
30	Industrial complexes	10	Mineral extraction complexes
		20	Nuclear and chemical management complexes
		30	Mineral processing complexes
		40	Animal and plant products processing complexes
		50	Manufacturing complexes
		60	Cleaning and maintenance complexes
		80	Mechanical power generation complexes
		85	Marine and water maintenance complexes
		90	Warehousing and distribution complexes
32	Water and land management complexes	10	Agricultural and horticultural complexes
		20	Designated land areas
		50	Marine ways and waterway complexes
		55	Marine and water protection complexes
		65	Natural areas
		85	Water control and retaining complexes
35		10	Medical complexes

Code	Main Category	Code	Subcategory
	Medical, health, welfare and sanitary complexes	50	Welfare complexes
		70	Funerary complexes
		85	Animal complexes
		90	Animal medical, health, welfare, funerary and sanitary complexes
40	Recreational complexes	5	Amusement complexes
		35	Historic complexes
		60	Performing arts complexes
		75	Social recreation complexes
42	Sport and activity complexes	40	Indoor activity complexes
		50	Outdoor activity complexes
		85	Swimming complexes
45	Residential complexes	10	Living complexes
50	Waste disposal complexes	20	Non-aqueous waste collection and distribution complexes
		30	Drainage collection complexes
		35	Wastewater collection complexes
		40	Dry waste collection and distribution complexes
		60	Non-aqueous waste treatment and disposal complexes
		70	Drainage storage, treatment and disposal complexes
		75	Wastewater storage, treatment and disposal complexes
		80	Dry waste storage, treatment and disposal complexes
55	Piped supply complexes	5	Gas extraction, storage and treatment complexes
		10	Liquid fuel extraction, storage and treatment complexes
		15	Water extraction, storage and treatment complexes
		20	Gas supply complexes

Code	Main Category	Code	Subcategory
		50	Liquid fuel supply complexes
		70	Water supply complexes
60	Heating, cooling and refrigeration complexes	10	Heating complexes
		40	Cooling complexes
65	Ventilation and air conditioning complexes	-	-
70	Electrical power generation and distribution complexes	10	Electrical power generation complexes
		30	Electricity distribution complexes
75	Communications, security, safety and protection complexes	10	Communications complexes
80	Transport complexes	5	Aerospace complexes
		20	Cable transport complexes
		35	Road complexes
		50	Railway complexes
		70	Marine and waterways transport complexes
		90	Transport interchange complexes
90	Circulation and storage complexes	50	Storage complexes
		90	Plant and control complexes

### A.1.3. OmniClass

In **OmniClass**, building types are classified under the Construction Entities by Function tables. The classification is developed by the Construction Specification Institute, BuildingSMART and the National Institute of Building Sciences. The building type is classified under Table 11<sup>81</sup>. This classification is primarily in the United States but is also relevant in international BIM applications.

OmniClass is based on and combines elements of existing classification systems, such as:

- MasterFormat (for construction specifications)
- UniFormat (for functional building components)
- ISO 12006-2, an international standard for construction classification.

<sup>81</sup> About OmniClass - Construction Specifications Institute (2025). <https://www.csiresources.org/standards/omniclass/standards-omniclass-about>.

**Table 3-A. Types of building categories following OmniClass 2.1**

<b>Code</b>	<b>Main Category</b>	<b>Code</b>	<b>Subcategory</b>
11	Assembly Facility	11	Convention and Exhibition Facility
		14	Meeting Facility
		21	Entertainment Assembly Facility
12	Education Facility	11	Daycare or Preschool Facility
		21	K through 12 Learning Facility
		24	Higher Education Facility
		29	Library
13	Public Service Facility	11	Government Facility
		21	Military Facility
		27	Public Welfare Facility
		29	Juvenile Facility
14	Cultural Facility	15	Monument and Memorial
		21	Museum
		24	Religious Institution
15	Recreation Facility	11	Outdoor Recreation Facility
		21	Indoor Recreation Facility
16	Housing Facility	11	Single Family Residence
		15	Movable Housing Facility
		21	Multiple Family Residences
		27	Dormitory
		31	Special Care Residence
		42	Senior Housing
17	Hospital and healthcare building	05	Office Showroom
		07	Department Store
		09	Big Box Retail
		11	Specialty Store
		13	Garden Center
		15	Grocery Store

Code	Main Category	Code	Subcategory
		17	Convenience Store
		19	Vehicle-Related Retail/Commercial
		21	Exchange or Market
		25	Mixed-Use Retail/Commercial Building
18	Health Care Facility	12	Hospital
		15	Outpatient Care Facility
		17	Medical Office Building (MOB)
		22	Ambulatory Care Facility
		25	Residential Health Care Facility
		28	Mobile, Transportable, Relocatable Health Care Unit
		32	Mental, Behavioural Care Facility
		35	Maternity Facility
		38	Animal Healthcare Facility
		42	Dental Facility
		45	Medical Center
		48	Medical Warehouse
		52	Ambulance Shelter
55	Death Facility		
23	Hospitality Facility	12	Dining Establishment
		15	Tavern, Bar, or Micro-Brewery
		18	Nightclub
25	Lodging Facility	12	Hotel
		55	Animal Lodging Facility
27	Office Facility	12	Administrative Building
		15	Military Headquarters Office
		18	Headquarters Office
		22	Regional Administrative Office
		25	Multi-tenant Office Building
		28	Business Park

Code	Main Category	Code	Subcategory
		32	Flex Space Office Building
		35	Creative/Loft Office Building
		38	Office Building
		42	Office/Research and Development Building
		45	Office/Warehouse Building
		48	Underground Administrative Structure
		52	Administrative Structure, Other Than Building
		55	Operational Support Building
29	Research Facility	12	Scientific Research and Development Facility
		28	Manufacturing Research and Development Facility
35	Production Facility	11	Manufacturing Facility
		15	Agricultural Facility
		19	Mineral Extraction Facility
		23	Craft Production Facility
		55	Entertainment Production Facility
37	Storage Facility	12	Dry Storage Facility
		15	Salvage Yard
		19	Underground/Cave Storage
		23	Loft/Multi-Story Warehouse
		26	Covered Storage Facility
		32	Open Storage Facility
		35	Environmentally Controlled Storage Facility
		39	Hazardous Storage Facility
		45	Gas Plant and Storage Facility
		49	Bulk Liquid Fuel Storage Facility
		55	Bulk Liquid Non-Fuel Storage Facility
41	Water Infrastructure Facility	11	Water Holding and Collection Facility
		21	Water Distribution Facility

Code	Main Category	Code	Subcategory
		24	Water Treatment Facility
		27	Special Water Production Facility
		35	Fire Protection Water Facility
		39	Marine Improvement
		43	Fish Passage
		47	Ground Improvement Structure
42	Energy Infrastructure Facility	11	Energy Production Facility
		21	Energy Distribution Node
		24	Energy Storage Facility
		27	Energy Distribution Facility
		38	Heat and Refrigeration Facility
43	Waste Infrastructure Facility	11	Waste Collection and Holding Facility
		21	Waste Processing Facility
44	Information Infrastructure Facility	11	Information Node
		21	Information Distribution Facility
		55	Electronics and Communications Equipment Maintenance Facility
51	Transportation Facility	11	Aerospace Transportation Terminal
		21	Marine Transportation Terminal
		24	Rail Transportation Terminal
		27	Motor Vehicle Transportation Terminal
		31	Vehicle Maintenance and Parking Facility
		34	Airfield Pavement
		45	Roadway
		49	Traffic Control Facility
		53	Sidewalk or Other Pavement
		58	Railway
		65	Bridge
67	Tunnel		

Code	Main Category	Code	Subcategory
		75	Seaway Facility
90	Mixed-Use Facility	11	Sub-Facility
95	Land	11	Land Purchase, Condemnation, Donation, or Transfer
		15	Public Domain Withdraw
		19	License or Permit
		23	Improvement to Facility or Site
		27	Contaminated Land
		31	Not Real Property
		35	Office Site
		39	Planned Development (PUD)
		43	Residential (Single-Family) Site
		47	Agricultural-Undeveloped
		51	Retail Site
		55	Retail Pad
		59	Subdivision-Industrial Site
		63	Subdivision-Office Site
		67	Subdivision-Residential Site
		71	Water-Related Site
75	Wilderness Site		
79	Commercial Site		
83	Land Easement		
87	Industrial Site		
91	Multi-Family Site		

#### A.1.4. Norwegian Standard NS 3457-3

NS 3457 is harmonised with Norway's official real estate registry and meets Statistics Norway's requirements for housing censuses. It is utilised in various contexts, including calculations of greenhouse gas emissions and lifecycle costs, area analyses, registration of damage to buildings, document management, processing construction cases, statistics, market overviews, and taxation. The original terminology has been translated from

Norwegian<sup>82</sup>, so slight variations in meaning may occur due to linguistic and contextual differences.

