Drastic

Demonstrating affordability, sustainability and circularity

Design Guidance Framework Based on Multi-cycle Sustainability and Circularity Assessment

DELIVERABLE D2.1

Deliverable Information

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Executive Summary

The Horizon Europe research project Drastic aims to reduce whole life carbon and increase circularity across the European built environment. In meet this objective, five pilot projects will demonstrate varied and innovative solutions to reduce operational and embodied carbon emissions while promoting the reclamation and reuse of materials. Drastic's goal is to show how these solutions, combined with improved business models, can lead the way towards the decarbonisation of the EU's building stock by the year 2050.

This report outlines the background and rationale of the process and design guidelines and associated sustainability assessment framework developed for the Drastic project. The framework builds upon existing frameworks and uses primary data collected through various workshops and meetings. It is developed to address sustainability and circularity in tandem. Its purpose is to support the construction sector, which struggles with the joint implementation of circularity and sustainability, by providing a cohesive method in which the multitude of existing frameworks and assessment indicators are harmonised.

The current standardised life cycle assessment and life cycle costing methods apply a life cycle approach from the traditional linear "take-make-waste" economy and overlook the circular economy. When circularity is considered, it is primarily from a recycling standpoint. Moreover, the principle of sufficiency is ignored or even not measurable. AS a result, Drastic developed this framework that incorporates multi-cycle LCA and LCC, embracing aspects of circularity and sufficiency, and promotes extending the lifespan of buildings, in line with the EU's decarbonisation goals.

The key concepts of the framework are:

- Circularity: to maintain the value of materials, components, and buildings for as long as possible through strategies like reuse, repair, refurbishment, and recycling. Key focal points include minimizing raw material consumption, designing products for easy disassembly and reuse, prolonging product lifespans through maintenance and repair, and using recyclables and recovering raw materials from waste flows.
- Sufficiency: to avoid the demand for energy, materials, water, and land while delivering human well-being for all within planetary boundaries.
- Multi-cycle life cycle approach: approaching a product's life cycle with consideration of cascading scenarios based on circular economy strategies in the different life cycle stages of a product during the design and development of the product, to preserve and prolong the service life of the product, and thereby increasing the sustainability of the product.

A decision tree was developed to serve as the primary guidance tool in the decision-making processes of product design. It provides a clear visual map of the decision paths, prompting users to consider all indicators derived from the tree's key concepts, leading to a series of outcomes. In this case, these outcomes are the necessary data required for sustainability assessments and ensuring data traceability for further applicability. The decision tree includes three types of indicators:

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- Qualitative indicators for raising awareness among product designers and manufacturers.
- Quantitative indicators for collecting data.
- Evidence indicators for ensuring traceability.

This guidance and assessment framework will be implemented in the development of five pilot projects. The version of the framework presented in this report concentrates on the product level to support manufacturers and product designers. Implementing the framework in the pilot projects at product level as well as building level will help refine the model for broader use in the construction sector, benefiting all targeted stakeholders (i.e., building product developers, architects, real estate developers, and environmental assessors). The framework will also be employed in subsequent tasks to iteratively assess the pilot projects and to validate their ability to reduce total environmental impacts (including whole life carbon) and total life cycle costs, and to enhance the level of circularity compared to current business-as-usual reference projects. Furthermore, the guidance and assessment framework will contribute essential input to a sustainability, quality, and multi-cycle traceability toolbox, which will be integrated into a digital platform developed within the Drastic project.

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Acronyms

ASI	Avoid - Shift - Improve
BAU	Business As Usual
BCI	Building Circularity Indicator
CE	Circular Economy
CEN	European Committee for Standardization / Comité Européen de Normalisation
CDW	Construction and Demolition Waste
CFF	Circular Footprint Formula (of the Product Environmental Footprint method)
CPR	Construction Product Regulation
CRM	Critical Raw Material
DBL	Digital Building Logbook
DoP	Declaration of Performance
EC	European Commission
EN	European Standard
EOL	End-of-life / End Of Life
EPBD	Energy Performance of Buildings Directive
EPD	Environmental Product Declaration
eq.	equivalents
EU	European Union

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FSC	Forest Stewardship Council
FU	Functional Unit
GHG	Greenhouse Gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre (of the EC)
LCA	(Environmental) Life Cycle Assessment
LCC	Life Cycle Costing
MLCA	Multi-cycle Life Cycle Assessment
MLCC	Multi-cycle Life Cycle Costing
PEF	Product Environmental Footprint
RSL	Reference Service Life
RSP	Reference Study Period
S-LCA	Social Life Cycle Assessment
TCO	Total Costs of Ownership
WLC	Whole Life Carbon
WP	Work Package

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Glossary

Building	The highest hierarchical assessment level considered in this framework, such as a house or an office building, consisting of elements.
Circularity / circular economy (CE)	A system that emphasizes maintaining the value of materials, components, and buildings for as long as possible through strategies like reuse, repair, refurbishment, and recycling. Key focal points include minimizing raw material consumption, designing products for easy disassembly and reuse, prolonging product lifespans through maintenance and repair, and using recyclables and recovering raw materials from waste flows.
Component	The lowest hierarchical assessment level considered in this framework, consisting of materials, such as a construction product (e.g. a brick or a prefabricated façade element) or a work section (e.g. brickwork) depending on the subject of the guidance and assessment.
Construction product / building product	Item manufactured or processed for incorporation in construction works, supplied by a single responsible body (CEN, 2019).
Element / building element	The middle hierarchical assessment level, considered in this framework, such as an external wall or a flat roof, consisting of components.
Functional unit (FU)	Quantified performance of a product system for use as a reference unit (ISO, 2006).
Life Cycle	Consecutive and interlinked stages of a product. Examples of interlinked stages for goods include: material acquisition, design and development, manufacturing, delivery, installation, use, end-of-life treatment and disposal (ISO, 2020).
Multi-cycle life cycle approach	Consideration of cascading scenarios based on the R-strategies in the different life cycle stages of a product during the design and development of the product, to preserve and prolong the service life of the product, thereby increasing the sustainability of the product.

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Planetary boundaries	Safe operating limits for humanity to avoid catastrophic environmental change, encompassing critical variables like climate change, biodiversity loss, land-system change, and ocean acidification (Rockström et al., 2009).
R-hierarchy/-imperatives/-ladder/-levels/-strategies	R-strategies are a hierarchical framework presented as a sequential ladder from R0 (Refuse) to R9 (Recovery), reflecting increasing levels of circularity and resource efficiency. This hierarchy is more detailed than the waste hierarchy and aims to maintain the value of materials throughout their life cycle.
Reference service life (RSL)	Service life of a product [or building] which is known to be expected under a set of reference in-use conditions and is described as part of the functional unit (CEN, 2019).
Reference study period (RSP)	Period over which the time-dependent characteristics of the object of assessment are analysed, which can differ from the RSL (CEN, 2011).
Scenario	Collection of assumptions and information concerning an expected sequence of possible future events (CEN, 2019).
Sufficiency	Policies, measures, and daily practices that avoid the demand for energy, materials, water, and land while delivering human well-being for all within planetary boundaries (IPCC, 2022).
Sustainability	State of global system, including environmental, social and economic aspects, in which the needs of the present are met without compromising the ability of future generations to meet their own needs. The three aspects interact, are interdependent, and often referred as the three dimensions of sustainability (ISO, 2022).
Work section	Basic operation of a construction project that typically involves only one trade, such as work on a part of building, a type of material (e.g. brickwork), or a special activity (e.g. demolition) (Designing Buildings construction wiki, 2023). Within this framework we consider a work section as work involving one trade around a type of material.

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1 Introduction

1.1 General Context

This first deliverable of work package 2 (WP2) of the Drastic project provides the background and explanations of the developed process and design guidelines and associated sustainability assessment framework. To develop this Drastic guidance and assessment framework, we built upon existing frameworks (e.g. Level(s) (EC DG ENV, 2023), Whole Life Carbon Roadmap (BPIE, 2022), and TOTEM (OVAM et al., 2024). Preferably those that are already widely accepted and applied within the construction sector (e.g. the Layers of Brand (Brand, 1995) and current European standards (CEN, 2011, 2015, 2019)) and/or integrated into European policies (e.g. the Construction Product Regulation (CPR) (EC DG GROW, n.d.) and EU Taxonomy (EC DG FISMA, n.d.)) – further details on these existing frameworks and their application within our Drastic framework are elaborated in chapters 2 and 0. In that sense, this is not a completely new framework from scratch but rather one that can be easily implemented within the current practice.

Another key issue was to arrive at an integrated framework in which the effects of circular design principles can be assessed in relation to their potential contributions to environmental and economic impacts across a product's life cycle. Currently, a disconnect exists between life cycle assessments (LCA) and circularity assessments, highlighting the necessity to clarify their interrelation (Lam et al., 2022). This framework is developed to address sustainability and circularity in tandem. Its purpose is to aid the construction sector, which struggles with the joint implementation of circularity and sustainability, by offering a cohesive method to harmonise the multitude of existing frameworks and assessment indicators.

This chapter first continues with a description of the project and WP2, then it gives the goal and scope of the framework, followed by the methodology applied to arrive to this framework, and concludes with explaining the structure of the remainder of the report.

1.1.1 About Drastic and WP2

Drastic is a four-year project which aims to reduce whole life carbon (WLC) and increase circularity across the European built environment. Through five 'Demonstrator' pilot projects, see Figure 1, Drastic aims to showcase varied and innovative solutions to reduce WLC and the climate impact of construction across the entire value chain in Europe, whilst increasing and improving circularity within the built environment (drasticproject.eu, 2024).

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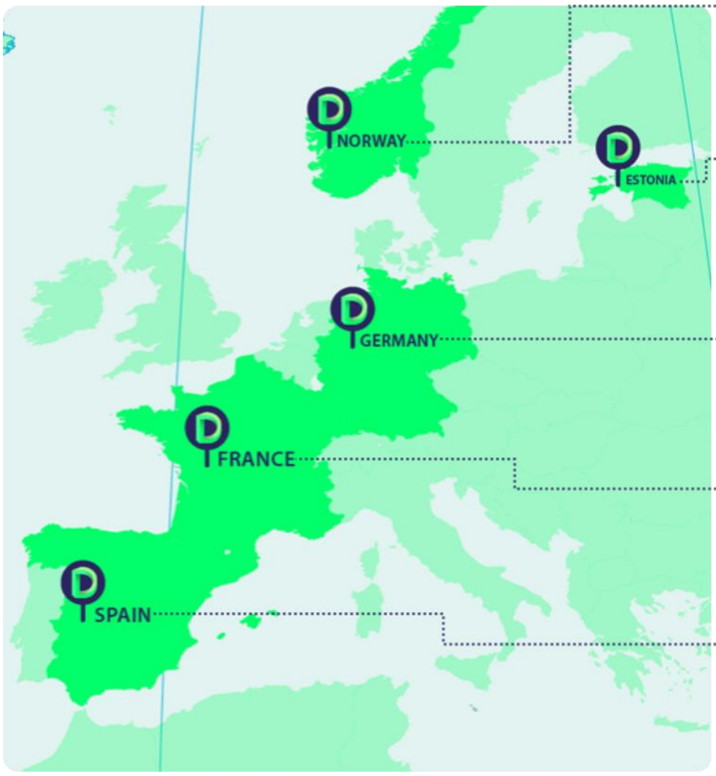

Solution: prefab structure with reclaimed timber and steel reversible connectors
- Location: Hønefoss, Norway
- Building function: temporary commercial buildings
- Base material: wood, steel
- Strategy focus: reuse, remanufacture, repurpose

Solution: prefab timber façade frame with building-integrated photovoltaics for deep energy retrofit
- Location: Rapla, Estonia
- Building function: apartment buildings
- Base materials: wood, mineral wool, services (heating, ventilation and photovoltaics)
- Strategy focus: reuse, remanufacture, repurpose, recycle

Solution: reversible external thermal insulation composite (ETIC) façade system for deep energy retrofit
- Location: Düsseldorf, Germany
- Building function: privately owned apartment buildings
- Base materials: cement-based mortar, mineral wool, glass fibre
- Strategy focus: reuse, repurpose, recycling

Solution: ceiling plates and indoor partition walls for reuse of interior space plans
- Location: Saint Denis, France
- Building function: office retrofit
- Base materials: mineral wool, plasterboard, glass
- Strategy focus: reuse, remanufacture, recycling

Solution: reclaimed structural steel elements and repurposed white slag as supplementary material of concrete
- Location: Balaguer, Spain
- Building function: utility buildings, warehouses
- Base materials: steel, white slag, concrete
- Strategy focus: reuse, remanufacture, repurpose

Figure 1: The five Drastic Demonstrators and their solutions that currently are under development.

The Drastic Demonstrators target different layers of buildings (i.e. Layers of Brand – section 3.4.1), to achieve reduction of operational and embodied carbon emissions and foster material reclamation and reuse. Drastic aims to show how these solutions, combined with improved business models, can lead the way towards a whole life cycle decarbonisation of EU building stock by 2050. To achieve this, five steps linked to specific project sub-objectives and corresponding with five WPs of the project will be taken:

1. Development of a sustainability and circularity guidance and performance assessment framework (WP2).
2. Enabling roll-out of circular product and building developments covering retrofit, transformation, and deconstruction/new built and demonstrating them to technology readiness level 6-7 (WP3).
3. Facilitating implementation of the above by developing a sustainability, quality, and multi-cycle traceability toolbox embedded in a digital platform (WP4).
4. Ensuring market uptake via ecosystem development and by providing relevant stakeholders evidence of performance of the developed Drastic solutions by local study and demonstration cases (WP5).
5. Building awareness widely with key target audiences of the need to rapidly accelerate action on multi-cycle sustainability and circularity in the construction sector and of Drastic's potential and Demonstrators (WP6).

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The linkages between these different steps, specific sub-objectives and WPs are presented in Figure 2.

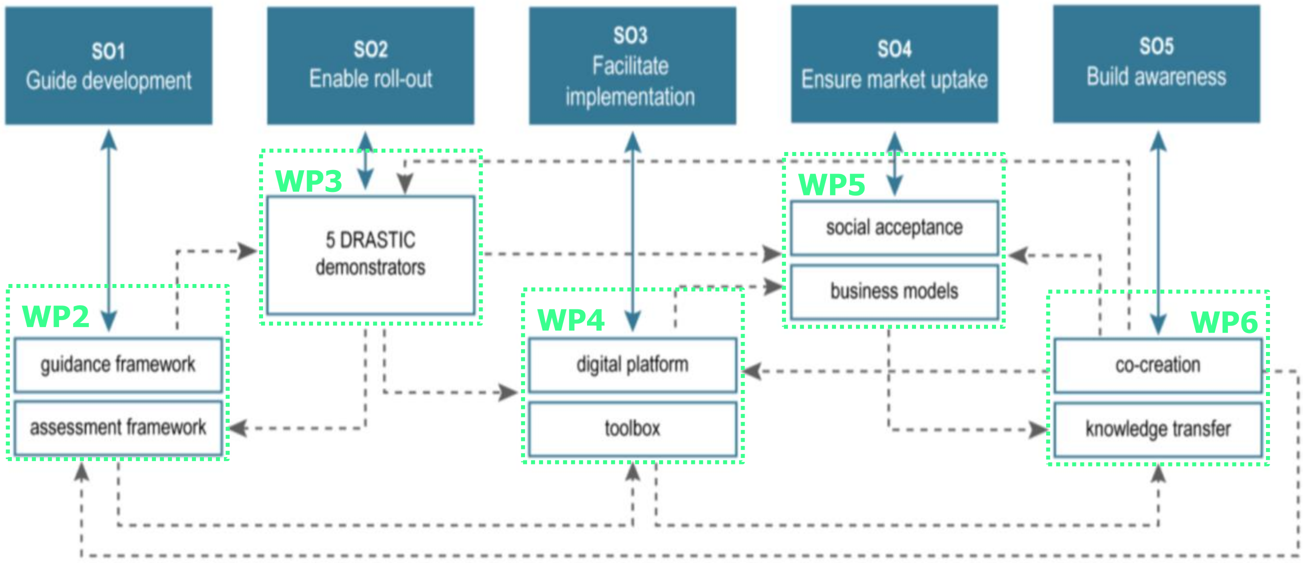

Figure 2: Interlinkages of the sub-objectives (SO) and WPs of Drastic.

