CIRCULAR BUILDINGS

Guideline for creating Circular Material Passports

Financed by:

Iceland Liechtenstein Norway grants

Programme operator:

REPÚBLICA PORTUGUESA
AMBIENTE E AÇÃO CLIMÁTICA

Promotor:

SMART WASTE PORTUGAL
BUSINESS DEVELOPMENT NETWORK

Partners:

3drivers engenharia inovação ambiente

U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

Plataforma Tecnológica Portuguesa da Construção

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TECHNICAL INFORMATION

Title

Circular Buildings – Guideline for creating Circular Material Passports

Promotor

Associação Smart Waste Portugal

Partners

3drivers – Engenharia, Inovação e Ambiente, Lda.

Faculdade de Engenharia da Universidade do Porto

Plataforma Tecnológica Portuguesa da Construção

Edition

Final Version - September 2021

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PREAMBLE

A building materials passport is a tool to maximize reuse potential. The topic is fairly recent one, with varying approaches being adopted for their development. Unlike Environmental Product Declarations, there is no standardization for material passports, which prevents their wide use in the construction sector. The most well-known project that focused on this topic was BAMB2020 - Building As Material Banks, a European project concluded in 2019, which resulted in the creation of a public platform with circa 300 materials passports. However, this platform is no longer publicly available. There is, therefore, an evident need for clear and standardized orientations for the creation and implementation of materials passports, which this present guideline intends to address.

This guideline is an output of the Circular Buildings project, which is funded by EEA grants under the Environment, Climate Change and Low Carbon Economy Programme. The project seeks to increase the application of Circular Economy principles in the construction sector through the development of decision support tools directed at stakeholders in the value chain, which promote an increase in the reuse of materials and a reduction in the production of waste. Two additional guidelines were developed within the project, namely the “Guideline for improving efficiency indicators of buildings” and “Guideline for promoting circularity in Environmental Product Declarations”.

PREÂMBULO

Um passaporte de materiais de construção é uma ferramenta para maximizar o seu potencial de reutilização. Trata-se de um tema bastante recente, com diferentes abordagens a serem adotadas para o seu desenvolvimento. Ao contrário das Declarações Ambientais de Produto, não existe normalização para os passaportes de materiais, o que impede a sua ampla utilização no setor da construção. O projeto mais conhecido que se centrou neste tópico foi o BAMB2020 - *Building As Material Banks*, um projeto europeu concluído em 2019 que resultou na criação de uma plataforma pública com cerca de 300 passaportes de materiais. No entanto, esta plataforma já não se encontra disponível ao público. Existe, portanto, uma necessidade evidente de orientações claras e normalizadas para a criação e implementação de passaportes de materiais, à qual o presente guia pretende responder.

Este guia é um resultado do projeto Edifícios Circulares que é financiado pelo EEA Grants ao abrigo do Programa Ambiente, Alterações Climáticas e Economia de Baixo Carbono. O projeto procura aumentar a aplicação dos princípios da economia circular no sector da construção através do desenvolvimento de ferramentas de apoio à decisão dirigidas aos intervenientes na cadeia de valor, que promovem um aumento na reutilização de materiais e uma redução na produção de resíduos. Foram desenvolvidos dois guias adicionais no âmbito do projeto, nomeadamente o “Guia para a melhoria dos indicadores de eficiência dos edifícios" e a "Guia para a promoção da circularidade nas Declarações Ambientais de Produto".

1 BACKGROUND

The construction sector is a high-polluting and resource intensive industry, being responsible for about 50% of all extracted raw material and for over 35% of the EU's total waste generation. Additionally, the greenhouse gas emissions (GHG) arising from material extraction, manufacturing of construction products, construction and renovation of buildings are estimated at 5-12% of total GHG emissions (EC 2020a). Given these significant impacts, the European Commission has identified this to be a critical value chain in the transition towards a Circular Economy in the New Circular Economy Action Plan (EC 2020a).

This strategy was also followed in Portugal and materialized in the National Circular Economy Action Plan (República Portuguesa Ambiente 2017), where an agenda for the transition of the construction sector was proposed to increase its material efficiency and productivity, focusing on the stages of design, manufacturing, reuse and recycling.

In the EU Member States the stock build-up, i.e. investment in new buildings and infrastructures, is at a relatively steady level. Therefore, the focus should be placed on making the most of what already exists in the built environment—ultimately extending the functional lifetime of buildings through renovation rather than demolition (Circle Economy 2021).

In order to promote resource efficiency, minimize construction and demolition waste (CDW) production and promote the transition to a Circular Economy in the construction sector, it is essential to resort to reliable and standardized information on the material composition of the building stock and related products (EEA 2020).

