SIRCULAR

DELIVERABLE 1.1:

SIRCULAR Framework Analysis WP1

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OVERVIEW	
Project Acronym	SIRCULAR
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Abbreviations and Acronyms

ACRONYM	DESCRIPTION
BAMB	Buildings As Material Banks
BIM	Building Information Modelling
BoM	Bill of Materials
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Methodology
C2C	Cradle to Cradle
CDW	Construction and Demolition Waste
EMS	Environmental Management System
EPD	Environmental Product Declarations
EU	European Union
FSC	Forest Stewardship Council
GHG	GreenHouse Gas
GBCA	Green Building Council of Australia
GBCI	Green Business Certification Inc
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
ISO	International Standardisation Organisation
IWBI	International WELL Building Institute
KPI	Key Performance Indicator
LBC	Living Building Challenge
LCA	LifeCycle Assessment
LCC	LifeCycle Cost

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LEED	Leadership in Energy and Environmental Design
LFI	Linear Flow Index
MCI	Material Circularity Index
MMR	Material Recovery Rate
MP	Materials Passports
MRS	Material Reutilization Score
NDC	Nationally Determined Contributions
PDCA	Plan-Do-Check-Act
PM	Particulate Matter
ROI	Return On Investment
SDG	Sustainable Development Goals
SM	Square Meters
VOC	Volatile Organic Compounds
WP	Work Package

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Background: About the SIRCULAR project

SIRCULAR is coordinated by RINA-C and combines the expertise of 22 partners from six European countries, including universities, SMEs, NGOs, and industries. During the next three-and-a-half-years, SIRCULAR will transform the building sector into a circular and sustainable industry, aligned with the Built4People partnership principles.

We will test and demonstrate innovative technologies and services across four regional clusters: initially in Estonia and Spain, followed by Germany and Greece. These clusters will engage construction companies, housing companies, universities, and local administrative entities, focusing on buildings owned or occupied by vulnerable population groups, in line with the SIRCULAR just and affordable transition approach.

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Executive Summary

This document is providing an overview of the frameworks indicators and methodology to be applied in the SIRCULAR project. It establishes the grounds of the project in terms of conceptual definitions and how the evaluation frameworks for recyclability and circularity can be applied along the project. Based on existing frameworks, the most relevant ones have been selected to be analysed. Lessons learnt, best practices and potential indicators are obtained from the frameworks in order to determine the level of applicability of each one.

Secondly, based on the potential indicators determined by the frameworks, a set of KPIs are selected in the context of SIRCULAR project, classified in “mandatory”, “recommended” and “optional” metrics. Moreover, these are classified in three scopes of application: technological solution, part of the building (e.g., one wall) or whole building. Formulas and guidelines about the calculation methods are described to support the development of other project activities, concluding with a set of data requirements for data collection from the demos.

Lastly, the proposed methodology based on LEVEL(s) is outlined, where 3 main stages are set. From project conceptual design based on the expected outcome to the final assessment after the application of the technologies, passing through the baseline where the designs are prepared. This methodology provides the guideline about how to deal with the evaluation of the project results.

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1. Introduction

This deliverable is covering the grounds of the SIRCULAR project, where evaluation frameworks are analysed in order to support the selection of indicators to be applied in the final assessment. Then, guided by this deliverable, other activities should take into consideration the methodology and data requirements that are extracted here.

1.1 Objectives of the Deliverable

Under this document, as part of task 1.1 of the project, the first aim is the analysis of the currently existing decarbonization and circularity frameworks. The main goal of this analysis is to get a basis where the rest of the activities can be supported, like the material recyclability and circularity calculation within T1.2 or the overall SIRCULAR assessment methodology. By a review of the frameworks, conclusions and best practices are obtained.

Furthermore, potential KPIs are identified from each framework, which guides the definition of the metrics to be followed in the project (covering Recyclability and Circularity aspects). The KPIs are not only integrated into the methodology developed in T1.2, but also in other activities of the project to validate the expected outcomes.

Special mentions should be done to the EU LEVEL(s) framework for assessing the sustainability performance of the building, which guides the proposed methodology of the project, as well as lessons learnt, best practices and indicators are extracted from it. Furthermore, the proposed assessment framework under SIRCULAR has been aligned with LEVEL(s), not only from the methodology perspective, but it has been also considered as one of the primarily frameworks being applicable, extracting multiple indicators from it.

LEVEL(s) is also related to the SDG (Sustainable Development Goals) and relevant EU directives. In particular to the SDG13 Climate Action and SDG11 Sustainable Cities and Communities. However, SIRCULAR extends to reach other SDG, such as SDG3 about health and well-being by introducing comfort and indoor environmental quality indicators or SDG7 Affordable and clean energy where renewable energy contribution indicator is also included.

The target audience of this document is wide and diverse, including researchers and academics, project stakeholders, industry professionals or policy makers, among others. As it establishes the grounds for assessment and identifies KPIs for the Recyclability and Circularity aspects, it could be considered as a guideline to be followed for the rest of stakeholders.

1.2 Structure of the Document

Within the document, it is structured as follows:

- Decarbonization and circularity frameworks' analysis, where each of the selected frameworks is summarised by the key topics. This section outlines all the frameworks with a short summary, its applicability into SIRCULAR and potential KPIs.
- Definition of Key Performance Indicators, which selects the most suitable indicators from the previous frameworks to be applicable in SIRCULAR project, as well as it concludes with a set or preliminary data requirements.
- Methodology to be followed in the project to carry out the baseline and evaluation activities, guided by LEVEL(s) methodology.

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1.3 Relation to Project Documents

This is the first technical deliverable of the project (whereas administrative and management ones were submitted); therefore, not relation with past technical documents is applicable. However, it influences on the following deliverables:

- D1.2 with definition of the Material Circularity Index, as well as other indicators.
- D1.4 under the air quality indicator definition to be applied in the T1.4.
- D4.4, where monitoring programmes with be defined, considering the inputs of data requirements to calculate the indicators.

1.4 Overall Approach

Within the deliverable, the approach has followed the next steps:

1) Definition of frameworks to be analysed, sharing responsibilities between partners as listed in Table 1 and extracting the lessons learnt / best practices from each framework.
2) Establishing the potential KPIs from the selected frameworks and re-refine them to be adapted and used within the SIRCULAR framework.
3) Setting the preliminary data requirements for the calculation of the KPIs to serve as input for the monitoring programmes.
4) Provision of the methodology to be followed within the SIRCULAR project.

Table 1: Frameworks under evaluation and responsible partner in charge of the analysis

Framework	Responsible partner
LEED	RINA-C
BREEAM	CARTIF
C2C	ITeC
Living building challenge	ICLEI
Green Star	CERTH
Well Building Standard	ICLEI
ISO 14001	CARTIF
Material Passport	ITeC
EU LEVEL(s)	CARTIF
ISO 59020 Circular economy	ITeC
ISO 20887	ITeC
Material Circularity Indicator methodology	RINA-C

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With respect to interdependencies with other project activities, WP1 is closely related to T1.2 and T1.4, where calculation methodologies are defined for material circularity and recyclability, as well as indoor air quality. It also establishes the basis for WP2 where the platform should include the calculation methodologies for the KPIs defined under this deliverable. Moreover, WP4 is influenced by this deliverable as data from demos should be provided in order to enable the KPIs calculation, whereas monitoring programmes will be defined in T4.4. Finally, under the concept definition, this deliverable sets a common understanding of some concepts that are applicable across all the project activities.

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2. Concepts definition

Common concepts are pivotal for a common understanding of the approach. That is why this section aims the definition of the concepts to be used within the SIRCULAR project, having a common framework for the key aspects within multiple WPs. Table 2 collects all the definitions to be used within the SIRCULAR project.

Table 2: Concepts definition for the SIRCULAR project

Concept	Definition
Bill-of-Materials	A bill of materials (BoM) is a list of the parts or components that are required to build a product. For each of the components the precise type and amount of material is listed.
Circularity	Designing and constructing structures to enable the continuous reuse, recycling, and regeneration of materials and resources, minimizing waste and maximizing their lifecycle.
Construction product	A building component manufactured as a distinct unit to serve a specific function or functions (e.g. window, prefabricated façade, etc.).
Decarbonisation	Process of reducing greenhouse gas emissions throughout a building's lifecycle by adopting energy-efficient designs, using low-carbon materials, transitioning to renewable energy sources, and implementing sustainable construction and operational practices.
Disassemblability	The non-destructive taking-apart of construction product into constituent materials or components efficiently for reuse, recycling, or maintenance, promoting sustainable building practices.
Embodied carbon emissions	Greenhouse gas emissions are associated with the materials and processes used throughout a building's lifecycle, excluding energy use.
Energy use	Consumption of energy resources from heating and cooling systems to ensure thermal comfort values in buildings.
Greenhouse gas emissions in use	Greenhouse gas emissions are associated with energy use for heating and/or cooling buildings.
Recyclability	Ability of construction materials to be processed and reused as raw materials for new products, reducing waste and conserving resources.

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Reuse	According to the Waste Framework Directive, it means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived.
Sustainability	Design, construction, and operation of buildings in ways that minimize environmental impact, promote energy and resource efficiency, enhance occupant well-being, and ensure long-term resilience while reducing waste and carbon footprint.

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3. Decarbonization and circularity frameworks' analysis

3.1 Review of existing frameworks

This section is dedicated to the review of the different frameworks that were proposed within Table 1. Each section is dedicated to summarise one-by-one the frameworks, providing a discussion at the end of the chapter to determine which is better adapting the SIRCULAR necessities. Basically, a summary of the framework is described, how the framework applies for recyclability and circularity aspects according to SIRCULAR definition and the potential KPIs are extracted from each one.

3.1.1 LEED

The first framework is LEED, whose summary can be found in Table 3 below.

Table 3: LEED framework summary

Name of the framework under evaluation: LEED [1]	
Summary	The US Green Building Council developed the Leadership in Energy and Environmental Design system-LEED-better known as-to provide a recognized certification system for sustainable building practices around the world. Buildings are rated according to energy efficiency, water conservation, indoor environmental quality, and use of sustainable materials. Certification levels under LEED are as follows: Certified, Silver, Gold, and Platinum, on a point system basis. There are rating systems for different types of projects, including New Construction, Existing Building, and Residential Projects. Benefits of sustainable design include minimized impact on the environment, improved health of occupants, and increased marketing potential of buildings.
SIRCULAR approach	
Recyclability aspects	LEED encourages recyclability by offering credits for the use of materials containing recycled content, implementing waste management policies, and promoting design practices in buildings that facilitate reuse or material recycling. It addresses reducing construction waste, minimising environmental impact from materials, and developing systems to support recycling during construction and continued operation.
Circularity aspects	LEED tackles these issues of circularity with the promotion of sustainable practices is the Leadership in Energy and Environmental Design framework of LEED, with the aim of aligning the principles of such a circular economy. Circularity means designing systems and materials to reduce waste, allow for the highest reuse, and create closed-loop processes. Among the main issues that LEED addresses about circularity are efficiency in resources, reutilization of materials, and waste minimization in the life cycle of a building.

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Other aspects	The LEED framework addresses an extensive variety of issues related to building performance, occupants' well-being, and environmental impacts. Besides the perspective of recyclability and circularity, it also considers in-depth comfort, energy, and other key issues through holistic points across several categories, focusing on the optimization of performance while minimizing harm to the environment and enhancing the health and comfort of the occupants.
Potential KPIs	• KPI1: Percentage of Renewable Energy Usage • KPI2: Reduction in Greenhouse Gas Emissions • KPI3: Energy Use Intensity • KPI4: Water Use Intensity • KPI5: Percentage of Water Reused or Recycled • KPI6: Reduction in Potable Water Use • KPI7: Percentage of Recycled Content in Materials • KPI8: Indoor Air Quality (IAQ) Score • KPI9: Thermal Comfort Satisfaction Rate • KPI10: Percentage of Sustainably Certified Products • KPI11: Occupant Satisfaction Score
Other considerations to be taken into account from the framework	
n.a.	

3.1.2 BREEAM

Second framework is BREEAM, which is quite related to LEED. Table 4 provides the information following the same approach as before.

Table 4: BREEAM framework summary

Name of the framework under evaluation: BREEAM [2]	
Summary	BREEAM (Building Research Establishment Environmental Assessment Method) was developed in 1990 by the Building Research Establishment (BRE)[1] in the UK. It was the world's first method of assessing the sustainability of buildings, responding to growing concerns about the environmental impact of buildings throughout their life cycle, from construction to operation. Since its launch, BREEAM has expanded to cover a wide range of building types and uses, including new construction, refurbishment and large-scale community developments.
SIRCULAR approach	

[1] https://bregroup.com/

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Recyclability aspects	BREEAM promotes the use of recyclable materials and those with high recycled content, awarding credits for materials with Environmental Product Declarations (EPDs), based on the product Lifecycle Assessment (LCA) with ISO 14040:2006 [3], ensuring transparency regarding environmental impacts, including recyclability. It encourages comprehensive waste management plans during construction and demolition to maximise recycling and reduce landfill waste, with on-site segregation of recyclable materials. BREEAM also supports responsible sourcing of materials to reduce the reliance on finite resources. In the post-occupancy phase, BREEAM promotes recycling facilities within buildings to support ongoing waste management. This ensures recyclability is integrated throughout a building's lifecycle, reducing environmental impact and supporting circularity principles.
Circularity aspects	BREEAM incorporates circularity principles by promoting durable design and LCA to minimise material use and extend building lifecycles. It supports demountability and disassembly to enable buildings to be easily adapted or deconstructed, maximising reuse. Deep renovation is encouraged to reduce demolition and extend asset lifespans. BREEAM also promotes modular construction for easier reconfiguration and material reuse, along with sustainable procurement of materials from responsible sources, prioritising renewables. These strategies align with BREEAM's goal of reducing reliance on finite resources, promoting reuse, and ensuring resilience across a building's lifecycle, supporting the circular economy.
Other aspects	BREEAM supports circularity by addressing energy and water efficiency, reducing operational energy and embodied carbon through the use of renewable energy systems and efficient resource management. It promotes on-site/near-site renewable energy generation and recognises buildings that become carbon positive by exporting excess energy. BREEAM also encourages durable design, ensuring buildings are resilient to changes over time, with an emphasis on reducing environmental impact while enhancing occupant health and well-being through good air quality, natural lighting, and thermal comfort. Pollution reduction is also addressed to minimise emissions, waste, and light pollution, supporting sustainability goals aligned with the circular economy.
Potential KPIs	RECYCLABILITY ASPECTS • BREEAM_KPI1: Percentage of recycled materials used in construction (%): Measures the percentage of recycled content materials out of the total materials used in the project. • BREEAM_KPI2: Percentage of construction waste diverted from landfills (%): Indicates the percentage of waste generated during construction that is recycled, reused, or diverted from landfills. • BREEAM_KPI3: Recyclability rate of materials (%): Evaluates the percentage of materials used in the project that can be recycled at the end of their lifecycle.

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- BREEAM_KPI4: Number of products with EPDs (Environmental Product Declarations): Tracks the number of materials used that come with EPDs, providing information on their environmental impact and recyclability.
- BREEAM_KPI5: Post-occupancy waste recycling rate (%): Monitors the effectiveness of the recycling systems implemented during the building's operation, measured by the amount of waste recycled compared to the total waste generated.

CIRCULARITY ASPECTS

- BREEAM_KPI6: Percentage of materials designed for disassembly or reuse (%): Measures the proportion of materials and components in the building that are designed to be easily disassembled and reused in future projects.
- BREEAM_KPI7: Proportion of reused materials from existing structures (%): Indicates the percentage of materials sourced from previous demolitions or refurbishments and reused in the new project.
- BREEAM_KPI8: Design flexibility score (qualitative): Assesses the building's ability to be adapted to different future uses, based on its modularity and ease of reconfiguration.
- BREEAM_KPI9: Deep renovation to new construction ratio (%): Measures the ratio of projects that opt for deep renovations versus demolition and new construction, supporting the extension of building lifecycles.
- BREEAM_KPI10: Projected material durability (years): Evaluates the expected lifespan of materials used, ensuring their long-term sustainability and contribution to circularity.

OTHER CIRCULAR-RELATED ISSUES

- BREEAM_KPI11: Operational energy consumption (kWh/m²/year): Measures the energy consumed per square meter of the building annually, promoting the use of energy-efficient systems and technologies.
- BREEAM_KPI12: Proportion of renewable energy generated on-site (%): Evaluates the percentage of energy generated from on-site renewable sources, such as solar panels or wind turbines, compared to the total energy consumption.
- BREEAM_KPI13: Water consumption reduction (%): Measures the percentage reduction in water consumption compared to standard buildings, encouraging the use of water-saving technologies like greywater recycling and rainwater harvesting.
- BREEAM_KPI14: Embodied carbon emissions (kg CO_2e/m^2): Tracks the total carbon emissions embedded in the building materials and construction processes, calculated per square meter of the building's area.
- BREEAM_KPI15: Indoor air quality (CO_2 levels in ppm, PM2.5, VOCs): Monitors levels of indoor air pollutants (e.g., carbon dioxide, particulate

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	matter, volatile organic compounds) to ensure a healthy environment for occupants. • BREEAM_KPI16: Carbon positive building status (yes/no): Determines whether the building produces more renewable energy than it consumes, potentially becoming carbon positive.
Other considerations to be taken into account from the framework	
It should be noted that there is a cost associated with BREEAM certification of a project. The price varies depending on factors such as the type, size and complexity of the project, as well as the level of certification desired (e.g. Pass, Good, Excellent).	

3.1.3 Cradle to Cradle - C2C

The next one is Cradle to Cradle, in short C2C, whose information is available on Table 5.

Table 5: C2C framework summary

Name of the framework under evaluation: Cradle to Cradle Certified® [4]	
Summary	The Cradle to Cradle Certified® standard is a multi-attribute, science-based standard for designing and manufacturing products that contribute to a healthy, equitable, and sustainable future. It goes beyond traditional environmental standards by evaluating products based on their ability to be reused, recycled, or composted at the end of their life. Key Requirements of C2C: • Material Health: All materials used in the product are assessed for their chemical safety and impact on human and environmental health. • Product Circularity: Products are designed for continuous reuse and recycling, minimizing waste and resource depletion. • Clean Air & Climate Protection: Production processes and the product itself minimize greenhouse gas emissions and other air pollutants. • Water & Soil Stewardship: Water and soil resources are conserved and protected throughout the product's life cycle. • Social Fairness: Companies demonstrate ethical and fair labour practices and respect human rights. Certification Process: Products are assessed against these five categories, with the possibility of achieving Bronze, Silver, Gold, or Platinum certification levels based on their performance in each category. The certification process involves a thorough assessment of the product and its manufacturing processes, along with ongoing monitoring and improvement. Benefits of C2C Certification • Demonstrates a commitment to sustainability: C2C certification is a globally recognized mark of sustainable product design and manufacturing.