With the developments done within WP2, the Demonstrators in WP3 will be guided iteratively in their decision making in sustainability, circularity, and sufficiency principles during their design process of their innovations. Moreover as part of WP2, the Demonstrators will be assessed and validated regarding their reduction in total environmental impacts – including WLC – reduction in total life cycle costs, and increased level of circularity compared to current business-as-usual (BAU) equivalents. The developed guidance and assessment framework will provide the necessary input for the toolbox which will be further embedded in the digital platform of WP4.

1.2 Goal and Scope of the Guidance and Assessment Framework

As indicated above, the goal of the Drastic guidance and assessment framework is to guide the Demonstrators in their decision making during their product development process and to iteratively assess and validate their performance during the project. The framework needs to be developed in such a way that the partners can identify and remediate potential hotspots for further product improvements and design optimisation. Drawing from the experiences with the guidance and assessment framework, it will continue to evolve over the coming years. This framework is expected to extend its application beyond the Drastic project, contributing to and enhancing other existing frameworks (e.g. Level(s), standardisation (e.g. through Technical committee 350 of CEN (CEN/TC 350)), and digital building logbook (DBL) platforms (e.g. Madaster). The performances that will be assessed, i.e., main topics that are within the scope of this framework are: circularity, sufficiency, and sustainability from a multi-cycle life cycle approach.

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A widespread definition of **sustainable development** is "development that meets the environmental, social and economic needs of the present without compromising the ability of future generations to meet their own needs". Environmental, social and economic aspects are often referred to as the three dimensions of sustainability (ISO, 2022). Of these three dimensions the Drastic guidance and assessment framework mainly focusses on environmental and economic aspects, while social aspects are only addressed as an interdependent result of the other two aspects. For instance, the social aspect affordability: it can result from environmentally sustainable practices that reduce resource depletion and pollution, thereby lowering costs and fostering economic stability that makes goods and services more accessible to all. Social life cycle assessment (S-LCA) methods do exist (such as the guidelines by UNEP (2020) – resulting in an impact assessment of social impacts and providing information on social and socio-economic aspects regarding five stakeholder groups) but are excluded from this project. Compared to the field of environmental LCA and economic life cycle costing (LCC), S-LCA can be considered as a relatively new field with less mature assessment methods. Moreover, investigation of the social aspects regarding acceptance is a topic of WP5 during the whole project. How sustainability from a multi-cycle life cycle approach is addressed in the Drastic project is explained in more detail in section 2.4.

In Drastic, sufficiency and circularity are considered as strategies that support sustainable development. Guidance towards developing regenerative buildings, or net positive solutions that contribute to reconcile human well-being and nature and restoring ecosystems (Cole et al., 2013) are currently not included in this framework. Regenerating resource loops is not (yet) a commonly applied circularity strategy nor part of the R-hierarchy (see section 3.4.2). Regenerative buildings are therefore seen as higher ambition beyond the scope of this framework. Sections 2.2 and 2.3 provide more details on how circularity and sufficiency are used within the scope of the Drastic project.

1.3 Methodology

The development of this guidance and assessment framework involved collecting primary data through various workshops and meetings, as well as utilising secondary data previously gathered for other goals than for this specific project or even by others than persons involved in this project. These secondary data were then further refined and integrated with the primary data to inform the framework. More specifically, the following data have been collected:

- Secondary data collection – desktop-based research based on results from other projects, scientific publications, and grey literature in four topics:
    - Types of design support (see section 2.1).
    - Circular economy and circularity in a built environment context (see section 2.2 and Appendix A).
    - Sufficiency in general and in a circular built environment context (see section 2.3 and Appendix B).
    - Life cycle approaches (see section 2.4 and Appendix C).
- Primary data collection – information collected firsthand for the specific purpose of this framework via:

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  - Gap analysis and brainstorming on multi-cycle sustainability and circularity assessments with the contributing partners of this deliverable during live meetings and online meetings.
  - A workshop on accelerating circularity from a sufficiency perspective was held on 15 April 2024 with 60 high level stakeholders at the World Circular Economy Forum to validate sufficiency indicators (Appendix B). For the validation, the template included as Appendix D was used.
  - A stakeholder co-creation workshop on 23 April 2024 hosted online, with 24 attendees from all over the world and different backgrounds, to receive additional input and insights to enhance the assessment and guidance framework. Screenshots of parts of the Miro boards used during the breakout sessions of this workshop are added in Appendix E including a link to the recording of the joint sessions.
  - A deep dive workshop on 14 May 2024 with the project partners at the first Drastic general assembly in Tallinn, Estonia, to discuss (in three smaller groups) how circularity strategies and circularity and sufficiency indicators can apply for one of their specific products to collect data on possibilities to define product-specific scenarios based on the discussions. Appendix F contains images of the three sheets produced during the workshop.
- Quality control – validation by external peers:
  - Finally, Drastic was invited to present the preliminary assessment and guidance framework (i.e. the scope of the framework and preliminary versions of *Figure 8: The Drastic Decision Tree.* and *Figure 14: Visual mapping of the interaction between the R-strategies and life cycle stages.)* at the yearly plenary meeting of CEN/TC 350 in Stockholm on 20 June 2024, in which great interest was shown by the experts present on the multi-cycle sustainability topic, and additional input was given on sustainable refurbishment.

The collected data were qualitatively analysed and thematically organised based on the topics, ultimately forming the basis of the developed framework. In the development phase, VITO researchers participating in Drastic conceived the idea of creating a decision tree to serve as the primary guidance tool in the decision-making processes of product design (see section 2.1). A decision tree was chosen for its ability to offer a distinct visual representation of decision-making pathways, compelling the user to contemplate all potential topics encompassed within the tree, which leads to a series of outcomes. In this case, the outcomes are the necessary data to be gathered for sustainability assessments and ensuring data traceability for further applicability in for example DBLs, or potentially, for a narrative of the object assessed.

1.4 Structure of This Document

The emphasis of this report is, as indicated by the name of the deliverable, on the design guidance part of the Drastic framework although the assessment part will also be touched upon in this report but in outline. The content of the remainder of this document is as follows:

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- Chapter 2 describes the theoretical context of the Drastic guidance and assessment framework.
- Chapter 3 presents the decision tree developed to provide guidance on circularity, sufficiency, and applying a multi-cycle life cycle approach.
- Chapter 4 concludes this deliverable by describing the first observations based on the development process of this framework and the next steps with/for this framework.

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2 Theoretical Context of the Drastic Framework

This chapter lays out the theoretical foundation for the guidance and assessment framework, including possible types of design support, circularity, sufficiency, and implementation of a multi-cycle life cycle approach. The latter three topics are contained as performance indicators in the decision tree developed, which will be presented in the chapter 3.

2.1 Types of Design Support

Previous researchers investigated various ways of supporting circular design. A paper by Van Stijn and Gruis (2020) analysed existing circular design frameworks and focuses on advancing the circular economy within the built environment by developing and implementing circular building components with the use of generative or evaluative tools as design supports. Generative tools offer initial (upfront) support for the synthesis of circular design, while evaluative tools are applied towards the end (downstream) of the circular product development process or when the product is on the market (retrospective assessment, e.g. for identifying potential product improvements). The full list of different potential circular design supports identified by Van Stijn and Gruis is described in Table 1 including remarks on their applicability in general and in some instances specifically for Drastic.

Table 1: Possibilities for circular design support, adapted from Van Stijn and Gruis (2020).

Type of design support	Description	Remark on applicability
Guidelines or criteria	General principles and standards for circular design and guidance with specific actions.	Provide clear direction to follow and rules. It may be too generic and lacks detailed implementation steps.
Step-by-step guides	A structured process or methodology for developing circular designs.	Detailed and structured path that reduces the complexity. It can be rigid and may not fit all scenarios.
Design canvases	Visualisation tools that help designers map out and organise different aspects of their circular design, such as the technical, industrial, and business models.	Encourage holistic thinking and enhance communication through visualisation. It may not be useful for all the Demonstrators and requires extensive time to create.
Design archetypes	Examples of templates that showcase successful circular designs that can inspire and guide designers.	Provide inspiration and proof of concepts. It may not be directly comparable to the project’s specification due to narrow scope, and there is a risk of limiting further innovation.

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Type of design support	Description	Remark on applicability
Design strategies	Specific approaches or techniques that can be used to achieve circularity in a design.	It focuses on actionable techniques and can be innovative and creative. It may require extensive knowledge and additional needs to identify the priorities.
Design parameters	Key factors or variables that need to be considered when designing for circularity, such as material choices, product lifespan, and end-of-life (EOL) scenarios.	Identify critical design aspects and enhance the overall results by combining different aspects. It can become complex and needs expert understanding.
Design options	Specific choices or alternatives available for each design parameter.	It provides a range of possibilities for exploring the full picture. It can lead to decision paralysis and requires thorough analysis.
Case examples	Real-world examples of circular designs that can illustrate how different design supports have been applied in practice.	Practical insights that can be used as validation. It can be context-specific and may not always be replicable.

These findings support the selection of the following approaches applied in this project according to what has been defined as generative tools and evaluative tools in the reviewed paper:

- Guidance framework:

  The guidance framework offers support in synthesising the design process upfront. It provides Demonstrators with a set of principles, strategies, and options to explore and create various possibilities for circular products or components. By offering a structured approach and a range of potential solutions, the guidelines empower Demonstrators to develop innovative and circular designs that align with circular economy principles (cf. "generative tools").

- Assessment framework:

  The assessment framework is employed at the end of the product development process. These frameworks provide a structured way to assess and evaluate the circularity of existing or proposed designs. By analysing different indicators, evaluative frameworks enable designers to index the effectiveness and circularity of their designs. This assessment helps identify areas for improvement and ensures that the final product aligns with circular economy goals (cf. "evaluative tools").

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Given the analysis and categorisation of design supports, a decision tree and data collection protocol are selected for the guidance and assessment frameworks by merging several types of design support. This ensures a robust approach to both the synthesis and evaluation of circular building components, ultimately demonstrating innovation and alignment with circular economy principles.

2.2 Circularity

2.2.1 Circular economy

Circularity or circular economy (CE) emphasises **maintaining the value of materials**, components, and buildings for as long as possible through strategies like reuse, repair, refurbishment, and recycling. Circularity contrasts with the traditional linear "take-make-waste" model, which still dominates our economy, and specifically the construction sector, and contributes to high levels of resource extraction, waste generation, and greenhouse gas emissions (Figure 3).

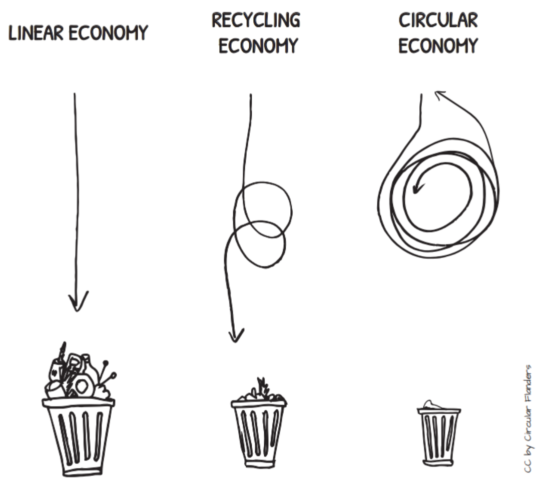

Figure 3: From a linear economy to a circular economy (source: Circular Flanders).

In the scope of the Drastic project the definition of Van Buren et al. (2016) is used: "the focus point in a circular economy is to not unnecessarily destroy resources. This implies far more than the reduction of waste through recycling, [and includes]: reducing the consumption of raw materials, designing products in such a manner that they can easily be taken apart and reused after use (eco-design), prolonging the lifespan of products through maintenance and repair, and the use of recyclables in products and recovering raw materials from waste flows" (Van Buren et al., 2016).

Kirchhnerr et al.'s (2017) review highlights that many definitions of circularity are reductive, failing to consider a systemic perspective that integrates environmental, economic prosperity, and social equity. These definitions often do not incorporate waste hierarchies (R-hierarchy – section 3.4.2), which are essential for prioritising actions based on their environmental impact. The circular economy concept is often used ambiguously in the literature, with a strong focus on waste and the EOL stage. Few instances effectively focus on closing the loops, and most publications use the term without a deeper connection

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to its meaning, demonstrating a "misunderstanding of the CE concept and its application in the construction sector" (Mrad & Frölén Ribeiro, 2022).

To effectively contribute to a sustainable society, it is essential to accurately assess circular strategies to ensure they align with environmental goals. A significant risk is the rebound effect, where efficiency gains from circular strategies lead to increased consumption in other areas, ultimately negating environmental benefits. Additionally, some circular solutions may not result in lower environmental impacts over their entire life cycle, with initial benefits potentially leading to greater resource use and emissions over time if solutions are not (re)used in their intended circular application. Another concern is the shortening service time of buildings, with buildings being used for shorter periods, demolished, and replaced to maximize short-term financial gains, disregarding long-term sustainability (Guo et al., 2021). To mitigate these risks, a multi-cycle assessment is necessary to comprehensively evaluate the true environmental impact of circular practices, ensuring they contribute positively to sustainability goals in the long term.

2.2.2 Circular solutions for the built environment

In the scope of this project, a literature review on measuring circularity in the built environment shows that while LCA remains the most accepted methodology for assessing environmental impacts, it is often applied from a linear perspective, considering one functional cycle in a static manner. This is due to the lack of widely accepted allocation approaches and consistent system boundaries to assess circularity in a multi-cycle perspective (Andersen et al., 2022; Lam et al., 2022; Lei et al., 2021; van Stijn et al., 2021). Consequently, complementary indicators are needed to evaluate circularity alongside environmental impacts, improving transparency and decision-making.

A comprehensive mapping of circularity indicators, resulting from a systematic literature review of more than 900 publications, is provided in Appendix A. Most common circularity indicators focus on material efficiency, aiming to reduce the consumption of raw materials by shifting towards bio-based and secondary materials. Less than a third (29%) of these indicators relate to current circularity (input of secondary materials from the design stage), while the majority (about 70%) address future circularity at the EOL (potential harvesting, reuse, or recycling scenarios). The diversity and lack of harmonisation among circularity assessment frameworks create confusion among stakeholders and hinder the adoption of circular practices by decision-makers. Existing methods often focus on material flows and disassembly, neglecting crucial aspects like adaptability, repairability, and multi-cycle considerations.

Most existing circularity frameworks neglect multiple life cycles and the integration of an R-hierarchy, risking the subversion of the circular economy concept (Kirchherr et al., 2017). This omission limits the potential benefits of circular strategies. By integrating multi-cycle considerations and sufficiency indicators (see section 2.3), circularity assessments can better capture the long-term value and environmental benefits of building components and materials. This approach allows for cascading scenarios throughout a product's life cycle, acknowledging the interdependence and hierarchy of different R-strategies. Higher-value strategies, such as repair and reuse, should be prioritised over lower-value ones like recycling and (energy) recover(y). This comprehensive understanding enhances

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the circularity of buildings and building components, ultimately leading to more sustainable construction practices (see section 3.4.2).

2.3 Sufficiency

Sufficiency is defined by the IPCC as policies, measures, and daily practices that avoid the demand for energy, materials, water, and land while delivering **human well-being for all** within planetary boundaries (Intergovernmental Panel on Climate Change (IPCC), 2023). It focuses on adjusting consumption patterns, reducing the demand for resources, while maintaining or improving quality of life. This approach is driven by fulfilling human needs — such as food, water, energy, health, mobility, and communication — and ensuring well-being for all (through access to clean air, water, nutritious food, and healthcare services) rather than developing technological solutions. Sufficiency seeks to foster a culture of moderation and sustainability, challenging the paradigms of continuous growth and consumerism (Saheb, 2021), to ensure development within planetary boundaries for all.

Planetary boundaries define the safe operating limits for humanity to avoid catastrophic environmental change. These boundaries encompass critical variables like climate change, biodiversity loss, land-system change, and ocean acidification (Rockström et al., 2009). Staying within these boundaries is essential for maintaining a habitable planet and ensuring long-term sustainability, as well as a good life for all. A decent standard of living, or a good life, involves meeting basic physical needs such as nutrition, sanitation, access to energy, and eliminating extreme poverty, as well as achieving qualitative goals like high life satisfaction, healthy life expectancy, secondary education, democratic quality, social support, and equality, while staying within sustainable levels of resource use to avoid destabilizing critical planetary processes (O'Neill et al., 2018). A shift to sufficiency measures becomes more urgent with the fact that, as of 2023, six out of the nine planetary boundaries are already trespassed, as shown in Figure 4.