This information can be obtained through digital tools, such as material passports (MP), which were identified by several entities, at the EU and national level, as a valuable solution to increase circularity in the construction sector (República Portuguesa Ambiente 2017; EC 2020b; EEA 2020; Circle Economy 2021).

Moreover, it is equally important to highlight the political agenda of the European Green Deal (EC 2019), particularly the EU Circular Economy Action Plan. One important measure is the revision of the Construction Product Regulation (European Parliament and the Council of the European Union 2011), which will address the sustainability performance of construction products by possibly introducing recycled content requirements. Furthermore, the 'Renovation Wave' initiative, announced in the Green Deal, aims to significantly improve energy efficiency in the EU building stock, namely through optimized life cycle performance and longer life expectancy of build assets.

Given this context, it can be expected that the new European strategic framework will incentivize the wide implementation of material passports in the construction sector.

2 GOAL AND SCOPE

2.1 DEFINITION OF CIRCULAR MATERIAL PASSPORT

Materials passports are a relatively recent area of research within the domain of circular construction. Several authors provide different definitions and scopes for this tool (Luscuere 2016b; EPEA and SundaHus i Linköping 2017; Munaro *et al.* 2019) . The present guideline provides the following definition:

> ***A Circular Material Passport is a digital set of data that provides information on the technical characteristics of a construction product and identifies its environmental impacts and its potential for recovery, reuse and recycling.***

A Circular Material Passport provides an identity for a certain product and assigns value to it, enabling the recovery of materials by providing information for maintenance, recovery, reuse and recycling.

Materials passports have recently been identified as a promising tool to support decision-making of stakeholders towards promoting circularity during the design, use, end-of-life and recovery of a building (Figure 1). This tool plays a particularly important role in the design stage of building**,** by positively influencing the innovation and design of construction materials and products that will be (re)used, recovered, and recycled.

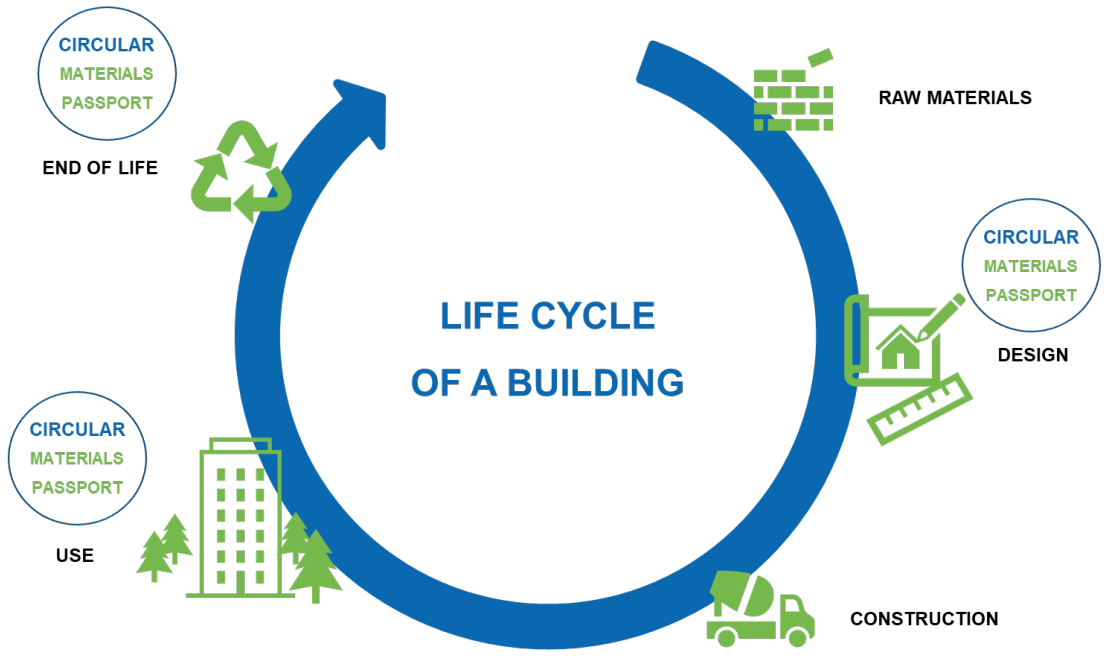

Figure 1: Application of the Circular Material Passport in the life cycle of a building

The Circular Material Passport intends to achieve the following objectives:

- Provide information about the technical characteristics of construction products;
- Promote traceability of the changes and uses of construction products during their life cycle;
- Describe how construction products are implemented in a building and how they are connected to it and to other products;
- Assess the recovery, reuse and recycling potential of construction products.