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	• Drives innovation: The standard encourages companies to develop innovative solutions for material health, circularity, and environmental protection. • Enhances brand reputation: C2C certification can improve a company's reputation and appeal to environmentally conscious consumers. • Facilitates market access: Some markets and procurement programs favour C2C certified products. Current Version and Future Developments: The latest version of the standard (Version 4.1 [4]) was released in 2023 and includes updates to all five categories, with a particular emphasis on climate protection and social fairness. The Cradle to Cradle Products Innovation Institute continues to develop and evolve the standard to reflect the latest scientific understanding and address emerging sustainability challenges.
SIRCULAR approach	
Recyclability aspects	One of the Cradle to Cradle® principles is to eliminate the concept of waste, that is tackled in the category Material Reutilization principle of Version 3.1 of the standard. According (Ref. 16)[2] : • Eliminate the Concept of 'Waste': "A significant focus of Cradle to Cradle® as a product design framework is to promote the creation of an optimized materials economy that eliminates the concept of "waste." This category of the program is intended to create incentives for industry to eliminate the concept of "waste" by designing products with materials that may be perpetually cycled to retain their value." • "Material reutilization is a key component of Cradle to Cradle design is the concept of technical nutrients and biological nutrients flowing perpetually in their respective metabolisms. Products are evaluated for their nutrient potential and nutrient actualization, as well as the role the manufacturer plays in material/nutrient recovery." • The intention of this category is to provide a quantitative measure of a product's design for recyclability and/or compostability. The larger the percentage of a product and/or its components that remain in a technical and/or biological metabolism, the better the score for this category". • Material reutilization Score (MRS), the nutrient management strategy and the nutrient cycling are the indicators used to evaluate this category. The MRS is calculated as:

[2] C2C - Public resources https://c2ccertified.org/resources. Cradle to cradle certified®, Product Standard v.4.1., 2016. Cradle to Cradle Products Innovations Institute, prepared by MBDC in collaboration with the Environmental Protection Encouragement Agency, GmbH

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$$\frac{\left[\begin{array}{c}\% \ recycled \ or \ rapidly \ renewable \\ product \ content\end{array}\right] + 2\left[\begin{array}{c}\% \ of \ product \ recyclable \\ or \ biodegradable/compostable\end{array}\right]}{3} x100$$

Version 4.1 of the C2C standard maintains a strong emphasis on recyclability within its Product Circularity requirements. However, it introduces refinements to enhance its effectiveness:

- Streamlined Material Categorization: The standard simplifies the categorization of materials into "Technical Nutrients" and "Biological Nutrients," aiding clarity in recycling and reuse pathways.
- Enhanced Design for Disassembly: Requirements for easy disassembly and material separation are further strengthened, encouraging modular design and the use of standardized components for efficient recovery and recycling.
- Emphasis on Reuse and Remanufacturing: The standard now places greater emphasis on higher-order circularity strategies like reuse and remanufacturing, promoting the extension of product life and reduction of material consumption.

The term "cycling" is used throughout the standard. Per the Definitions section, this term refers to the processing of material, parts, or whole products toward a new use cycle via a technical or biological cycling pathway. The term encompasses the various methods of doing so, including reusing, repairing, refurbishing, remanufacturing, repurposing, recycling, composting, and biodegradation. The terms cyclable and recyclable are not widely used in the standard. This is because these terms have been deconstructed into their critical underlying elements – sourcing, design (including design for disassembly and compatibility for cycling), and systems. All three of these are necessary to ensure that materials are cyclable and recyclable.[3]

The primary goal of *the Section 5.7: Product Designed for Disassembly* is to assess how well a product is designed to be taken apart at its end-of-life, enabling efficient material recovery and recycling.

Evaluation Criteria. While the standard does not provide a rigid formula, it outlines key criteria to consider when evaluating a product's disassembly potential:

1) Fastener Choice: Prioritize the use of standardised and easily accessible fasteners like screws or clips over permanent connections like adhesives or welding. This allows for easier and less destructive disassembly.
2) Minimization of Permanent Connections: The fewer permanent connections used, the better. If adhesives are necessary, they should ideally be reversible or designed to facilitate separation during recycling.
3) Clear Labelling & Component Identification: Components should be clearly labelled or marked to aid in identification during disassembly. This facilitates efficient sorting and material recovery.

[3] C2C Certified v4.1 Product Standard - User guidance

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	4) Modular Design: A modular design, where components can be easily separated and replaced, is preferred as it simplifies disassembly and enables potential reuse or repair. 5) Disassembly Instructions: Providing clear and accessible disassembly instructions or guides is crucial. These should detail the required tools, steps, and any safety precautions. 6) Tool Requirements: The tools needed for disassembly should be minimal, readily available, and commonly used, avoiding the need for specialized equipment. Evaluation Process. The evaluation process typically involves: • Review of Design Documents: Assessors will thoroughly review the product's design documents and schematics to understand its construction and identify potential disassembly challenges. • Physical Disassembly (if possible): Ideally, a physical disassembly of the product or a representative sample will be conducted to observe the ease of disassembly in practice. • Expert Consultation (if necessary): In complex cases, assessors may consult with disassembly or recycling experts to gain further insights into the product's disassembly potential.

Circularity aspects	The Product Circularity category in Version 4.1 undergoes significant enhancements to foster a more comprehensive circular economy approach:
	
	• Prioritization of Circular Business Models: The standard now explicitly encourages the adoption of circular business models such as leasing, product-as-a-service, and take-back programs, incentivizing product longevity and material recovery.
	• Expanded Focus on Material Reutilization: The standard places increased emphasis on strategies to ensure materials are reused at their highest possible value, minimizing downcycling and waste.
	• Integration with the EU Green Deal: Version 4.1 aligns more closely with the circular economy principles of the EU Green Deal, facilitating compliance and market access for companies operating in the European Union.
	
	Product Circularity consists of three requirements focus areas: Circular Sourcing, Circular Design, and Circular Systems. The individual standard sections fit into the framework as follows:
	
	• Circular Sourcing requirements focus on maximizing the amounts of cycled and/or responsibly sourced renewable content in products to support the demand side of circularity:
	    o Section 5.3: Increasing Demand: Incorporating Cycled and/or Renewable Content. The documentation needed is:
	        ▪ Bill of Materials (BOM): A detailed BOM clearly identifying the cycled and/or renewable content used in each material component of the product.

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- Origin & Quality Documentation for Cycled Content: Evidence demonstrating the source and quality of any cycled content used, including supplier certifications and chain of custody records.
- Sustainability Compliance for Bio-based Materials: For materials derived from renewable sources, documentation showing compliance with relevant sustainability standards.
- Environmental Benefits Assessment: A Life Cycle Assessment (LCA) or similar study quantifying the positive environmental impacts associated with using cycled and/or renewable content.
- Marketing and Communication Materials: Any marketing materials or communication strategies that emphasize the incorporation of cycled and/or renewable content in the product.

In essence, this documentation serves to verify the claims made about the use of cycled and renewable materials, ensuring transparency and accountability within the C2C certification process.

- Circular Design requirements focus on intentional product design that will enable cycling after use. This includes identifying the appropriate cycling pathways for products and materials, selecting materials with high cycling capacity and value, and designing the product so that it is compatible with the intended cycling pathways:
  - Section 5.1 Defining the Product's Cycles: Technical (reuse, repair, refurbish, remanufacture, repurpose, recycling -mechanical or chemical-) and/or Biological (nutrient extraction, anaerobic digestion, composting (home), composting (industrial), biodegradation (soil), biodegradation (water), biodegradation (anaerobic)).
  - Section 5.4 Material Compatibility for Technical and/or Biological Cycles: Assessment showcasing that materials are suitable for their intended cycles (technical or biological) and evidence demonstrating that these materials won't cause harm or contamination to other materials during recycling or composting processes.
  - Section 5.6 Circular Design Opportunities and Innovation, where is needed clear descriptions of any unique or innovative design features implemented to enhance the product's circularity and explanation of how these specific design features contribute to improving the product's overall circularity performance.
  - Section 5.7 Product Designed for Disassembly: Demonstration (through diagrams, descriptions, etc.) that the product can be disassembled efficiently. Details on the methods and tools required for disassembly. Information on how the design facilitates the separation of different materials for effective recycling or reuse.

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	- Circular Systems requirements focus on ensuring the product is cycled after use. Initially, this requires developing a plan to address the challenge(s) inhibiting development of the cycling:
	  - Section 5.2 Preparing for Active Cycling, the required documentation by level is:
	    - Material selection strategy prioritizing cycled and/or renewable materials: This demonstrates a conscious effort to integrate materials that support a circular economy into the product design.
	    - Design for disassembly plan facilitating material separation and recovery: This shows the product is designed to be easily taken apart at its end-of-life, promoting efficient material recovery and recycling.
	    - Supplier engagement strategy to ensure access to cycled and/or renewable materials: This highlights proactive efforts to collaborate with suppliers and ensure the availability of necessary materials for circularity.
	    - Internal training and awareness programs on circularity principles for relevant staff: This demonstrates the commitment to educating and empowering employees to contribute to the company's circularity goals.
	    - Feasibility study or life cycle assessment (LCA) exploring the environmental benefits of using cycled and/or renewable materials: This provides evidence-based support for the choices made, quantifying the positive impacts on the environment.
	  - Section 5.5 Circularity Data and Cycling Instructions: firstly material composition details, disassembly instructions, information on material recovery processes, recycling or composting guidelines, secondly clear instructions on how to properly handle the product at its end-of-life to facilitate recycling or other circular pathways. This might include: how to identify materials for cycling, any necessary product maintenance, specific recovery, reprocessing, or recycling instructions
	  - Section 5.8 Active Cycling: Description of any existing or planned programs aimed at actively cycling the product or its materials. Information about any partnerships, take-back systems, or other initiatives implemented to support active cycling. Evidence (if applicable) demonstrating the product's successful participation in active cycling programs.

Other aspects	Version 4.1 also introduces updates to address a broader range of environmental concerns: - Material Health: The standard further strengthens chemical restrictions, especially at the Bronze level, aligning with leading chemical regulations and enhancing human and environmental safety.

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	• Clean Air & Climate Protection: Requirements for renewable energy use and greenhouse gas emissions reduction are tightened, encouraging greater climate action. • Water & Soil Stewardship: The standard promotes more efficient water use and wastewater treatment practices, enhancing protection of aquatic ecosystems. • Social Fairness: Version 4.1 includes enhanced requirements for social responsibility, including due diligence in supply chains and respect for human rights.
Potential KPIs	Material Health • Toxic chemical content: Percentage of toxic chemicals used in the product compared to a benchmark. • Material health certification: Percentage of materials with certifications like Cradle to Cradle certification or other health-focused certifications. • Health impact assessment: Score or rating based on a health impact assessment tool. Material Stewardship • Recyclability rate: Percentage of the product that can be recycled or reused. • Recycled content: Percentage of recycled materials used in the product. • Biodegradability rate: Percentage of the product that can be composted or biodegraded. Renewable Energy • Renewable energy usage: Percentage of renewable energy used in the manufacturing process. • Carbon footprint reduction: Percentage reduction in carbon footprint compared to a baseline. • Renewable energy certifications: Number of certifications related to renewable energy usage. Water Stewardship • Water consumption: Amount of water used per unit of product. • Water efficiency: Water consumption per unit of product compared to a benchmark. • Water pollution reduction: Percentage reduction in water pollution. Social Fairness • Fair labour practices: Compliance with fair labour standards and certifications. • Community impact: Positive impact on local communities, measured by factors like job creation or community development initiatives. • Social responsibility certifications: Number of certifications related to social responsibility.

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Other considerations to be taken into account from the framework
To improve the score in a final product, C2C suggest initiating or having in mind the following actions: About Circular Design: – Increased end-of-use cycling – Greater engagement with users for end-of-use cycling – Prolonged use of the product: longevity – Decreased need to extract and produce virgin materials. For Circular Systems: Strong partnership is needed

3.1.4 Living building challenge

About Living building challenge case, Table 6 provides the insights for the framework.

Table 6: Living building challenge framework summary

Name of the framework under evaluation: Living Building Challenge [5]	
Summary	The Living Building Challenge is a philosophy, advocacy tool, and certification defining the most advanced measure of sustainability in the built environment today. It addresses all buildings at all scales and is an inclusive tool for transformative design. Whether the project is a single building, a renovation, an infrastructure project, or a park, the Living Building Challenge provides a framework for design, construction, and improvement of the symbiotic relationships between people and all aspects of the built and natural environments. The internal logic of the Living Building Challenge is based on pragmatic, tested experience with what has already been built in the marketplace. The Living Building Challenge consists of seven performance categories, or "Petals": Place, Water, Energy, Health + Happiness, Materials, Equity, and Beauty. Each Petal is subdivided into Imperatives. There are 20 Imperatives spread throughout the seven Petals: 10 Core Imperatives that address the fundamental tenets of each Petal and 10 more that push performance into the realm of positive impact. The Core Imperatives are not only integral to LBC, but together they also comprise the requirements of the Core certification and form the foundation for Petal certification. Although it is ambitious to achieve all of the requirements of the Living Building Challenge, the performance-based approach creates a clarity and ease of use. The Imperatives are performance-based and position the ideal outcome as an indicator of success. The specific methodology used to meet the expectations of the Living Building Challenge is not up to the Institute, but rather to the co-creative process of the design teams, owners, and occupants themselves.

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Recyclability aspects	For material [within the Material petal]
	• Responsible material - Core Imperative 12 [Strong focus on wood, not on another specific material]:
	  ○ The project must contain one Declare label (a label for product developed by ILFI) product per 200 square meters (sm) of Project Floor Area, up to twenty distinct products from five manufacturers.
	  ○ 50% of wood products must be FSC (Forest Stewardship Council), salvaged, or harvested on site either for the purpose of clearing the area for construction or to restore or maintain the continued ecological function of the site. The remainder must be from low risk sources.
	  ○ The project must divert 80% of the construction waste material from the landfill and provide dedicated infrastructure for the collection of recyclables and compostable food scraps during occupancy.
	In order to meet high diversion rates, project teams are expected to go beyond business as usual in order to stimulate and support recycling innovators if necessary. Project teams are encouraged to examine alternative construction methods that might reduce the amount of product waste, particularly where no recycling infrastructure exists locally, and to consider the challenges of recycling when determining whether to use specific products in the project.
	At the building level [within the Energy petal]:
	• Energy + Carbon reduction – Core Imperative 07:
	Under "Embodied carbon":
	New Building and Building Renovation projects must demonstrate a 20% reduction in the embodied carbon of primary materials and exterior materials compared to a baseline building of equivalent size, function, and energy performance. Building Renovation projects may count the reuse of in-situ primary and exterior materials against the required 20%.
	Under "Embodied carbon reduction clarifications":
	Project teams that reuse an existing building may count the reuse of any in-situ primary materials and exterior materials against the required reduction percentage. When pursuing I08 Net Positive Carbon, the impacts of any new materials added to the reused building must also be calculated and offset.
	Similarly, the use of salvaged or recycled primary and exterior materials may contribute to meeting the reduction requirement. This reduction can be quantified by removing the embodied carbon impacts of the materials that would have otherwise been sourced new.

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	For water [within the Water petal] • Net positive water – Imperative 06: All projects must supply one hundred percent of the project's water needs through captured precipitation or other natural closed-loop water systems, and/or through recycling used project water, and all water must be purified as needed without the use of chemicals. No potable water may be used for non-potable uses. All projects must address all grey and black water through on-site treatment and management through reuse, a closed loop system, or infiltration.
Circularity aspects	"Circularity" is not mentioned namely within the document. However, they have an interesting approach to local sourcing for different resources (material – wood, food and agriculture, water) For material [within the Material petal] • Responsible sourcing - Imperative 14: The intent of this Imperative is to support sustainable extraction of materials and transparent labelling of products. All projects must advocate for: – The creation and adoption of third-party certified standards for sustainable resource extraction and fair labour practices for extraction of rock, metal, and minerals. – Certification under the Natural Stone Sustainability Standard – ANSI/NSI 373 by quarries and/or manufacturers of all dimension stone products used within the project. • Living Economy Sourcing – Imperative 15: The intent of this Imperative is to foster local communities and businesses, while minimizing transportation impacts. The project must incorporate place-based solutions and contribute to the expansion of a regional economy rooted in sustainable practices, products, and services. • Net positive waste – Imperative 16: The intent of this Imperative is to integrate waste reduction into all phases of projects and to encourage imaginative reuse of salvaged "waste" materials. All projects must strive to reduce or eliminate the production of waste during design, construction, operation, and end of life in order to conserve natural resources and to find ways to integrate waste back into either an industrial loop or a natural nutrient loop. All projects must feature at least one salvaged material per 500 square meters (sm) of Project Floor Area, or be an adaptive reuse of an existing structure. All projects must create a Materials Conservation Management Plan that explains how the project optimizes materials in each of the following phases: – Design Phase, including the consideration of deconstruction and appropriate durability in product specifications.

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	– Construction Phase, including product optimization and collection of waste materials for reuse or recycling. – Operation Phase, including a collection plan for extra consumables and durables. – End of Life Phase, including a plan for adaptable reuse and deconstruction. All projects must divert waste material from the landfill to the following levels (by weight or volume) during construction. Projects located on sites with existing infrastructure must complete a pre-building audit that inventories available materials and assemblies for reuse or donation. For urban agriculture [within the Place petal] • Urban agriculture – Imperative 02: All projects must dedicate a portion of their total Project Boundary to growing food, or they must dedicate a smaller portion of their total Project Boundary to growing food and must also directly provide weekly community access to healthy local food. For biowaste [within the Materials petal] • Responsible materials – Core Imperative 12: At a minimum, the project must include a functional collection area and have a policy or contract to process recyclables and compost for beneficial use during the occupancy phase of the project.
Other aspects	Comfort [within the Health and Happiness petal]: • Healthy Interior Performance – Imperative 10: To promote good indoor air quality performance, all projects must: – Provide the results from an Indoor Air Quality test one to six months after occupancy, or provide readings from an ILFI-approved continuously monitored indoor air quality system showing compliance with respective thresholds (listed in Tables 10-1 and 10-2). In addition, all projects must provide at least two of the following for occupant control: – Sufficient operable windows to provide natural ventilation for at least six months of the year. – Ability for the occupants to influence their local airflow and temperature through direct input or controls. Pollution and hazardous materials [within the Materials petal]: • Red list – Imperative 13:

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	The intent of this Imperative is to foster a transparent materials economy free of toxins and harmful chemicals.
Potential KPIs	KPIs for materials: • 50% of wood products must be FSC, salvaged, or harvested on site either for the purpose of clearing the area for construction or to restore or maintain the continued ecological function of the site. The remainder must be from low risk sources. • The project must divert 80% of the construction waste material from the landfill and provide dedicated infrastructure for the collection of recyclables and compostable food scraps during occupancy. • Incineration or allocation as "alternative daily cover" is not considered diverted and must be counted as waste. • All projects must source 80% or more of all wood, by cost or volume, as either Forest Stewardship Council (FSC) certified, or as salvaged, or from the intentional harvest of on-site timber for the purpose of clearing the area for construction or restoring/maintaining the continued ecological function of the on-site bionetwork, and the remaining 20% of wood must be from low-risk sources. KPIs for local materials sourcing: Manufacturer location for materials must adhere to the following restrictions: • 20% or more of the materials construction budget must come from within 500 kilometres of the construction site • 30% of the total materials construction budget must come from within 1000 km of the construction site or closer. • An additional 25% of the materials construction budget must come from within 5000 km of the construction site. • The remaining 25% of materials may be sourced from any location. KPI on embodied carbon in the building: New Building and Building Renovation projects must demonstrate a 20% reduction in the embodied carbon of primary materials and exterior materials compared to a baseline building of equivalent size, function, and energy performance. Building Renovation projects may count the reuse of in-situ primary and exterior materials against the required 20%. KPI on recycled water: All projects must supply one hundred percent of the project's water needs through captured precipitation or other natural closed-loop water systems, and/or through recycling used project water, and all water must be purified as needed without the use of chemicals. No potable water may be used for non-potable uses.