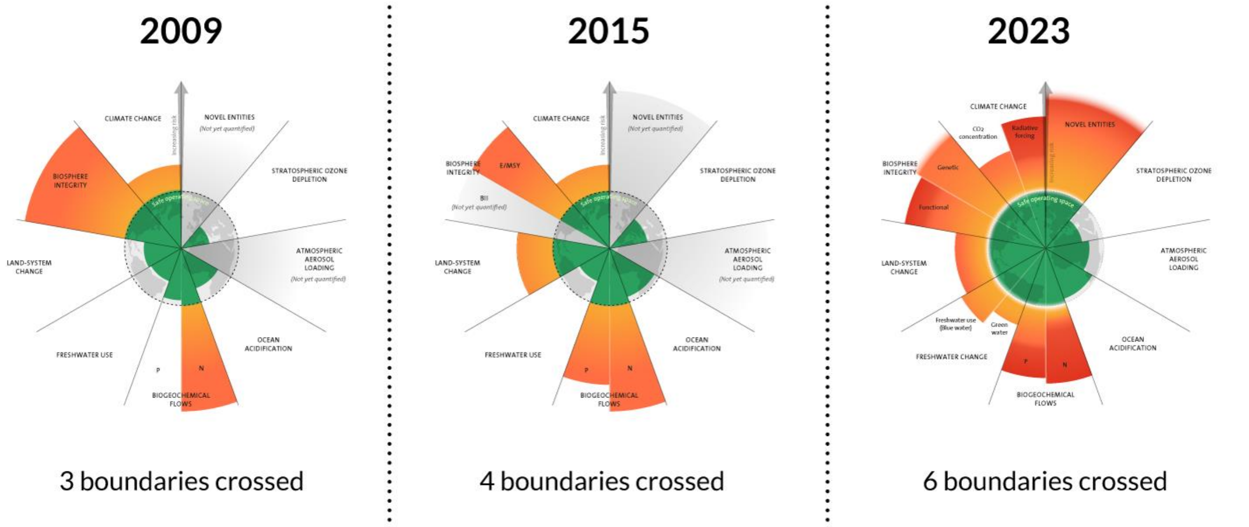

Figure 4: The progression of the planetary boundaries and the trespassing since 2009 (source: Stockholm Resilience Centre, Stockholm University).

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Sufficiency aims to keep human activity within these limits by limiting consumption, or at the least promoting sustainable consumption and reducing resource use (O'Neill et al., 2018). Humanity faces the challenge of how to achieve a high quality of life for over 7 billion people without destabilizing critical planetary processes. Using indicators designed to measure a 'safe and just' development space, we quantify the resource use associated with meeting basic human needs and compare this to downscaled planetary boundaries for over 150 nations. We find that no country meets basic needs for its citizens at a globally sustainable level of resource use. Physical needs such as nutrition, sanitation, access to electricity and the elimination of extreme poverty could likely be met for all people without transgressing planetary boundaries. However, the universal achievement of more qualitative goals (for example, high life satisfaction) would require a level of resource use that is 2–6 times the sustainable level, based on current relationships. Strategies to improve physical and social provisioning systems, with a focus on sufficiency and equity, have the potential to move nations towards sustainability, but the challenge remains substantial (O'Neill et al., 2018). In building practices, this includes minimising the demand for new construction materials and energy by optimising existing resources and structures.

Efficiency measures aim to reduce energy consumption per unit of economic output, often through technological advancements. However, these measures alone are insufficient to achieve long-term climate goals due to rebound effects, where the gains in efficiency lead to increased overall consumption (Wei & Liao, 2016). In terms of material efficiency, although important for "sustainable" resource use, it still is insufficient on its own to address environmental challenges. One major issue is the rebound effect, where increased efficiency lowers costs and inadvertently boosts consumption, offsetting environmental gains. The Earth's finite resources mean that even highly efficient use cannot curb overconsumption driven by population and economic growth, as well as by Western standards of living. Moreover, material efficiency tends to focus on a micro level, such as individual products and processes, and so fails to tackle broader systemic and structural issues. A holistic approach that includes changes in consumption patterns, lifestyle choices, and economic structures is necessary to ensure a good and healthy life for all within the planetary boundaries (Deckert, 2016). Finally, although a circular economy enhances efficiency by promoting R-level strategies, it has limitations such as energy-intensive recycling processes and the degradation of material quality over time (Deckert, 2016). Therefore, while efficiency improvements are important, they must be part of a broader, more holistic approach to sustainability.

Unlike efficiency, sufficiency directly targets the reduction of overall energy and resource consumption. It emphasises changes in behaviour on the institutional and system levels, questioning the infrastructure and frameworks that drive overconsumption. Sufficiency targets the reduction in demand of energy and materials, rather than targeting the supply thereof, thus, directly addressing the root cause making it a more reliable strategy for long-term sustainability (IPCC, 2022). In consequence, sufficiency brings upon several co-benefits, such as the preservation of ecosystems by reducing the need for new energy production and material extraction. This helps protect biodiversity and maintain ecosystem services that are crucial for human survival and climate regulation. In the construction sector, sufficiency measures such as adapting living spaces and repurposing existing structures can significantly reduce the demand for construction materials and energy. This not only lowers greenhouse

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gas emissions but also minimises the environmental impact of urban development (Bierwirth & Thomas, 2019).

The **ASI (Avoid - Shift - Improve) framework** is a strategy for sustainable development that integrates sufficiency (Avoid), alternative sustainable solutions (Shift), and efficient technologies (Improve) (Creutzig et al., 2022). It encourages avoiding unnecessary consumption, shifting to more sustainable modes of production and consumption, and improving technological and operational efficiency. This framework aims to balance short-term and long-term goals, addressing both demand and supply-side solutions to achieve sufficiency. In the context of the built environment, it involves systemic planning and design to minimise energy needs, promote renewable energy sources, and enhance energy flexibility, thereby ensuring a holistic approach to sustainability (Erba & Pagliano, 2021). More specifically, if this framework were to be applied to the construction sector, it might involve (as shown in Figure 5):

- avoiding new construction by adapting and reusing existing buildings and infrastructure,
- shifting to sustainable construction practices and materials with lower environmental impacts (with higher R-strategies),
- improving the efficiency of construction processes and building operations and while keeping business-as-usual.

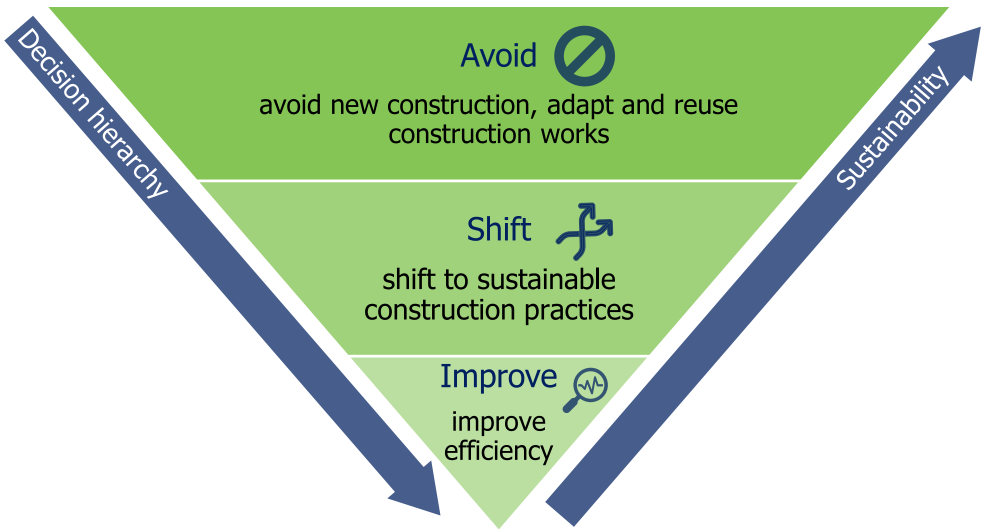

Figure 5: Avoid - Shift - Improve framework for sustainable development in the construction sector.

The literature on sufficiency indicators is currently sparse, particularly in the domain of the built environment and construction. Additionally, there is significant overlap with certain circularity indicators. Inventorying sufficiency indicators can help create a structured framework to distinguish the concept from circularity. These indicators should capture avoidance and reductions in resource use, changes in consumption patterns, and, when possible, improvements in well-being. However, developing comprehensive and widely accepted indicators is challenging due to the systemic nature of sufficiency and the multifaceted nature of the construction sector. A comprehensive list of sufficiency

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indicators for the built environment was identified through a literature review (Appendix B). The results show that indicators for sufficiency mostly fit into three categories:

1. indicators focused on urban scale and land management (avoiding construction),
2. indicators focused on energy (avoiding energy consumption), and
3. indicators addressing the circularity of material resources (extending the lifespan of existing products).

Indicators focused on material resources tend to overlap with circularity indicators while, however, targeting higher R-strategies (Refuse, Rethink, Reduce, Reuse). In the scope of the Drastic project a shortlist of sufficiency indicators is proposed, selected through expert consultation to fit the scope and scale of project solutions.

2.4 Multi-cycle Life Cycle Approach

2.4.1 Life Cycle Approaches, Standards and Legislation in the Construction Sector

LCA is a common practice to quantify the environmental impact of products and buildings. It addresses the environmental aspects and potential environmental impacts – related to a functional unit of the object of the assessment – throughout a product's life cycle from raw material acquisition through production, use, EOL treatment and final disposal (ISO, 2006). An LCA results in an environmental profile of the product containing quantified environmental impact indicators. When an LCA considers all life cycle stages, it is also referred to as assessing the whole life embodied environmental impacts.

To quantify the economic impact of products, LCC is a commonly used method. Within the construction sector, an LCC analysis quantifies the total costs of ownership (TCO), which includes construction, operation, maintenance, and EOL costs, while excluding non-construction expenses, revenues, and externalities. (ISO, 2017a).

Mature assessment methods for LCA as well as LCC exist and are widely used in different sectors. CEN/TC 350 is responsible for the development of European standards for the assessment of the sustainability aspects of new and existing construction works. The aim of the CEN/TC 350 standardisation framework is to provide standardised methodologies and indicators for the sustainability assessment – i.e. from an environmental, economic and social perspective – of buildings and civil engineering works with the use of a life cycle approach. In 2020, subcommittee 1 of TC 350 (CEN/TC 350/SC 1) was created to develop standardised approaches on CE for the construction sector. The first deliverable from TC 350/SC 1 are still under development – a draft standard on the framework, principles, and definitions is expected to be available for enquiry in fall 2024.

The standards from TC 350 prescribing assessment methods for LCA are EN 15804+A2 (CEN, 2019) on product level and EN 15978 (CEN, 2011) on the building level – the latter is currently being revised. The EN 15804+A2 is commonly used for drafting Environmental Product Declarations (EPDs) of construction products. The standard on LCC on the building level is EN 16627 (CEN, 2015). On the product level, there is no LCC standard, however, an LCC on building still requires input based on

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technical and cost information of individual products within the building. Like all standards, the TC 350 standards reflect best practices in the industry and are applied on voluntary basis.

However, with the revised CPR, which has been adopted on 10 April 2024 (European Parliament, 2024), the declaration of environmental aspects in the Declaration of Performance (DoP) for products that fall under the CPR will become mandatory. Over time, the number of environmental indicators required to be declared according to EN 15804 will increase: once the CPR is fully implemented, likely in the second half of 2025, the Global Warming Potential (GWP) life cycle impact category will be mandatory in the DoP. This will be followed by all core impact categories of EN 15804 four years later by 2029, and eventually, all life cycle impact categories by the year 2031, six years after the date of application (Nieto Sanz, 2024). Appendix C lists all life cycle impact categories in line with EN 15804+A2: Table C1 includes the core impact categories and Table C2 the additional categories. In addition, the revised Energy Performance of Buildings Directive (EPBD) requires life cycle GWP calculations on building level – more on this topic in next sub-section.

2.4.2 Whole Life Carbon

Whole life carbon (WLC) refers to the total greenhouse gas (GHG) emissions associated with a building over its entire life cycle, including not only operational emissions (from heating, cooling, and energy use in the building) but also embodied emissions (emissions from material extraction and production to construction site activities) and EOL emissions (from demolition and waste handling). WLC is part of the foreseen MLCA – by assessing the whole life cycle, the WLC will be equal to the life cycle impact assessment results of the impact category GWP.

The European Union (EU) has established a legislative framework aiming to achieve a fully decarbonised building stock by 2050. The EPBD has published guidance on measuring and reducing WLC in buildings, emphasising the importance of WLC assessments in understanding a building's comprehensive carbon footprint. It mandates WLC reporting for all new buildings, which will be enacted by 2030. This involves considering the following steps in reporting:

1. For each life cycle stage, report kg CO_2 eq./m^2 per year (of useful floor area based on a reference study period of 50 years) as the WLC indicator.
2. Data selection, scenario definition and calculations should be according to EN 15978.
3. The scope of the physical building should be as defined in the Level(s) framework indicator 1.2.
4. National tools or methods can be used if they meet the minimum Level(s) requirements.
5. Revised CPR for data regarding specific products shall be used.
6. The energy performance certificate should incorporate the WLC indicator.

Member states of the EU aim to publish a comprehensive WLC roadmap by the start of January 2027, with initial targets and maximum limit values for all new buildings set from 2030. These values will consider building types and climate zones, among other factors when introducing WLC benchmarks (Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the Energy Performance of Buildings (Recast), 2024).

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2.4.3 Moving From Linear to Multi-cycle Life Cycles

The three mentioned TC 350 standards consider a modular approach, i.e. each life cycle stage is covered by a module. Modules A-C cover the information on the current life cycle of the construction work and Module D the information beyond the system boundary. Figure 6 shows the most recent published version of that modular structure, taken from EN 15643 (CEN, 2021) – the overarching standard on the TC 350 framework level.

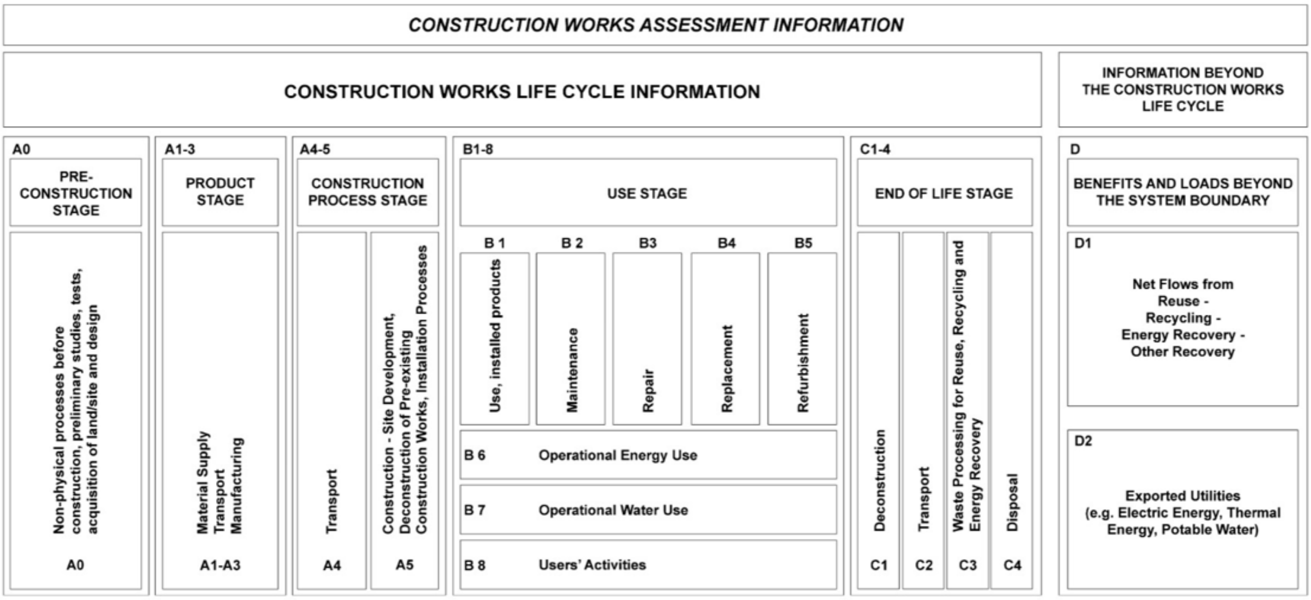

Figure 6: Information modules applied in the assessment of environmental, social, and economic performance of construction works of the CEN/TC 350 standards (source: EN 15643:2021).