2.2 OBJECTIVE OF THE GUIDELINE

The European Commission developed the new Level(s) framework to encourage stakeholders to design and construct sustainable buildings by considering a building's life cycle and Circular Economy concept. This strategic tool is an assessment and reporting framework that provides a methodology for the holistic analysis of environmental sustainability of buildings using a set of indicators for office and residential buildings (Dodd *et al.* 2020).

The purpose of this guideline is to define the structure of a circular material passport and to provide a robust methodology for characterizing the circularity of construction products, thereby promoting this tool among the stakeholders in the construction sector. The circular material passport distinguishes itself from previous efforts to define material passports since it is aligned with the Level(s) framework.

This guideline aims to answer the following question:

What type of information is required to promote circularity in building design, management, and end-of-life to support decision-making in construction?

To address this question, the guideline aims to achieve the following specific objectives:

- Promote circularity in the construction sector, namely by highlighting the importance of information regarding resource use, service life extension, and end-of-life of buildings and their components;
- Develop a methodology that can support and promote recycling and reuse potential to reduce resource use and environmental impacts of buildings;
- Quantify and communicate the circularity potential of construction products as an added value for stakeholders in the sector;
- Promote the standardization of the tool and a level-playing field in the sector, focusing on providing a simple yet scientifically robust tool to be used by the different agents of the construction value chain.

2.3 TARGET AUDIENCE OF THIS GUIDELINE

The Circular Material Passport is mainly targeted at architects, engineers, real estate developers or building owners as they actively manage and decide the construction, maintenance, and demolition of buildings. However, this tool can also serve building users, facility managers and owners since it can provide them with insights into the existing building's value. This information also has the potential to support the transfer of information between the users and maintenance team on how to best use/maintain/repair or adapt the building and its systems and products.

3 STATE-OF-THE-ART

This section describes the literature review of material passports and defines the basis of knowledge and the background for work developed.

3.1 LITERATURE REVIEW

Benachio *et al.* (2020) reviewed the recent developments of how Circular Economy can be used inside the construction industry, focusing on six areas of research: development of Circular Economy, reuse of materials, material stocks, Circular Economy in the built environment, life cycle assessment (LCA) and material passports. The authors concluded that one area that required further development in the academia is the creation of Building Material Passports (BMP), having found just three works in that area (Sauter *et al.* 2018; Honic *et al.* 2019; Munaro *et al.* 2019) from which only two had the goal of creating a BMP. The need for more research on understanding the prerequisites and barriers existing in the process of creating a BMP from the academia was, therefore, identified.

According to several authors (Munaro *et al.* 2019; Honic *et al.* 2019; Luscuere 2016b) that worked in this area, a material passport is an active information tool that describes detailed characteristics of materials or systems embedded in the buildings' projects and it embraces the potential to give value from recovery and reuse.

Honic *et al.* (2019) created a BMP for a building with different variants to analyse its environmental impacts. They found that, in the studied case, concrete had a better recycling potential than timber. Munaro *et al.* (2019) also developed a BMP, but for the wood frame system in the Brazilian industry. These authors found that the lack of Environmental Product Declarations (EPD) and, consequently, reliable input data in the country hinders the creation of more BMPs, demonstrating the need for building material manufacturers to publish EPD for their products to create a reliable data source for BMPs.

Honic *et al.* (2019) state that the existence of a consolidated database of BMPs can help the evaluation and optimization of recycling potential and environmental impacts, which agrees with other areas of research that show the immense potential of using Circular Economy tools and practices earlier in the project to reduce the negative environmental impacts constructions can have. However, there are still problems in the process of creating BMPs, as Munaro *et al.* (2019) described a series of challenges in the political, commercial, and social areas that still need research and better collaboration between stakeholders to make this process more accessible and feasible.

The knowledge gap identified by Benachio *et al.* (2020), however, has been explored by the BAMB project, which is a key reference for BMP and described separately in the following section 3.1.1. The Madaster platform, another key reference, is described separately in section 3.1.2.

3.1.1 BAMB2020 Project

BAMB2020 - Building As Material Banks (2015-2019) was a project initiated in Europe with 15 partners from 7 different countries that established the goal of “enabling a systemic shift in the building sector by creating circular solutions”. The project focused mostly on BMPs and reversible building design, in which a project should consider all life cycle stages, ensuring high reuse and the transformation potential of the building.

The project produced several useful reports on material passports (EPEA and SundaHus i Linköping 2017; Heinrich and Lang 2019) and results that help the development and establishment of this practice in the construction industry.

According to BAMB2020, Materials Passports are *"[…] sets of data describing defined characteristics of materials in products that give them value for recovery and reuse"*. They shall increase the potential of materials, such as residual value, enable circular product design and provide a tool to transform the construction sector from a linear to a Circular Economy (BAMB 2020). Table 1 lists the parameters created for the creation of MP according to BAMB2020. The influence of diverse stakeholders on the type of information recorded in a passport is also highlighted, i.e., not all data entered in a MP is relevant to all actors in the construction sector.