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Other considerations to be taken into account from the framework
ILFI has developed other certification programs: Zero Energy Certification, Zero Carbon Certification, Declare. They refer quite often to those certifications/labels within LBC. No focus is made on concrete. The main material which has specific targets is the wood.

3.1.5 Green Star

Green Star framework is summarised in Table 7.

Table 7: Green Star framework summary

Name of the framework under evaluation: Green Star [6]

Summary

Green Star is a voluntary environmental framework designed primarily for the evaluation of the building environment's sustainability and well-being. It was established in 2003 by the Green Building Council of Australia (GBCA) in response to an increasing request for a unified standard in Australia that could evaluate the environmental performance of buildings beyond traditional building standards. Specifically, the framework rates projects beyond simple energy efficiency analysis, including a broad range of sustainability issues, such as water efficiency, indoor environmental quality, materials selection, and reuse and recycling of building materials [7]. Dividing these categories into credits (subcategories), each addressing an initiative to improve environmental performance, it awards points for actions demonstrating that the project has met the overall Green Star objectives. The respective certification of commercial buildings concerns the three below stages (Figure 1) and depends on the design and delivery of the fit-out phase of the green building:

- 4 Star: 45–59 points, indicating "Best Practice,"
- 5 Star: 60–74 points, indicating "Australian Excellence," and
- 6 Star: 75–100 points, indicating "World Leader."

Figure 1. Green Star rating scale according to Green Building Council Australia [8]

Green Star provides a holistic view of a building's environmental attributes and performance by evaluating these areas. In an EU context, particularly for an

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infrastructure or construction project, the Green Star Framework serves as a comprehensive tool that can be adapted to assess recyclability and circularity as part of its sustainability approach. Below are presented the focal key features of the Green Star framework, focusing on the buildings' performance [9]:

1) Carbon neutrality focus: Emphasizes designs that achieve net-zero carbon emissions in operations.
2) Health and wellbeing: Incorporates measures to enhance indoor environmental quality for occupants.
3) Resilience and adaptation: Encourages designs that are resilient to climate change impacts.

More precisely, the Green Star rating system evaluates buildings across several key categories that are listed below [10]:

1) Energy Efficiency: Measures how effectively a building uses energy, encouraging designs that reduce consumption and reliance on non-renewable energy sources.
2) Water Conservation: Assesses strategies for reducing water usage and promoting efficient water management systems.
3) Indoor Environmental Quality: Examines factors that affect occupant health and comfort, such as air quality, lighting, acoustics, and thermal conditions.
4) Materials Selection: Evaluates the use of sustainable, recycled, or low-impact materials in construction.
5) Land Use and Ecology: Considers the project's impact on local ecosystems and promotes biodiversity.
6) Emissions: Addresses the reduction of pollutants and greenhouse gas emissions.
7) Innovation: Rewards projects that implement innovative sustainable practices beyond the standard criteria.

SIRCULAR approach

Recyclability aspects

The framework approaches recyclability through its Materials and Life Cycle Assessment (LCA) categories:

- Materials Credits: These credits are awarded for the use of sustainable and recyclable materials. Green Star promotes the selection of materials that are either:
    - Recyclable at the end of their life.
    - Composed of a significant percentage of recycled content.
    - Sourced from sustainable suppliers with environmental certifications.
- Waste Management: The framework emphasizes waste reduction strategies during construction by encouraging projects to minimize waste and prioritize recycling of construction and demolition waste. This includes:
    - Setting targets for reducing waste to landfill.

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	o Encouraging separation of waste streams to enhance recycling efforts. o Assessing the use of materials that can be easily disassembled and recycled at the end of a building's life cycle. • Life Cycle Analysis (LCA): Projects are encouraged to undertake life cycle assessments, which measure the environmental impacts of materials across their entire life cycle, from extraction to end-of-life disposal. LCA tools can help assess the recyclability of materials used, influencing material choices based on their potential for recycling
Circularity aspects	Green Star approaches circularity through resource efficiency, material optimization, and closed-loop thinking: • Circular Design Principles: Green Star incentivizes designs that extend the lifespan of buildings, reduce the need for new materials, and allow for adaptability, refurbishment, or disassembly. The framework encourages strategies such as modular building designs and the reuse of existing structures, contributing to the circular economy by promoting the reuse of materials in new projects. • Life Cycle Thinking: As part of circularity, Green Star requires an assessment of the environmental impact over the entire life cycle of a project. This is where the Life Cycle Assessment (LCA) also plays a vital role. LCA helps quantify the circularity of materials by evaluating their durability, potential for reuse, recyclability, and waste generation reduction over time. • Material Recovery and Reuse: Green Star rewards projects that integrate reclaimed or reused materials into the design, construction, or operation of a building. This encourages the repurposing of building components from demolition or refurbishment projects, creating a more circular flow of materials. • Supply Chain Engagement: Circularity also involves sourcing materials. Green Star encourages projects to engage with suppliers who practice closed-loop manufacturing, ensuring that materials can be reused or recycled back into the supply chain. • Operational Circularity: In the post-construction phase, the Green Star framework promotes operational practices that support circularity, such as energy efficiency, water recycling, and the use of renewable materials in ongoing building management.
Other aspects	n.a.
Potential KPIs	The Green Star framework provides some potential KPIs, focusing on recyclability, circularity, and overall sustainability issues associated with the SIRCULAR project: • Recycled Content Percentage in Materials Used: Measures the proportion of recycled content in the materials selected for construction

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	or refurbishment. A higher percentage indicates better alignment with recyclability goals. • Material Recovery Rate (MRR): Assesses the efficiency of recovering building materials after demolition or deconstruction. A high MRR indicates that a significant portion of the building materials can be recovered for reuse or recycling. • Waste Intensity (kg/m²): Measures the total waste generated per square meter of built area, with a focus on minimizing waste production and maximizing the recyclability of materials used. • Adaptability and Flexibility Index: Measures how well a building is designed to accommodate future changes in use or occupancy, contributing to circularity by reducing the need for extensive renovations or demolition. • Operational Resource Efficiency: KPIs related to operational circularity could include measures of water and energy efficiency, such as: o Water Recycling Rate: Percentage of water recycled or reused in the building. o Energy Efficiency per Square Meter (kWh/m²): Measures the building's energy performance, emphasizing circular practices by reducing energy consumption over time. • Sustainability Supply Chain Score: Evaluates the sustainability credentials of suppliers and their materials, particularly focusing on suppliers who use closed-loop manufacturing processes or offer products with high recycled content.
Other considerations to be taken into account from the framework	
In the building sector, Green Star offers significant market advantages, promoting the benefits of sustainable buildings, such as lower operating costs, enhanced occupant comfort, and reduced environmental footprint. In 2021, the Green Building Council of Australia (GBCA) launched the Green Star Buildings tool, a next-generation rating system designed to drive the transformation of the built environment towards net-zero carbon emissions.	

3.1.6 Well Building Standard

Table 8 provides the description of the Well Building Standard case.

Table 8: Well Building Standard framework summary

Name of the framework under evaluation: Well Building Standard [11]	
Summary	This framework, as its name says, mainly focuses on comfort and well-being. Thus, it does not really focus on circularity and recyclability, apart from considering the limitation of hazardous waste and materials. WELL Certification and the WELL AP credentialing program are third-party administered through IWBI's (International WELL Building Institute) collaboration with Green Business Certification Inc. (GBCI), which also

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administers LEED certification, the global green building program, and the LEED professional credentialing program.

Launched in October 2014, after six years of research and development, WELL is the premier Standard for buildings, interior spaces and communities seeking to implement, validate and measure interventions that support and advance human health and wellness.

WELL was developed by integrating scientific and medical research and literature on environmental health, behavioural factors, health outcomes and demographic risk factors that affect human health with leading practices in design, operations and management. WELL also references existing standards and best practice guidelines set by governmental and professional organizations.

WELL v2 consolidates previous iterations and pilots into a single rating system that is designed to accommodate all project types and sectors. The system is intended to grow in specificity and specialty over time, adapting to accommodate diverse project types and geographies and in response to new evidence and ever-evolving public health imperatives.

There are ten concepts in WELL v2, as depicted in Figure 2.

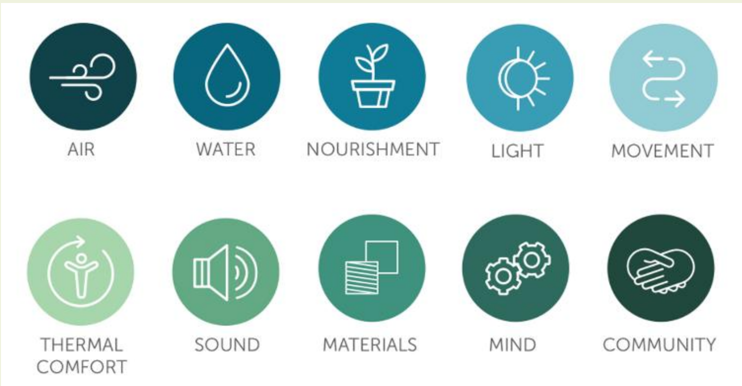

Figure 2. Conceptual pillars in WELL v2

Each concept consists of features with distinct health intents. Features are either preconditions or optimizations.

The International WELL Building Institute (IWBI) delivers the cutting-edge WELL Building Standard, the first standard to be focused exclusively on the ways that buildings, and everything in them, can improve our comfort, drive better choices, and generally enhance, not compromise, our health and wellness.

SIRCULAR approach

Recyclability aspects

The more obvious concept (amongst the 10) related to recyclability is “Materials”. The intent of this concept is mostly focusing on “*reducing human exposure […] to chemicals that may impact health during the construction, remodelling, furnishing and operation of buildings*”. Thus, they focus more on

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	limiting the toxicity of the materials and buildings, rather than optimising the recyclability. "The WELL Materials concept advances two strategies for selecting building materials and products. One is to increase literacy on materials by promoting ingredient disclosure, whereas the second is to promote the assessment and optimization of product composition in order to minimize impacts to human and environmental health. Both strategies aim to bridge data gaps in the supply chain, supporting innovation in green chemistry and advancing market transformation towards healthier and more sustainable products." About the waste management, they plead *"for the safe management of some types of waste".* This category is the most related one to recyclability, although it does not really push for reusing or recycling materials, but mostly for *"the safe management and minimization of wastes associated with hazardous chemicals present in commonly used products"*. They plead for "A protocol for handling and minimizing hazardous wastes, which involves separation of hazardous from other solid wastes and procuring adequate receptors for recycling or final disposal, can help mitigate chemical pollution and associated health concerns. By raising awareness and properly managing hazardous wastes, as well as by selecting products that are easier to reuse and have a lower impact on human health, projects may minimize the generation of such wastes and the release of hazardous materials into the environment." The only action they recommend under this category is to *"implement a waste management plan"*.
Circularity aspects	• Site remediation (X04) [Category under "Materials"]: It promotes the possibility to reuse land. However, the whole point is about the "*assessment, testing and remediation for the development of contaminated sites*". • Materials Transparency (X07) [Category under "Materials"]: Amongst other labels and certifications, it is recommended to select "*Cradle-to-Cradle Certified™ product, or a product with a Material Health Certificate from the Cradle to Cradle Products Innovation Institute*".
Other aspects	• Hygrothermal: The first concept is "Air", with categories such as Ventilation design, Enhanced Air Quality, Enhanced Ventilation System, Air Quality Monitoring, Microbe and Mold Control… • Comfort: There is a concept of "Comfort", with categories such as Thermal Performance, Thermal Zoning, Thermal Comfort Monitoring, Humidity Control…
Potential KPIs	No interesting KPIs for Recyclability and Circularity. There might be some interesting thresholds regarding the pollutant levels for the hygrothermal aspect.

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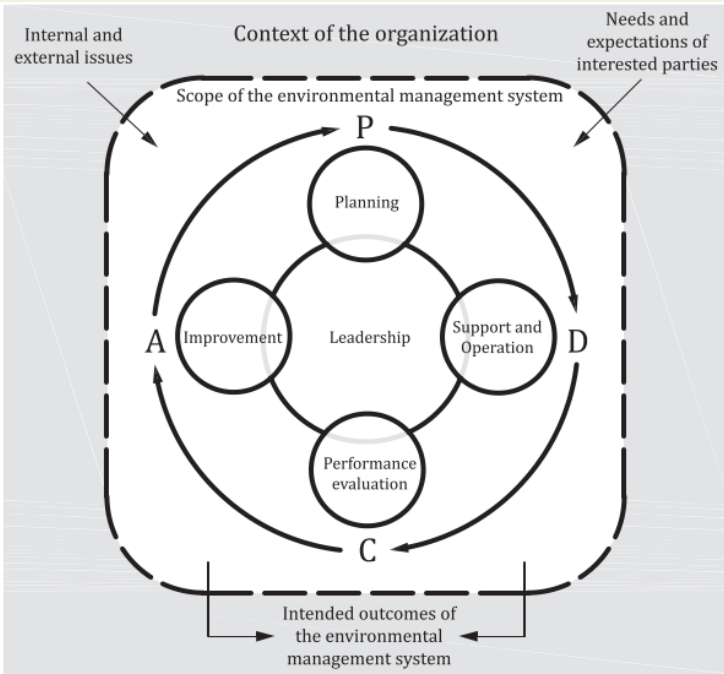
Other considerations to be taken into account from the framework
n.a.

3.1.7 ISO 14001

Next, ISO 14001:2015, which is described below, in Table 9.

Table 9: ISO 14001 framework summary

Name of the framework under evaluation: ISO 14001 [12]	
Summary	The UNE-EN ISO 14001:2015 standard specifies requirements for an environmental management system (EMS) applicable to any organization that seeks to improve its environmental performance systematically. It is a revision of the 2004 edition and integrates a framework to help organizations manage their environmental responsibilities in a way that contributes to sustainability. The standard adopts the Plan-Do-Check-Act (PDCA) cycle, as illustrated in Figure 3, to ensure continuous improvement, focusing on not just compliance with legal obligations, but also pollution prevention and resource optimization.  *Figure 3. ISO 14001 PDCA schema* Structure of the Standard ISO 14001:2015 is organized into several key sections: 1) Scope: The standard applies to organizations of any size or sector and covers environmental aspects that the organization can control or influence, considering a life cycle perspective.

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2) Terms and Definitions: It clarifies essential terms like "environmental aspect," "environmental impact," "environmental management system," and "continuous improvement" to ensure a common understanding.
3) Context of the Organization: Organizations must identify internal and external factors that can affect their ability to achieve the intended outcomes of the EMS. They must also consider the needs and expectations of interested parties and define the boundaries of their environmental management system.

Leadership

Leadership is a critical component of this standard. Top management is required to demonstrate commitment by ensuring the integration of environmental management system requirements into the organization's business processes. Leaders must also communicate the importance of compliance with environmental policies and ensure that resources are available for effective system operation.

Planning

The standard emphasizes the need for planning actions to address risks and opportunities related to environmental aspects and compliance obligations. This involves identifying significant environmental aspects, which are those that can have notable impacts on the environment, and setting environmental objectives that are specific, measurable, and aligned with the organization's environmental policy.

Support

To ensure the effectiveness of the EMS, organizations must provide necessary resources, including competence, training, and communication both internally and externally. Additionally, the documentation of relevant information is required to maintain control and consistency within the system.

Operation

Operational control is essential. Organizations are required to identify, plan, and implement processes that may have significant environmental impacts. This also includes preparing for environmental emergencies through emergency response planning.

Performance Evaluation

Monitoring and measurement are key components in assessing environmental performance. Organizations must establish mechanisms to ensure that activities are conducted in accordance with established criteria and evaluate compliance with legal obligations. Regular internal audits must also be conducted to ensure the system's effectiveness.

Continuous Improvement

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	The standard stresses the importance of addressing nonconformities through corrective actions and encourages continual improvement of the environmental management system. Organizations are expected to seek opportunities to improve their environmental performance on an ongoing basis.
SIRCULAR approach	
Recyclability aspects	The ISO 14001:2015 standard addresses recyclability issues primarily through a life cycle approach and the assessment of environmental aspects related to an organization's products and services. This framework encourages organizations to evaluate the environmental impacts across all stages of the product life cycle, from raw material acquisition through production, use, and end-of-life disposal. Recyclability is a key consideration within this approach, particularly when analysing waste management, reuse, recycling, and disposal of materials.
Circularity aspects	The ISO 14001:2015 framework promotes circularity by encouraging a life cycle approach, requiring organizations to assess the environmental impacts of their products and services from raw material acquisition through to end-of-life disposal. It emphasizes the need for design and development processes that minimize waste and maximize resource efficiency, integrating principles of sustainable resource use, recycling, and reuse. The standard also advocates for operational controls that facilitate material recovery, recycling, and proper disposal, with a focus on resource efficiency throughout the supply chain. Additionally, it highlights the importance of managing waste through reuse, refurbishment, and recycling, ensuring that circularity principles are applied across the entire life cycle of an organization's activities.
Other aspects	ISO 14001:2015 approaches circular-related issues like comfort and energy efficiency by emphasizing a life cycle perspective and encouraging organizations to address broader environmental aspects such as energy use, emissions, and resource efficiency. It requires organizations to consider energy consumption during the design, operation, and disposal phases of their products or services, thereby integrating energy efficiency into the overall environmental management system. The framework also promotes sustainable resource use, which includes energy conservation and the reduction of resource waste in all operations. Additionally, operational controls are encouraged to ensure that energy-related processes are optimized to minimize environmental impacts, supporting a transition towards more sustainable, circular practices.
Potential KPIs	These KPIs help organizations track and measure progress in achieving circular economy objectives, improving resource efficiency, and reducing environmental impacts in line with ISO 14001:2015. • Material Efficiency KPIs: 　○ Percentage of Recycled Materials Used: The proportion of recycled or reclaimed materials in the total materials used in production processes.