In LCA, input and output flows of a process, product or system are partitioned between the object under study and one or more other systems when there are shared flows. This partitioning is known as allocation (ISO, 2006). Allocation is necessary for distributing environmental impacts among different products or co-products when the life cycles of different products overlap, for instance a process sourcing secondary raw materials and the processes that utilize them. The EN 15804+A2 and EN 15978 standards adopt the recycled content method as allocation method (also referred as the 100:0 method). This implies that recycled content is considered burden-free. In other words, the environmental life cycle impacts of recycled materials or reused products are fully (100%) attributed to the initial product providing the recycled or reused content, with no impact (0%) assigned to the product utilising the recycled or reused content. Only the processing of the recycled materials or reused products following the EOL of the initial supplying product is considered for the current product assessment. Module D was introduced to account for the potential net benefits of the current product beyond its life cycle to ensure that the benefits of recycled or reused content are not double counted. This module enables manufacturers to showcase the potential benefits derived from designing their products to be recyclable or reusable after the EOL of their products. The recycled content method is more focused on present reuse and recycling, thereby mainly considering sustainability in the shorter

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term and providing less incentive for future circularity. Products primarily made from virgin raw materials tend to show a higher net benefit in module D compared to products mainly composed of secondary raw materials.

Besides the LCA method in the CEN/TC 350 standards, there is also the Product Environmental Footprint (PEF) method by the Joint Research Centre (JRC) of the European Commission (EC). The PEF method is endorsed by the European Commission and is anticipated to be utilized, for instance, in the Sustainable Batteries Initiative. However, it is not recommended in the European Level(s) assessment framework for sustainable buildings, which instead refers to EN 15978 for the LCA related indicator (EC DG ENV, 2023).

A key distinction between the PEF method and the CEN/TC 350 LCA method lies in the allocation approach. The PEF method distributes benefits and loads across product life cycles, incorporating the Circular Footprint Formula (CFF) to reflect this sharing principle. The CFF can address multi-functionality in recycling, reuse, and energy recovery scenarios. It features an 'A factor' to allocate burdens and credits from recycling or reuse between the life cycle that provides the recycled (or reused) materials and the one utilising them. This A factor aims to reflect the market situation by including recycled content as well as recyclability at EOL in the formula. The factor can be set at 0.2, 0.5 or 0.8, where 0.2 indicates a low supply of recyclable materials and high demand, 0.5 representing a balance of supply and demand, and 0.8 indicating a high supply of recyclable materials and low demand.

Notwithstanding, neither of the two LCA methods accounts for multiple cycles with a CE approach. The current standardised LCA as LCC assessment methods apply a life cycle approach from the traditional linear "take-make-waste" economy and do not consider the circular economy. When circularity is considered, it is primarily from a recycling standpoint. Furthermore, the concept of sufficiency is not considered at all or even measurable. Consequently, Drastic developed this framework that considers multi-cycle LCA and LCC, embracing aspects of circularity and sufficiency, and advocating for the extension of the lifespan of building, in line with the EU's decarbonisation goals.

In the scope of the Drastic project a **multi-cycle** life cycle approach is defined as an approach that enables **cascading scenarios** based on the R-strategies to **preserve and prolong the service life** of buildings, components, and materials, thereby reducing resource demand (water, energy, and materials). For this purpose, the CEN/TC 350 method serves as the foundation for the multi-cycle LCA (MLCA) methodology, as it is more commonly applied within the construction sector compared to the PEF method (cf. Level(s)). Noteworthy, there has been alignment between both methods, such as the selection of impact categories and impact assessment models (see Appendix C), which will also be used in the Drastic framework. How these R-strategies based scenarios interact with life cycle stages resulting in MLCA and MLCC approaches is explained further in the section 3.5.

2.4.4 Lifespans

Level(s) considers a building lifespan of 50 years (Dodd et al., 2022), which does not reflect a lifespan that would match with a multi-cycle life cycle approach in which the service life of components and materials, and ultimately also buildings, are prolonged. Therefore, a distinction will be made between a reference service life (RSL) and a reference study period (RSP) in the MLCA and MLCC. For now, an

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RSP of 100 years is envisaged. However, the convenor of working group 8 of CEN/TC 350 has mentioned RSP requests of 200 years by Scandinavian municipalities for studies on sustainable refurbishments, as discussed at the plenary meeting in Stockholm. In the next phase, the Drastic project will consider whether a sensitivity analysis on a 100 or 200 years RSP is needed. The RSL will be dependent on the object of the assessments, due to differences in technical characteristics, functionality, and specific application of the object in a building.

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3 The Drastic Decision Tree

A decision tree was developed to provide the Demonstrators comprehensible and uniform guidance by compelling them to contemplate on the topics of circularity, sufficiency, and multi-cycle LCA-LCC, as defined and described in the theoretical framework above. This chapter describes the main goals and structure of the decision tree. Furthermore, it gives information on the types of indicators and the key indicators covered by the decision tree.

The version of the decision tree presented in this deliverable concentrates on the component scale to support manufacturers and product designers. The questions posed within the decision tree also apply on the larger building and element scale, albeit with some nuance differences. As the project progresses, applying the decision tree to various Demonstrators at both product and building scales will enable the refinement of this model for wider use in the construction sector. This will also allow architects and real estate developers, the other key stakeholders of this framework, to utilise the decision tree.

3.1 Main Goals of the Decision Tree

The decision tree is structured according to life cycle stages, from production to EOL, and within those, according to the ASI framework: give precedence to avoiding overshifting and improving when possible. The decision tree covers the R-strategies (from refuse to recovery) with a clear hierarchy prioritising the highest R-strategies over more energy intensive and lower-value transformation processes (such as recycling). The decision tree presented is not an assessment framework per se. It is not intended at providing a final rating or score on multi-cycle circularity or sustainability. Instead, it supports product designers and manufacturers to define multi-cycle scenarios for their solutions, going beyond one-cycle recycling, and contributing to extend the lifespan of the product before disassembly is needed. This decision tree has three main goals:

1. Raising awareness and triggering product manufacturers to reflect on higher R-strategies in the process of product development.
2. Collecting data fundamental to assess life cycle environmental impacts, life cycle costs and circularity, compatible with EN 15804+A2 (CEN, 2019), EN 15978 (CEN, 2011), EN 16627 (CEN, 2015), ISO 15686-5 (2017b), the EU taxonomy (EC DG FISMA, n.d.), and the Level(s) assessment framework (EC DG ENV, 2023).
3. Ensuring traceability throughout the decision-making process (and afterwards) by providing a structure to collect evidence to support the selected multi-cycle scenarios.

The ultimate envisioned end goal of the decision tree is to create a narrative of the product (or building, in the case of a building designer using the decision tree – henceforth, please interpret "product" as "product or building") life cycle considering sufficiency and circularity, supported by an information data sheet defining the multi-cycle scenarios for the assessment framework.

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3.2 Structure of the Decision Tree

The decision tree begins by questioning the necessity of the product, assessing whether it addresses a genuine need from a social and economic perspective and if it can be dematerialised to minimise material usage. If the product is considered essential, the next step involves exploring the capacity of the solution to extend the product's lifespan and reduce resource demand (water, energy, and materials) compared to BAU.

In relation to resource use, the decision tree checks whether the product utilises secondary materials, differentiating R-strategies, or if it depends on primary materials, categorising them as biobased, virgin fossil, toxic, or scarce. This evaluation includes assessing the sustainability and locality of resource sourcing and examining opportunities for waste reduction during production and construction.

As the decision-making process continues, the focus shifts to the product's end of cycle, the potential for reuse in its original function without transformation, its adaptability without physical modifications, and the feasibility of restoring its technical performance through repairs. For products that can no longer be reused or repaired, the tree considers options for refurbishing or remanufacturing, evaluating the potential for parts to be used to create new products. The decision tree concludes by assessing recycling options, determining whether established methods exist and if recycling is not feasible, the potential for energy recovery is evaluated before considering landfill as the last resort.

The decision tree presented in Figure 8 shows the general overview of the interlinkages and hierarchy of sufficiency and circularity indicators at multiple scales. A legend of the different shapes used in the decision tree is included as Figure 7. Additionally, a zoomable version of the decision tree is available on the following Miro board. As mentioned above, the decision tree will be further finetuned in the next steps of the Drastic project, for broader application in the construction sector.

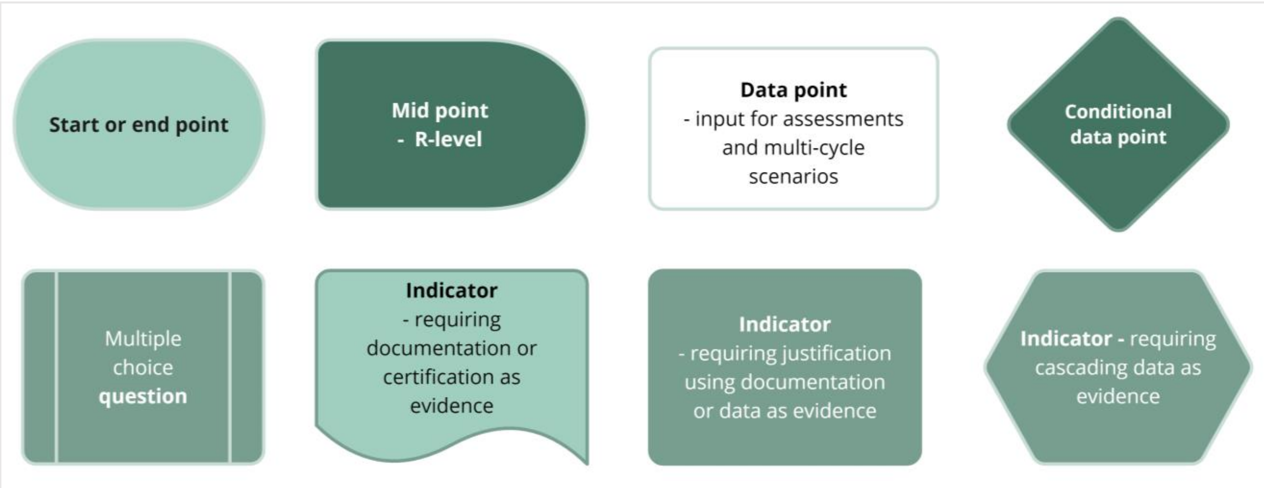

Figure 7: Legend of the Drastic Decision Tree.

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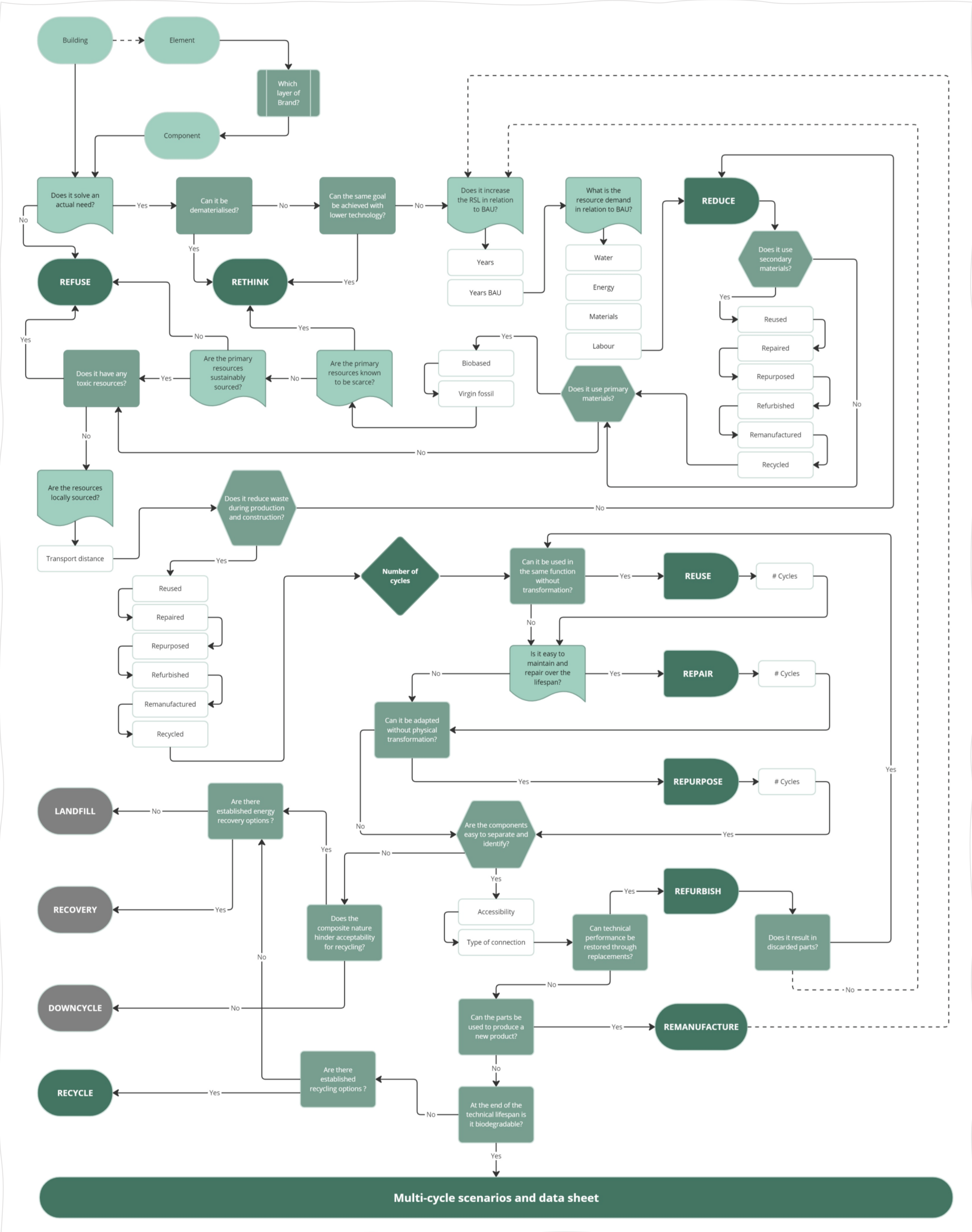

Figure 8: The Drastic Decision Tree.

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3.3 Types of Indicators in the Decision Tree

The decision tree includes three types of indicators, aligned to the three main goals. These are further detailed below, including mock-ups (see Figure 9, Figure 10, and Figure 11) as examples of how a decision tree user will be additionally informed about an indicator. Some indicators can support multiple goals depending on the stage at which they are applied. For instance, the indicator "Does it reduce resource consumption?" enables users to collect quantitative data during the design phase and can also be linked to the traceability platform to provide evidence in subsequent steps.

3.3.1 Qualitative Indicators for Raising Awareness Among Product Designers and Manufacturers

Qualitative indicators, which are not directly measurable, aim to **raise awareness from the design stage**. Examples of these indicators include questions such as whether a product can be dematerialized (achieving the same function without using any materials) or if the same goal can be achieved with lower technology (using less complex, less effort-intensive, and lower-energy solutions). Other examples include direct links to multi-cycle scenarios, such as the product's capacity to be reused without any transformation or adapted without physical alteration (Figure 9). Throughout the project, these qualitative indicators in the decision tree will be refined and supplemented with examples of best practices from the Demonstrators, along with recommendations for further reading.