Table 1: Parameters for creating BAMB Material Passports

Source: Adapted from Heinrich and Lang (2019), EPEA Nederland BV & SundaHus I Linköping AB (2017) and Boström (2017)

IDENTIFICATION	▪ Product name ▪ Manufacturer name ▪ Brand name	▪ Registration number and manufacturer's country ▪ Description of product function ▪ Description of product complexity
VALUE TO THE USER	▪ Product application ▪ Product reuse ▪ Disposal of construction waste and renovation ▪ Removal, relocation and reuse in the same building or reuse in other buildings ▪ Environmental product declaration (EPD)	▪ Product safety data sheet (PSDS) ▪ Product technical file (dimensions, thermal and acoustic qualifications, strength, transparency, among others) ▪ Energy classification ▪ Regulatory compliance certificates ▪ General database of construction products ▪ BIM object
POTENTIALS	▪ Description of the potential use	▪ Additional information on the characteristics of the product that contribute to its circularity

3.1.2 Madaster

Madaster is a commercial online platform developed by Madaster Services BV and Winvision BV, which registers the raw materials used in buildings, with the core objective of minimizing the disposal of construction and demolition waste through the production of material passports (MP) and other reference tools.

The Madaster MP provides a systemic overview of integrated data and its applications, such as the economic value of materials and the management of material circularity. Table 2 indicates the parameters for creating a MP according to Madaster.

Table 2: Madaster MP parameters

Source: Adapted from Druijff (2019)

GENERAL IDENTIFICATION	▪ Portfolio and owner name ▪ Building name ▪ Username ▪ Address ▪ Registration information - Designation - Surface area (m^2) - Lot number - Legislative restrictions ▪ Madaster information - Classification method (code) - Latest BIM information	- Building use - Gross surface area (m^2) Delivery and renewal date ▪ Labels - BREEAM® - GPR-score - LEED® - MPG score indicator ▪ Energy - Energy label - Energy performance coefficient - Energy index
DATA SOURCE	▪ Identification of active data sources	▪ Validation and explanation of data sources
BUILDING - MATERIALS	▪ Identification of the quantity and type of materials used in each layer category of buildings	
BUILDING - PRODUCT	▪ Identification of the quantity and type of products used in each layer category of buildings	
CIRCULARITY	▪ Madaster Circularity Indicator (MCI)	
ADDITIONAL DATA	▪ Disclaimer	▪ About Madaster

The entity developed the Madaster Circularity Indicator (MCI), which adapts a parameter originally developed by the Ellen MacArthur Foundation, aiming to improve the building design through the circularity of materials and, consequently, increase the circular value of buildings (Madaster 2018).

3.2 RISK ANALYSIS

Even though material passports have been identified as a valuable solution to promote circularity in buildings, it is a fairly recent tool and not widely used in the sector. In this context, the state-of-the-art analysis allowed to identify the main barriers associated with the development and use of material passports, which the present guideline aims to address.

This guideline focuses on the harmonization of the general passport parameters and the standardization of circularity parameters to ensure transparency, robustness, and acceptance of material passports amongst stakeholders of the sector. An overview of the identified barriers and the considered mitigation measures adopted in the present guideline are summarized in Table 3.

Table 3: Overview of current barriers in the development and use of material passports and proposed mitigation measures

NO.	BARRIERS	MITIGATION MEASURE PROPOSED IN THIS GUIDELINE
i	Lack of awareness and standardization	Well-structured guideline and simple instructions to generate a material passport
ii	Neglect of structural and insulation materials	Consideration of all types of materials from a building in the material passport
iii	Interoperability between different scales of passports	Possibility to sum up materials passports to obtain a building passport
iv	Misleading estimate of building and material lifetime	Consideration of typical service lives for building parts and elements provided by Level(S)
v	Data uncertainty	Consideration of different types of data resorting to the NativeLCA methodology
vi	Data input fatigue of the user	Strict set of non-redundant parameters
vii	Misinterpretation of data	All data input must be accompanied by an additional explanation by the user
viii	Material passports as mere inventories of raw materials	Inclusion of criteria for design for disassembly and waste scenarios for improved end-of-life treatment