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- Waste Diversion Rate: The percentage of total waste that is diverted from landfills through recycling, composting, or reusing.
    - Waste Reduction Rate: Measures the reduction of waste generation compared to a previous baseline, emphasizing circularity in resource management.
- Energy Efficiency KPIs:
    - Energy Consumption per Unit of Output: The amount of energy used to produce a unit of product or service, indicating energy efficiency improvements.
    - Renewable Energy Usage: The percentage of total energy consumption derived from renewable sources, supporting sustainable energy use.
    - Energy Savings from Process Improvements: Energy saved due to implementing energy-efficient technologies or processes.
- Resource Efficiency KPIs:
    - Water Usage per Unit of Production: Measures the amount of water used in operations, indicating water efficiency and conservation efforts.
    - Raw Material Usage Efficiency: The amount of raw materials consumed per unit of output, demonstrating how effectively materials are used in production.
- Product Lifecycle KPIs:
    - Product Recyclability Rate: The percentage of a product's components that can be recycled or reused at the end of its life.
    - End-of-Life Product Recovery Rate: The proportion of products that are recovered for recycling, refurbishment, or reuse at the end of their life cycle.
- Carbon Footprint and Emissions KPIs:
    - Greenhouse Gas (GHG) Emissions per Unit of Output: The amount of GHG emissions produced per unit of product or service, reflecting efforts to reduce carbon intensity.
    - Emission Reductions: Quantifies the decrease in emissions from energy consumption or processes over time, supporting sustainability goals.
- Sustainable Procurement KPIs:
    - Percentage of Sustainably Sourced Materials: The proportion of materials sourced from sustainable or certified suppliers, promoting a circular supply chain.

Other considerations

n.a.

3.1.8 Material Passport

The case of Material Passport is summarised within

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Table 10 below.

Table 10: Material Passport framework summary

<table>
<tr><th colspan="2">Name of the framework under evaluation: Material Passport [13]</th></tr>
<tr><td>Summary</td><td>Materials passports (MP) are (digital or manual) sets of data describing defined characteristics of materials and components in products and systems that give them value for present use, recovery, and reuse.

The Material Passport, in essence, acts as a comprehensive record of a product's material composition, facilitating informed decision-making at its end-of-life. This directly addresses the challenges highlighted in the SIRCULAR project, such as the need for improved waste identification and source separation, which are crucial for enhancing recycling rates and promoting the reuse of construction materials.

By providing detailed information about the materials used in a product, the Material Passport empowers stakeholders across the construction value chain to make informed choices about reuse, recycling, and proper disposal. It fosters transparency and trust in the quality of recycled and CDW-derived products, mitigating concerns about potential health risks and uncertainties about material composition. The Material Passport can play a pivotal role in driving the adoption of circular models in the construction sector by providing a standardized and reliable source of information about materials, thereby facilitating the integration of circular practices into building design, construction, and renovation processes. It can also contribute to the development of a more robust market for recycled, deconstructed, and CDW-derived products by increasing confidence in their quality and origin.

In the context of the SIRCULAR project's Task 1.1, which focuses on defining a framework for circularity, the Material Passport can be seen as a valuable tool for operationalizing circularity principles. It provides a practical mechanism for tracking and documenting the flow of materials throughout their lifecycle, enabling the assessment of a building's circularity index and supporting the identification of opportunities for material reuse and recycling.

Some examples of material passport platforms:
• Madaster [14]: This Dutch platform functions as an online library of building materials linked to their physical locations. It allows stakeholders across the construction value chain to upload data on the products and components within a structure, automatically generating material passports. Madaster's vision is to transform buildings into 'material banks', enabling the recovery and reuse of valuable resources at the end of a building's life.
• Circularise [15]: This blockchain-powered platform facilitates the traceability and transparency of materials throughout supply chains. It</td></tr>
</table>

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	enables the creation of digital product passports, serving as a reliable record of a building's composition, including its carbon footprint. This information can be selectively shared with clients and regulatory bodies. • BAMB (Buildings As Material Banks) Materials Passports platform [16]: This initiative aims to bridge a market gap by offering a 'one-stop-shop' for characterizing the circular economy value across a building's lifecycle. The platform is particularly focused on facilitating the use and reuse of components and materials while minimizing waste generation. • UKGBC's Circular Passport Platform [17]: This UK-centric platform acts as an online registry of materials used in buildings. It also serves as a database of sustainable building products and a product selection platform, assisting in minimizing embodied carbon in construction projects.
SIRCULAR approach	
Recyclability aspects	• Madaster: The platform primarily focuses on facilitating the identification and quantification of materials within a building, enabling a clear understanding of their potential for recycling at the end of the building's life. By creating a detailed inventory of materials, Madaster helps to streamline the recycling process and maximize the recovery of valuable resources. • Circularise: The platform's blockchain technology enables the traceability of materials throughout their lifecycle, including their origin, processing, and use. This transparency facilitates informed decisions about recycling and ensures that materials are recycled appropriately, maximizing their value and minimizing waste. • BAMB: The platform focuses on characterizing the circular economy value of materials and components throughout a building's lifecycle. This includes assessing their recyclability potential and providing information on appropriate recycling processes and end markets. • UKGBC's Circular Passport Platform: The platform serves as a registry of materials used in buildings, facilitating their identification and potential for recycling at the end of a building's life. It also provides information on sustainable building products, encouraging the use of materials with high recyclability potential.
Circularity aspects	• Madaster: Madaster's core concept of transforming buildings into 'material banks' inherently promotes circularity. It encourages the reuse and repurposing of building components and materials, reducing the need for new extraction and manufacturing. • Circularise: Circularise's digital product passports provide a comprehensive record of a product's material composition and history, enabling stakeholders to assess its suitability for reuse or repurposing. This fosters a circular approach by extending the lifespan of materials and reducing the demand for virgin resources.

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		• BAMB: emphasis on facilitating the use and reuse of components and materials directly supports circularity principles. By creating a marketplace for salvaged materials and components, it encourages their reintegration into new construction projects, reducing the need for new production. • UKGBC's Circular Passport Platform: By acting as a product selection platform, the UKGBC platform promotes circularity by enabling stakeholders to choose materials and components that are designed for reuse, repair, and recycling. This encourages a shift towards a more circular approach in construction practices.
Other aspects		• Madaster: By promoting the efficient use of resources and reducing waste, it contributes to lowering the overall environmental impact of the construction sector. • Circularise: The platform's ability to track a product's carbon footprint throughout its lifecycle helps to identify areas for improvement and encourages the adoption of more sustainable practices. It also promotes transparency and accountability within supply chains, incentivizing the use of environmentally friendly materials and processes. • UKGBC's Circular Passport Platform: By providing information on the carbon footprint of different materials and products, it empowers stakeholders to make informed choices that contribute to reducing greenhouse gas emissions.
Potential KPIs		• Recyclability Rate • Reuse Rate • Embodied Carbon • Waste Reduction • Cost Savings • Supply Chain Transparency
Other considerations to be taken into account from the framework		
The MP do not itself assess the data output and are not an evaluator of data. Instead, they provide information that supports assessments and certifications by other parties and allows existing assessments and certifications to be entered into the passport as uploaded documents. MP are outputs of the materials passport platform.		

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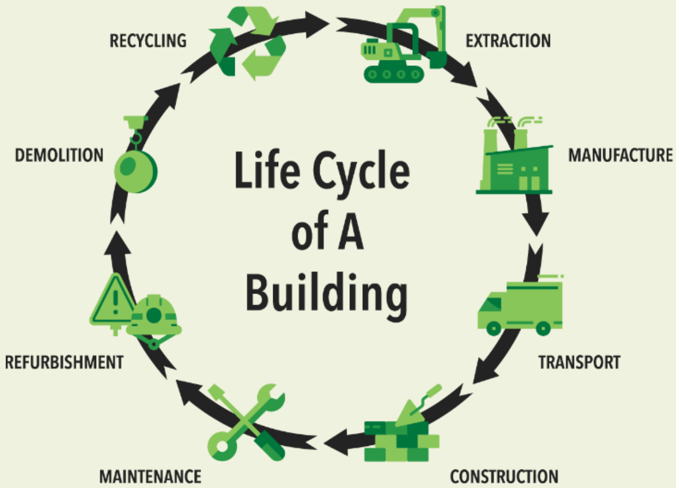
3.1.9 EU LEVEL(s)

European LEVEL(s) framework is described in Table 11.

Table 11: EU LEVEL(s) framework summary

Name of the framework under evaluation: EU LEVEL(s) [18]	
Summary	Level(s) is the EU initiative / framework for sustainable buildings and how to measure this aspect in the built environment. It is an assessment and reporting tool for sustainability performance of buildings, firmly based on circularity. Level(s) covers the full life cycle of the building, as represented in Figure 4 [19], and fosters the application of LCA / LCC approaches.  *Figure 4. Life Cycle of a building definition according to LEVEL(s) [19]* It is based on six macro-objectives [20]: 1. Greenhouse gas emissions along a building's life cycle with focus on two main topics: i) Near zero energy consumption during the use phase, supplemented by the contribution of cost effective and low/zero emission energy technologies and infrastructure; ii) Embodied greenhouse gas emissions along the buildings whole life cycle, including those associated with product manufacturing, maintenance, repair, adaptation, renovation and end of life. 2. Resource efficient and circular material lifecycles, under the scope of material efficiency and circular utility. This shall encompass actions along the life cycle relating to: building design, structural engineering and construction management, construction product manufacturing, replacement cycles and flexibility to adapt to change, and the potential for deconstruction. The overall objective shall be to optimise material use, reduce waste and introduce circularity into designs and material choices.

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3. Efficient use of water resources as the combination of efficiency measures to minimise water use and supply-side measures such as grey water reuse.
4. Healthy and comfortable spaces in terms of quality of the indoor air for specific parameters and pollutants, the degree of thermal comfort during an average year, the quality of artificial and natural light and associated visual comfort, and the capacity of the building fabric to insulate occupiers from internal and external sources of noise.
5. Adaptation and resilience to increased overheating in summer and inadequate heating in winter, increased risk of extreme weather events, which could compromise the security and integrity of building elements, and increased risk of flood events, which could overwhelm drainage systems and damage structures and materials.
6. Optimised life cycle cost and value by achieving lower life-cycle costs and more productive and comfortable spaces to live and work.

It combines three different levels (see Figure 5 [21]) within the workflow of a design and build project:

I. Level one does not provide metrics and is about information at the early stages on the concepts that the chosen indicators will cover. It provides a simple structure that can be presented to clients to prioritize attention on sustainability aspects.
II. Level two is diving into the areas identified as main priorities and quantifying actuals, allowing comparison between different design options and monitoring of the construction according to standardized units and methods.
III. Level three looks at actual monitoring and feedback. It establishes what works in practice compared to the models. This also identifies lessons learned from the design to inform and improve future projects.

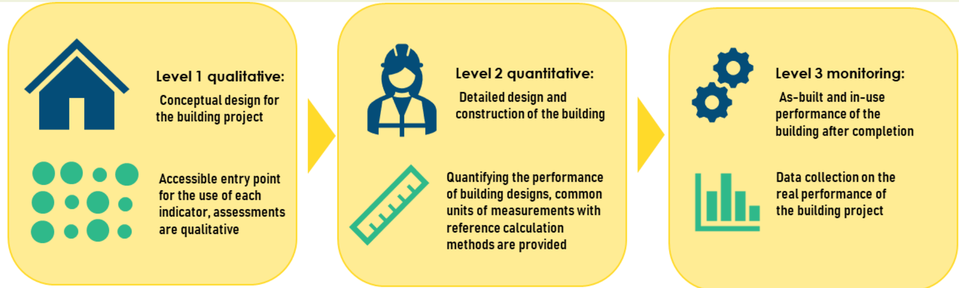

Figure 5. Levels of assessment under LEVEL(s) [21]

LEVEL(s) contributes to Sustainable Development Goals (SDGs), in particular the SDG13 Climate Action and SDG11 Sustainable Cities and Communities. As well, it provides the bridge between the ambition of the European Green Deal initiative on sustainable buildings and the realities of professional building operations within the EU.

LEVEL(s) sets a certain level of flexibility as is allows a project team to decide which objectives to focus on, which indicators to work with and finally, at what

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	level. At the same time, it can be applied at each stage of a building´s life cycle (conceptualisation, assessing performance at design and construction and/or follow-up after completion). Finally, this framework can be used on building renovations as well as on new builds. It is not a certification scheme. Rather it is designed to equip the EU buildings sector with a shared reference point, or common language, when assessing or monitoring building performance.
SIRCULAR approach	
Recyclability aspects	Within the indicator "Resource efficient and circular material lifecycles", both Construction & Demolition waste and materials and Design for deconstruction, reuse and recycling are considering recyclability aspects.
Circularity aspects	LEVEL(s) helps understanding the full life cycle of a building and brings the circular economy into building design and use. Macro-objective 2 "Resource efficient and circular material lifecycles" looks for material efficiency and circular utility. It introduces circularity into designs and material choices
Other aspects	The LEVEL(s) framework includes aspects such as environmental performance, health and comfort, life cycle cost and value, and potential risks to future performance. Then, it is not only considering sustainability in terms of recyclability and circularity, but also: • Energy • Water • Comfort • Costs • Climate change

Potential KPIs	• Greenhouse gas emissions along a building's life cycle → Minimize the whole life carbon output, consider both energy consumption during the use phase of the building and embodied energy.
	  ○ Use stage energy performance (kWh/m2/yr)
	  ○ Life cycle Global Warming Potential (CO2 eq./m2/yr)
	• Resource efficient and circular material lifecycles → Optimize the building design to support lean and circular flows.
	  ○ Bill of quantities, materials and lifespans (Unit quantities, mass and years)
	  ○ Construction & Demolition waste and materials (kg of waste and materials per m2 total useful floor area)
	  ○ Design for adaptability and renovation (Adaptability score)
	  ○ Design for deconstruction, reuse and recycling (Deconstruction score)
	• Efficient use of water resources

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- Use stage water consumption (m3/occupant/yr)

- Healthy and comfortable spaces → Create buildings that are comfortable, attractive and productive (indoor air for specific parameters and pollutants, degree of thermal comfort, quality of artificial and natural light, visual comfort and noise).
  - Indoor air quality
  - Time outside of thermal comfort range
  - Lighting and visual comfort
  - Acoustics and protection against noise
- Adaptation and resilience → Futureproof building performance (climate impacting on thermal comfort, resilience and resistance to extreme weather events (including flooding: fluvial, pluvial and coastal), sustainable drainage).
  - Protection of occupier health and thermal comfort
  - Increased risk of extreme weather
  - Sustainable drainage
- Optimised life cycle cost and value → Long term view of the whole life costs and market value of more sustainable buildings, including life cycle costs (construction, operation, maintenance, refurbishment and disposal), integration of sustainability aspects into market value assessment and risk rating processes.
  - Life cycle costs (€/m²/yr)
  - Value creation and risk factors

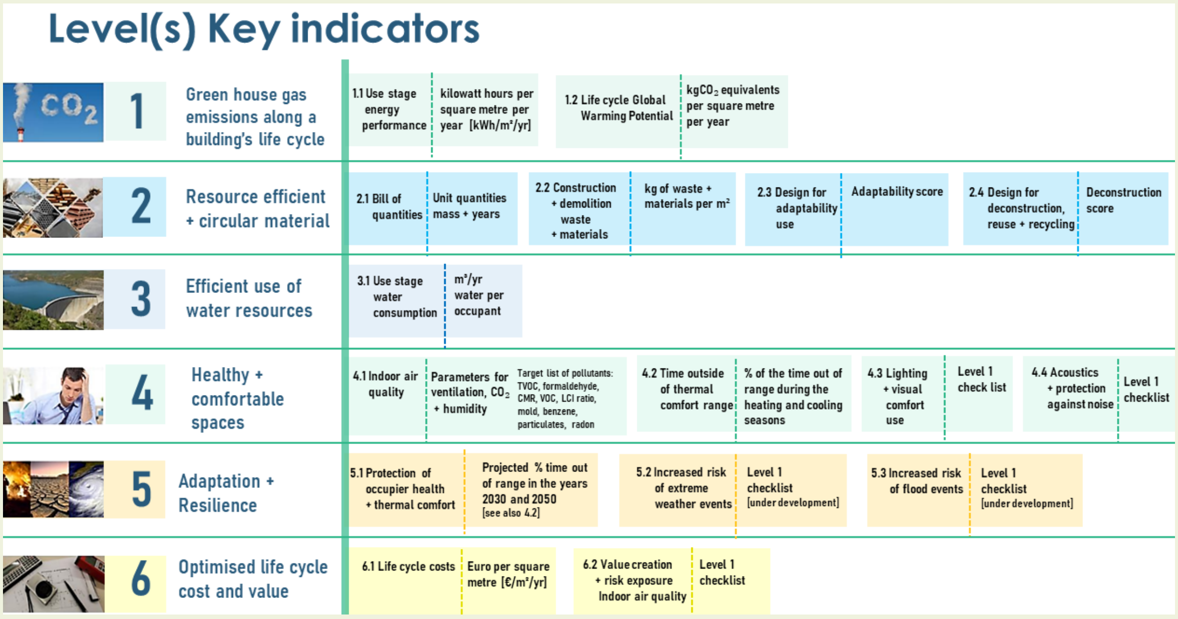

Figure 6. LEVEL(s) Key Performance Indicators [22]

Other considerations to be taken into account from the framework

Calculator available at https://ec.europa.eu/buildings-performance-calculator.

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3.1.10ISO 59020 Circular economy

Following the list of frameworks, Table 12 includes ISO 59020.