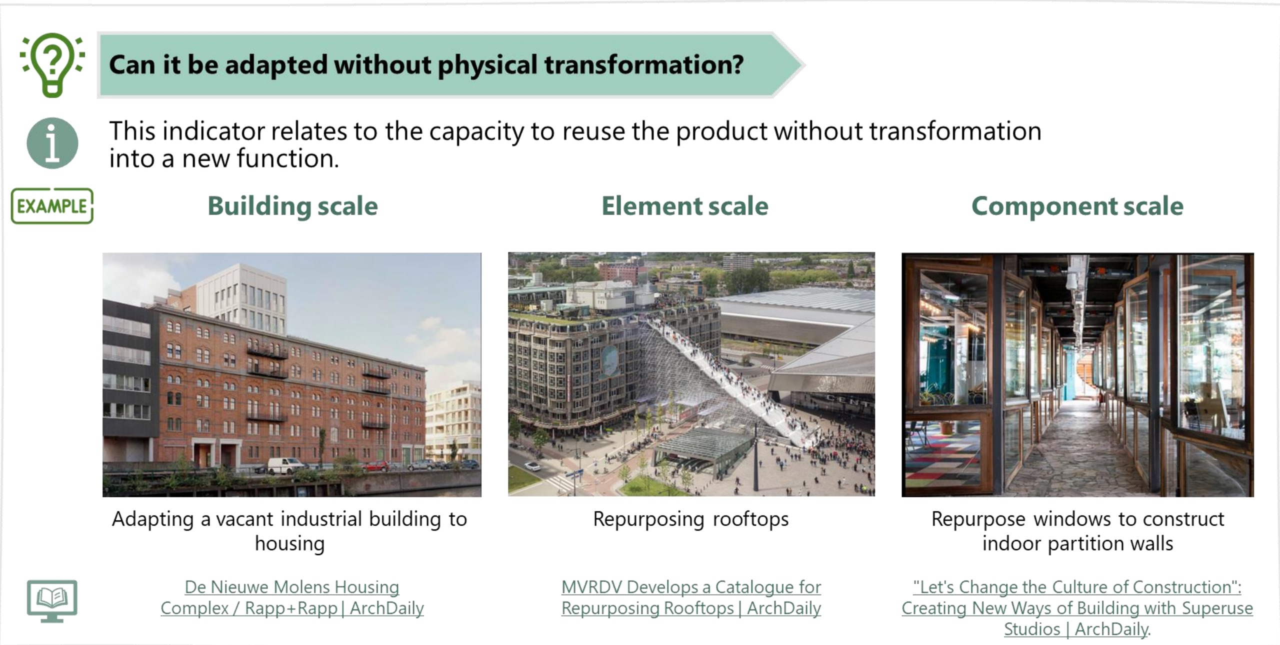

Figure 9: Mock-up of the adaptation without physical transformation indicator – an example of a qualitative indicator for raising awareness.

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3.3.2 Quantitative Indicators for Collecting Data

Quantitative indicators in the decision tree require data input to guide users through the process of data collection step by step to ensure that they collect the information required for the multi-cycle LCA. This approach helps users gradually build **an information data sheet** that can support sustainability assessments using various methodologies, including the Level(s) framework and LCA. These indicators include the RSL of the solution, resource demand (water, energy, and materials) during the production stage (Figure 10), the amount of secondary materials (categorised by R-strategy), and primary materials. Additionally, they encompass the expected number of cycles in the solution that can be reused, repaired, or repurposed. At the end of the decision tree, the collected data is compiled into a comprehensive data sheet, defining specific multi-cycle scenarios in a cascading approach.

What is the resource demand in relation to BAU?

This indicator relates to composing a data sheet for collecting data needed for the multi-cycle sustainability assessment framework.

Please collect the following data for BAU and your innovative solution, for the defined functional unit, in case of a comparative assessment.

	BAU		Solution	
	Module A1	Module A3	Module A1	Module A3
Water	... liter/FU	... liter/FU	... liter/FU	... liter/FU
Energy	... MJ/FU	... MJ/FU	... MJ/FU	... MJ/FU
Materials	... kg/FU	... kg/FU	... kg/FU	... kg/FU
Labour	... €/FU	... €/FU	... €/FU	... €/FU

Link to online data collection sheet

Figure 10: Mock-up of the resource demand indicator to be used to collect data for the sustainability assessment – an example of a quantitative indicator for collecting data.

3.3.3 Evidence Indicators for Ensuring Traceability

In addition to the qualitative and quantitative indicators, some indicators in the decision tree are fundamental for ensuring traceability throughout the entire life cycle of the product or building. These are known as evidence indicators because they **justify decisions and ensure transparency**. For example, an indicator for the reduction of resource demand would involve providing results from the environmental LCA. To demonstrate the sustainable sourcing of materials, one might offer certifications such as FSC. Indicators related to repairability, and maintainability could be supported by including a preventive maintenance plan (Figure 11), while ease of disassembly can be evidenced by supplying disassembly instructions and scores. These indicators help document and support each decision, promoting accountability and clarity in the development process.

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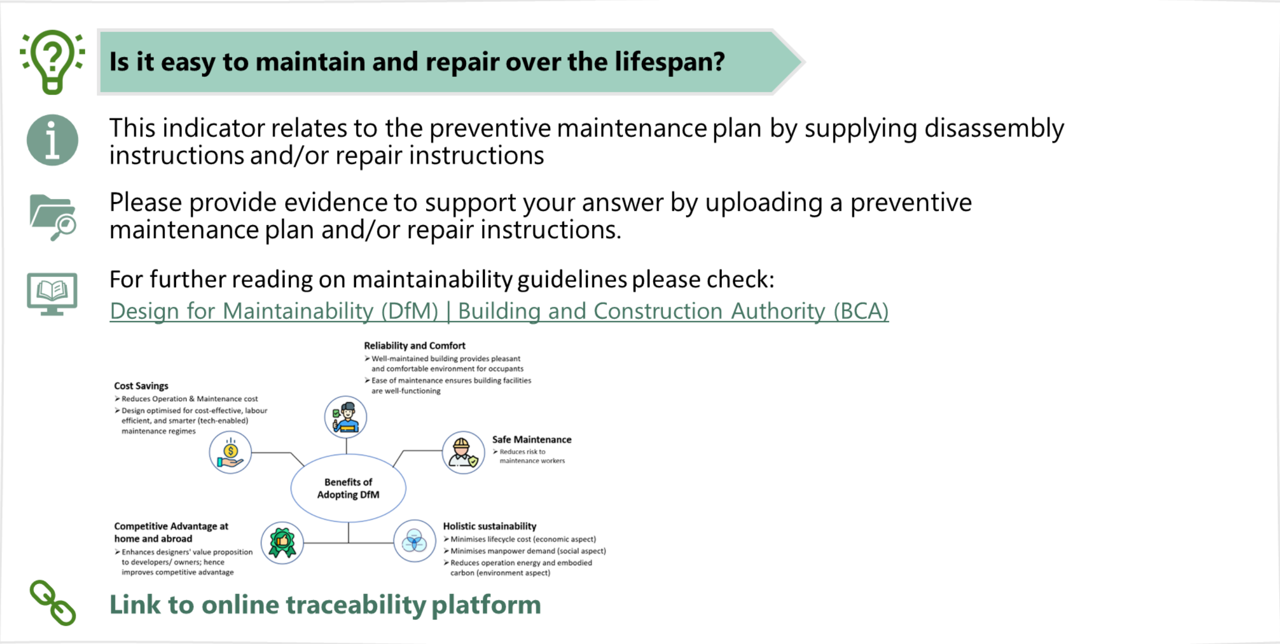

Figure 11: Mock-up of the maintenance and repair indicator with a request for providing evidence to ensure traceability – an example of an evidence indicator.

3.4 Key Indicators in the Decision Tree

The next sub-sections provide more background on the six key indicators covered by the decision tree.

3.4.1 Layers of Brand and Hierarchical Levels

In this framework, the building is understood as a composed interrelation of layers that determine its physical coherence, as defined by Brand (1995), with six shearing layers defined by Brand (site, skin, structure, space plan, services, and stuff). The decision tree enables users to select the specific shearing layer they are addressing, allowing for a gradual analysis of the building, reducing complexity, and facilitating the location of the different elements and components in their role in relation to the whole building (Figure 12).

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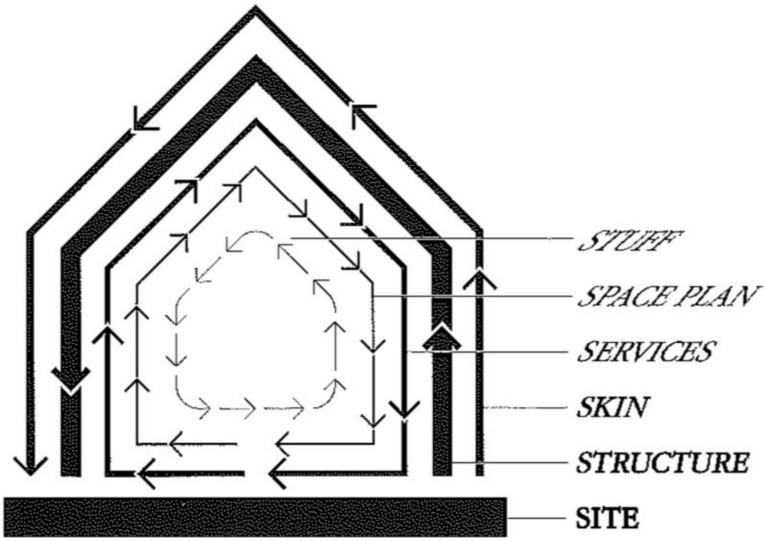

Figure 12: Diagram representing the six shearing layers (Brand, 1995).

These six layers are defined as follows:

1. Site: relation of the building with the surrounding urban landscape.
2. Skin: the building envelope and interface with the exterior.
3. Structure: the support of construction systems.
4. Services: the infrastructures, such as plumbing, electrical systems, heating, and ventilation.
5. Space plan: the interior layout and distribution of spaces.
6. Stuff: furnishings and furniture.

The layer Stuff was not included in these guidelines as no core indicators for multi-cycle circularity were identified in relation to it, and it is also not representative of the demonstrators in the project.

To support the assessment, the following four hierarchic levels of analysis have been distinguished: building, building elements, building components, and building materials, as illustrated by Figure 13.

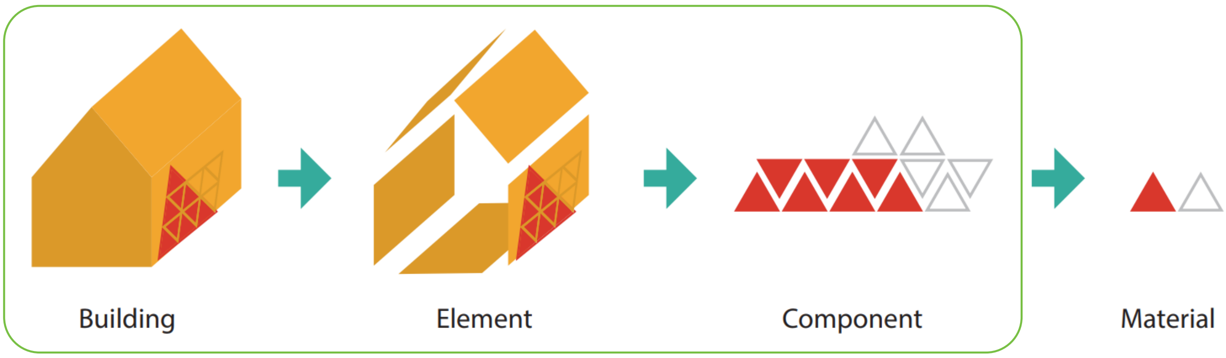

Figure 13: The hierarchical levels of analysis (source: TOTEM (Trigaux et al., 2023)). The Drastic Decision Tree provides guidance in the levels in the green rectangle. The lowest level "materials" is assessed as parts of a component.

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These hierarchical levels are defined as follows:

- Building: the highest guidance and assessment level, such as a house or an office building, and consists of elements. Some circularity indicators can be only applicable to the building level, while the environmental impact is a sum of the environmental impact of all the building elements.
- Element: the middle level, such as an external wall or a flat roof, consisting of components.
- Component: the lowest guidance and assessment level considered in the Drastic framework, consisting of materials. Depending on the subject of the guidance and assessment, a component can be a construction product (e.g. a brick or a prefabricated façade element) supplied by a single responsible body or a work section involving one trade around a type of material (e.g. brickwork).
- Materials: are not considered as subjects for guidance and assessment in this framework and will be only assessed as the smaller parts of a component.

3.4.2 R-strategies

In this framework the hierarchy of R-strategies (also called R-hierarchy, R-imperatives, R-ladder, or R-levels) is fundamental to define the multi-cycle circularity scenarios. The R-strategies are often presented in a sequential ladder from R0 (Refuse) to R9 (Recovery), expressing the increasing level of circularity, with sufficiency strategies at the top. In principle, the higher the R-strategy in the ladder, the fewer resources are used and the lower the environmental impacts. The decision tree guides the user to achieve the higher value R-strategy, starting from Refuse, and limiting low-value strategies such as recycling, as introduced in the section Circularity of the theoretical context (see section 2.2).

The PBL (Netherlands Environmental Assessment Agency) definitions of the R-strategies were used as a starting point for this framework (Potting et al., 2017). However, since these definitions were initially created for the product chain, some adaptations have been proposed in the current framework to improve clarity and ensure alignment with the built environment, as presented in Table 2.

The R-strategies are referred to in three key points of the decision tree: 1) input material, 2) output construction and demolition waste (CDW), and 3) multi-cycle scenarios. In the input of materials, users can specify the origin of secondary materials, from reused to recycled. This integrates a cascading approach, ensuring that users consider the lowest levels of transformation (reuse) before the highest levels of transformation (recycle) when selecting secondary materials.

In relation to the output of construction waste, the same hierarchy is used. This indicator specifically refers to the outputs of the construction phase at the building scale, as this is one of the mandatory data requirements for the assessment in the European Level(s) framework. In the Level(s) framework, the split of materials is less detailed than in the decision tree (considering only reuse, recycling, downcycling, recovery, and landfill), but the data input in the decision tree can easily be aggregated to fulfil Level(s) requirements.

The final output of the decision tree is a data sheet detailing the multi-cycle circularity scenarios of the building or construction product. This sheet estimates the number of cycles a component or building

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can be reused, repaired, or repurposed, extending its lifespan before more interventive and impactful strategies are required. Repurposing is prioritised in the R-ladder because it allows the product to be used in a different function without further transformation. When refurbishment and remanufacturing occur, the new product created should, by definition, achieve the original (or improved) level of performance, effectively resetting its lifespan, which is indicated in the tree with a dashed line. The multi-cycle scenarios consider that the same product (or building) can be reused, repaired, repurposed, refurbished, and remanufactured multiple times before reaching the EOL stage, at which point they should ideally be recycled, minimising downcycling, energy recovery, and landfill.

Table 2: The definitions of the R-strategies framework for the CE, adapted for the built environment.

R0	**Refuse**	make product redundant by abandoning its function or by offering its function with a radically different solution
R1	**Rethink**	make product use more intensive (through sharing or multi-functionality)
R2	**Reduce**	increase efficiency in production or use by consuming fewer natural resources and materials
R3	**Reuse**	reuse by another consumer of a discarded product which is still in good condition and fulfils the original function
R4	**Repair**	repair and maintenance of defective product so it can be used with its original function
R5	**Refurbish**	restore an old product and bring it up to date (intervention on-site with replacements)
R6	**Repurpose**	use the product or its parts in a new product with a different function without transformation
R7	**Remanufacture**	use parts of discarded products in a new product with the same function
R8	**Recycle**	process materials to obtain the same (high grade) or lower (low grade) quality
R9	**Recover**	incineration of materials with energy recovery

3.4.3 Refuse and Rethink

The framework integrates sufficiency from the initial stages of design, raising awareness of the importance of assessing if the solutions proposed are addressing actual needs and considering opportunities for dematerialization or achieving goals with lower technology. These indicators lead to refuse and rethink strategies first, aligned with the ASI framework described in the section 2.3 on

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sufficiency, avoiding producing or building something before considering shifting to more sustainable or circular alternatives.

As a starting point for the decision tree, users are requested to demonstrate a genuine need for the proposed solutions. This demonstration can envelope a clear problem statement, supported by specific functional requirements or market demands. At the building scale, for example, an extension to an existing building should be refused if the available space is frequently vacant and not intensively used. If the need for the solution is demonstrated, opportunities for dematerialization should also be considered. This involves reframing the problem to verify if the solution can be achieved without extracting, producing, or transforming material resources—such as providing a service instead of a product. For instance, addressing housing scarcity by better distributing the existing floor area, rather than constructing new houses, exemplifies dematerialization. Additionally, a third indicator is related to achieving the goal using lower technology, which can be more sustainable, cost-effective, and less resource intensive. For example, at the building scale, this could involve adopting natural ventilation and bioclimatic design strategies instead of installing complex heating, ventilation, and air conditioning systems.

3.4.4 Reduce Resource Demand

Data collection for MLCA and MLCC should encompass various resource flows utilised by the products, including raw materials, energy, water, and associated costs such as labour. Comparing these resource flows with those of their BAU counterparts will highlight any resource and/or cost reductions. The decision tree will be used to inform Demonstrators which data needs to be collected, and as shown on the mock-up in Figure 10 a link to a data collection file (which will be further elaborated in Task 2.3 of the Drastic project) will be shared.