Following a more detailed explanation of the identified current challenges and measures on how to overcome them:

i. Material passports are still a relatively new concept that is currently neither well-known, nor widespread amongst stakeholders of the building sector. However, there is a growing awareness of the Circular Economy concept that is mirrored, for example, in the new European Level(s) framework. The framework considers an indicator that measures “Design for deconstruction” and “Ease of recovery and recycling”, in which points are awarded for circularity. The recommended methodology for “Ease of recovery and recycling” was developed by the German Green Building Council’s DGNB scheme, however, there is no standardized methodology at the national or international level, or within the construction industry. This stands in contrast to, for example, Environmental Product Declarations (at international level ISO 14025 (ISO/TC 207/SC3 2006), at European level EN 15804 (CEN/TC 350 2019) and EN 15978 (CEN/TC 350 2011)), or the Product Environmental Footprint method from the European Union. This guideline addresses this issue by providing a methodology for the creation of circular materials passports and promoting the use of this tool amongst stakeholders of the construction sector, therefore, drawing attention to the need of creating a legal standard for this tool.

ii. In current research and practices of Circular Economy in the construction sector, the focus is mostly on moveable parts of the building, such as e.g., furniture, appliances, flooring etc. (Heisel and Rau-Oberhuber 2020). However, structural and insulating materials make up for the highest quantity of materials used in a building. Therefore, it is important to provide circularity measures for these types of materials as well. The current guideline integrates all building elements, including structural and insulating materials, for the analysis of the circularity and waste paths.

iii. Different scales have been proposed for creating passports of construction: they range from materials and products to the full building scale. This can lead to problems regarding interoperability because of differences in the data inventory. The proposed data structure for a MP in this guideline

has the advantage that it allows for data entries from all types of building layers and scales (including structure and insulation). Therefore, multiple MP can be summed up to provide joint information as a Building Material Passport.

iv. The lifetime of buildings and their components is a highly uncertain parameter that directly affects the circularity potential and moment of potential recovery, reuse, recycling of materials. However, much research is going on to improve the estimate of lifetimes. Moreover, different methods exist to counteract the uncertainty of the lifetime parameter. This includes the use of probability density functions, such as the Weibull or log-normal distribution, instead of a fixed parameter, or the analysis with ranges. However, this guideline recommends using the reference values proposed by the EU's Level(s) framework, since they do not require a mathematical understanding of the parameters of probability distributions.

v. Data uncertainty goes beyond the estimation of building lifetimes. When a material passport is based on incorrect data, it loses its validity or, in the worst case, provides misinformation that leads to a building design with a higher environmental impact. To mitigate this risk, the present guideline suggests following the NativeLCA methodology (Silvestre *et al.* 2015) and considering, whenever possible, specific primary data, then national average data, and only then generic data. In this way, the MP can achieve the highest possible robustness.

NativeLCA methodology is a methodology published by Silvestre, Lasvaux, Hodková, de Brito, & Pinheiro (2015) to optimize the use of available data when conducting a life cycle assessment (LCA) for construction products.
The methodology divides data between three types of datasets: 1) site-specific data, 2) average data, 3) generic data. More specifically this includes for 1) individual Environmental Product Declaration (EPD) or specific research studies; 2) individual average EPD by the producer or average joint EPD; 3) average LCA data sets (country specific or for Europe) or generic LCA datasets.
The methodology then provides guidelines for the selection of relevant datasets depending on the goal and scope of the study. For example, in general, specific primary data from industry is preferable. However, such data usually cannot be adapted to reflect a national context because of confidentiality issues, in which case generic data would be preferred.

vi. Data input fatigue due to the repeated input of the same type of data was identified by stakeholders as a limiting factor to adapt MP (EPEA and SundaHus i Linköping 2017) Therefore, the present guideline tries to consider this phenomenon in its definition of the circular MP: Instead of focusing on a MP that provides information regarding all aspects of the product, a structure is defined including a strict set of non-redundant parameters with the essential information to answer the objective defined in the present guide, namely promoting the circularity of construction products and materials.

vii. One of the challenges of creating a material passport involves the different ways of providing data. Particularly with diverse levels of detail and format, which raises questions about the accuracy of the information recorded in the passports and makes it difficult to implement or use material passports in the construction market (Luscuere 2016a). Therefore, this guideline recommends a clear definition of all parameters of the MP, namely their explanation, thus ensuring the robustness

and comparability of information. Moreover, this helps to ensure quality in future updates of the Circular Material Passport to reflect changes in the product use.

viii. A material passport should not merely be a list of raw materials: Much like in a cooking recipe, the list of ingredients needs further instructions on how to be mixed. For a MP this means additional information needs to be provided to enable the disassembly, sorting, and reversibility of materials at the end-of-life. Therefore, this guideline includes criteria for the design for disassembly and waste scenarios for ease of recovery, reuse and recycling.

4 CONTENT OF THE CIRCULAR MATERIAL PASSPORT

It is important that a Circular Material Passport (CMP) provides reliable and standardized information on building products and their components, cataloguing and disseminating their reproducible circularity characteristics.