Table 12: ISO 59020 framework summary

Name of the framework under evaluation: ISO 59020:2024, "Measuring and evaluating performance in circularity" [23]	
Summary	ISO 59020 sets out guidelines for organisations to measure and assess their circularity performance. It emphasises the importance of the transition from a linear to a circular economy, addressing various issues such as resource depletion, biodiversity loss, waste and pollution. The standard sets out principles for measuring circularity, including system boundaries, data quality and meaningful outcomes. It also provides a framework for measuring and assessing circularity performance, including boundary definition, data acquisition and reporting. In addition, it includes a taxonomy of circularity indicators and guidance on how to select and use them.
SIRCULAR approach	
Recyclability aspects	ISO 59020 for assessing recyclability issues involves the following steps: • Material identification: Analysis of the material composition. • Recyclability assessment: The possibility that the materials used can be recycled in the available facilities and assessing the actual results of the recycling efforts. • Regulatory: Analysis of regulations on recyclability to ensure that the product complies with the established requirements. • Environmental impact: Provides information on how to calculate the percentage of recycled material derived from the output streams and the percentage of effective recirculation in the biological cycle, assessing the environmental impact it causes during its entire life cycle.
Circularity aspects	ISO 59020 defines circularity as "*the degree of alignment with the principles for a circular economy*." It provides a framework for measuring and assessing circularity performance, which includes setting system boundaries, acquiring data, and reporting results. The standard also includes a taxonomy of circularity indicators, which can be used to measure various aspects of circularity, such as resource inflows and outflows, energy use, and water management. The standard emphasizes the importance of considering the entire life cycle of a product and its impact on the environment, society, and the economy when assessing circularity.
Other aspects	ISO 59020 addresses other environmental issues, such as energy use and water management, through specific circularity indicators. It also encourages the use of complementary methods, such as life cycle assessment (LCA), to assess the environmental impacts of circular activities. The standard highlights the

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	importance of considering potential trade-offs between economic, environmental, and social values when implementing circular practices. It also emphasizes the need for transparency and avoid greenwashing when communicating environmental claims.
Potential KPIs	Key Performance Indicators (KPIs) from ISO 59020: • Average recycled content of an inflow (X): This KPI is directly relevant to SIRCULAR's focus on utilizing recycled and deconstructed materials in construction. Tracking the proportion of recycled materials used in the project's construction processes will showcase its commitment to circularity and resource efficiency. It aligns with SIRCULAR's objective to minimize reliance on virgin materials and reduce carbon emissions. • Average reused content of an inflow (X): Given SIRCULAR's emphasis on reuse and deconstruction, this KPI is crucial for measuring the extent to which reused components and products are incorporated into the project. It directly supports the project's aim to promote the reuse of building materials and reduce waste. • Per cent actual recycled material derived from outflow (X): This KPI is essential for evaluating the effectiveness of SIRCULAR's recycling efforts at the end-of-life stage of its construction projects. It measures the proportion of materials that are successfully recycled after a building's deconstruction or renovation, contributing to the project's goal of reducing waste and promoting a circular flow of resources. • Per cent actual reused products and components derived from outflow (X): This KPI is particularly relevant to SIRCULAR's focus on reuse and deconstruction. It measures the proportion of products and components that are reused after being recovered from deconstruction or renovation projects. Increasing this KPI demonstrates the project's success in extending the lifespan of building materials and reducing the need for new production. • Average per cent of energy consumed that is renewable energy: SIRCULAR aims to promote sustainable practices throughout the construction process, including energy use. This KPI allows the project to track its progress in utilizing renewable energy sources during construction and operation, contributing to its decarbonization goals. • Material productivity: While not a core indicator in ISO 59020, material productivity can be a useful KPI for SIRCULAR to assess the economic efficiency of its resource utilization. It measures the revenue generated per unit of material input, highlighting the project's ability to create value while minimizing resource consumption. • Resource intensity index: This indicator can be adapted to the project level to evaluate the decoupling of economic growth from resource use. It can help SIRCULAR demonstrate its contribution to a more sustainable and resource-efficient construction sector.

Other considerations to be taken into account from the framework
n.a.

3.1.11 ISO 20887

ISO 20887:2020, “Sustainability in construction. Design for demobilisation or reuse”, is collected in Table 13.

Table 13: ISO 20887 framework summary

Name of the framework under evaluation: ISO 20887:2020, “Sustainability in construction. Design for demobilisation or reuse” [24]	

Summary	ISO 20887:2020 provides an overview of the design principles for dismantling and adaptability (DfD/A) and possible strategies for integrating these principles into the design process of buildings and infrastructures, with the aim of facilitating their dismantling and the reuse or recycling of their materials at the end of their service life.
	
	It focuses on promoting sustainability throughout the life cycle of buildings, applying principles of circular economy and resource efficiency.
	
	The principles described in the standard are divided into:
	• Adaptability principles:
	  o Versatility
	  o Convertibility
	  o Scalability
	• Disassembly principles:
	  o Ease of access to components and services.
	  o Independence
	  o Avoidance of unnecessary treatment and finishing
	  o Support for business models of reuse (circular economy)
	  o Simplicity
	  o Standardisation
	  o Safety in dismantling
	
	Each of the principles developed should be examined at each of the established levels of analysis: systems, elements, component or assembly, sub-component and material.
	
	Generally, the standard stresses the importance of using recyclable materials, designing structures that allow easy disassembly and designing constructions with a high degree of adaptability, thus prolonging the useful life of materials and reducing waste generation.
	
	Life cycle assessment, analysing the total environmental impact of a building, is used to help improve the circularity of materials, reduce the carbon footprint and minimise resource consumption.

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	Finally, the standard promotes the documentation and traceability of the materials used, which facilitates their recovery and recycling at the end of the building's useful life, encouraging the innovation of more sustainable materials and construction methods.
SIRCULAR approach	
Recyclability aspects	There are several recyclability issues in the standard, ranging from material selection to building dismantling design: • Material selection: The use of materials with a high degree of recyclability is encouraged, either by the ability of the material to be recycled at the end of its useful life, or by the use of materials containing recycled content. • Separation and disassembly design: The importance of designing components that are easy to disassemble, as well as avoiding the combination of materials that cannot be easily separated, which hinders the recycling process. • Documentation and traceability: By having documentation of all materials used, it facilitates the identification and recovery of recyclable materials at the end of their useful life. • Life Cycle Assessment: Thanks to this assessment, it considers how the recycling of materials impacts on the overall balance of resources, energy and emissions over the lifetime of the building. • Innovation: The standard encourages the use of new materials and techniques that improve recyclability.
Circularity aspects	The standard looks at circularity issues in all phases of the life cycle of a building or infrastructure: • Design for Circularity: Creating buildings that can be easily disassembled, creating designs that consider circularity from the outset, allows for the reuse of materials and components. • Life Cycle Assessment: With this method of assessment, in the end-of-life phase, the ability of materials to be recovered and reintroduced into the life cycle is considered, closing the cycles of these materials. • Reuse and recycling: The standard places importance on the use of components and materials that are easily recyclable and reusable. • Waste management: A design supporting circularity will lead to waste minimisation and reuse, creating end-of-life management strategies. • Adaptability: The importance of a design that is adaptable to different uses will lead to the reuse of materials and components. • Documentation and traceability: By having documentation of all materials used, it facilitates the identification and recovery of recyclable materials at the end of their useful life. • Innovation: The standard encourages the use of new materials and techniques that improve recyclability.

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	• Circular economy: The standard creates systems where materials have the longest possible useful life and are regenerated at the end of their useful life.
Other aspects	The standard addresses other issues related to sustainability and the life-cycle impact of buildings, such as occupant comfort and energy efficiency.
Potential KPIs	Potential KPIs from UNE-ISO 20887 for the SIRCULAR Project Adaptability • Versatility: The standard suggests measuring versatility by the percentage of usable space with multiple daily, weekly, or monthly uses without major modifications. This KPI could be valuable for SIRCULAR, especially if the project aims to design flexible spaces that can accommodate various functions over time, contributing to resource efficiency and reducing the need for new construction. • Convertibility: The standard proposes measuring convertibility by the percentage of usable space designed for easy conversion to multiple uses. This KPI could be relevant if SIRCULAR intends to create adaptable spaces that can be modified with minimal effort to meet changing needs, promoting longevity and reducing waste. • Expandability: The standard suggests evaluating expandability based on the number of additional floors or the percentage of additional floor area possible without major changes to the foundation or structure. This KPI could be useful if SIRCULAR plans to design buildings with the potential for future expansion, accommodating growth and reducing the need for demolition and new construction. Disassembly • Ease of Access to Components and Services: The standard proposes a 0-5 rating scale for accessibility, considering the ease of reaching components and the extent of damage to surrounding materials during access. This KPI could be valuable for SIRCULAR to ensure that buildings are designed for easy maintenance, repair, and replacement of components, promoting longevity and reducing waste. • Independence: The standard suggests a 0-5 rating scale for independence, evaluating the ability to remove or upgrade parts without affecting connected systems. This KPI could be important for SIRCULAR to ensure that building components and systems are designed for independent maintenance, repair, and replacement, facilitating future adaptations and reducing waste. • Reversible Connections: The standard proposes a "yes or no" evaluation for each connection type, assessing whether it's reversible. It also suggests measuring the percentage of connection types that can be reversed for material recovery at a higher level. This KPI could be crucial for SIRCULAR to ensure that buildings are designed for easy disassembly

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	and material recovery at the end of their life, promoting reuse and recycling. • Standardization: The standard suggests measuring the level of standardization through percentages of the overall construction (cost, volume, or mass) for dimensions, components, connections, modularity, and interoperability. This KPI could be helpful for SIRCULAR to track the use of standardized components and systems, which can facilitate disassembly, reuse, and recycling, contributing to resource efficiency and waste reduction.
Other considerations to be taken into account from the framework	
n.a.	

3.1.12 Material Circularity Indicator methodology

Finally, the Material Circularity Indicator, which is included in Table 14.

Table 14: Material Circularity Indicator framework summary

Name of the framework under evaluation: The Material Circularity Indicator Methodology (2019) by the Ellen MacArthur Foundation and Granta Design [25]	
Summary	The Material Circularity Indicator (MCI) measures how circular a product is, based on its material flows. It considers how much the product uses recycled or reused materials and components, how long and well it serves its purpose (compared to an industry average), and how much of it can be recycled or reused after its use. The product's material flows are divided into restorative (recycled or reused) and linear (virgin or wasted) parts. The MCI score is between 0 and 1, with higher values meaning more circularity. The MCI can be determined focusing on the product as a whole or using a comprehensive approach, which evaluates each component and material individually before aggregating the outcomes. It can also be applied to a company's range of products (MCI at company level).
SIRCULAR approach	
Recyclability aspects	To calculate the MCI, recycled material flows are considered in input and output, as well as reuse. The quantification of the following flows may be relevant for recyclability issues: • Recycled Feedstock • Reused components • Recycling Collection Rates • Recycling Process Efficiencies & Waste associated with recycling Utility (considering lifetime and intensity of use; higher utility has benefits similar to reuse)

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Circularity aspects	Circularity is evaluated through the MCI index, by subtracting from 1 the linear flow of material, weighted by an utility factor of the product which measures how well the product performs compared to an average product in terms of lifetime and utilisation. The elements considered in the material flows include the input materials for production (virgin or recycled materials and components), the product's utility during its use phase (considering durability, repairability, and shared consumption against industry standards), and the product's end-of-life fate, distinguishing between landfill and energy recovery versus recycling and reuse, and including the effectiveness of its end-of-life recycling and reuse processes.
Other aspects	No other indexes are included in this document. It is suggested that Circulytics (a framework of indicators by EllenMcArthus Foundation) can be used for tracking circular economy performance of companies.
Potential KPIs	• KPI1: Material Circularity Indicator (MCI) – comprehensive approach, dividing by component. • KPI2: Linear Flow Index (LFI) (measures the proportion of material flowing in a linear fashion) • KPI 3: Utility factor F(X) (considering lifetime and intensity of use)
Other considerations to be taken into account from the framework	
The MCI methodology has also been adapted by Ellen McArthur Foundation and Granta Design to include the fraction of a product's biological feedstock that comes from Sustained Production. The methodology can also be applied at company level, by considering its reference products. The official methodology doesn't state explicitly how to apply the MCI to a building. However, if the MCI of a building is calculated, it could be treated as a product, applying the comprehensive approach (breakdown by components).	

3.1.13 Comparative with other additional frameworks

Within the exercise of analysing the aforementioned frameworks, three additional ones were found. However, these have not been examined with the same level of detail as they were identified in a later stage. However, to complement the previous ones, a short description, comparative and potential KPIs are obtained. These frameworks are: Eco-Management and Audit Scheme (EMAS)[4], Passivhaus[5] and National Circularity Assessment Framework for Buildings Toolkit[6] (recently launched).

Eco-Management and Audit Scheme (EMAS)

EMAS is a management tool for voluntary use by businesses and other organisations, making it possible to assess, improve and publicise their environmental behaviour. EMAS companies and

[4] https://green-business.ec.europa.eu/emas_en
[5] https://passivehouse.com/
[6] https://www.unops.org/news-and-stories/news/harnessing-circularity-to-drive-climate-action

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organisations are characterised by their voluntary effort to protect the environment, beyond compliance with environmental legislation. This effort is recognised by the European Union with the following logo. EMAS scheme is developed and promoted by European Union.

EMAS scheme is similar than ISO 14001 but with some differences:

- Initial environmental review of all direct and indirect environmental aspects. Significant environmental aspects associated with the procurement procedures shall be addressed.
- Focus on continual improvement of environmental performance.
- Proof of legal compliance.
- External reporting required (validated environmental statement). Open dialogue with external stakeholders.
- Active involvement of employees and their representatives.

It proposes a set of environmental performance indicators

(a) Core indicators focus on performance in the following key environmental areas: (i) Energy; (ii) Material; (iii) Water; (iv) Waste; (v) Land use with regard to biodiversity; and (vi) Emissions.
(b) Specific environmental performance indicators. Each core indicator is composed of: (i) a figure A indicating the total annual input/output in the given area; (ii) a figure B indicating an annual reference value representing the activity of the organisation; and (iii) a figure R indicating the ratio A/B; Each organisation shall report on all 3 elements for each indicator.
(c) The indication of the total annual input/output in the given area, figure A, shall be reported as follows: indicators and qualitative information.

For more information see "C. Reporting based on environmental performance (pag 4.) from Annex IV to Regulation (EC) No 1221/2009 of the European Parliament and of the Council on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS)"[7].

Passivhaus

The Passivhaus (or Passive House) Standard is a rigorous, energy-efficient building standard focused on reducing a building's ecological footprint while providing high levels of occupant comfort. It is applicable to residential, commercial, and institutional buildings. Key aspects include: Thermal insulation, airtightness, high performance windows and doors, thermal bridge-free design, mechanical ventilation with heat recovery, optimal solar orientation and shading. There are different certification levels for new construction and existing buildings: 1. Classic, 2. Plus, 3. Premium, whereas variations for specific contexts exists (EnerPHit, Passive House Low Energy Building). Classic focuses on core energy efficiency and comfort principles, making it the baseline for Passivhaus certification. Plus encourages sustainable energy generation on-site, emphasizing environmental stewardship. Premium aims at buildings that actively contribute energy back to the grid or achieve net-positive energy performance.

Benefits of Passivhaus standard include energy saving (typically up to 90% less heating and cooling energy demand compared to conventional buildings), comfort and sustainability (reduced reliance on non-renewable energy sources contributes to lowering greenhouse gas emissions). While recyclability is not explicitly mandated in the Passivhaus standard, its emphasis on sustainability encourages using recyclable materials and designing for long-term environmental responsibility. This is particularly

[7] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R2026

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relevant in advanced certifications like Passivhaus Plus and Premium, where the broader sustainability footprint is assessed. By reducing energy demand drastically and integrating renewable energy systems (e.g., solar panels), Passivhaus projects contribute to a broader circular approach by reducing dependence on finite resources and reusing naturally available energy flows.

All previous frameworks emphasize energy efficiency to some degree (e.g., LEED, BREEAM, Living Building Challenge focus on energy savings). Passivhaus has the most quantitative energy metrics, focusing on airtightness, thermal performance, and passive design. All frameworks aim for environmental stewardship and reduced ecological footprint. Passivhaus prioritizes energy performance over other sustainability aspects like biodiversity or social equity, which are covered in frameworks like Living Building Challenge or ISO 59020. Premium Passivhaus certification complement other ESG, such electromobility, with the possible energy surplus. ISO 20887 (sustainability in design for disassembly) and ISO 14001 encourage lifecycle thinking, as do C2C and Material Passport. Passivhaus focuses more on operational efficiency rather than full lifecycle assessment, which is central to ISO 20887, C2C, and Material Passport.

In terms of KPIs, Passivhaus lists the following ones:

- KPI1: Heating energy demand ≤ 15 kWh/m²/year
- KPI2: Cooling energy demand ≤ 15 kWh/m²/year
- KPI3: Primary energy demand ≤ 60 kWh/m²/year
  - Primary energy demand is reduced for Plus and Premium certification to ≤ 45 kWh/m²/year and ≤ 30 kWh/m²/year, respectively.
- KPI5: Air change per hour at 50 Pa.
  - For new construction ≤ 0.6 h-1 and for existing ≤ 1 h-1.
- KPI6: Renewable energy generation with reference to projected building footprint
  - For Plus certification ≥ 60 kWh/m²/year and for premium ≥ 120 kWh/m²/year.

National Circularity Assessment Framework for Buildings Toolkit

This framework evaluates the state of a country's current circular economy, focusing on its material and waste flow, economic and social aspects, and environmental impacts in the buildings and construction sector. It is important to remark that it does not focus at the building level.

This analysis is structured according to the five action areas and seven enabling domains defined and validated by the GlobalABC international network of experts in 2023. In addition, the indicators provide a means to evaluate progress in future iterations of this assessment from both quantitative and qualitative perspectives.

This framework comprises three main categories (Material and waste flow, Environmental impacts, Economic and social impacts) with some indicators aimed to measure those, at the country level. The scope of the framework is summarised in the following two points[8]:

1) Strengthening actions at the national level: The framework reflects practical measures for governments and other stakeholders to advance circular economies. Among others, it seeks to drive impact across the flows of materials and waste, economic and social aspects, and environmental impacts.

[8] https://drive.google.com/file/d/1OeMsdH5mUXLuisAhdSQr5yhnl8rtDmxx/view?pli=1

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2) Identifying gaps and connecting to Nationally Determined Contributions (NCDs): The framework offers a baseline assessment for each country, enabling them to pinpoint circularity gaps and set priority targets to include in their NDCs. Furthermore, the assessment results will guide the development of strategic actions to enhance circularity in the buildings and construction sector at the national level.

The framework is focused on a wide scope like cities; therefore, out of the SIRCULAR scope, although it considers buildings as part of the urban space. In this specific aspect, some KPIs are identified, but, they are similar to the defined by the analysed frameworks. Some of them related to the SIRCULAR objectives are listed below:

- Material and waste flow via the renovations, new construction and demolished ratio of buildings across the city.
- Carbon emissions due to construction materials produced and consumed (embodied carbon emissions).
- Share of materials on the Living Building Challenge (LBC).

3.2 Conclusions from the frameworks' review

LEED

LEED is a globally recognised certification system developed by the US Green Building Council to promote sustainable building practices. It evaluates projects based on criteria such as energy efficiency, carbon emissions reduction, water conservation, materials use, and indoor environmental quality. LEED certifications—Certified, Silver, Gold, and Platinum—are awarded through a points-based system. It applies to a wide range of project types, including new construction, existing buildings, and residential projects. Its adaptability and international recognition make it the leading certification in North America.