**Table 4-A. Types of building categories following NS 3457-3**

Code	Main Category	Code	Subcategory
1	Dwelling	11	Detached house
		12	Small house except for the detached house
		13	Multi-dwelling building
		14	Residence for communities
		15	Housing barracks
		16	Holiday house
		17	Building in the primary industry used for leisure purposes
		18	Garage, outhouse, or annexe linked to dwelling
2	Industrial building and warehouse	21	Industrial building
		22	Building for power supply
		23	Warehouse
		24	Fishery and agricultural building
3	Office and business building	31	Office building
		32	Business building
		33	Exhibition and congress building
4	Transport and communication building	41	Terminal building
		42	Garage and hangar building
		43	Telecommunication building
5	Hotel and restaurant building	51	Hotel building
		52	Restaurant building
		53	Service building
6	Educational, sports and cultural buildings	61	School buildings
		62	University and college buildings
		63	Laboratory buildings

<sup>82</sup> NS 3457-3:2013 (2013). <https://online.standard.no/en/ns-3457-3-2013>.

Code	Main Category	Code	Subcategory
		64	Museum and library buildings
		65	Sports buildings
		66	Art and cultural buildings
		67	Religious and life philosophy buildings
		68	Activity and experience buildings
7	Hospital and healthcare building	71	Hospital
		72	Residential and treatment building
		73	Health services building
8	Public safety building	81	Prison
		82	Emergency building
		83	Control and surveillance building

## A.2. Building area

### A.2.1. SfB Classification

SfB divides building spaces into functional groups, often using numbers and letters for categorisation<sup>83</sup>. The specific structure may vary by country (e.g., Sweden, the Netherlands, and the UK used adapted versions).

*Table 5-A. Types of building areas following SfB Classification*

Code	Main Category	Code	Subcategory
10-19	Circulation Areas	10	Entrance areas
		11	Corridors, hallways
		12	Staircases
		13	Elevators, lifts
		14	Ramps, escalators
		15	Emergency exits and fire escapes
		16	External circulation
20-29	Service & Utility Areas	20	Sanitary areas
		21	Changing rooms, lockers
		22	Shower rooms, bathing facilities
		23	Laundry rooms
		24	Waste disposal areas, bins
		25	Cleaning supply areas, janitor rooms
		26	Technical service areas
		27	Mechanical and electrical rooms
		28	Storage for service equipment
30-39	Living & Working Areas	30	Offices, workspaces
		31	Residential living spaces
		32	Kitchens and dining areas
		33	Meeting rooms, conference spaces
		34	Classrooms, training spaces
		35	Recreational and lounge areas

<sup>83</sup> <https://www.bimtag.nl/files/NL-SfB-Codering.pdf>

Code	Main Category	Code	Subcategory
		36	Libraries, archives
		37	Laboratories, research spaces
		38	Worship and religious spaces
		39	Exhibition and display areas
40-49	Storage & Industrial Areas	40	General storage rooms
		41	Warehouse spaces
		42	Cold storage, refrigeration areas
		43	Secure storage
		44	Garages, vehicle storage
		45	Workshop and production areas
		46	Maintenance and repair areas
		47	Server rooms, IT storage
		48	Temporary storage
50-59	Special Function Areas	50	Hospitals and healthcare spaces
		51	Sports and fitness areas s
		52	Entertainment areas
		53	Retail spaces
		54	Hospitality areas
		55	Educational spaces
		56	Security control rooms
		57	Research and high-tech labs
		58	Military and defense areas
		59	Other specialized functional areas

### A.2.2. Uniclass

In **Uniclass**, building areas are classified under the “Spaces/Activities” table, which defines different functional areas within buildings and construction projects<sup>84</sup>. These areas and spaces

<sup>84</sup> Download | UniClass (2025). <https://uniclass.thenbs.com/download>.

are categorised based on their intended use and purpose. These classifications help organise BIM design, construction, and facility management spaces.

**Table 6-A. Types of building areas following Uniclass**

Code	Main Category	Code	Subcategory
20	Administrative, commercial and protective service spaces	10	Legislative spaces
		15	Administrative spaces
		45	Motor vehicle maintenance and fuelling spaces
		50	Commercial spaces
		55	Postal communications spaces
		60	Military protective spaces
		62	Parade spaces
		65	Law enforcement spaces
		70	Judicial spaces
		75	Detention spaces
		80	Weapons training spaces
		85	Security spaces
		90	Fire and incident support spaces
95	Protected zones		
25	Cultural, educational, scientific and information spaces	05	Commemoration spaces
		10	Educational spaces
		20	Design spaces
		30	Scientific and laboratory spaces
		40	Training spaces
		50	Exhibition spaces
		70	Information spaces
		75	Learning resources spaces
		80	Preparation spaces
		90	Worship spaces
30	Industrial spaces	10	Mineral extraction spaces
		20	Nuclear and chemical management spaces
		30	Mineral processing spaces

Code	Main Category	Code	Subcategory
		40	Animal and plant products processing spaces
		50	Manufacturing spaces
		60	Cleaning and maintenance spaces
		80	Kinetic power generation spaces
		85	Marine and water maintenance spaces
		90	Warehousing and distribution spaces
32	Water and land management spaces	10	Agricultural and horticultural spaces
		15	Dam spaces
		35	Ground spaces
		40	Land managed spaces
		50	Marine ways and waterway spaces
		65	Natural spaces
		80	Semi-natural spaces
		85	Water control and retaining spaces
		95	Waterways spaces
35	Medical, health, welfare and sanitary spaces	10	Medical spaces
		50	Welfare spaces
		60	Food management spaces
		70	Funerary spaces
		80	Sanitary spaces
		85	Animal spaces
		90	Animal medical, health, welfare and funerary spaces
40	Recreational spaces	05	Amusement spaces
		20	Dining spaces
		35	Historic spaces
		55	Outdoor play and social areas
		60	Performing arts spaces
		65	Performing arts ancillary spaces

Code	Main Category	Code	Subcategory
42	Sport and activity spaces	15	Courts, pitches and field sports spaces
		40	Indoor activity spaces
		55	Outdoor activity spaces
		80	Sports and activity ancillary spaces
		85	Swimming spaces
		90	Water activity spaces
		95	Winter sports spaces
45	Residential spaces	10	Living spaces
50	Waste disposal spaces and locations	10	Gas waste collection spaces
		20	Non-aqueous waste collection spaces
		25	Drainage collection locations
		30	Drainage collection spaces
		35	Wastewater collection spaces
		40	Dry waste collection spaces
		50	Gas waste treatment and disposal spaces
		60	Non-aqueous waste treatment and disposal spaces
		70	Drainage treatment and disposal spaces
		75	Wastewater treatment and disposal spaces
55	Piped supply spaces	5	Gas extraction and treatment spaces
		10	Liquid fuel extraction and treatment spaces
		15	Water extraction and treatment spaces
		20	Gas supply spaces
		30	Fire-extinguishing supply spaces
		40	Steam supply spaces
		50	Liquid fuel supply spaces
		60	Process liquid supply spaces
		65	Ventilation and air conditioning spaces