This section describes the content of the proposed CMP. It focuses on the technical characteristics of the product, the contextual information regarding its use and location and its circularity potential. CMP has a lean structure, including a strict set of non-redundant parameters with the essential information to promote circularity in the built environment.

The proposed structured of the CMP is implemented in an MS Excel file, which is provided along with the present guideline.

4.1 A MATERIAL PASSPORT FOR ALL LIFE CYCLE STAGES

A CMP can be used to take stock of construction products at different life cycle (LC) stages of the building. The construction (LC stage A), use (LC stage B), and end-of-life (LC stage C) differ in regard to the material input and output and the according material cycle (for more information on the definition of LC modules please refer to “Circular Buildings – Best practice guide for promoting circularity in EPD”). The material input and output of the three life cycle stages of the building are visualized in Figure 2.

For the construction of a new building, a CMP provides information on new products to be installed in the building (i.e. material input for the building under study). The CMP also documents if the product was produced from virgin material or from recovered material from a different building (i.e. material output from a building outside the system boundaries). Moreover, a CMP can provide an estimate of how the product, in the far future, considering a long building lifespan, can be recovered, reused or recycled (i.e. material output from the building under study).

For the demolition of an existing building, a CMP can be used as an inventory of the material in stock. It provides information how, at this moment in time, the product can be recovered, reused or recycled (i.e. material output from the building under study). However, the data collection for a CMP from an existing building is not as accurate as for a new buildings, since there is no specific information available from the original manufacturer of the product.

For the renovation of an existing building, a CMP can provide information for all types of flows mentioned above: an old product needs to be removed from the building (i.e. material output from the building under study), a new product needs to be installed as a substitute for the old one (i.e. material input for the building under study), and the new product itself might be produced with recovered material from a different building (i.e. material output from a building outside the system boundaries). Please note that these processes refer to the LC stage B4 “replacement”. For LC stage B5 “refurbishment” where a new element, such as an external thermal insulation system is added to the building under study, there should only be a material input for the building and a possible material output from a building outside the system boundaries, if the refurbishment product is made with recovered material from another building.

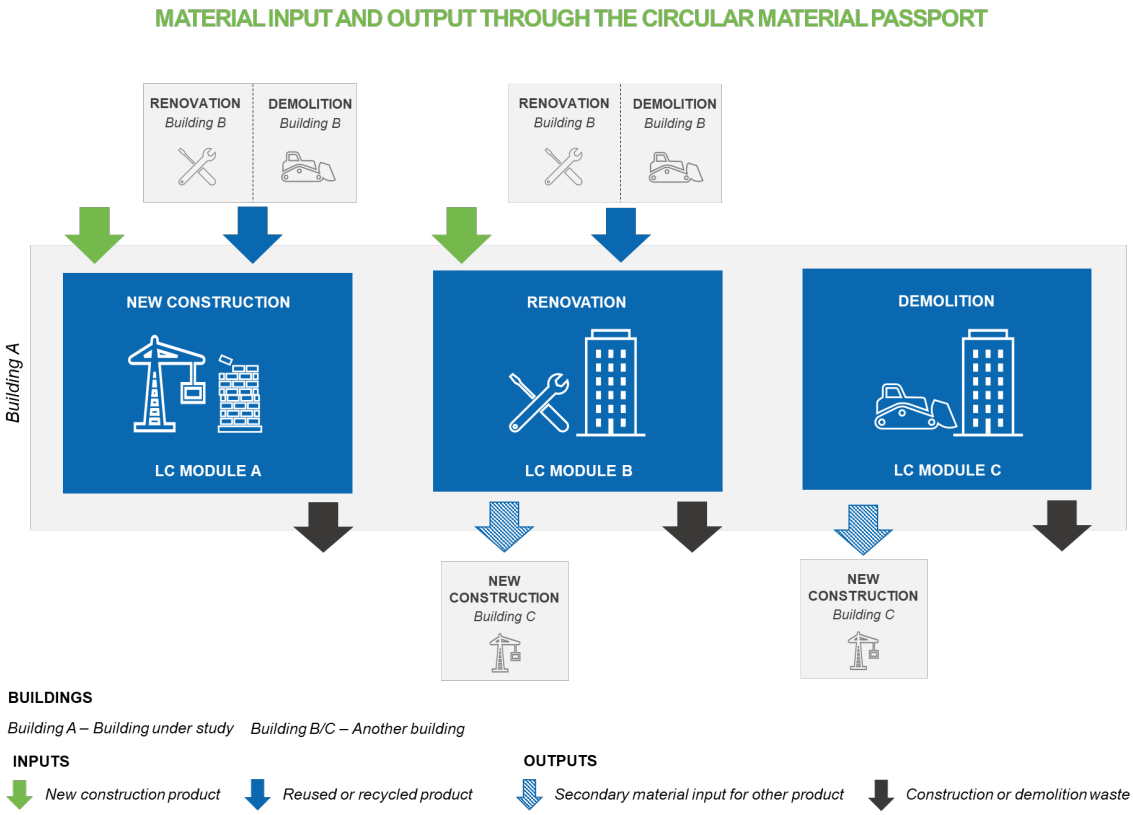

Figure 2: Material input and output at different life cycle stages of the building as captured in a CMP

4.2 GENERAL STRUCTURE

The general structure of the Circular Material Passport is divided into three aspects, as depicted in Figure 3. Each one is described in more detail in the following sections.