In the context of the SIRCULAR project, LEED aligns with principles of recyclability and circularity by awarding credits for materials with recycled content, promoting waste management practices, and encouraging designs that enable material reuse and recycling. These strategies support lifecycle resource efficiency and waste minimisation, key to advancing a circular economy. Additionally, LEED emphasises energy performance, focusing on renewable energy use, greenhouse gas reductions, and operational efficiency. Potential KPIs for LEED include energy use intensity, percentage of renewable energy usage, indoor air quality scores, and percentage of recycled content in materials.

LEED framework can complement the BREEAM framework by contributing strong energy performance benchmarks, making the two frameworks potentially synergistic depending on project priorities and location.

BREEAM

BREEAM is a sustainability framework that assesses aspects such as energy, water, materials, waste, and occupant well-being. It emphasises circularity through LCA, material reuse, and design for adaptability and disassembly. These strategies align with principles of the circular economy, promoting resource efficiency, resilience, and waste reduction throughout the building's lifecycle. Its alignment with European policies further reinforces its relevance in projects seeking circularity and resource optimisation. The scale of application includes new building construction, refurbishment and large-scale community developments.

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In the context of the SIRCULAR approach, BREEAM focus on responsible sourcing, waste reduction, and durable design supports the goals of projects targeting circular renovation and sustainability. Potential KPIs for BREEAM include metrics such as the percentage of recycled materials used, waste diverted from landfills, and design flexibility to accommodate future uses. These KPIs align with the principles of circularity and resilience by focusing on the lifecycle of materials and their adaptability of within building designs.

BREEAM and LEED frameworks offer a complementary relationship: BREEAM's emphasis on circularity can balance LEED's strengths in energy and carbon management, supporting holistic sustainability in building projects. BREEAM is more aligned with European policies and regulations, such as those related to the circular economy and decarbonisation. This makes it particularly relevant in the context of the SIRCULAR project, which operates in a European framework and seeks sustainable solutions that adapt to these regulations. In conclusion, in the framework of the SIRCULAR project, BREEAM is best suited to address circularity and resource management, thanks to its focus on the life cycle of materials, design for disassembly, and its alignment with European policies

Cradle to Cradle – C2C

The Cradle to Cradle Certified is a standard for defining and manufacturing products that contribute to a healthy, equitable, and sustainable future. It evaluates products depending on their re-use capacity, recyclability and composting. This standard evaluates five key aspects; material health, circularity, clean Air & Climate Protection, water & Soil Stewardship and social Fairness. In the certification process products may obtain several qualifications (Bronze, Silver, Gold, or Platinum) depending on their performance in the related topics.

Version 4.1 reinforces several aspects like greenhouse gas emissions reduction, use of renewable energy sources, recycled materials and social equity among others. This is very close aligned with the EU Green Deal.

In addition the standard encourages circular building models such as leasing, product as a service and demands designs which facilitates the disassembling process and the reuse of materials.

Thanks to several KPIs, this standard measures different aspects such as materials toxicity, water consumption, recyclability ratio, and others, fostering good practises to minimize the environmental impact and increase sustainability throughout the entire value-chain.

Living building challenge

This framework is focused on sustainability in the built environment, addressing both a single building, a renovation, an infrastructure project, or a park. It consists of seven performance categories, namely "Petals" within the framework: 1) Place; 2) Water; 3) Energy; 4) Health + Happiness; 5) Materials; 6) Equity; 7) Beauty. It should be remarked each petal is split into imperatives for the core certification. These are performance-based and position the ideal outcome as an indicator of success.

Living Building Challenge offers a core imperative focused on materials, but mainly wood. In fact, it sets "50% of wood products" should be FSC, salvaged or harvested on site. In terms of circularity, this is not mentioned in the framework, although it states some interesting approaches to local sourcing for different resources (material (wood), food and agriculture, water).

Special mention to be done to the "Net positive waste – Imperative 16". It aims the waste reduction into all phases of projects and to strive to reduce or eliminate the production of waste during design, construction, operation, and end of life in order to conserve natural resources.

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On top of that, this framework also entails a local materials sourcing approach with some KPIs like "30% of the total materials construction budget must come from within 1000 km of the construction site or closer".

In short, this framework has no focus in other materials beyond wood, for instance, concrete. Therefore, it is very limited for its consideration into SIRCULAR. Having this in mind, only some imperatives, like the waste and potentially the local materials sourcing, could be included in the assessment procedure as an added value beyond the main outcomes of the project.

Green star

Green Star is a voluntary sustainability framework established in 2003 by the Green Building Council of Australia (GBCA) to assess and enhance the environmental performance of buildings. It evaluates multiple aspects of sustainability, including energy efficiency, water conservation, indoor environmental quality, materials selection, and land use and ecology. Green Star ratings range from 4-Star (Best Practice) to 6-Star (World Leader), based on a points-based system. This holistic framework supports diverse project types, from new construction to refurbishment and interior fit-outs, promoting sustainability across the lifecycle of buildings.

In the context of the SIRCULAR approach, Green Star supports recyclability through LCA categories, rewarding the use of recycled materials, strategies for waste reduction, and designs that prioritise reuse and disassembly. It aligns with circular economy principles by encouraging modular designs, material recovery and reuse, and engaging with supply chains practicing closed-loop manufacturing. Furthermore, its emphasis on life cycle thinking helps quantify the environmental impact of materials and building systems over their lifespan. Potential KPIs for Green Star include the recycled content percentage in materials, waste intensity, adaptability index, and operational resource efficiency. These indicators reflect Green Star's alignment with circularity and resource optimisation goals.

In conclusion, Green Star is well-suited for projects seeking to address circularity and sustainability goals in the built environment. Its emphasis on material recovery, life cycle thinking, and modular designs complements the objectives of the SIRCULAR project, particularly when combined with other frameworks like BREEAM or LEED to support holistic sustainability in building projects. However, designed primarily for Australia and New Zealand, its adoption outside this region is more limited, and its closer alignment with European policies puts it at a disadvantage compared to BREEAM.

Well building standard

First of all, it highly important to remark this framework is mainly focused on comfort and well-being, without a real implementation based on circularity and recyclability. WELL is the premier Standard for buildings, interior spaces and communities seeking to implement, validate and measure interventions that support and advance human health and wellness. It includes ten concepts: 1) Air; 2) Water; 3) Nourishment; 4) Light; 5) Movement; 6) Thermal comfort; 7) Sound; 8) Materials; 9) Mind; 10) Community.

According to the previously mentioned concepts, the only one adapting to SIRCULAR is "Material", although it is centred into "reducing human exposure […] to chemicals that may impact health during the construction", neither circularity nor recyclability. Even though it considers the waste management, it relates to the chemicals in such a waste.

It is worthwhile highlighting the comfort aspects (thermal comfort), with special emphasis in thermal performance, as well as "Air" aspect with the concept of "Enhanced Air Quality" that could be of

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interest. Nevertheless, as these pillars are also covered by other frameworks, it can be concluded that WELL is not applicable within SIRCULAR project.

ISO 14001:2015

The ISO 14001:2015 framework, which evaluates environmental management systems (EMS), appears initially relevant and useful for application in the SIRCULAR project, though with some limitations. This standard promotes a systematic approach to environmental management, which aligns well with SIRCULAR's objectives, particularly in terms of decarbonization and circularity within the construction sector.

First, the circularity approach in ISO 14001:2015, which addresses the life cycle of products and services, promotes the evaluation and minimization of environmental impacts from raw material acquisition to waste disposal. This is closely aligned with SIRCULAR's mission to enhance the sustainability of the built environment by implementing technologies that foster resource efficiency and emission reduction. Additionally, the framework encourages recyclability and reuse, both key elements in the circular economy that SIRCULAR aims to integrate.

However, despite its overall applicability, ISO 14001:2015 is primarily focused on internal organizational management and may require adjustments to fully address the specific technical aspects of the construction sector and the innovations needed in SIRCULAR. For instance, while the standard covers energy efficiency and emission reduction, it is less specific about areas such as the integration of new sustainable construction technologies or the project's people-centric approach, which emphasizes placing communities at the core of the transition to sustainability.

In conclusion, the ISO 14001:2015 framework provides a strong foundation for promoting environmental management within the scope of the SIRCULAR project, particularly in implementing systems that enhance circularity and decarbonization in processes. However, it could be supplemented with more specific approaches that address the technological and social needs of the project.

Material passport

Material Passport (MP) is a digital or manual tool that collects and organizes detailed data about the characteristics of materials and components within a product. Its main goal is adding value in the current use of the materials and in the end of their life cycle. It is intended to improve waste identification and separation as well which foster the recycling and reuse of materials.

In the market exist several platforms that implement the functionalities of Material Passport such as Madaster which promotes the concept of transforming buildings into "material banks". Circularise based on blockchain to ensure the traceability and transparency of the materials. BAMB, focused on the reuse of components and circular economy or UKGBC's Circular Platform which acts as a registry of sustainable materials. The more common potential KPIs are Recyclability Rate, Reuse Rate, Embodied Carbon, Waste Reduction, Cost Savings, and Supply Chain Transparency.

In summary Material Passport is a key tool to promote a circular economy in the construction sector promoting transparency on material composition. This allows contractors to take informed decisions about materials, how to recycle and reuse them, reducing the waste in the end of their life cycle.

EU LEVEL(s)

LEVEL(s), as EU initiative / framework for sustainable buildings, focuses on sustainability based on circularity. It covers the full life cycle of the building and makes us of LCA / LCC tools. It splits into 6

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macro-objectives: 1) Greenhouse gas emissions; 2) Resource efficient and circular material lifecycles; 3) Efficient use of water; 4) Healthy and comfortable spaces; 5) Adaptation and resilience; 6) Optimised life cycle cost.

The coverage of the framework is both building renovations as well as on new construction. This is very related to the SIRCULAR's objective and the implementation of the solutions in the two demo sites (Estonia and Spain). Additionally, SIRCULAR is employing LCA tools within the platform development, being the main approach of LEVEL(s).

Despite these benefits, it should be mentioned LEVEL(s) is mostly assessing buildings, even though some indicators like "Resource efficient and circular material lifecycles" aim the waste and materials use. This framework looks for full life cycle of a building and brings the circular economy into building design and use. Therefore, it can be concluded that LEVEL(s) is a very aligned framework, whereas other approaches should complement it, above all, more focused on materials themselves and not in the application of the materials into the building renovation or construction.

From LEVEL(s), it should be also considered the applicability of other aspects like Energy, Water, Comfort, Costs and/or Climate change. They are also interesting from the SIRCULAR perspective to evaluate other pillars within SIRCULAR objectives.

ISO 59020:2024

The ISO 59020:2024 framework, which focuses on measuring and evaluating circularity performance, appears to be particularly well-suited for the SIRCULAR project. Its emphasis on transitioning from a linear to a circular economy and providing a detailed methodology for assessing circularity aligns directly with SIRCULAR's core objectives of decarbonization and enhancing circularity in the construction sector.

One of the key strengths of ISO 59020 is its comprehensive approach to circularity, which includes defining system boundaries, acquiring relevant data, and reporting results—essential aspects for evaluating circular practices in construction projects. The framework's inclusion of circularity indicators, such as resource inflows and outflows, energy use, and water management, provides a robust foundation for measuring and improving the circularity of construction processes and materials, which are central to SIRCULAR's goals of resource efficiency and waste reduction. Furthermore, the emphasis on life cycle assessments (LCA) to measure the environmental impact of circular activities enhances the framework's applicability to construction, where the entire building lifecycle must be considered.

In terms of recyclability, ISO 59020 offers clear steps for assessing material composition, recyclability, and regulatory compliance, making it useful for tracking the use and end-of-life recovery of materials in SIRCULAR's construction projects. KPIs such as the percentage of recycled and reused materials and renewable energy use are highly relevant to SIRCULAR, helping to measure progress in reducing reliance on virgin materials and promoting sustainable energy use during construction.

In conclusion, ISO 59020:2024 is an effective framework for the SIRCULAR project as it provides detailed tools for assessing and improving circularity, aligning well with the project's goals. Its focus on resource efficiency, recyclability, and sustainability makes it a valuable asset for SIRCULAR, particularly when complemented by project-specific considerations such as social impact and innovative construction technologies. That is why some of the proposed indicators are valuable to be included in the assessment framework.

ISO 20887:2020

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The ISO 20887:2020 framework, which focuses on sustainability in construction and design for dismantling or reuse, is highly relevant and applicable to the SIRCULAR project, as it promotes principles that facilitate dismantling and material reuse at the end of a building's life, aligning directly with the project's goals of circularity and decarbonization.

This framework emphasizes adaptability and disassembly, principles aimed at extending the useful life of materials and reducing waste generation. From selecting recyclable materials to designing components that are easy to disassemble, ISO 20887 provides a clear foundation for creating buildings that are compatible with a circular economy. The SIRCULAR project, which focuses on resource efficiency and emissions reduction, can benefit greatly from the framework's concepts, especially in the use of reusable materials and design strategies that facilitate material recovery and recycling at the end of a building's life cycle.

Moreover, the framework addresses important aspects such as life cycle assessment, which measures the environmental impact of materials throughout the entire building lifecycle, and material traceability, which ensures that components can be effectively recovered and reused. These principles are highly relevant to SIRCULAR's goals of promoting sustainability in construction and reducing overall environmental impact.

In conclusion, ISO 20887:2020 is partially applicable framework for the SIRCULAR project. It offers clear strategies to maximize material lifespan and minimize waste through adaptability and disassembly, supporting the circular economy and sustainability principles that the project aims to achieve. However, its effectiveness will depend on how its principles are integrated into the design and construction phases of the project.

Material Circularity Indicator

Material Circularity Indicator (MCI) analyses the material flows considering the use of recycled and reused materials. It scores from 0 (linear) to 1 (circular). This indicator considers recycled input/output flows, reuse, collection rates, and recycling efficiency. It also evaluates utility. Calculations can be done both on the one hand focusing on the product as a whole and on the other hand breaking a product into components.

To conclude, Material Circularity Index quantifies the product circularity based on recycled components, recyclability and durability. It helps companies to improve the material efficiency and durability in terms of circularity.

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4. Key Performance Indicators

This section is dedicated to the KPI definition according to the frameworks explained before. To do so, a clustering of KPIs has been proposed. Moreover, re-definition of the KPIs has been required to adapt the frameworks definition into the SIRCULAR concepts.

4.1 Classification of KPIs

Starting with the classification of KPIs, Figure 7 shows a table about how to group the KPIs in SIRCULAR. Two main clusters are proposed:

- Scope of application of the KPI, split into three levels:
  - Solution when the KPIs is simply applied to the SICULAR elements, for instance, an insulation layer.
  - Part of the building when the KPI is being calculated in the parts of the building where SIRCULAR solutions are deployed, such as a façade where the SIRCULAR insulation materials are applied.
  - Whole building when interested to determine performance of the entire elements of the building.
- Application degree to classify the compulsory calculation of KPIs, split into three categories:
  - Mandatory for those KPIs that are aligned with the expected outcomes of the project, i.e., quantification of the project impacts.
  - Recommended, when the KPIs is not a "must", but it is highly impacting in the SIRCULAR solutions and are used to calculate mandatory KPIs (e.g., energy use that derivates into greenhouse gas emissions).
  - Optional for those KPIs that could be of project interest to determine secondary performance parameters, such as comfort, social or economic aspects.

		SCOPE			DATA	BASELINE	FEASIBILITY	
		Solution	Part of the building	Whole building	Requirements	Methods	Estonian	Spanish
APPLICATION DEGREE	Mandatory							
	Recommended							
	Optional							

Figure 7. Classification of the KPIs

Apart from this classification, the table above aims the collection of data requirements per KPIs, baseline calculation methods and feasibility in the pilots. However, within D1.1, this is out of the scope, while this deliverable is just defining KPIs and concepts. Task 4.4 will be dedicated to detail the monitoring programmes, starting from the KPIs definition and feasibility studies in the demos.

4.2 Selection of potential KPIs from frameworks

From the frameworks, multiple KPIs are available to be used within SIRCULAR framework. Table 15 summarises the KPIs selected from the frameworks to be applicable in SIRCULAR. These are classified under the scopes and application degrees explained above. Additionally, it is identified the framework where the KPI comes from. For instance , "Reduction in Greenhouse Gas Emissions (LEED, C2C, ISO14001)" is similarly defined in LEED, C2C and ISO14001 frameworks.

Moreover, there exist some KPIs with similar definitions but similar names, such as "Energy Use Intensity" from LEED, "Operational energy consumption" from BREEAM2, "Energy Efficiency per

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Square Meter" from Green Star or "Use stage energy performance" from LEVEL(s). In this sense, the common concepts definition is key to understand how SIRCULAR interprets the KPIs to assure a common way of calculation. For that end, KPIs are re-named in some case to align with SIRCULAR definitions.

Having said that, summarising the KPIs, within mandatory indicators, the ones related to Greenhouse Gas Emissions, embodied carbon emissions, Global Warming Potential, Recycled Content in Materials, reuse of materials and circularity are included. Recommended indicators are focused on energy (not only from the energy performance perspective, but as useful indicator for greenhouse gas emissions calculations), materials databases from construction, including the supply chain (helpful for the MCI calculation), comfort, Indoor Air Quality and recyclability rate (as complement for the MCI). Finally, the optional ones are related to waste, water, renewable energy and socio-economic aspects. This last KPI set has been obtained from the German "LEED" framework, named DGNB[9] (German Sustainable Building Council) because the analysed frameworks do not cover social and economic aspects.