Code	Main Category	Code	Subcategory
		70	Water supply spaces
		90	Piped solids supply spaces
60	Heating, cooling and refrigeration spaces	30	Rail and paving heating spaces
		40	Space heating and cooling spaces
		60	Refrigeration spaces
		80	Drying spaces
70	Electrical power generation and lighting spaces	10	Electrical power generation spaces
		20	Electricity transmission spaces
		30	Electricity distribution spaces
75	Communications, security, safety and protection spaces	10	Communications spaces
		30	Signalling spaces
		40	Electronic security spaces
		50	Safety and protection spaces
		60	Environmental safety
		70	Control and management spaces
		80	Protection spaces
80	Transport spaces	5	Aerospace ground spaces
		10	Loading and embarkation spaces
		15	Aerospace maintenance spaces
		20	Cableways
		30	Cable transport storage and maintenance spaces
		35	Road spaces
		40	Pathway spaces
		45	Vehicle storage spaces
		50	Railway spaces
		70	Marine and waterways transport spaces
		90	Transport hubs
92	Grid systems		

Code	Main Category	Code	Subcategory
		94	Bridge and structure spaces
		96	Tunnel and shaft spaces
		98	Transport kinematic envelopes
82	Vehicle spaces	61	Passenger spaces
90	General spaces	10	Circulation spaces
		20	Common spaces
		30	Construction voids
		40	General levels
		50	Storage spaces
		60	Unoccupied voids
		90	Plant and control spaces

### A.2.3. OmniClass

OmniClass categorises building areas based on their function and use under Table 49 – Spaces, which also describes different types of spaces within buildings and construction projects.

**Table 7-A. Types of building areas following OmniClass**

Code	Main Category	Code	Subcategory
11	Space Planning Types	11	Planned Work Space
		13	Planned Building Service Space
		15	Planned Amenity/Support Space
		17	Planned Circulation Space
		19	Planned Parking Space
13	Void Areas	11	Light Well
		13	Air Shaft
		15	Occupant Void Area
15	Wall Spaces	11	Exterior Wall Space
		13	Interior Wall Space
17	Encroachment Spaces	10	Interior Encroachment
		15	Perimeter Encroachment
21	Parking Spaces	11	Exterior Parking Spaces

Code	Main Category	Code	Subcategory
		13	Interior Parking Spaces
23	Facility Service Spaces	11	Vertical Penetration
		12	Horizontal Infrastructure/Service Space, Non-Occupied
		13	Control Room
		15	Loading Dock
		17	Restroom
		19	Utility Equipment Room
		21	Waste and Recycling Spaces
		23	Building Service Support Spaces
		25	Equipment Platform
		27	Interstitial Space
		29	Unimproved Shell
31	Alteration or Conversion Space		
25	Circulation Spaces	11	Primary Circulation Spaces
		13	Transitional Circulation Spaces
		15	Connector
		17	External Circulation Spaces
		19	Secondary Circulation Spaces
		21	Restricted Spaces
		23	Refuge Spaces
31	Education and Training Spaces	11	Breakout Space
		13	Lecture and Classroom Spaces
		15	Class Laboratories
		17	Training Spaces
		19	Study Spaces
33	Recreation Spaces	11	Athletic Recreation Spaces
		13	Swimming Pools
		15	Non-Athletic Recreation Spaces
		17	Wellness Spaces

Code	Main Category	Code	Subcategory
35	Government Spaces	11	Judicial Spaces
		13	Legislative Spaces
		15	Military Spaces
37	Artistic Spaces	11	Performance Spaces
		13	Display Spaces
		15	Creative Spaces
41	Museum Spaces	11	Museum Gallery
45	Library Spaces	11	Library
47	Spiritual Spaces	11	Worship spaces
		13	Ceremonial Spaces
		15	Procession Spaces
		17	Death Spaces
49	Environmentally Controlled Spaces	11	Anechoic Chamber
		13	Hazard Containment
		15	Clean Room
		17	Temperature and Pressure Chamber
		19	Data Center
		21	Controlled Space Support
		23	Miscellaneous Environmentally Controlled Spaces
51	Healthcare Spaces	11	General Examination Spaces
		14	Inpatient Care Spaces
		17	Multi-Medical Service Support Spaces
		21	Diagnostic Imaging Spaces
		24	Diagnostic Imaging Support Spaces
		27	Radiation Diagnostic and Therapy Spaces
		31	Heart and Lung Diagnostic and Treatment Spaces
		34	General Diagnostic Procedure and Treatment Spaces
		37	Eye and Ear Healthcare Spaces

Code	Main Category	Code	Subcategory
		41	Endoscopy/Gastroenterology Spaces
		44	Surgical Spaces
		47	Clinical Laboratory Spaces
		51	Clinical Laboratory Support Spaces
		54	Pharmacy Spaces
		57	Medical Services Logistic Spaces
		61	Rehabilitation Spaces
		64	Dental Spaces
		67	Medical Research and Development Spaces
		91	Veterinary Spaces
53	Laboratory Spaces	11	Chemistry Laboratories
		13	Biosciences Laboratories
		15	Physical Sciences Laboratories
		17	Astronomy Laboratories
		19	Earth and Environmental Sciences Laboratories
		21	Forensics Laboratories
		23	Psychology Laboratories
		25	Bench Laboratories
		27	Dry Laboratories
		29	Integration Laboratories
		31	Wet Laboratories
		33	Laboratory Storage Spaces
35	Laboratory Support Spaces		
55	Commerce Activity Spaces	11	Office Spaces
		13	Banking Spaces
		15	Trading Spaces
		17	Demonstration Spaces
		19	Sales Spaces
		21	Commercial Service and Repair Spaces

Code	Main Category	Code	Subcategory
		23	Commercial Support Spaces
		27	Hotel, Motel, Hostel, and Dormitory Service Spaces
		29	Commerce Activity Support Areas
57	Service Activity Spaces	11	Grooming Activity Spaces
		13	Food Service
		15	Child Care Spaces
		17	Resting Spaces
		21	Laundry/Dry Cleaning Space
		23	Smoking Space
59	Production, Fabrication, and Maintenance Spaces	11	Material Handling Area
		13	Batching Space
		15	Production Process
		17	Printing and Reproduction Spaces
		19	Quality Control and Test Spaces
		21	Production Service and Repair Spaces
		23	Production and In-Process Storage Spaces
		25	Production Support Spaces
		29	Greenhouse Spaces
61	Protective Spaces	11	Animal Securing Spaces
		13	Detention Spaces
		15	Spaces for Protection from the Elements
		17	Spaces for Protection from Violence
63	Storage Spaces	11	Warehouse Spaces
		13	Non-Warehouse Storage Spaces
		15	Moveable Storage Spaces
		17	Environmentally Controlled Storage Spaces
		19	Specialty Storage Spaces
65	Private Residential Spaces	11	On-call Room
		13	Bathroom

Code	Main Category	Code	Subcategory
		15	Mud Room
		17	Laundry Room
		19	Bedroom
		21	Nursery
		23	Kitchen
67	Alternate Workplace	11	Customer Site
		13	Home Office
		15	Rent-An-Office
		17	No Fixed Location
		19	Supplier Site
69	Building Associated Spaces	11	Roof
		13	Roof Terrace
		15	Penthouse
		17	Antenna Farm
		19	Heliport
		21	Balcony
		23	Deck
		25	Pedestrian Travel Spaces

#### A.2.4. Norwegian Standard NS 3457-4

In NS 3457-4, a system code is allocated for each category level. The original terminology has been translated from Norwegian<sup>85</sup>, so minor variations in meaning may arise due to linguistic and contextual differences. NS 3457-4 is utilised alongside calculations related to life cycle costs, area analyses, recording of damage to buildings, document management, processing of construction cases, statistics, market overviews, rentals, and taxation in Norway.