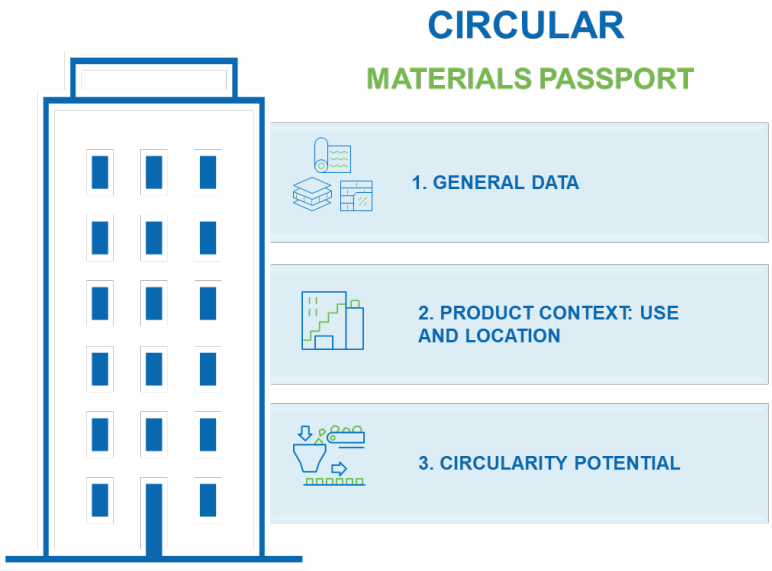

Figure 3: General structure of Circular Material Passport

Section 4.3 provides the general parameters specific to the construction product. Section 4.4 refers to the use and location of the material or product under study. Lastly, section 4.5 refers to the characterization of the product's potential circularity.

4.3 GENERAL DATA

The first section of the Circular Material Passport provides the general data of the product, focusing on its technical information. The data input fields of this component are described in Table 4.

Table 4: Input parameters of the first section of the Circular Material Passport – General data

PARAMETER	DESCRIPTION	TYPE OF PARAMETER
PASSPORT NUMBER	Provides a unique number attributed to the CMP	Automatic field
PRODUCT NAME	Identifies the name of the product	Open answer (text)
PRODUCT CATEGORY	Classifies the product into a particular category of building products	Closed answer (unique selection from list of categories)
FUNCTION	Describes the function(s) of the product	Open answer (text)
MANUFACTURER	Identifies the manufacturer of the product	Open answer (text)
DATA SOURCES	Identifies the data sources used to create the passport (e.g., manufacturer's specifications)	Closed answer (multi-selection from list of categories)

4.3.1 Additional information on Product Category

This parameter involves the selection of an option from a list of pre-defined categories as shown in Table 5. The categories specified in the Level(s) framework (Donatello *et al.* 2021) were considered to ensure a standard categorization of the construction products, aligned with recommendations at the EU level.

The classification of a construction product is performed through three tiers, as depicted in Table 5. The top tier must be defined as "shell", "core" or "external elements".

Table 5: Classification of different building elements and components into “shell”, “core” and “external element”

Source: Donatello *et al*. (2021)