[9] https://www.dgnb.de/en

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Table 15: Extraction of KPIs from the evaluated frameworks

		SCOPE		
		Solution	Part of the building	Whole building
Application degree	Mandatory	- Reduction in Greenhouse Gas Emissions (LEED, C2C, ISO14001) - Percentage of Recycled Content in Materials (LEED, BREEAM, Green Star, ISO14001) / Average recycled content of an inflow (ISO59020) - Embodied carbon emissions (BREEAM) - Life cycle Global Warming Potential (LEVEL(s)) - Average reused content of an inflow (ISO59020) - Material Circularity Indicator (MCI)	- Reduction in Greenhouse Gas Emissions (LEED, C2C, ISO14001) - Percentage of Recycled Content in Materials (LEED, BREEAM, Green Star, ISO14001) / Average recycled content of an inflow (ISO59020) - Embodied carbon emissions (BREEAM) - Life cycle Global Warming Potential (LEVEL(s)) - Average reused content of an inflow (ISO59020) - Material Circularity Indicator (MCI)	- Reduction in Greenhouse Gas Emissions (LEED, C2C, ISO14001) - Percentage of Recycled Content in Materials (LEED, BREEAM, Green Star, ISO14001) / Average recycled content of an inflow (ISO59020) - Embodied carbon emissions (BREEAM) - Life cycle Global Warming Potential (LEVEL(s)) - Average reused content of an inflow (ISO59020) - Material Circularity Indicator (MCI)
	Recommended	- Recyclability rate of materials (BREEAM, C2C, ISO14001, Material Passport) - Supply Chain Transparency (Material Passport) - Construction & Demolition waste and materials (LEVEL(s))	- Energy Use Intensity (LEED) / Operational energy consumption (BREEAM) / Energy Efficiency per Square Meter (Green Star) / Use stage energy performance (LEVEL(s)) - Time outside of thermal comfort range (LEVEL(s)) - IEQ / IAQ (LEED, BREEAM)	- Energy Use Intensity (LEED) / Operational energy consumption (BREEAM) / Energy Efficiency per Square Meter (Green Star) / Use stage energy performance (LEVEL(s)) - Time outside of thermal comfort range (LEVEL(s)) - IEQ / IAQ (LEED, BREEAM)

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			- Recyclability rate of materials (BREEAM, C2C, ISO14001, Material Passport) - Supply Chain Transparency (Material Passport)	- Recyclability rate of materials (BREEAM, C2C, ISO14001, Material Passport) - Supply Chain Transparency (Material Passport)
	Optional	- Percentage of construction waste diverted from landfills (BREEAM)	- Occupant Satisfaction Score (LEED) - Percentage of construction waste diverted from landfills (BREEAM) - Operation costs (DHNB) - Cost savings	- Net positive waste – Imperative 16 (Living Building Challenge) - Local material sourcing - Water consumption reduction (BREEAM, C2C) - Percentage of Renewable Energy Usage (LEED, BREEAM, C2C) - Occupant Satisfaction Score (LEED) - Percentage of construction waste diverted from landfills (BREEAM) - Operation costs (DHNB) - Cost savings

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4.3 KPIs for SIRCULAR

As explained before, the KPIs selected from the frameworks provide a set of definitions that require to be renamed for the SIRCULAR purposes. Under this perspective, Table 17 provides the list of KPIs grouped by scope and application degree with the final names to be used in SIRCULAR to make them understandable. Next section provides the overview of each individual KPI, including the way of being calculated.

4.3.1 Definition of the KPIs

From the selected KPIs for SIRCULAR, summarised in Table 17, the definition of them is contained in the following lines, including the tips about how to calculate them.

- Greenhouse Gas Emissions in use

First performance metric is used to evaluate and quantify a building's efforts to minimize its greenhouse gas emissions in operation. In contrast to the definitions in LEED, C2C and ISO14001, within SIRCULAR, it is differentiated the GHG emissions from the operation and building lifecycle. This specific case is related to the energy intensity use and how to lower carbon emissions for heating and cooling requirements. It is measured in tons of CO_2 per square meter (tCO_2/m^2). The equation for the calculation is provided below, where, per each energy carrier (i), the energy use (in kWh/m^2) is multiplied by the CO_2 conversion factor (CO2CF), whose value depends on each country.

$$GHG_{in\_use} = \sum_i Energy_{use\_i} \times CO2CF_i$$

- Percentage of Recycled / Reused Content in Materials

It reflects the proportion of recycled materials used in the construction products, looking for reducing the demand for virgin resources and minimizing environmental impact. The metric is obtained from ISO 59020 and it is measured in percentage. Per each material (i), the ratio of the mass between recycled content and total mass of the material is obtained.

$$\%\ of\ recycled\ content = \left(\sum_i \frac{Mass\ of\ recycled\ content}{Total\ mass\ of\ the\ material} \right) \times 100$$

The way to calculate the mass of recycled content should follow the next stages:

1. Identify sources of recycled material that have been used by consumers and collected for recycling or materials recovered from industrial processes (e.g., production scrap reused as input).

2. Define the scope of the product or process to determine which parts or components of the product include recycled material.

3. Obtain information from suppliers in base of certifications or data from suppliers regarding the proportion of recycled content in the materials they provide.

4. Measure the mass thanks to technical datasheets, supplier certificates, or physical measurements if necessary.

5. Validate the data as per ISO 59020, excluding recycled materials that do not meet the specific requirements of the standard.

6. Calculate the total mass of recycled content.

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- Embodied carbon emissions (LCA)

It obtains the GHG emissions associated with the extraction, production, transportation, construction, maintenance, and disposal of materials used in a building or product throughout its lifecycle. Unlike operational carbon emissions, which arise from energy use during the building's operation, embodied carbon is "locked in" from the very start and cannot be reduced once construction is complete.

These emissions cover the lifecycle stages as follows: 1) Material Extraction (Mining, harvesting, and processing of raw materials); 2) Manufacturing (Production of building materials such as cement, steel, and glass); 3) Transportation (Emissions from transporting raw materials, components, and finished products); 4) Construction (carbon emissions from on-site activities and the use of construction machinery); 5) Maintenance and Renovation (Emissions from repairs, replacements, or refurbishments during the operational phase); 6) End of Life (Emissions from demolition, recycling, or disposal of building materials).

The way to calculate is using LCA (LifeCycle Assessment) software tools and it is obtained in kilograms or metric tons of CO_2 equivalent ($kgCO_2e$ or tCO_2e). It follows a set of steps:

i. Identify Materials and Quantities: List all materials used in the construction project (e.g., concrete, steel, wood) and their respective quantities (mass or volume).

ii. Determine Emission Factors: Use emission factors ($kgCO_2e$/unit) from reliable databases.

iii. Calculate Material-Specific Embodied Carbon: For each material, multiply the quantity by its emission factor, according to the formula:

$$Material\ carbon\ emission = Quantity \times Emission\ factor$$

iv. Account for Transport and Construction Emissions

v. Aggregate Emissions: Sum the embodied carbon across all materials and processes to determine the total embodied carbon for the project.

vi. Lifecycle Assessment (LCA).

- Lifecycle Global Warming Potential

As defined in the LEVEL(s) framework, it quantifies the total (GHG) emissions associated with a building throughout its entire lifecycle. It is pretty much similar to the embodied carbon emissions as it also covers material extraction, manufacturing, transportation, construction, operation, maintenance, and end-of-life disposal or recycling and is measured in the same units. However, it is here included as additional indicator as it can be focused on different stages of the building lifecycle as Product stage (A1-A3); Construction process stage (A4-A5); Use stage (B1-B7); End-of-life stage (C1-C4) and beyond the system boundary (D): Potential reuse, recovery, or recycling benefits. LEVEL(s) framework provides an Excel tool as the way to calculate the multiple indicators defined in the framework; hence, no equation metric is here included, but Excel sheet should be used.

- Material Circularity Indicator

The MCI indicator developed by Ellen McArthur Foundation and Granta Design is a number ranging from 0 to 1. It is calculated based on virgin raw material mass, unrecoverable waste mass, and product utility. For a single product j, the MCI_j is calculated as:

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$$MCI_j = max\left(0;\ 1 - \frac{0.9}{X_j} \cdot LFI_j\right)$$

Where LFI_j is the Linear Flow Index for product j, quantified as:

$$LFI_J = \frac{V_j + W_j}{2M_j + \frac{W_{Fj} - W_{Cj}}{2}}$$ or, in a simpler case where $W_{Fj}=W_{Cj}$, $$LFI_j = \frac{V_j + W_j}{2M_j}$$

And X_j is the product j Utility factor, computed multiplying the lifetime ratio and the intensity ratio:

$$X_j = \frac{L_j}{L_{av\,j}} \cdot \frac{U_j}{U_{av\,j}}$$

Where:

- V_j (amount of virgin material)= M_j (1 − ($F_{r,j}$+$F_{u,j}$))
- $F_{r,j}$ is the recycled material and $F_{u,j}$ is the reused material
- W_j (amount of unrecoverable waste)= $W_{0,j}$+$W_{F,j}$
- $W_{0,j}$ is the waste from the linear flow and $W_{F,j}$ is the waste from the recovering process
- M_j is the total mass of the product j
- L_j is the product lifetime over
- $L_{av\,j}$ is the average lifetime of similar products on the market
- U_j is the intensity of use per year

$U_{av\,j}$ is the market average for intensity of use the MCI needs to be adapted and scaled up to be applied to building components and/or to a whole building. If the MCI of a building product is calculated, it could be treated as a product, applying the comprehensive approach (breakdown by components). Additionally, other literature sources have expanded the methodology by also considering product disassemblability and by calculating the circularity index for systems (composed of more products).

Support from the industrial partners could be needed for:

- bill of materials, and components
- demonstrating sustainable sourcing
- choosing the average product for the use phase comparison, including average lifetime and utility
- specific recycling efficiencies

Parameters that could be obtained from public sources are:

- average recycled content of feedstock
- sector recycling collection rates
- average recycling efficiencies

More information on the adaptation of the index to SIRCULAR project will be provided in deliverable D1.2.

- Final / Primary energy use

Within this metric, two indicators are included. First one refers to final energy use, which considers the amount of energy consumed by end users to satisfy the building needs to reach thermal comfortable values, but also including lighting, or operating appliances. It represents the energy delivered to the point of use. It is measured in kWh or kWh/m^2 when normalised by the area. Per each

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energy carrier (i), it sums the contribution per each one of the energy resources to account for the total energy use. This can be split into thermal and electricity by simply accounting the energy delivered for thermal uses or electricity uses.

$$Final\ energy\ use = \sum_i Energy\ delivered\ to\ endusers$$

On the other hand, primary energy use accounts for the total energy consumed, including the energy used in extraction, conversion, and delivery processes. It measures the energy contained in raw resources (e.g., coal, natural gas, wind) before being converted into usable forms like electricity. For its calculation, it multiplies the final energy use by the primary energy factor (PEF) associated to the energy carrier (i), which depends on the country.

$$Primary\ energy\ use = \sum_i Final\ energy\ use_i \times PEF_i$$

- Time outside of thermal comfort range

It assesses indoor environmental quality from the thermal comfort perspective. This metric quantifies the percentage of time occupants experience comfortable values. Usually, metrics like PMV (Predicted Mean Vote) and PPD (Percentage of People Dissatisfied) provide way to calculate this indicator, they required datasets difficult to be measured, such as clothing or indoor air speed. For this reason, ASHRAE Standard 55 [26] is applied, which is illustrated in Figure 8. It relates temperature and humidity that are more commonly measured parameters, determining the bands within comfortable values are accepted (shaded area on the graph).

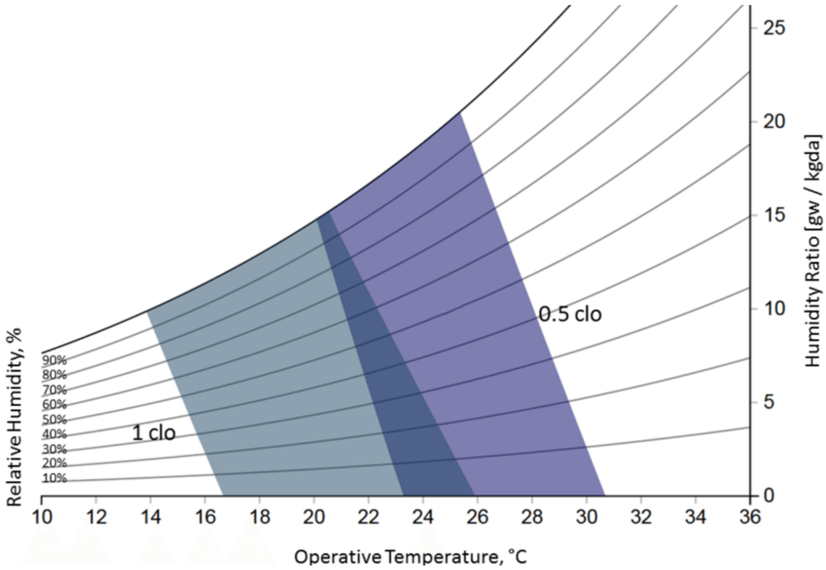

Figure 8. ASHRAE Standard 55 [26]

Having said that, the calculation is basically the ration between the temperature-humidity measurements that are outside the comfortable bands and the total measurements within a time range (to be defined by the user).

$$Time\ outside\ comfort = \frac{Temperature - humidity\ measurement\ pair\ outside}{Total\ samples\ for\ temperature - humidity} \times 100$$

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- IEQ / IAQ

In contrast to thermal comfort IEQ (Indoor Environmental Quality) / IAQ (Indoor AIR Quality) are referring to healthy and productive indoor environments. Within the definition of IEQ, IAQ refers the air pollutants, while acoustics is another metric. Lighting quality and ergonomics are out of the scope of SIRCULAR; therefore, not considered.

On the sense of the CO2 concentration, there exist four different levels defined on the ISO 16000-9 for several kind of buildings and their uses. In the context of the SIRCULAR project these levels/categories are defined as follows:

- CAT I, High Air Quality. CO_2 concentration is below 350 ppm over the base CO_2 concentration. For uses that require a very high air quality such as Hospitals, day care centres or critical meeting rooms.
- CAT II, Good Air Quality. Additional CO_2 concentration above outdoor air: ≤ 500 ppm for offices, meeting rooms and homes with standard ventilation.
- CAT III, Acceptable Air Quality. The limit for this category is under 800 ppm over the external CO2 concentration, suitable for residential buildings with standard ventilation.
- CAT IV, Poor Air Quality. More than 800 ppm over the base CO2.

In the case of other contaminants particles on air, the standard LEED stablishes rigids limits of VOC (Volatile Organic Compounds): ≤ 300 µg/m³, PM10 (Particles with a diameter ≤ 10 micrometres) ≤ 50 µg/m³) and PM2,5 (Particles with a diameter ≤ 2.5 micrometres) ≤ 15 µg/m³ and formaldehyde ≤ 100 µg/m³. These limits are accepted for the WHO (World Health Organization) and followed not only for the standard LEED but also for WELL.

- Recyclability rate of materials

It reflects the proportion of a material or product that can be effectively recycled at the end of its life cycle. This concept is addressed in BREEAM, Cradle to Cradle (C2C), ISO 14001, and Material Passports frameworks. It measures the percentage of a material or product that can be potentially and effectively recycled at the end of its lifecycle (in contrast to the recycled content that provides the actual reused amount of material). The calculation varies slightly depending on the framework, but the general methodology involves assessing the recyclable portion of the material (including the biodegradable content as appointed by C2C) compared to its total weight, i.e.:

$$\% \; of \; recycability \; rate = \left(\sum_i \frac{Mass \; of \; potentially \; Recyclable \; Material}{Total \; mass \; of \; the \; material} \right) \times 100$$

- Supply Chain Transparency

More than a metric, it is a way to provide information as it refers to the ability to trace, document, and provide detailed information about the origin, processing, and movement of materials or products throughout their lifecycle. Material Passports, as a concept and tool, play a crucial role in enabling supply chain transparency, particularly in the context of sustainable building practices and the circular economy.

Basically, the way of obtaining this indicator is by using a Material Passport, which is a digital or physical document containing comprehensive information about the characteristics, origin, and lifecycle of materials or products, i.e., a database of the material. However, it is included as

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recommended KPI as it would allow to keep a traceable database of the materials for the calculation of other metrics or KPIs.

- Materials waste

This KPI comes from LEVEL(s) framework and it focuses on minimizing waste generation and optimizing material efficiency throughout a building's lifecycle. LEVEL(s) provide an Excel sheet for the calculation of the materials waste during Construction & Demolition stages. However, it requires to follow a set of steps for its application:

a) Planning:
    a. Conduct a pre-demolition audit to assess material quantities and potential for reuse or recycling.
    b. Develop a waste management plan, outlining strategies for waste reduction and material recovery.
b) Design:
    a. Incorporate design for deconstruction principles to facilitate future disassembly and material reuse.
    b. Select materials that are recyclable and have lower environmental impacts.
c) Construction and Demolition:
    a. Implement on-site waste segregation to enhance recycling rates.
    b. Engage with certified waste management contractors to ensure compliance with environmental standards.
d) Monitoring and Reporting:
    a. Track waste generation and management practices throughout the project.

- Net positive waste

This metric is a core component of the Living Building Challenge and it is included in the imperative 16. This imperative aims to integrate waste reduction strategies into all phases of a project's lifecycle, encouraging the imaginative reuse of salvaged materials and minimizing the environmental impact associated with material extraction, processing, and disposal. It complements the one from LEVEL(s) as “Materials waste” accounts the current waste, “Net positive waste” looks for the planning of minimising the waste generation. It combines the waste with material reuse and landfill diversion.

Net positive waste requires that the project meet aggressive material diversion rates throughout the design, construction, operation, and end of life phases of the building. It is intended that all projects must divert waste material from the landfill to the following levels (by weight or volume) during construction.

Table 16: Waste material divertion from the landfill

MATERIAL	MINIMUM DIVERSION RATE
Metal	99%
Paper and cardboard	99%
Soil and biomass	100%

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Rigid foam, carpet, and insulation	95%
All others – combined weighted average	90%
Demolition Waste	80%

- Local material sourcing

As part of the Petals of the Living Building Challenge framework, the local material sourcing encourages the use of materials sourced from within defined proximity radii. This KPIs is directly linked with the environmental impact in terms of reducing transport, supporting the local economy and regional supply chain.

The KPIs is distance-based procurement rules outlined in the Materials Petal. These rules define proximity radii for sourcing materials based on their type and weight. The proximity radii guidelines are classified as follows:

- Heavy Materials (e.g., stone, concrete, and soil): Must be sourced from within 400 km of the project site.
- Moderately Heavy Materials (e.g., timber, metals): Must be sourced from within 800 km.
- Light Materials (e.g., finishes, mechanical systems): May be sourced from within 1,600 km.

According to the previous list, the KPI is basically looking for a classification of the materials between the three aforementioned groups to comply with the red list and ethical sourcing requirements.

- Water consumption

This KPI comes from the BREAM and C2C frameworks. Although it is differently defined in each one of the frameworks, for SIRCULAR, it has been re-redefined as it is not focused on the water consumption reduction, but simply consumption. Basically, it aims at assessing how a product or process impacts in the water resources, including the manufacturing and construction stages of the building. While frameworks are focused on the use of resources to optimise the water usage (e.g., taps) or water recycling, within SIRCULAR, it is just how water resources are used in the lifecycle of the building. Having said that, the way to calculate is obtaining the cold-water consumption from the water meters or bills to account the cubic meter (m^3) of water.

- Renewable Energy Use

Renewable sources impact in the energy use because the PEF is 0 for this energy; therefore, not accounting to the primary energy use. As well, similarly, CO2CF is 0; hence, not contributing to the GHG emissions. Renewable energy use can be split into electricity (e.g., photovoltaics or heat pumps with performance levels higher than 2.5) or thermal (e.g., solar thermal). This renewable energy use can be during the manufacturing process, transport (eV) or operation phases. Then, the KPI sums all the renewable energy use in the whole lifecycle, with emphasis in each stage (j) of the building lifecycle, as well as the renewable source (i).

$$Renewable\ energy\ use = \sum_{i,j} Renewable\ source\ energy\ production_{i,j}$$

- Occupant Satisfaction Score

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Based on surveys, this KPIs evaluates satisfaction of building occupants concerning various environmental factors, related to the applied solution. According to LEED framework, aspects like temperature and thermal comfort; noise levels; indoor air quality or aesthetics should be included. The KPI is measured in the level of dissatisfaction. If less than 20% of occupants express dissatisfaction, the KPI could be considered as successful.