**Table 8-A. Types of building areas following NS 3457-4**

Code	Main Category	Code	Subcategory
1	Room for human needs	11	Staying room
		12	Hygiene room

<sup>85</sup> NS 3457-4:2015 (2015). <https://online.standard.no/en/ns-3457-4-2015>.

Code	Main Category	Code	Subcategory
		13	Protection room
		14	Storage room
2	Room for human work and activity	21	Working room
		22	Production room
		23	Activity room
		24	Assembly room
		25	Laboratory
		26	Examination and treatment room
3	Storage room	31	Material room
		32	Equipment room
		33	Valuable storage room
		34	Maternity room
		35	Display room
		36	Animal room
		37	Plant room
4	Technical room	41	Technical operation room
		42	Technical control room
		43	Other technical room
5	Communication room	51	Distribution room
6	Unassigned room	61	Unassigned room

### A.3. Building element

#### A.3.1. SfB Classification

The SfB Classification is the only of three classifications that bases the building elements on a numeric coding system, typically structured in three levels:

- Main building elements (structural and functional systems)
- Materials and components
- Work processes and execution.

*Table 9-A. Types of building elements following SfB Classification*

Code	Main Category	Code	Subcategory
0	Sites, Project, Building systems	0	Indirect project fittings
		1	Site facilities
		2	Plant fittings
		3	Risk coverage
		4	Project organisation
		5	Company organisation
		11	Ground
		13	Floor beds
		16	Retaining walls, Foundations
		17	Pile foundations
2	Primary elements, Carcass	21	External walls
		22	Internal walls
		23	Floors, galleries
		24	Stairs, ramps
		27	Roofs
		28	Building frames, other primary elements
3	Secondary elements	31	External wall openings
		32	Internal wall openings
		33	Secondary elements to floors
		34	Secondary elements to stairs
		37	Secondary elements to roofs
		38	Other secondary elements
4	Finishes	41	Exterior Parking Spaces

Code	Main Category	Code	Subcategory
		42	Interior Parking Spaces
		43	Floor finishes
		44	Stair and ramp finishes
		45	Ceiling finishes
		47	Roof finishes
		48	Finishing packages
5	Services mainly piped and ducted	52	Waste disposal, drainage
		53	Liquids supply
		54	Gases supply
6	-	63	Lighting
		64.0	Communication; general
		65.0	Security; general (collection level)
		66.3	Transport; general
		67.9	fixed building-related services for building management system
		68.9	fixed building-related services for asset management system
7	Fittings	71	Circulation fittings
		72	Rest, work fittings
		73	Culinary fittings
		74	Sanitary, hygiene fittings
		75	Cleaning, maintenance fittings
		76	Storage, screening fittings
8	Loose furniture, equipment	81	Circulation loose furniture, equipment
		82	Rest, work loose furniture, equipment
		83	Culinary loose furniture, equipment
		84	Sanitary, hygiene furniture, equipment
		85	Cleaning, maintenance furniture, equipment
		86	Storage screening loose furniture, equipment
9	Terrain	90	Terrain

### A.3.2. Uniclass

Uniclass defines building elements primarily in the “Elements/Functions (EF)” table V1.15, which focuses on the functional components of a building

*Table 10-A. Types of building elements following Uniclass*

Code	Main Category	Code	Subcategory
0	Sites, Project, Building systems	0	Indirect project fittings
		1	Site facilities
		2	Plant fittings
		3	Riskcoverage
		4	Project organisation
		5	Company organisation
		11	Ground
		13	Floor beds
		16	Retaining walls, Foundations
		17	Pile foundations
2	Primary elements, Carcass	21	External walls
		22	Internal walls
		23	Floors, galleries
		24	Stairs, ramps
		27	Roofs
		28	Building frames, other primary elements
3	Secondary elements	31	External wall openings
		32	Internal wall openings
		33	Secondary elements to floors
		34	Secondary elements to stairs
		37	Secondary elements to roofs
		38	Other secondary elements
4	Finishes	41	Exterior Parking Spaces
		42	Interior Parking Spaces
		43	Floor finishes

Code	Main Category	Code	Subcategory
		44	Stair and ramp finishes
		45	Ceiling finishes
		47	Roof finishes
		48	Finishing packages
5	Services mainly piped and ducted	52	Waste disposal, drainage
		53	Liquids supply
		54	Gases supply
6	-	63	Lighting
		64.0	Communication; general
		65.0	Security; general (collection level)
		66.3	Transport; general
		67.9	fixed building related services for building management system
		68.9	fixed building related services for asset management system
7	Fittings	71	Circulation fittings
		72	Rest, work fittings
		73	Culinary fittings
		74	Sanitary, hygiene fittings
		75	Cleaning, maintenance fittings
		76	Storage, screening fittings
8	Loose furniture, equipment	81	Circulation loose furniture, equipment
		82	Rest, work loose furniture, equipment
		83	Culinary loose furniture, equipment
		84	Sanitary, hygiene furniture, equipment
		85	Cleaning, maintenance furniture, equipment
		86	Storage screening loose furniture, equipment
9	Terrain	90	Terrain

### A.3.3. OmniClass

**OmniClass** produces the same information with a small adjustment in naming. OmniClass defines building elements in Table 21 – Elements, which is similar to UniFormat and focuses on the functional and structural components.

*Table 11-A. Types of building elements following OmniClass*

Code	Main Category	Code	Subcategory
01	Substructure	10	Foundations
		20	Subgrade Enclosures
		40	Slabs-on-Grade
		60	Water and Gas Mitigation
		90	Substructure Related Activities
02	Shell	10	Superstructure
		20	Exterior Vertical Enclosures
		30	Exterior Horizontal Enclosures
03	Interiors	10	Interior Construction
		20	Interior Finishes
04	Services	10	Conveying
		20	Plumbing
		30	Heating, Ventilation, and Air Conditioning (HVAC)
		40	Fire Protection
		50	Electrical
		60	Communications
		70	Electronic Safety and Security
		80	Integrated Automation
05	Equipment and Furnishings	10	Equipment
		20	Furnishings
06	Special Construction and Demolition	10	Special Construction
		20	Facility Remediation
		30	Demolition
07	Sitework	10	Site Preparation
		20	Site Improvements

Code	Main Category	Code	Subcategory
		30	Liquid and Gas Site Utilities
		40	Electrical Site Improvements
		50	Site Communications
		90	Miscellaneous Site Construction

#### A.3.4. Norwegian Standard NS 3451

NS 3451<sup>86</sup> aligns with the classification standards of the NS 3457 series, which facilitates the identification and retrieval of information between them. NS 3451 promotes communication and collaboration among construction and real estate stakeholders and is widely used in life cycle assessments, building damages, and more.

*Table 12-A. Types of building elements following NS 3451*

Code	Main Category	Code	Subcategory
2	Building	21	Ground and foundation
		22	Load-bearing construction
		23	External wall
		24	Internal wall
		25	Slab
		26	Roof
		27	Inventory
		28	Stairs, balcony, etc.
		29	Other building parts
3	HVAC installations	31	Sanitary installations
		32	Heating
		33	Fire extinguishing
		34	Gas and compressed air
		35	Process cooling
		36	Air treatment
		37	Comfort cooling

<sup>86</sup> NS 3451:2022 (2022). <https://online.standard.no/en/ns-3451-2022>.