3.4.5 Raw Materials

The decision tree prioritises the integration of secondary materials, derived from the reprocessing of previously used materials, recovered, and reintroduced into the manufacturing cycle. This includes for instance reusing structural steel elements, reclaimed and repurposed wood elements, or the integration of recycled content in new products. In a logic of sufficiency, primary materials should be used only when secondary materials are not enough to achieve the desired outcomes (considering the required amounts or levels of performance). Primary raw materials require newly mined minerals and/or are directly extracted from natural resources. Biobased materials are derived from renewable biological sources and can have a lower environmental impact due to their renewable nature and should be prioritised over virgin fossil materials. Examples include wood, bamboo, hemp, etc. Virgin fossil raw materials are extracted from non-renewable fossil resources and have high impacts associated with extraction and production. These include petrochemical-based products such as plastics, synthetic insulation, etc., and their use in construction should be limited, which is the reason why they are the last possible option for material input in the decision tree.

In addition to considering the amounts of material input, the decision tree also accounts for specific indicators fundamental to a resilient and regenerative built environment, by promoting the use of

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materials that reduce harmful environmental, social, and health impacts while encouraging ecological restoration and future-proofing the construction ecosystem. These indicators relate to material toxicity, material scarcity, and sustainable sourcing.

In relation to material toxicity, the aim is to support a non-toxic, ecologically restorative, and transparent construction ecosystem. This involves avoiding materials deemed dangerous or carcinogenic for humans or the environment, avoiding the product ingredients in the Red List of the International Living Future Institute (2024), presented in Appendix G. Identifying toxic substances is crucial in determining multi-cycle scenarios, as they can hinder reusability and recyclability. Hazardous materials such as asbestos, lead paint, and those producing ionizing radiation must be disposed of according to local regulations.

In relation to the sourcing of primary materials, this decision tree promotes the responsible extraction of materials and ensures transparency in product labelling. It advocates for the development and adoption of third-party certified standards that ensure sustainable resource extraction and fair labour practices for rock, metal, minerals, and timber. Examples of certifications to be considered are, for instance the Forest Stewardship Council (FSC) for timber products (FSC International, 2023) or the Fair Stone Standard for stone products (Fair Stone, 2020).

The scarcity indicator evaluates whether the solution involves materials known to be scarce or classified as unsustainable/critical raw materials (CRMs) and identifies opportunities to minimise their use. Scarcity can be either physical or socio-economic. Physical scarcity pertains to natural resources that are limited and at risk of depletion, while socio-economic scarcity concerns the economic importance of these resources and the risks associated with their supply security. A list of critical raw materials in Europe is provided in Appendix H, however when assessing the indicators in the decision tree, users should refer to the most updated CRM list published by the EC should be considered (European Commission, 2023). The decision tree recommends minimising the use of scarce materials by opting for alternatives whenever possible, encouraging the use of secondary scarce materials, rethinking material suppliers, and redesigning solutions to enhance resilience.

3.4.6 Design for Disassembly

Two main indicators are used to establish a design for disassembly score, in relation to the questions "are the components easy to separate and identify". These are the accessibility of connections and the type of connection, based on the research by Durmisevic (2006) and van Vliet (2018), which ranks the different connections using a unitless score between 0 and 1. Scientific debate is ongoing on the determination and weighting of the scores, as these can be rather subjective, and on the demarcation between the detachability of different components (Cottafava & Ritzen, 2021). However, these indicators are the most addressed in different circularity assessment frameworks, including the *Madaster Circularity Indicator* (Madaster, 2021) and *Building Circularity Index* (BCI, 2022), and are thus considered as priority data requirements.

In relation to the type of connection, the scores indicated in Table 3 should be considered when using the decision tree:

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Table 3: Scores of types of connection (Van Vliet, M.M.; van Grinsven, J.; Teunizen, J., 2021).

Type of Connection		Score
Dry connection	Loose (no fixings)	1
	Click connection	
	Velcro connection	
	Magnetic connection	
Connection with added elements	Bolt and nut connection	0.8
	Spring connection	
	Corner connection	
	Screw connection	
	Connection with added elements (e.g., a façade suspension system)	
Direct integral connection	Pin connection (e.g., staples)	0.6
	Nail connection	
Soft chemical connection	Sealant connection	0.2
	Foam connection	
Hard chemical connection	Adhesive bond	0.1
	Cast bond	
	Weld joint	
	Cement bond	
	Chemical anchors	
	Hard chemical bond	

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In relation to the accessibility of the connections, the scores in Table 4 should be considered:

Table 4: Scores of the accessibility of connections (Van Vliet, M.M.; van Grinsven, J.; Teunizen, J., 2021).

Connection Accessibility	**Score**
Freely accessible	1.0
Accessibility with additional actions that do not cause damage	0.8
Accessibility with additional actions with repairable damage	0.4
Not accessible and/or causing irreparable damage	0.1

3.5 Implementing MLCA and MLCC

As explained in the section 2.4, Drastic will incorporate a multi-cycle life cycle approach that enables cascading scenarios based on the R-strategies with the CEN/TC 350 modular structure as the basis. These multi-cycle scenarios will be defined when following the different steps in the decision tree. Figure 14 shows how the R-strategies based scenarios can be included in the different life cycle modules while performing a LCA and LCC, and thus towards the implementation of an MLCA and MLCC. The assessment results from the MLCA and MLCC will provide the quantitative evidence to support the narrative created for the assessed object through the application of the decision tree. Based on the application of the decision tree throughout the project, the applicability of the mapping below will also be tested further and if needed also refined.

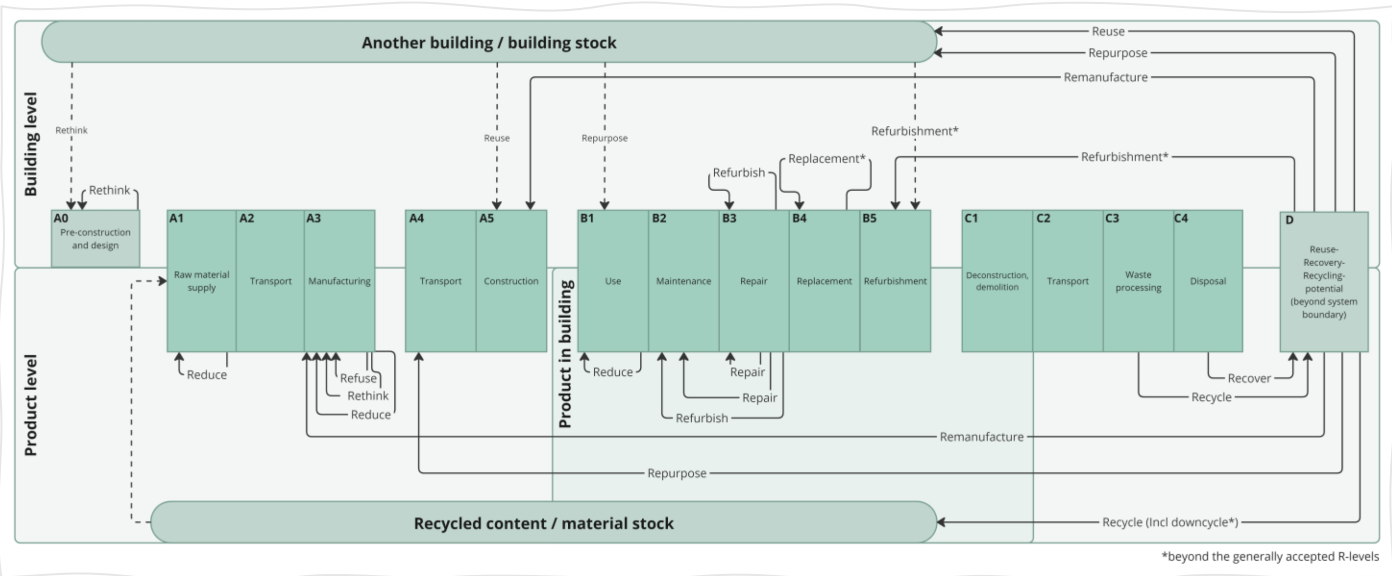

Figure 14: Visual mapping of the interaction between the R-strategies and life cycle stages.

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4 Conclusions

4.1 First Observations

The methods outlined in the section 1.3 enabled the creation of a design guidance framework based on multi-cycle sustainability and circularity assessment. Throughout this process, the decision tree presented in chapter 3 was developed to offer comprehensible and uniform guidance on the key issues of circularity, sufficiency, and a multi-cycle life cycle approach. Furthermore, the decision tree serves as the starting point for data collection and traceability of the environmental and economic impacts as and sustainability performances, as well as to define the multi-cycle scenarios needed in the assessment framework. The quantitative MLA and LCC assessment results will support the narrative created for the assessed object through the application of the decision tree.

Additionally, the following points were observed throughout this process:

- The hierarchy of the R-strategies does not align with life cycle modules in the CEN/TC 350 standards. For example:
    - The R-strategy 'Refurbish' involves restoring and updating an old product, whereas the life cycle module B5 'Refurbishment' concerns – large scale (substantial) modification and improvements to existing construction works (CEN, 2021) – and is only applicable at the building level, not the product level.
    - Replacement – substitution of a whole construction product, building element or installation with the same or an equivalent similar product, building element or installation to re-establish the required functional and technical performance or to fulfil new regulations (CEN, 2021) – corresponds with module B4 in the CEN/TC 350 standards but is not addressed by the R-strategies.

  This discrepancy may exist because the R-strategies were defined from a resource perspective focussing on products, rather than on reducing environmental impacts.
- The R-hierarchy and ISO 21928-2:2023, as referenced in EN 17680 on sustainable refurbishment (CEN, 2023) do not distinguish between upcycling and downcycling, although such differentiation appears necessary and is therefore included in the decision tree.

4.2 Next Steps and Tasks

A crucial subsequent step for implementing the decision tree by the Drastic Demonstrators is to draft the supplementary background information for each question posed in the decision tree as shown in the example mock-ups (Figure 9 to Figure 11). Once drafted, the Demonstrators can utilise the tree and supplementary information to enhance their product development process and optimise their design, incorporating principles of circularity, sufficiency, and a multi-cycle life cycle approach. Another key step is establishing the data collection sheet and traceability platform, which the Demonstrators can use in conjunction with the decision tree. During the data collection sheet's development process,

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the creation of a tool that automatically creates a narrative from the data collected will be explored. User-friendliness should be a central focus in these steps.

The above steps will take place in the following tasks:

- Task 2.3 – data collection protocol: to develop the data collection sheet to collect the data needed for the sustainability assessment in a harmonised way.
- Task 2.4 – product level sustainability assessment and validation of the Demonstrators: to support the product development in WP3 by using this guidance and assessment framework. This will be an iterative process for each Demonstrator based on three steps: 1) assessment of the BAU reference scenario, 2) screening of the Drastic solution in comparative assessment with the BAU reference scenario, 3) validation of the final Drastic product solution.
- Task 2.5 – building level sustainability assessment and validation of the Demonstrators: similar process alike the previous task but with the products of the Demonstrators implemented on building level.
- Task 4.5 of WP4 – implementation of the multi-cycle traceability and WP2 framework in a common digital building platform: to develop a toolbox allowing integration and visualisation of the WP2 results in a digital platform (as shown in Figure 2).

Furthermore, as previously noted in chapter 3, the presented Drastic decision tree will undergo further refinement throughout the project's progression. mplementing the decision tree in the development of the Demonstrators at both product and building levels will facilitate the refinement of this model for wider application in the construction sector, serving all intended stakeholders, being building product developers, architects, real estate developers, and environmental assessors. Project partners will be encouraged to provide feedback on the framework in subsequent phases, enabling us to establish a more precise definition and recommendations within the framework by the end of the project.

In addition to the refinement points derived from the tree's implementation in the above tasks, the following research areas will also be considered for further refinement:

- Integrating elements from EN 17680 on sustainable refurbishment (CEN, 2023) when applying the decision tree to existing buildings.
- The provision of case studies, design archetypes, and specific design strategies (as supplementary design support types – see section 2.1) for each product scale and layer of Brand.
- Exploring the aspect of affordability together with WP5, which focuses on social acceptance and business models (see Figure 2), for integration in the decision tree and narrative creation.

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Appendix A. Mapping of Circularity Indicators

Scale	Indicator	R-Strategy	ASI
Material	Mass of virgin material	Reduce	Improve
Material	Amount of scarce materials	Reduce	Avoid
Material	Amount of toxic materials	Refuse	Avoid
Material	Amount of non-renewable primary materials	-	Improve
Material	Amount of renewable primary materials	-	Shift
Material	Amount of secondary materials from recycling	Recycle	Shift
Material	Percentage of materials viable for secondary used	Reuse-Recycle	Shift
Material	Amount of unrecoverable waste	Reduce	Avoid
Material	Amount of materials viable for recycling	Recycle	Shift
Material	Amount of materials used for energy recovery	Recovery	Improve
Material	Percentage of waste stream downcycled	Recycle-Recovery	Improve
Material	Ease of recycling	Recycle	Improve
Material	Percentage actually recycled after use	Recycle	Shift
Material	Percentage actually collected after use	Reuse-Recycle	Shift
Component	Ease of recovery (harvesting)	Reuse-Recycle	Improve
Component	Ease of reuse	Reuse	Improve
Component	Detachability of connection type	Reuse-Recycle	Improve
Component	Accessibility of connection	Reuse-Recycle	Improve
Material/Component	Amount of secondary materials from reuse	Reuse	Shift
Material/Component	Amount of materials viable for reuse	Reuse	Shift
Component	Percentage of actual refurbished after use	Refurbish	Shift
Component	Percentage of actual remanufactured after use	Remanufacture	Shift
Component	Length of use phase	-	Avoid
Component	Number of maintenance cycles	Repair	Avoid
Component	Techno-functional quality	Repair	Avoid
Component/building	Intensity of use	Rethink	Avoid
Building	Spatio-functional adaptive capacity	Rethink	Avoid
Component,	Environmental impact according to LCA	Reduce	Avoid

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Scale	Indicator	R-Strategy	ASI
Component/building	Energy use	Reduce	Improve
Component/building	Water use	Reduce	Improve
Component/building	Economic value loss	-	Avoid
Component/building	Financial residual value	-	Improve

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Appendix B. Mapping of Sufficiency Indicators

Scale	Indicator	R-Strategy	ASI
building	adapted to local climate and environment	refuse	avoid
building	reduce new construction	refuse	avoid
all	absolute reduction of environmental impacts over the life cycle	reduce	avoid
building	stop demolition	refuse	avoid
component, building	reduction of construction materials consumption	reduce	avoid
material	no use of toxic materials	refuse	avoid
component, building	reduce demand of natural resources	reduce	avoid
component, building	solving actual needs	refuse	avoid
building	sharing products, spaces, and appliances	rethink	avoid
component, building	low tech solution	refuse	avoid
component	easy to disassemble connections	repurpose	improve
component, building	flexible design for future changes	rethink	improve
building	renovation of existing structures/buildings	refurbish	improve
component, building	easy maintenance	repair	improve
building	planned maintenance	repair	improve
component	increased lifetime of products and solutions	rethink	improve
component, building	renewable energy	reduce	improve
component, building	downsize energy systems	reduce	improve
building	optimising Indoor environmental quality and comfort	rethink	improve
building	space use optimisation	rethink	improve
all	reduction of costs over the life cycle	reduce	improve
component, building	efficient use of materials	reduce	improve
component, building	conversion capacity and adaptability	repurpose	shift
component, building	adaptability to changing needs	reuse	shift
component	repairable	repair	shift
component	reusable components	reuse	shift
material, component	upcycling materials in construction	repurpose	shift
component	use of recyclable materials	recycle	shift

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Scale	Indicator	R-Strategy	ASI
component	use of recycled materials	recycle	shift
component, building	local materials	reduce	shift
component, building	materials with low embodied energy	reduce	shift
component, building	use of reused materials	reuse	shift
building	occupancy (regularity, periodicity, diversity)	rethink	shift
building	flexible use	rethink	shift
component, building	reduce reliance on energy intensive systems	reduce	shift

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Appendix C. Environmental Impact Indicators

Overview of the environmental impact categories, indicators, units, and corresponding life cycle impact models considered for the MLCA in Drastic based on the EN 15804+A2 (CEN, 2019).

Table C1. Core environmental impact categories and indicators.