- Percentage of construction waste diverted from landfills

Related to material waste KPIs, it assesses the effectiveness of waste management practices during construction by measuring the proportion of waste materials that are reused, recycled, or otherwise diverted from landfill disposal. Complementary, it requires a Resource Management Plan (RMP) that outlines strategies for minimizing waste generation and maximizing diversion from landfills. This tracks and documents the types of waste produced (by using logbooks).

$$\% \, of \, construction \, waste \, diverted \, from \, landfills = \frac{kg \, of \, waste \, diverted \, from \, landfill}{Total \, kg \, of \, waste} \times 100$$

- Operation costs

Operation costs are the ongoing expenses associated with building. These costs form a significant portion of the building lifecycle costs and include expenditures on energy, water, maintenance, cleaning, and other operational activities required to sustain the building's functionality and occupant comfort. The way of calculating this KPI requires a set of steps:

- Identify the cost categories by breaking down all operational activities into measurable components, such as energy use, maintenance, and staffing.
- Collect data for each component by using bills, contracts, and historical maintenance records to estimate costs accurately.
- Define the time period where it is applied, e.g., monthly, annually, or over the building's lifecycle.
- Apply the standard formula:

$$Operation \, cost \, per \, category = Quatity \, of \, resources \, used \times unit \, cost$$

$$Operation \, costs = \sum_{cat} Operation \, cost \, per \, category$$

When applying the lifecycle perspective, the inflation and discount rates (r) should be applied to obtain the Net Present Value (NPV):

$$NPV = \sum_{y} \frac{Operation \, costs \, in \, year \, y}{(1+r)^y}$$

- Investment Costs

This KPI refers to the total expenditure required to acquire, develop, and deploy assets or projects. These costs can include initial capital expenses, infrastructure costs, equipment, installation, and sometimes associated indirect costs such as consulting fees or project management costs. Understanding and analysing investment costs are critical for evaluating the financial feasibility of a project and its return on investment (ROI). It is composed of two parts:

$$Investment \, costs = Direct \, costs + indirect \, costs$$

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- Direct Costs: Costs directly attributable to the asset or project (e.g., purchase of equipment, land, or software licenses). It includes:
    - Equipment purchases
    - Construction costs
    - Raw materials
    - Salaries for initial staff
- Indirect Costs: Ancillary costs required to complete the project but not directly tied to production (e.g., training, feasibility studies, or project management). Within these costs, it is included:
    - Consulting and planning fees
    - Permits and legal expenses
    - Initial training
    - Overhead allocations

- Manufacturing and implementation timeframes

It calculates the duration required to design, produce, and operationalise a project, product, or asset. These timeframes are critical for planning, resource allocation, and achieving the desired return on investment within a specified period. Timeframes typically include multiple phases, such as planning, production, testing, installation, and deployment, and may vary depending on the complexity, scale, and nature of the project.

The common components of the manufacturing and implementation timeframes are:

- Planning Phase:
    - Initial research, feasibility studies, and design
    - Approval processes and project scoping
- Manufacturing Phase:
    - Procurement of materials
    - Production of components
    - Quality assurance and testing of parts
- Implementation Phase:
    - Assembly or construction
    - Equipment installation and integration
    - Testing and commissioning
- Operationalisation:
    - Final quality checks
    - Staff training (if applicable)
    - Handover to operations team

- Risk assessment

Risk assessment is the systematic process of identifying, analysing, and prioritizing potential risks that could negatively impact manufacturing or implementation projects. Three levels are identified: low, medium, or high. The steps for the calculation of this KPI are:

a. Risk Identification of all potential risks related to the project's scope, resources, timelines, and deliverables.
b. Risk Analysis to assess the likelihood and impact.
c. Risk Prioritization with clear focus on high-likelihood and high-impact risks first.

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d. Risk Mitigation Planning through strategies to reduce or eliminate risks.
e. Monitoring and Review to continuously monitor risk factors throughout the project lifecycle.

It is important to highlight; the project already develops the risk identification and management strategies from the coordination (WP7). Nevertheless, this KPI does not aim to overlap the risk assessment from coordination, but complementing it with a low-level granularity identification. While risks at WP7 are general to the project success, this KPI aims to analyse risk in every step of the technology implementation process.

Both operational and administrative risks are included within this KPI. In terms of operational, this tracks discrepancies between planned and actual outcomes on-site. For the case of the administrative risks, some examples of analysis are the following questions:

- Will a quality certificate be required for installation? What is the probability of obtaining it?
- Will a special permit or concession be needed from the local authorities? What is the likelihood of securing it?

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Table 17: KPIs for SIRCULAR project

		SCOPE		
		Solution	Part of the building	Whole building
Application degree	Mandatory	- Greenhouse Gas Emissions in use - Percentage of Recycled / Reused Content in Materials - Embodied carbon emissions (LCA) - Life cycle Global Warming Potential - Material Circularity Indicator	- Greenhouse Gas Emissions in use - Percentage of Recycled / Reused Content in Materials - Embodied carbon emissions (LCA) - Life cycle Global Warming Potential - Material Circularity Indicator	- Greenhouse Gas Emissions in use - Percentage of Recycled / Reused Content in Materials - Embodied carbon emissions (LCA) - Life cycle Global Warming Potential - Material Circularity Indicator
	Recommended	- Recyclability rate of materials - Supply Chain Transparency - Materials waste - Investment Costs - Manufacturing timeframes	- Final / Primary energy use - Time outside of thermal comfort range - IEQ / IAQ - Recyclability rate of materials - Supply Chain Transparency - Operation costs - Investment Costs - Implementation timeframes - Risk assessment	- Final / Primary energy use - Time outside of thermal comfort range - IEQ / IAQ - Recyclability rate of materials - Supply Chain Transparency - Operation costs - Investment Costs - Implementation timeframes - Risk assessment
	Optional	- Percentage of construction waste diverted from landfills	- Occupant Satisfaction Score - Percentage of construction waste diverted from landfills - Cost savings	- Net positive waste - Local material sourcing - Water consumption - Renewable Energy Use - Occupant Satisfaction Score - Percentage of construction waste diverted from landfills

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4.4 Preliminary data needs for the KPI calculation

Finally, according to the KPIs defined before, a set of preliminary data requirements can be established as basis for the monitoring programmes in T4.4, which will determine the overall data needs and the ways to collect data. Table 18 summarises the KPIs in groups with similar data requirements and sets some of the possible data sources that can be used to provide the datasets.

Table 18: Preliminary data requirements for KPI calculation

KPI group	Data requirements	Possible data sources
(Primary) Energy use	Thermal energy use Electricity energy use Square meters PEF	Smart meters Bills
Greenhouse gas emissions	Thermal energy use Electricity energy use CO2 conversion factors	Smart meters Bills
Thermal comfort	Temperature Humidity	Sensors
Air quality	CO2 levels Other particles (PM2.5, PM10) Total VOC Formaldehyde Building & material characteristics	Sensors BIM (or similar) Specific sensors for particles
Embodied carbon emissions	Materials being used Specific characteristics of the material	BIM / Logbooks
MCI / PCI	Bill of materials (including amount of materials) Materials origin Utility factor (lifetime / average lifetime) Disassemblability	BIM Bills Traceability registers
Recycled and re-used content	Materials being used Materials origin Materials characteristics from origin	
Operational costs	Cost for the elements in the defined categories	Bills

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From the previous list, thermal and electricity energy use are critical measurements to obtain the GHG emissions in building operation stage. As well, thermal comfort and air quality indicators require sensors to measure real values in order to proceed with final assessment.

On the other hand, it is remarkable to say the materials data for many of the indicators, such as embodied carbon emissions or MCI. In this sense, BIM models, logbooks or material passports are very useful tools that can provide information about the materials. Some open tools for material passports could be very valuable from the project perspective in order to keep traceability of the materials. For that end, further research on the Madaster, BAMB and/or UKGBC's Circular Passport Platform is encouraged to be used.

Complementary to say, the air quality calculation methodology to be followed in T1.4 requires data from the buildings characteristics, such as areas, spaces, zones… As well, material characteristics, similarly to the embodied energy emissions, where tools like BIM or material passport could provide the input information.

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5. Evaluation methodology applicable in SIRCULAR

As final part of the deliverable D1.1, it is worth mentioning that a methodology is defined to support the project's development and the multiple stages. In this line, LEVEL(s) already propose a methodology based on three levels, as illustrated in Figure 9.

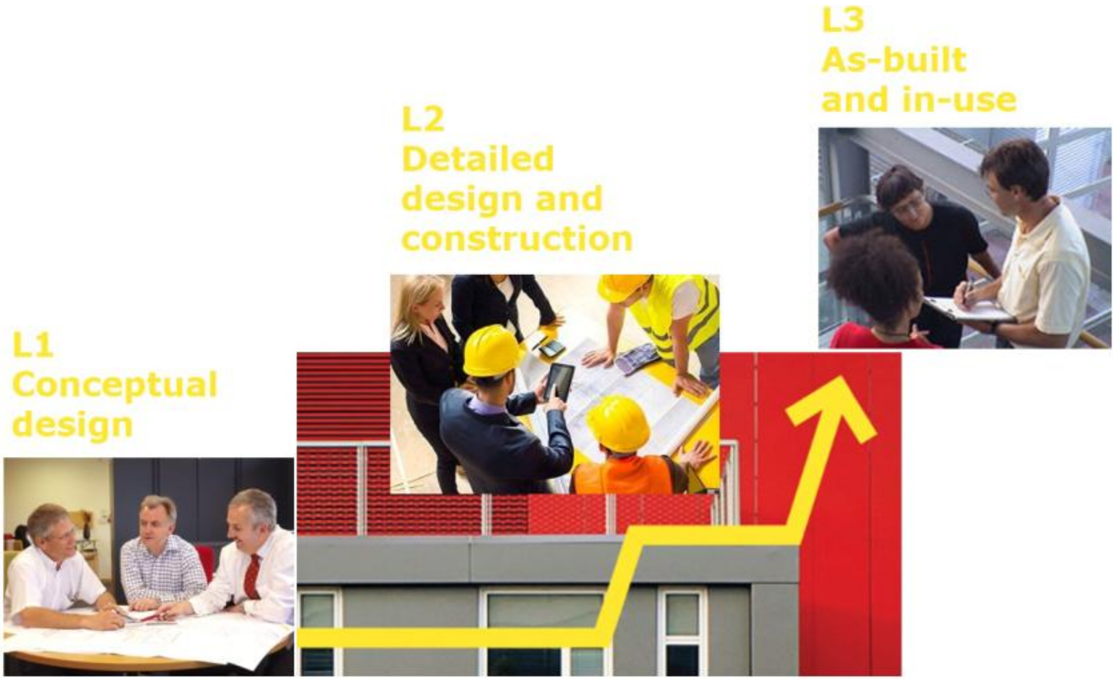

Figure 9. LEVEL(s) methodology steps

LEVEL(s) defines the steps as follows:

1) Step 1: To establish a project plan with the following objectives:
    a. Define which sustainability macro-objectives the project will address,
    b. Identify which indicators will be used to assess performance against,
    c. Establish to which 'level' project performance will be assessed,
    d. Plan what resources will be needed to assess performance and when in the project life cycle.
2) Step 2: To decide to which "level" project performance will be assessed, in accordance to the matrix that relates indicators and macro-objectives (see Figure 10).
3) Step 3: To plan the workflow requirement to make LEVEL(s) assessments: specific roles and responsibilities will need to be assigned within the project team; specific training or expertise may be required; dependant on the different aspects of performance to be assessed; the information and data required to make assessments will need to be managed.

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Macro-objective		Indicators	Level 1 Conceptual design	Level 2 Detailed design and construction	Level 3 As-built and in-use
Macro-objective 1 **Greenhouse gas and air pollutant emissions along a buildings life cycle**		1.1. Use stage energy performance			
		1.2. Life cycle Global Warming Potential			
Macro-objective 2: **Resource efficient and circular material life cycles**		2.1. Bill of quantities, materials and lifespans			
		2.2. Construction & demolition waste and materials			
		2.3. Design for adaptability and renovation			
		2.4. Design for deconstruction, reuse and recycling			
Macro-objective 3: **Efficient use of water resources**		3.1. Use stage water consumption			
		4.1. Indoor air quality			

Figure 10. Matrix with macro-objectives, indicators and levels of application within LEVEL(s)

Having explained the LEVEL(s) proposed methodology, it has been adapted to SIRCULAR to follow a similar approach. Table 19 maps the LEVEL(s) methodology stages and how SIRCULAR considers each step to be applied in the project working methodology. As well, linked to the ways to measure based on the previously defined indicators.

Table 19: Mapping EU LEVEL(s) methodology with SIRCULAR

Step / Level	LEVEL(s)	SIRCULAR	Way to measure
Level 1. The conceptual design	It covers the conceptual design and reporting on the concepts that have or are intended to be applied.	Objectives per Grant Agreement and common agreements.	Qualitative or quantitative from goals.
Level 2. The detailed design and construction performance of the building	Quantitative assessment of the designed performance and monitoring of the construction according to standardised units and methods.	Expected results from the designs of the SIRCULAR solutions to be applied in the demos.	Baseline KPIs (from simulation, existing data…).
Level 3. The as-built and in-use performance	Monitoring and surveying of activity both on the construction site and of the completed building and its first occupants.	Monitoring programmes and KPIs calculation.	Post-renovation KPIs calculation using real data.

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6. Conclusions

The transition to circularity and enhanced recyclability in buildings is critical for achieving sustainable construction practices. Integrating circular principles at every stage of a building's lifecycle—from design to demolition—can significantly reduce resource consumption and environmental impact. By prioritizing modular construction, material reuse, and the incorporation of recycled or recyclable materials, buildings can extend their lifespan, lower embodied carbon, and contribute to a closed-loop economy. These strategies also align with emerging regulations and societal expectations for greener, more resilient urban environments.

However, the shift toward circularity requires overcoming challenges such as fragmented supply chains, limited material databases, and the need for standardized metrics to assess circular performance. Additionally, the adoption of digital tools like Building Information Modeling (BIM) and material passports can enhance traceability and recyclability, paving the way for more efficient resource management in the construction sector. Circularity in buildings not only supports environmental sustainability but also offers economic opportunities by creating value from waste and reducing dependency on virgin resources.

Under this scope, this document has made an analysis of the currently existing frameworks for sustainable goals, being aligned with SDGs: SDG3, SDG7, SDG11 and SDG13. From each framework of the 12 analysed ones, a summary was extracted, focused on circularity and recyclability application in SIRCULAR project. Finally, potential indicators have been obtained. As conclusion, it can be said that all the frameworks define similar concepts, indeed some of them are complementing. From these 12, the most useful ones for SIRCULAR objectives are: LEVEL(s), MCI and Material passport as a tool to collect the materials information. In second term, some of them interesting and contributing to the indicators definition are C2C (gas emissions, recyclability and focus on materials), ISO 59020 and ISO 20887. However, others have been mainly neglected such as Well building standard (which is focused on comfort and well-being (KPIs covered by other frameworks)) and ISO14001 (whose focus is on internal organization management, although some KPIs could be used, but they are covered by other frameworks).

Furthermore, this deliverable has compiled the KPIs that could be potentially used from the frameworks. From the original definition, renaming has been done to make them clearer and more understandable according to the objectives and outcomes of the project. In total, 19 indicators are considered as part of the evaluation framework for SIRCULAR. These are split into “mandatory”, which are necessary for the final impact calculation (outcomes), “recommended” as useful or secondary indicators (used for calculating any mandatory one or due to calculating insights related to the solutions) and “optional” in case they provide any added value to the project. Similarly, they are classified by scope: solution if they are applied for assessing the specific project technology, part of the building when a solution is applied in certain area of the building and the evaluation is focused on that are and whole building, when the global performance is the objective. From these KPIs, also the preliminary data requirements have been extracted and, as next step, linked to the monitoring programmes, feasibility for calculation (mainly due to available data), baseline calculation methods and applicability in the demos will be defined.

Finally, a 3-step methodology is proposed, following the LEVEL(s) one in order to provide a way to achieve the multiple objectives of the project. From the design to the final evaluation, establishing the stages and how to apply the different methods.

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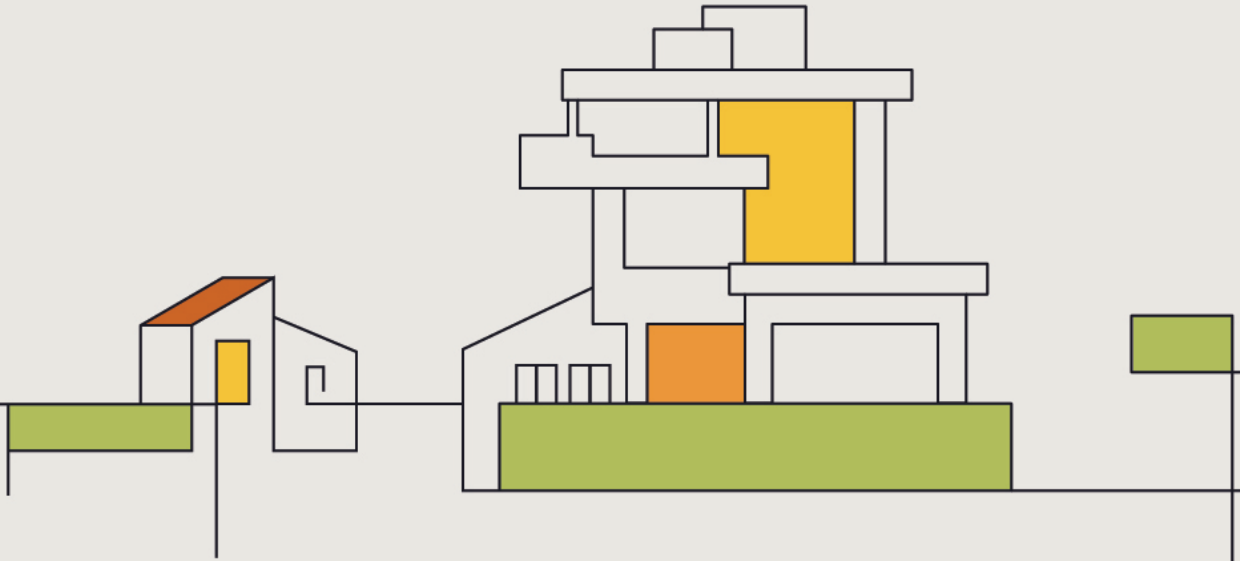

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