Code	Main Category	Code	Subcategory
		38	Water treatment
		39	Other HVAC installations
4	Electric power installations	41	Basic installations
		42	High voltage power supply
		43	Low voltage power supply
		44	Light
		45	Electric heating
		46	Backup electric power
		47	Local electric power production
		48	Electric power protection
		49	Other electric power installations
5	Electronic communication and automation installations	51	Basic installations
		52	Integrated communication
		53	Telephone and paging
		54	Alarm and signal
		55	Sound and image
		56	Automation
		57	Instrumentation
		58	(reserved, not in use)
		59	Other electronic communication and automation installations
6	Other installations	61	Prefabricated rooms
		62	Passengers and goods transport
		63	Transport systems
		64	Technical stage equipment
		65	Waste and vacuum cleaning
		66	Fixed special equipment
		67	Non-fixed special equipment
		68	Inventory

<b>Code</b>	<b>Main Category</b>	<b>Code</b>	<b>Subcategory</b>
		69	Other technical installations
7	Outdoor	71	Cultivated terrain
		72	Outdoor constructions
		73	Outdoor HVAC
		74	Outdoor electric power
		75	Outdoor communication and automation
		76	Roads and slabs
		77	Parks and gardens
		78	Outdoor infrastructure
		79	Other outdoor facilities

## A.4. Building materials

There should ideally be no discrepancies between existing classification structures when classifying building materials. Both SfB classification and Uniclass include a categorization system for materials, whereas OmniClass does not categorize materials separately.

The primary differences in categorization across these classification structures lie in the terminology used and the level of distinction made between materials based on their processing or application.

### A.4.1. SfB Classification

The SfB system categorizes materials primarily within Table 3 (Construction materials). It covers structural, finishing, and functional materials used in construction.

*Table 13-A. Types of materials following SfB*

Code	Main Category	Code	Subcategory
e	Natural stone	1	Igneous rock
		2	Marble
		3	Limestone (other than marble)
		4	Sandstone, gritstone
		5	Slate
		9	Other natural stone
f	Precast with binder	1	All-in aggregate concretes
		2	Concrete, mortars after hardening (main binder = cement)
		3	Terrazzo (precast); Granolithic (precast)
		4	Lightweight cellular concrete (precast)
		5	Lightweight aggregate concrete (precast)
		6	Asbestos-based materials (preformed)
		7	Gypsum (preformed) Glass fibre reinforced gypsum (GRG)
		8	Magnesia materials (preformed)
		9	Other materials precast with binder
g	Clay (dried, fired)	1	Dried clay
		2	Fired clay, vitrified clay, ceramics
		2	Fired clay, not mentioned in g3 or g6
		3	Glazed fired clay

Code	Main Category	Code	Subcategory
		6	Refractory materials
		9	Other dried or fired clays
h	Metal	1	Cast iron
		2	Steel, mild steel
		3	Steel alloys
		4	Aluminium, aluminium alloys
		5	Copper
		6	Copper alloys
		7	Zinc
		8	Lead, white metal
		9	Chromium, nickel, gold, other metals, metal alloys
i	Wood	1	Timber
		2	softwood
		3	Hardwood
		4	Wood laminates
		5	Wood veneers
		9	Other wood materials
j	Vegetable and animal materials	1	Wood fibres
		2	Paper
		3	Vegetable fibres other than wood
		5	bark, cork
		6	Animal fibres
		7	Wood particles
		8	Wood wool-cement
		9	Other vegetables and animal materials
m	Inorganic fibres	1	mineral wool/fibres
		2	Asbestos wool/fibres
		9	Other inorganic fibrous materials
n	Rubbers, plastics etc.	1	Asphalt

Code	Main Category	Code	Subcategory
		2	Impregnated fibre and felt
		4	Linoleum
		5	Rubbers
		6	Plastics, including synthetic fibres
		7	Cellular plastics
		8	Reinforced plastics
		9	Other rubber, plastics materials
o	Glass	1	Clear, transparent, plain glass
		2	Translucent glass
		3	Opaque, opal glass
		4	wired glass
		5	Multiple glazing
		6	Heat absorbing/rejecting glass, X-ray absorbing/rejecting glass, solar control glass
		7	Mirrored glass, 'one way' glass, anti-glare glass
		8	Safety glass, toughened glass, laminated glass, security glass, alarm glass
		9	Other glass, including cellular glass
p	Aggregates, loose fills	1	Natural fills
		2	Artificial aggregates in general
		2	Artificial granular aggregates (heavy)
		3	Artificial granular aggregates (light)
		4	Ash
		5	Shavings
		6	Powder
		7	Fibres
		9	Other aggregates, loose fills
q	Lime and cement binders, mortars, concretes	1	Lime
		2	Cement
		3	Lime-cement

Code	Main Category	Code	Subcategory
		4	Lime-cement-aggregate mixes
		4	Lime-cement-aggregate mixes, not mentioned in q5, q6, q7 and q9
		5	Cement aggregate mixes and aggregates for artificial stone
		6	Lightweight, cellular concrete
		7	Lightweight aggregate concrete
		9	Other lime-cement-aggregate mixes
r	Clay, gypsum, magnesia and plastic binders, mortars	1	Clay mortar mixes, refractory mortar
		2	Gypsum
		3	Magnesia
		4	Plastics binders
		9	Other binders and mortar mixes
s	Bituminous materials	1	Bitumen
		4	Mastic asphalt (fine or no aggregate)
		5	Clay-bitumen mixes
		9	Other bituminous materials
t	Fixing and jointing materials	1	Welding materials
		2	Soldering materials
		3	Adhesives, bonding materials
		4	Joint fillers
		6	Fasteners
		7	Architectural ironmongery
		9	Other fixing and jointing agents
u	Protective and process/property modifying materials	1	Anti-corrosive materials, treatments
		2	Modifying agents, admixtures
		3	Materials resisting special forms of attack
		4	Flame retardants, if described separately
		5	Polishes, seals, surface hardeners
		6	Water repellents, if described separately

Code	Main Category	Code	Subcategory
		9	Other protective and process/property modifying agents
v	Paints	1	Stopping, fillers, knotting, paint preparation materials
		2	Pigment, dyes, stains
		3	Binders, media
		4	Varnishes, lacquers
		5	Oil paints
		6	Emulsion paints where described separately
		8	Water paints
		9	Materials of type v, not mentioned before
w	Ancillary materials	1	Rust removing agents
		3	Fuels
		4	Water
		5	Acids, alkalis
		6	fertilisers
		7	Cleaning materials
		8	Explosives
		9	Other ancillary materials
y			Composite materials
z	Substances	1	By state
		2	By chemical composition
		3	By origin
		9	Other substances

#### A.4.2. Uniclass

Uniclass structures construction materials under table 1.1 “Materials (MA)”.

*Table 14-A. Types of materials following Uniclass*

Code	Main Category	Code	Subcategory
20	Combination inorganic/ organic materials	1	Adobe
		3	Aggregates

Code	Main Category	Code	Subcategory
		13	Ceramic
		16	Clays
		18	Cob
		21	Daub
		64	Pisé
		81	Soil
40	Inorganic materials	4	Asbestos
		12	Carbon
		15	Cement
		16	Cement replacement materials
		19	Concrete
		30	Fluids
		33	Gases
		35	Glass
		52	Metal
		84	Stone
60	Organic materials	2	Animal-based material
		8	Bituminous material
		15	Chlorofluorocarbons
		58	Oil
		61	Paper
		64	Plant-based material
		65	Plastics
		72	Resin
		74	Rubber

#### A.4.3. OmniClass

OmniClass does not organise material information in a table. However, it contains the Table 23: Products, which lists specific products. Because the products represent mostly electrical equipment, they are not considered relevant to the report.