Impact categories	Impact indicator	Unit	Model impact method
Climate change	Climate change - total	kg CO2 eq.	Baseline model of 100 years of the IPCC based on IPCC 2013
	Climate change - fossil	kg CO2 eq.	Baseline model of 100 years of the IPCC based on IPCC 2013
	Climate change - biogenic	kg CO2 eq.	Baseline model of 100 years of the IPCC based on IPCC 2013
	Climate change - land use and land use change	kg CO2 eq.	Baseline model of 100 years of the IPCC based on IPCC 2013
Ozone depletion	Ozone depletion	kg CFC 11 eq.	Steady-state ODPs, WMO 2014
Acidification	Acidification	mol H+ eq.	Accumulated Exceedance, Seppälä et al. 2006, Posch et al., 2008
Eutrophication	Eutrophication aquatic freshwater	kg P eq.	EUTREND model, Struijs et al., 2009b, as implemented in ReCiPe
	Eutrophication aquatic marine	kg N eq.	EUTREND model, Struijs et al., 2009b, as implemented in ReCiPe
	Eutrophication terrestrial	mol N eq.	Accumulated Exceedance, Seppälä et al. 2006, Posch et al., 2008
Photochemical ozone formation	Photochemical ozone formation	kg NMVOC eq.	LOTOS-EUROS ,Van Zelm et al., 2008, as applied in ReCiPe
Depletion of abiotic resources	Depletion of abiotic resources - minerals and metals	kg Sb eq.	CML 2002, Guinée et al., 2002, and van Oers et al. 2002.
	Depletion of abiotic resources - fossil fuels	MJ, net calorific value	CML 2002, Guinée et al., 2002, and van Oers et al. 2002.
Water use	Water use	m3 world eq. deprived	Available WAter REmaining (AWARE) Boulay et al., 2016

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Table C2. Additional environmental impact categories and indicators.

Impact categories	Impact indicator	Unit	Model impact method
Particulate matter	Particulate matter emissions	Disease incidence	SETAC-UNEP, Fantke et al. 2016
Ionizing radiation	Ionizing radiation - human health	kBq U235 eq.	Human health effect model as developed by Dreicer et al. 1995 update by Frischknecht et al., 2000
Eco-toxicity	Eco-toxicity - freshwater	CTUe	Usetox version 2 until the modified USEtox model is available from EC-JRC
Human toxicity	Human toxicity - cancer effect	CTUh	Usetox version 2 until the modified USEtox model is available from EC-JRC
	Human toxicity - non-cancer effects	CTUh	Usetox version 2 until the modified USEtox model is available from EC-JRC
Land use	Land use related impacts/ Soil quality	dimensionless	Soil quality index based on LANCA

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Appendix D. Template of the Sufficiency Workshop

How sufficient is this circular solution?

Tops:

In this page note down one sufficiency indicator on which the circular solution is aldready doing great and can be replicated (tops) and one sufficiency indicator that could be better and that would benefit from further development in the future (tips).

Tips:

Workshop lead by:

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Joana Gonçalves, VITO joana.goncalves@vito.be

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WCEF 2024 BRUSSELS, BELGIUM

WORLD CIRCULAR ECONOMY FORUM 2024

15 - 18 APRIL

Accelerating circularity from a sufficiency perspective

The built environment is one of the sectors with the highest circularity potential, but current circular strategies focus mainly on the more applied R-strategies (e.g. recycling and reuse). This workshop will apply sufficiency on different circular solutions in the construction industry, aiming at the lesser applied R-strategies (e.g. refuse and reduce). Centred around case studies from the Circular Building Coalition and the Drastic project, participants will be actively involved in one of the cases in a World Café setting to come to systemic innovations.

Programme

12:10	Welcome
12:20	Demonstration of solutions: video pitches
12:40	Introduction and scope of the roundtable discussions
12:45	Roundtable 1: What indicators are relevant for this circular solution?
13:05	Roundtable 2: How sufficient is this circular solution?
13:10	Big reveal: sharing the sufficiency check
13:20	Wrap-up

CIRCULAR BUILDINGS COALITION

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Circular Solution:

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Inventory of sufficiency indicators

Avoid

Is it adapted to local climate and environment?
Does it imply building something new?
Does it require new land take?
Does it lead to absolute reduction of environmental impacts over the whole life cycle?
Does it avoid demolition?
Does it reduce the amount of construction materials needed?
Does it avoid the use of toxic materials?
Does it avoid demand for natural resources (material, energy, water, land)?
Does it solve an actual need?
Can it be shared, leased, borrowed, or rented?
Could it be replaced by a solution with lower technology?

Avoid:
Opt out of or minimize resource use

Shift:
Transition to a more sustainable consumption alternative

Improve:
Enhance efficiency of a current product or service

Shift

Can it be adapted without physical changes?
How complex is it to adapt it to a different function?
Can it be repaired and/or contributes to repairability?
Can the components be reused in the same function without physical changes?
Is the value of materials maintained or improved?
Can the materials be infinitely recycled or biodigested?
Does it use recycled materials?
Does it use locally sourced materials?
Does it use materials with low embodied energy?
Does it reuse existing materials without further transformation?
Does it enable a consistent, regular, diverse and/or intensive use ?
Does it allow the users to determine a flexible use?
Does it reduce reliance on energy intensive systems/processes?

Improve

Are the components easy to separate and identify?
Is it designed anticipating the possibility of multiple functions?
Does the solution refurbish an existing product and bring it up to date?
Is it easy to maintain throughout the lifespan of the product?
Is there a plan to maintain the solution at the maximum level of quality?
Does it increase the lifespan in relation to the average product on the market?
Is it used, produced, and maitained with energy from renewable sources?
Does it downsize the need for energy systems?
Does it contribute to optimize indoor environmental quality?
Is the space optimized for the function?
Does it contribute to increase building density?
Is it integrated with the existing urban ecosystem and mobility infrastructure?
Does it add t the multifunctionality and diversity of the urban area?
Does it lead to overall reduction of costs over the whole life cycle?
Are materials used efficiently to avoid material loss and waste?

This inventory of indicators results from a systematic literature review conducted by VITO. If you want to know more about it do not hesitate to get in touch: joana.goncalves@vito.be

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What indicators are relevant for this circular solution?

In this page note down the 10 indicators from the previous page that the group selects as the most important to assess the sufficiency level of this circular solution. Are there indicators missing? Feel free to add!

1.

2.

3.

4.

5.

6.

7.

8.

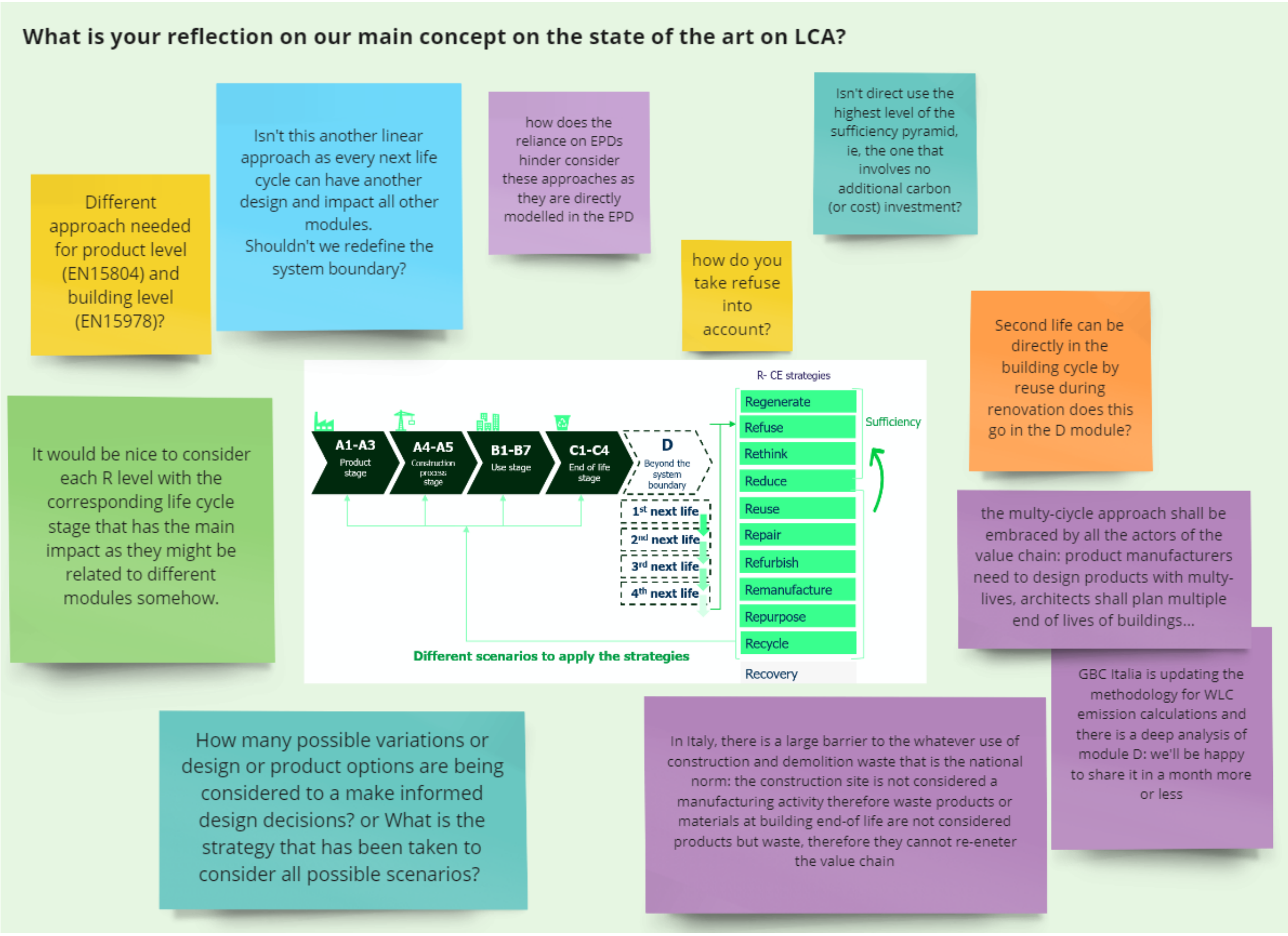
9.

10.

Appendix E. Online Stakeholder Workshop

Link to the **recording** of the joint session: https://youtu.be/D_uUBlel8xU?si=ctJG_BQ_tysvR9dM

Screenshot of a part of the Miro board used during the breakout session on **MLCA**:



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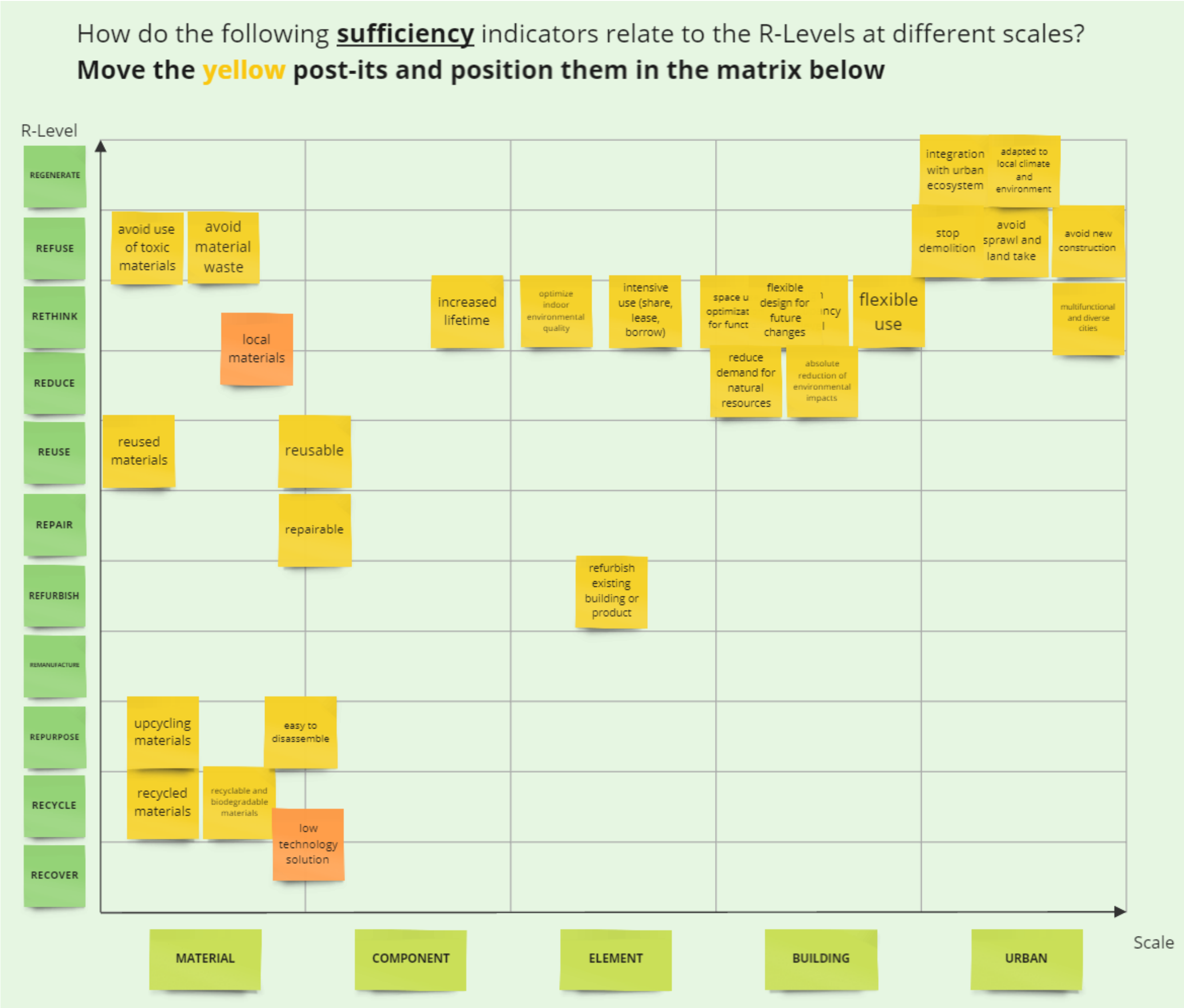
Screenshot of a part of the Miro board used during the breakout session on **Sufficiency**:



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Screenshot of a part of the Miro board used during the breakout session on **MLCC**:

	Challenges: difficulties, threats, risks	**Opportunities**: possibilities
How: module D & circularity: How would you move from linear LCC to multi-cycle LCC? How would you estimate the residual value? How would you tackle module D to link it to circularity?	degradation of products depending on conditions	cost savings, new thinking needed, perhaps different use price forecasting of materials that make up a product minus some the estimated cost for repair? - For residual value
How: scenarios: What are the dependencies of defining scenarios? What kind of scenarios should be considered with link to circular value retention?		future material availability/needs using something like integrated assessment models, so different scenarios for availability and demand could be considered prospective LCC high value of original materials enables new thinking in material ownership (manufacturer takes back own materials)
How: external costs: What is your reflection on adding external costs? How would you deal with the uncertainty and lack of consensus of external costs? What is your reflection on linking to environmental impacts pricing?	difficulties to give a price for pollution, harmful impacts (depends on conditions, scale of operation, also future increased knowledge of harmful impacts sending the wrong message by mixing environmental impacts and costs meaning the message would be pollute as long as you pay - i would keep them separated	