## A.5. Construction and demolition waste

The category of construction and demolition wastes (including excavated soil from contaminated sites) in the EU Waste Framework Directive has the assigned code 17, and the sub-classification of waste types is given in Table 15-A<sup>87</sup>:

*Table 15-A. List of subcategories for category 17 - Construction and Demolition Waste (CDW).*

Nr.	Waste subcategory	Nr.	Waste subcategory
01	concrete, bricks, tiles and ceramics	01	concrete
		02	bricks
		03	tiles and ceramics
		06	mixtures or separate fractions of concrete, bricks, tiles and ceramics containing hazardous substances
		07	mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06
02	wood, glass and plastic	01	wood
		02	glass
		03	plastic
		04	glass, plastic and wood containing or contaminated with hazardous substances
03	bituminous mixtures, coal tar and tarred products	01	bituminous mixtures containing coal tar
		02	bituminous mixtures other than those mentioned in 17 03 01
		03	coal tar and tarred products
04	metals (including their alloys)	01	copper, bronze, brass
		02	aluminium
		03	lead
		04	zinc
		05	iron and steel
		06	tin
		07	mixed metals
		09	metal waste contaminated with hazardous substances
		10	cables containing oil, coal tar and other hazardous substances

<sup>87</sup> Decision - 2014/955 - EN - EUR-LEX (2014). <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014D0955>.

Nr.	Waste subcategory	Nr.	Waste subcategory
		11	cables other than those mentioned in 17 04 10
05	soil (including excavated soil from contaminated sites), stones and dredging spoil	03	soil and stones containing hazardous substances
		04	soil and stones other than those mentioned in 17 05 03
		05	dredging spoil containing hazardous substances
		06	dredging spoil other than those mentioned in 17 05 05
		07	track ballast containing hazardous substances
		08	track ballast other than those mentioned in 17 05 07
06	insulation materials and asbestos-containing construction materials	01	insulation materials containing asbestos
		03	other insulation materials consisting of or containing hazardous substances
		04	insulation materials other than those mentioned in 17 06 01 and 17 06 03
		05	construction materials containing asbestos
08	gypsum-based construction material	01	gypsum-based construction materials contaminated with hazardous substances
		02	gypsum-based construction materials other than those mentioned in 17 08 01
09	other construction and demolition wastes	01	construction and demolition wastes containing mercury
		02	construction and demolition wastes containing PCB (polychlorinated biphenyls and terphenyls)
		03	other construction and demolition wastes (including mixed wastes) containing hazardous substances
		04	mixed construction and demolition wastes other than those mentioned in 17 09 01, 17 09 02 and 17 09 03

## APPENDIX B Additional results of the screening review

Table 1-B gives an overview of the most commonly applied technologies in the investigated subset of literature. The subset of literature was categorised into the 10 most frequently published technologies in the building industry. The results show that *BIM* (152) is the most used technology within the investigated article abstracts, followed by *Prefabrication* (117) and *AI & Machine learning* (46). The findings highlight the importance of BIM in the planning and managing circular aspects of the building industry.

**Table 1-B. Overview of most commonly applied technologies in investigated subset of literature.**

Category	Number of studies	Earliest publication year
BIM	152	2011
Prefabrication	117	2006
AI & Machine learning	46	2013
3D printing	38	2017
Digital twin	24	2019
Robotics	22	2019
Internet of Things	18	2019
Sensors	12	2013
Cloud	10	2016
VR	7	2019
CAD	6	2021

The development of topics over time can also be seen in Figure 1-B. While *Material reuse* and *Material recycling* represented a major share of all publications until the early 2000s, it was especially from 2015 onwards that the *Circular economy* topic took up a significant share of all published articles within a year. Due to the substantial increase in the total number of publications per year (see Figure 4 in 3.1.3), and a higher relative importance in more recent years, *Circular economy* is the most important topic amongst the investigated article abstracts (1255 studies), followed by *Material reuse* (799 studies) and *Material recycling* (563 studies). Because abstracts can be categorised into multiple topics, the sum of all studies across all topics is larger than the number of identified abstracts. Furthermore, although only one study from 1974 was included in this analysis, it has been categorised into three topics (*Material reuse*, *Material recycling*, and *Material recovery*). Thus, Figure 1-B indicates more than one category in that year.

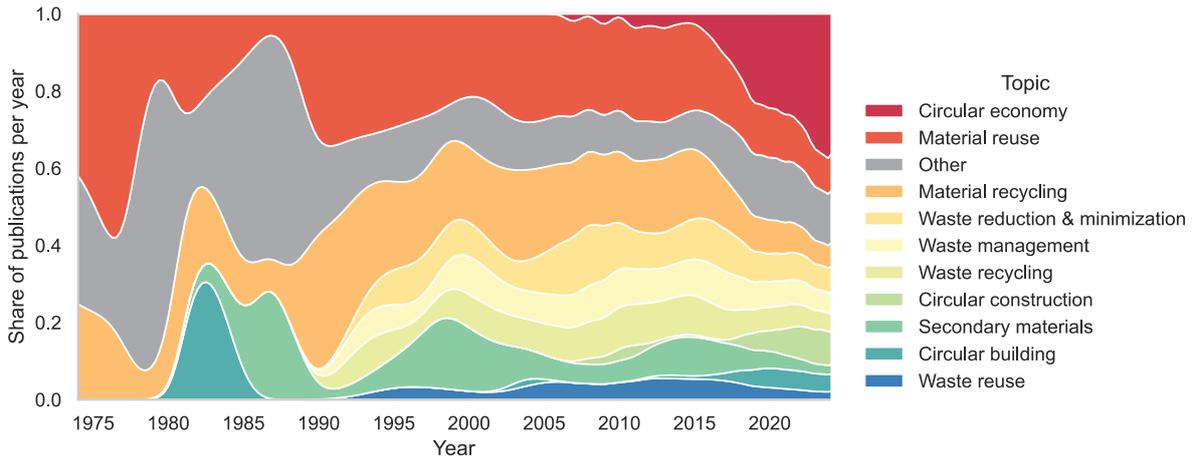


Figure 1-B. Share of the top ten topics with the most publications over time (from the highest to the lowest). The remaining topics are summarised as 'Other'.

Analysing the affiliations of the first authors of the 2649 investigated studies showed that studies came from 94 countries. Italy was the most productive country in the field, with 195 publications in total, followed by China (169) and the United Kingdom (166). The development of shares of the total number of publications amongst the 10 most productive countries over time is shown in Figure 2-B. Of the 10 most productive countries, 6 were European countries. In total, 1052 studies (39.7 % of all analysed publications) were published by first authors from EU countries.

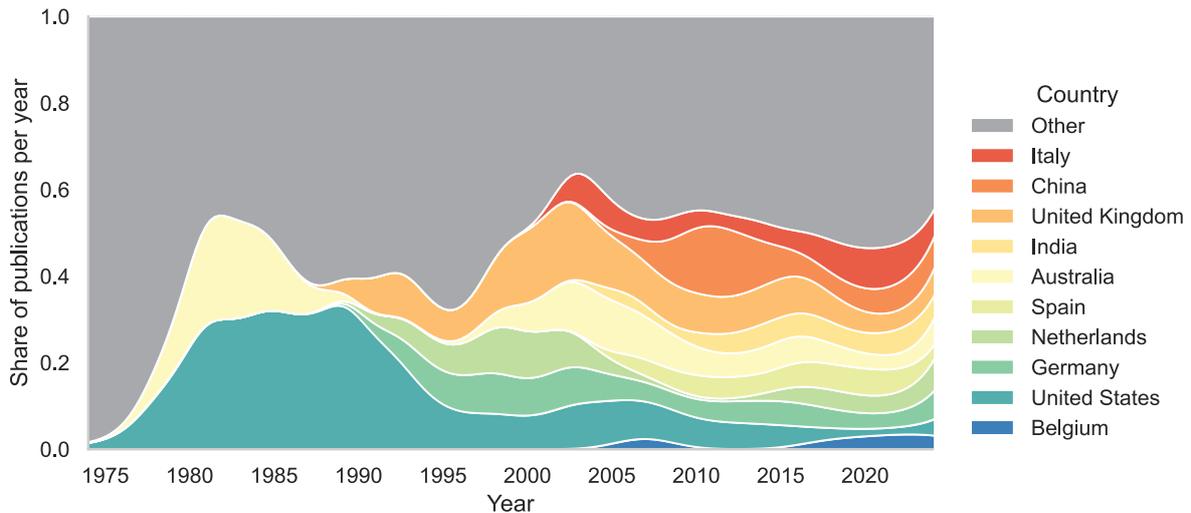


Figure 2-B. Share of the top 10 most productive countries over time (from the highest to the lowest). All remaining countries are summarised as 'Other'.

The Sankey diagram in Figure 3-B shows the links between the top ten contributing countries and topics, visually representing each country's specific contributions to a topic regarding publication numbers. A publication is allocated to a country by its first author's institution. Thicker flows and more intensive colours within the diagram indicate a higher number of publications.

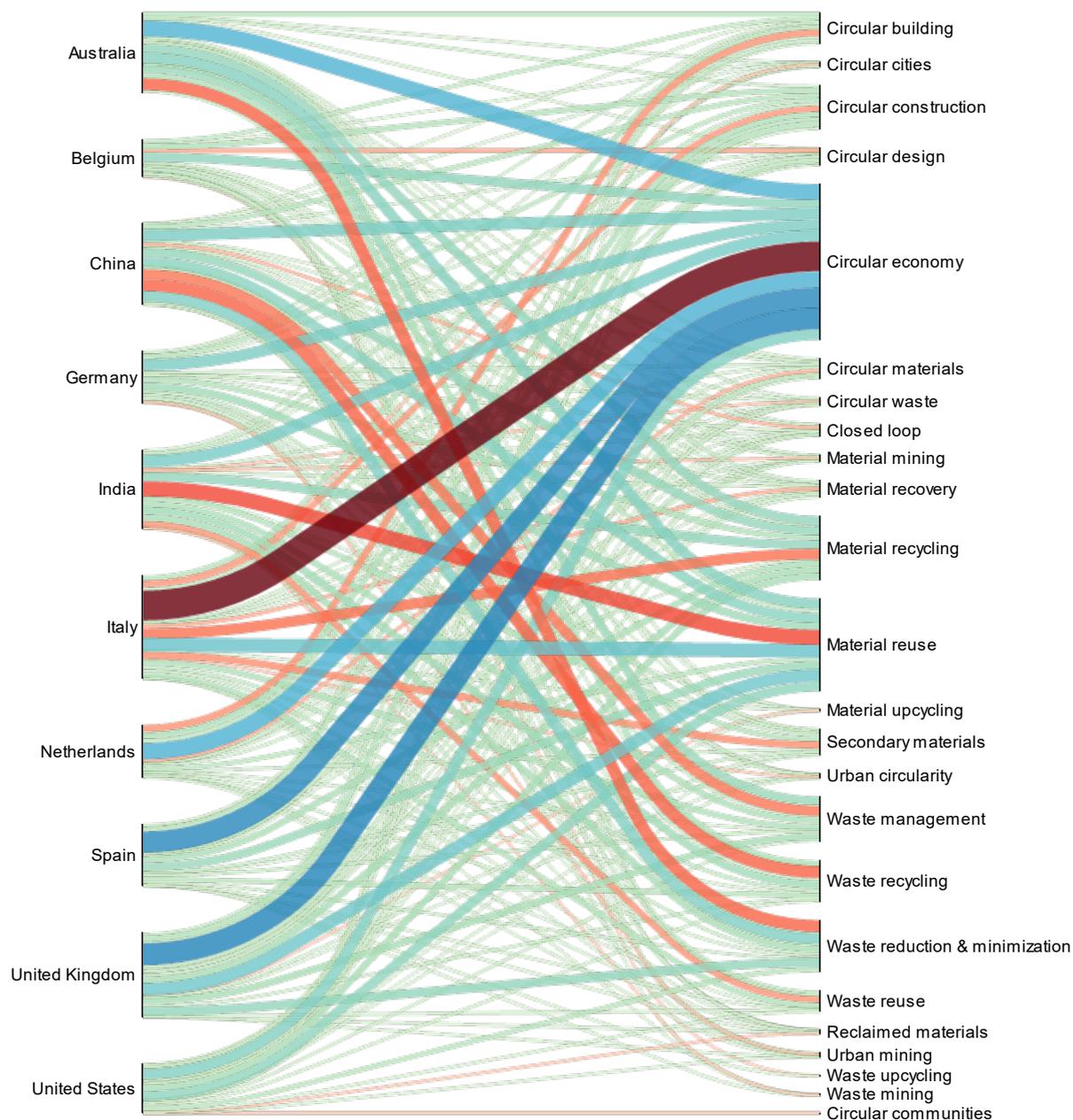


Figure 3-B. Sankey diagram linking the ten most productive countries to topics. The thickness and intensity of the colours indicate the number of studies from each country on a particular topic.

The 10 most-cited studies are shown in Table 2-B.

Table 2-B. The 10 most-cited articles among the investigated subset of literature.

No.	Cit.	Authors	Year	Title	Topic(s)
1	620	Pomponi F. and Moncaster A. <sup>88</sup>	2017	Circular economy for the built environment: A research framework	Circular economy; Circular building

<sup>88</sup> Pomponi, F. and Moncaster, A. (2016) 'Circular economy for the built environment: A research framework,' Journal of Cleaner Production, 143, pp. 710–718. <https://doi.org/10.1016/j.jclepro.2016.12.055>.

2	583	Dixit M.K. et al. <sup>89</sup>	2010	Identification of parameters for embodied energy measurement: A literature review	Material mining
3	540	Gálvez-Martos J.L. et al. <sup>90</sup>	2018	Construction and demolition waste best management practice in Europe	Circular economy; Circular waste; Secondary materials; Waste management; Waste reduction & minimization
4	438	Jaillon L. et al. <sup>91</sup>	2009	Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong	Waste reduction & minimisation
5	422	Singh N.B. and Middendorf B. <sup>92</sup>	2020	Geopolymers as an alternative to Portland cement: An overview	Secondary materials
6	378	Etxeberria M. et al. <sup>93</sup>	2007	Recycled aggregate concrete as a structural material	Material reuse
7	366	Aye L. et al. <sup>94</sup>	2012	Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules	Material reuse; Waste reduction & minimisation
8	354	Iyer R.S. and Scott J.A. <sup>95</sup>	2001	Power station fly ash - A review of value-added utilisation outside of the construction industry	Material recovery; Waste management
9	336	Nasir M.H.A. et al. <sup>96</sup>	2017	Comparing linear and circular supply chains: A case study from the construction industry	Circular economy
10	329	Leising E. et al. <sup>97</sup>	2018	Circular Economy in the building sector: Three cases and a collaboration tool	Circular economy; Circular building

<sup>89</sup> Dixit, M.K. et al. (2010) 'Identification of parameters for embodied energy measurement: A literature review,' *Energy and Buildings*, 42(8), pp. 1238–1247. <https://doi.org/10.1016/j.enbuild.2010.02.016>.

<sup>90</sup> Gálvez-Martos, J.-L. et al. (2018) 'Construction and demolition waste best management practice in Europe,' *Resources Conservation and Recycling*, 136, pp. 166–178. <https://doi.org/10.1016/j.resconrec.2018.04.016>.

<sup>91</sup> Jaillon, L., Poon, C.S. and Chiang, Y.H. (2008) 'Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong,' *Waste Management*, 29(1), pp. 309–320. <https://doi.org/10.1016/j.wasman.2008.02.015>.

<sup>92</sup> Singh, N.B. and Middendorf, B. (2019) 'Geopolymers as an alternative to Portland cement: An overview,' *Construction and Building Materials*, 237, p. 117455. <https://doi.org/10.1016/j.conbuildmat.2019.117455>.

<sup>93</sup> Etxeberria, M., Marí, A.R. and Vázquez, E. (2006) 'Recycled aggregate concrete as structural material,' *Materials and Structures*, 40(5), pp. 529–541. <https://doi.org/10.1617/s11527-006-9161-5>.