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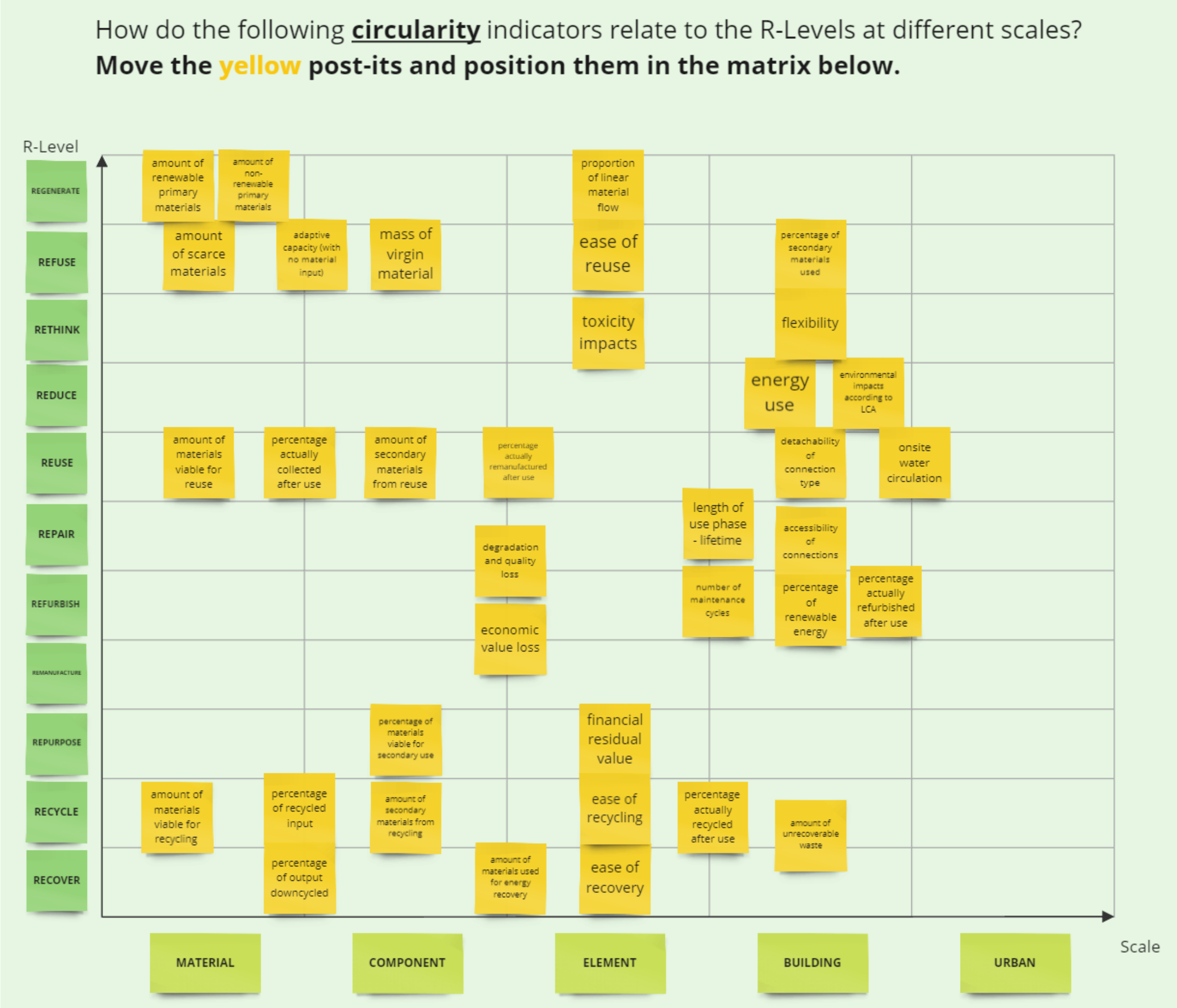
Screenshot of a part of the Miro board used during the breakout session on **circularity**:



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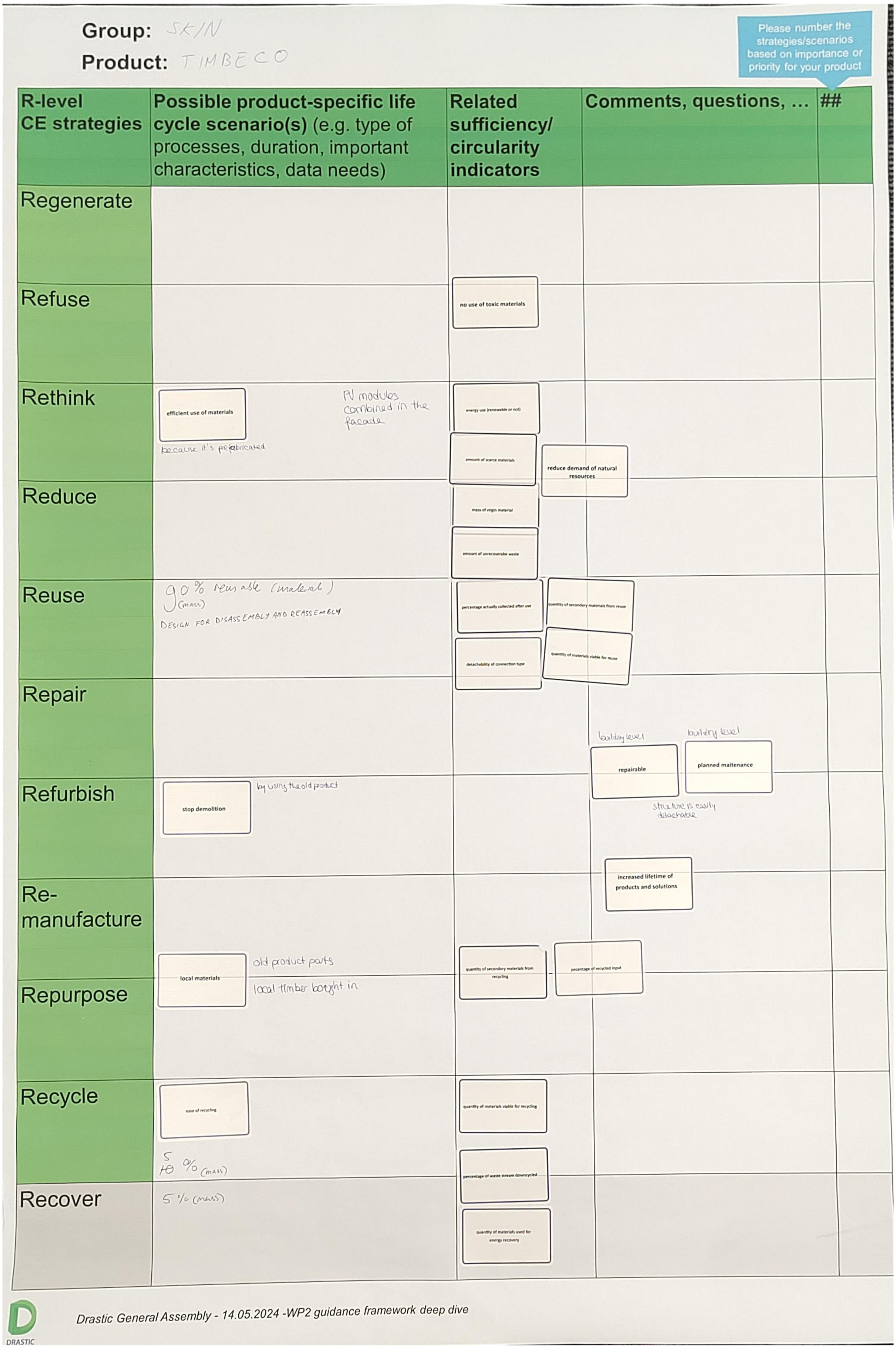
Appendix F. General Assembly Workshop

Skin layer: Estonian and German demo, selected product: Estonian prefab façade element



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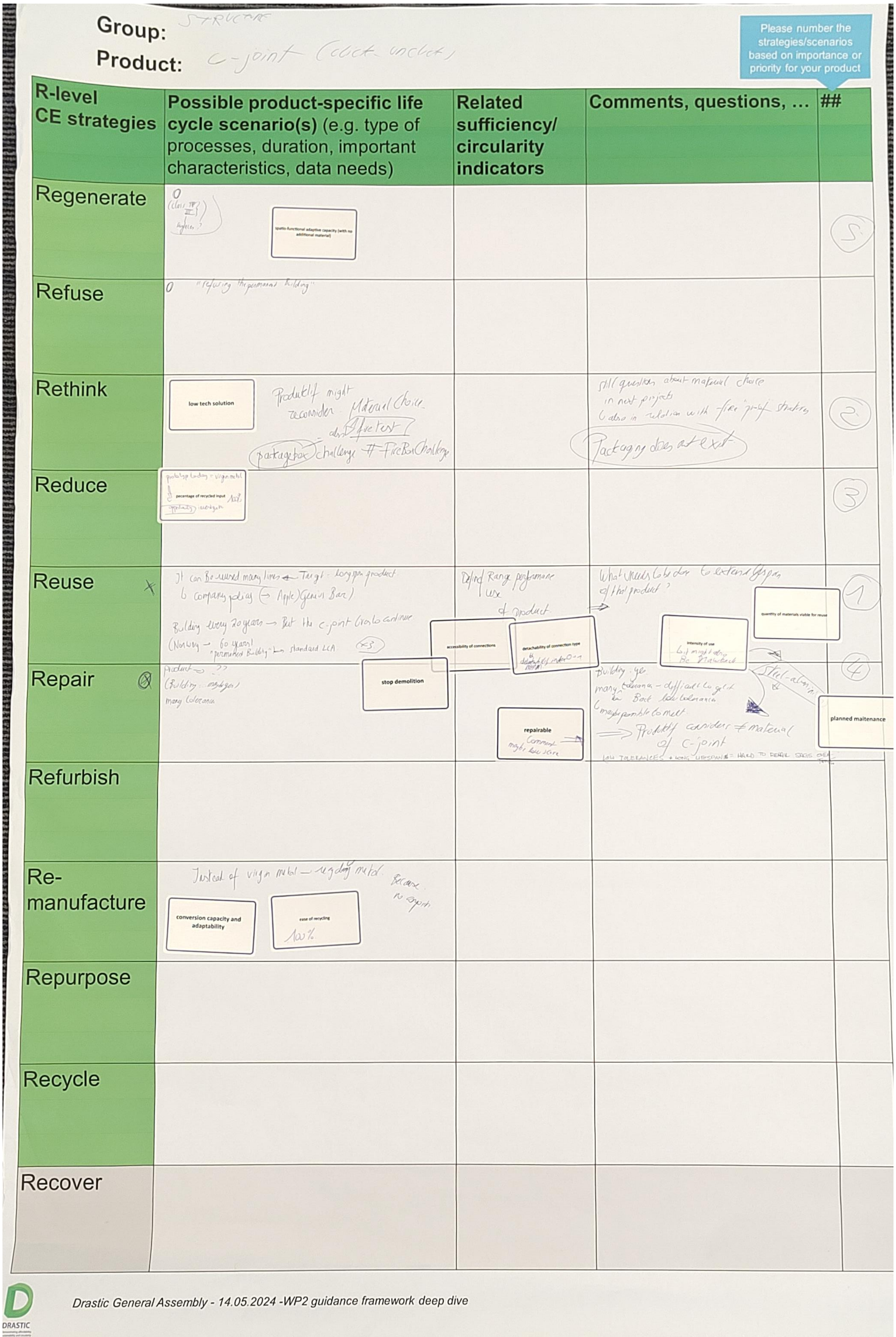
Structure layer: Spanish and Norwegian demo, selected product: C-joint - reversible connector from steel



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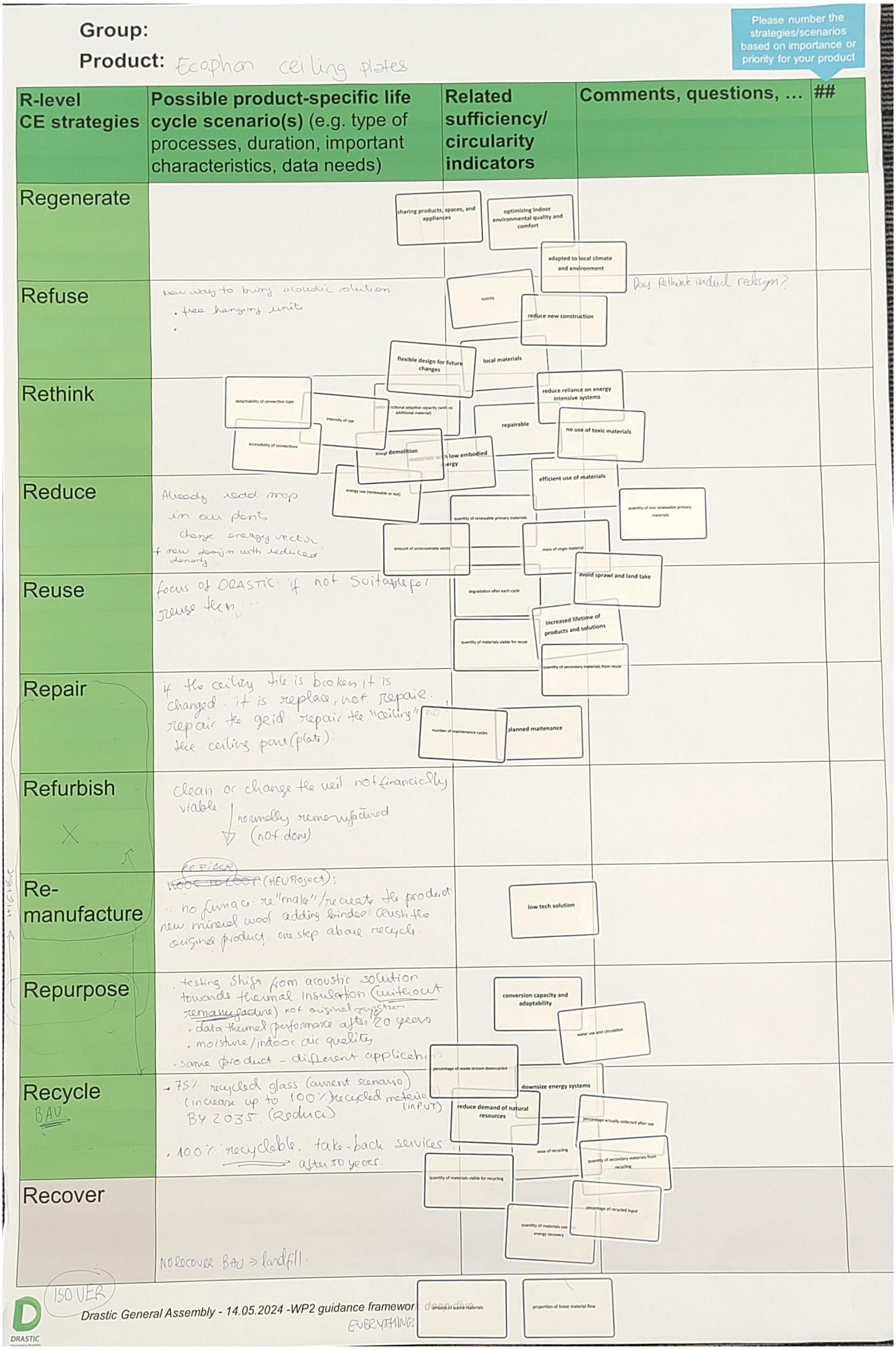
Space plan layer: French demo, selected product: ceiling plates



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Appendix G. Red List Product Ingredients

Antimicrobials (marketed with a health claim)	Monomeric, polymeric, and organophosphate halogenated flame retardants (HFRs)
Alkylphenols and related compounds	Organotin Compounds
Asbestos compounds	Perfluorinated and Polyfluorinated Alkyl Substances (PFAS) / Perfluorinated Compounds (PFCs)
Bisphenol A (BPA) and structural analogues	Phthalates (orthophthalates)
California-banned solvents	Polycyclic aromatic hydrocarbons (PAHs)
Chlorinated Polymers, including:	Short-chain and medium-chain chlorinated paraffins
• Chlorinated polyethylene (CPE) • Chlorinated polyvinyl chloride (CPVC) • Chloroprene (neoprene monomer) • Chlorosulfonated polyethylene (CSPE) • Polyvinylidene chloride (PVDC) • Polyvinyl chloride (PVC)	Toxic heavy metals: • Arsenic • Cadmium • Chromium • Lead (added) • Mercury
Chlorobenzenes	Polychlorinated biphenyls (PCBs)
Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs)	Wood Treatments containing creosote or pentachlorophenol
Formaldehyde (added)	

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Appendix H. List of Critical Raw Materials

Bauxite	Gallium
Antimony	Germanium
Arsenic	Hafnium
Baryte	Helium
Beryllium	Heavy rare earth elements
Bismuth	Light rare earth elements
Boron/Borate	Lithium
Cobalt	Magnesium
Coking Coal	Manganese
Copper	Natural Graphite
Feldspar	Nickel
Fluorspar	Niobium
Indium	Phosphate Rock
Phosphorus	Scandium
Silicon metal	Strontium
Tantalum	Titanium metal
Tungsten	Vanadium
Platinum group metals (PGMs)	Perfluorinated and Polyfluorinated Alkyl Substances (PFAS)
Platinum	Polymetallic nodules

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