<sup>94</sup> Aye, L. et al. (2011) 'Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules,' *Energy and Buildings*, 47, pp. 159–168. <https://doi.org/10.1016/j.enbuild.2011.11.049>.

<sup>95</sup> Iyer, R.S. and Scott, J.A. (2001) 'Power station fly ash — a review of value-added utilization outside of the construction industry,' *Resources Conservation and Recycling*, 31(3), pp. 217–228. [https://doi.org/10.1016/s0921-3449\(00\)00084-7](https://doi.org/10.1016/s0921-3449(00)00084-7).

<sup>96</sup> Nasir, M.H.A. et al. (2016) 'Comparing linear and circular supply chains: A case study from the construction industry,' *International Journal of Production Economics*, 183, pp. 443–457. <https://doi.org/10.1016/j.ijpe.2016.06.008>.

<sup>97</sup> Leising, E., Quist, J. and Bocken, N. (2017) 'Circular Economy in the building sector: Three cases and a collaboration tool,' *Journal of Cleaner Production*, 176, pp. 976–989. <https://doi.org/10.1016/j.jclepro.2017.12.010>.

## APPENDIX C Additional results of the literature review

The list of articles considered in the literature review is given in Table 1-C in alphabetical order.

*Table 1-C. The list of articles considered for the literature review*

No.	Authors	Year	Title	Article type	Publication
1	Akanbi et al. <sup>98</sup>	2018	Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator	Journal	Resources, Conservation and Recycling
2	Charef <sup>99</sup>	2022	The use of Building Information Modelling in the circular economy context: Several models and a new dimension of BIM (8D)	Journal	Cleaner Engineering and Technology
3	Göswein et al. <sup>100</sup>	2022	Circular material passports for buildings - Providing a robust methodology for promoting circular buildings	Conference	IOP Conf. Ser. Earth Environ. Sci.
4	Göswein et al. <sup>101</sup>	2022	Bridging the gap - A database tool for BIM-based circularity assessment	Conference	IOP Conf. Ser. Earth Environ. Sci.
5	Gupta et al. <sup>102</sup>	2022	Proposing building information modelling-based theoretical framework for construction and demolition waste management: strategies and tools	Journal	International Journal of Construction Management
6	Jayasinghe et al. <sup>103</sup>	2019	Information-based quality management in reverse logistics supply chain: A systematic literature review	Journal	Benchmarking
7	Kim and Kim <sup>104</sup>	2023	A design support tool based on building information modelling for design for deconstruction: A graph-based deconstructability assessment approach	Journal	Journal of Cleaner Production

<sup>98</sup> Akanbi, L.A. et al. (2017) 'Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator,' Resources Conservation and Recycling, 129, pp. 175–186. <https://doi.org/10.1016/j.resconrec.2017.10.026>.

<sup>99</sup> Charef, R. (2022) 'The use of Building Information Modelling in the circular economy context: Several models and a new dimension of BIM (8D),' Cleaner Engineering and Technology, 7, p. 100414. <https://doi.org/10.1016/j.clet.2022.100414>.

<sup>100</sup> Göswein, V. et al. (2022) 'Circular material passports for buildings – Providing a robust methodology for promoting circular buildings,' IOP Conference Series Earth and Environmental Science, 1122(1), p. 012049. <https://doi.org/10.1088/1755-1315/1122/1/012049>.

<sup>101</sup> Göswein, V., Carvalho, S., Lorena, A., et al. (2022) 'Bridging the gap – A database tool for BIM-based circularity assessment,' IOP Conference Series Earth and Environmental Science, 1078(1), p. 012099. <https://doi.org/10.1088/1755-1315/1078/1/012099>.

<sup>102</sup> Gupta, S., Jha, K.N. and Vyas, G. (2020) 'Proposing building information modeling-based theoretical framework for construction and demolition waste management: strategies and tools,' International Journal of Construction Management, 22(12), pp. 2345–2355. <https://doi.org/10.1080/15623599.2020.1786908>.

<sup>103</sup> Jayasinghe, R.S., Chileshe, N. and Rameezdeen, R. (2019) 'Information-based quality management in reverse logistics supply chain,' Benchmarking an International Journal, 26(7), pp. 2146–2187. <https://doi.org/10.1108/bij-08-2018-0238>.

<sup>104</sup> Kim, S. and Kim, S.-A. (2022) 'A design support tool based on building information modeling for design for deconstruction: A graph-based deconstructability assessment approach,' Journal of Cleaner Production, 383, p. 135343. <https://doi.org/10.1016/j.jclepro.2022.135343>.

8	Kuzminykh et al. <sup>105</sup>	2024	Promoting circularity of construction materials through demolition digitalisation at the preparation stage: Information requirements and openBIM-based technological implementation	Journal	Advanced Engineering Informatics
9	Mattaraia et al. <sup>106</sup>	2023	Structure for the classification of disassembly applied to BIM models.	Journal	Architectural Engineering and Design Management
10	Mohammed et al. <sup>107</sup>	2024	Design for steel structures deconstruction: an analytics system for construction waste minimization in a circular economy through BIM technology	Journal	Innovative Infrastructure Solutions
11	Royano et al. <sup>108</sup>	2023	Analysis of classification systems for the built environment: Historical perspective, comprehensive review and discussion	Journal	Journal of Building Engineering
12	Sanchez et al. <sup>109</sup>	2024	BIM Model View Definition (MVD) for disassembly planning of buildings	Conference	Proc. Int. Symp. Autom. Robot. Constr.
13	Sanchez et al. <sup>110</sup>	2023	Identifying key parameters for BIM-based disassembly planning	Conference	Proc. Int. Symp. Autom. Robot. Constr.
14	Schamne et al. <sup>111</sup>	2024	BIM in construction waste management: A conceptual model based on the industry foundation classes standard	Journal	Automation in Construction

<sup>105</sup> Kuzminykh, A. et al. (2024) 'Promoting circularity of construction materials through demolition digitalisation at the preparation stage: Information requirements and openBIM-based technological implementation,' *Advanced Engineering Informatics*, 62, p. 102755. <https://doi.org/10.1016/j.aei.2024.102755>.

<sup>106</sup> Mattaraia, L., Fabricio, M.M. and Codinoto, R. (2021) 'Structure for the classification of disassembly applied to BIM models,' *Architectural Engineering and Design Management*, 19(1), pp. 56–73. <https://doi.org/10.1080/17452007.2021.1956420>.

<sup>107</sup> Mohammed, A., Ghannam, M. and Elmasoudi, I. (2024) 'Design for steel structures deconstruction: an analytics system for construction waste minimization in a circular economy through BIM technology,' *Innovative Infrastructure Solutions*, 9(11). <https://doi.org/10.1007/s41062-024-01703-2>.

<sup>108</sup> Royano, V. et al. (2023) 'Analysis of classification systems for the built environment: Historical perspective, comprehensive review and discussion,' *Journal of Building Engineering*, 67, p. 105911. <https://doi.org/10.1016/j.jobe.2023.105911>.

<sup>109</sup> Sanchez, B. et al. (2024) 'BIM Model View Definition (MVD) for disassembly planning of buildings,' *Proceedings of the 41st ISARC*. <https://doi.org/10.22260/isarc2024/0155>.

<sup>110</sup> Sanchez, B., Herthogs, P. and Stouffs, R. (2023) 'Identifying key parameters for BIM-based disassembly planning,' *Proceedings of the 40th ISARC*. <https://doi.org/10.22260/isarc2023/0007>.

<sup>111</sup> Schamne, A.N. et al. (2024) 'BIM in construction waste management: A conceptual model based on the industry foundation classes standard,' *Automation in Construction*, 159, p. 105283. <https://doi.org/10.1016/j.autcon.2024.105283>.





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