TIER 1 BUILDING ASPECT	TIER 2 BUILDING ASPECT	TIER 3 BUILDING ASPECT
SHELL	Foundations (substructure)	(i) Piles; (ii) Basements; (iii) Retaining walls
	Loadbearing structural frame	(i) Frame (beams, columns and slabs); (ii) Upper floors; (iii) External walls; (iv) Balconies
	Non-load bearing elements	(i) Ground floor slab; (ii) Internal walls; (iii) Partitions and doors; (iv) Stairs and ramps
	Facades	(i) External wall systems; (ii) External wall systems (glazed); (iii) Cladding and shading devices; (iv) Façade openings (including windows and external doors); (v) External paints; (vi)External coatings and renders
	Roof	(i) Structure; (ii) Weatherproofing
	Parking facilities	(i) Above ground and underground (within the curtilage of the building and servicing the building occupiers)
CORE	Fittings and furnishings	(i) Sanitary fittings; (ii) Cupboards, wardrobes and worktops (where provided in residential property); (iii) Ceilings; (iv) Wall and ceiling finishes; (v) Wall and ceiling coating; (vi) Floor coverings and finishes; (vii) Floor coverings and coating; (viii) Skirting and trimming; (vii) Sockets and switches
	In-built lighting system	(i) Light fittings; (ii) Control systems and sensors
	Energy system	(i) Heating plant and distribution; (ii) Radiators; (iii) Cooling plant and distribution; (iii) Electricity generation; (iv) Electricity distribution
	Ventilation system	(i) Air handling units; (ii) Ductwork and distribution
	Sanitary systems	(i) Cold water distribution; (ii) Hot water distribution; (iii) Water treatment systems; (iv) Drainage system
	Other systems	(i) Lifts and escalators; (ii) Firefighting installations; (iii) Communication and security installations; (iv) Telecoms and data installations
EXTERNAL WORKS	Utilities	(i) Connections and diversions; (ii) Substations and equipment
	Landscaping	(i) Paving and other hard surfacing; (ii) Fencing, railings and walls; (iii)Drainage system

4.4 PRODUCT CONTEXT: USE AND LOCATION

The second section of the Circular Material Passport focuses on the existing products in a building. It provides information on their use and location to estimate the potential for reuse and recovery (Table 6).

Table 6: Input parameters of the second section of the Circular Material Passport – Product Context

PARAMETER	DESCRIPTION	TYPE OF PARAMETER
BUILDING IDENTIFICATION	Provides address and identification of type of building/infrastructure in which product is installed/implemented	Open answer (text)
INSTALLATION DATE	Indicates the year of installation of product	Closed answer (year)
LOCATION	Provides specific location of the product within the building (e.g., which floor, side of the building, etc.)	Open answer (text)
EXPECTED SERVICE LIFESPAN	Indicates the expected service lifespan of the product	Option selection: 1.closed answer (year) 2.use reference value provided in the passport (automatic field based on Product Category)
MAINTENANCE	Provides information on the best maintenance practices for the product with the aim to extend its service lifetime	Open answer (text)
EXPECTED END-OF-LIFE	Provides estimate of end-of-life time	Automatic field calculated in the passport with input values through the following formula: *Expected end of life = Installation date + Expected lifespan*

4.4.1 Additional information on Expected Service Lifespan

As indicated in the previous section, the Circular Material Passport will be aligned with the methodology and recommendations presented in the Level(s) framework, which includes typical service lifespans for Tier 2. In the absence of accurate and specific data, these references may be used (Table 7).

Table 7: Typical service lives for the minimum scope of building parts and elements

Source: Adapted from Donatello *et al*. (2021)

TIER 1 BUILDING ASPECT	TIER 2 BUILDING ASPECT	TIER 3 BUILDING ASPECT	EXPECTED LIFESPAN
SHELL	Loadbearing structural frame	- Frame (beams, columns and slabs) - Upper floors - External walls - Balconies	60 years
	Non-load bearing elements	- Ground floor slab - Internal walls - Partitions and doors - Stairs and ramps	30 years

TIER 1 BUILDING ASPECT	TIER 2 BUILDING ASPECT	TIER 3 BUILDING ASPECT	EXPECTED LIFESPAN
	Facades	- External wall systems	30 years (35 years glazed)
		- Cladding and shading devices	30 years (35 years glazed)
		- Façade openings (including windows and external doors)	30 years
		- External paints, coatings and renders	10 years (paint), 30 years (render)
	Roof	- Structure - Weatherproofing	30 years
	Parking facilities	Above ground and underground (within the curtilage of the building and servicing the building occupiers)	60 years
CORE	Fittings and furnishings	- Sanitary fittings	20 years
		- Cupboards, wardrobes and worktops (where provided in residential property)	10 years
		- Ceilings[1)]	30 years
		- Wall and ceiling finishes	20 years (finishes); 10 years (coating)
		- Floor coverings and finishes	30 years (finishes); 10 years (coatings)
		- Skirting and trimming	30 years
		- Sockets and switches	30 years
	In-built lighting system	- Light fittings - Control systems and sensors	15 years
	Energy system	- Heating plant and distribution	20 years
		- Radiators	30 years
		- Cooling plant and distribution	15 years
		- Electricity generation	15 years
		- Electricity distribution	30 years
	Ventilation system	- Air handling units	20 years
		- Ductwork and distribution	30 years
	Sanitary systems	- Cold water distribution - Hot water distribution - Water treatment systems	25 years

[1)] Estimated lifespan of the ceiling taken from Northern Territory Government (2017) and eTool Global (2015)

TIER 1 BUILDING ASPECT	TIER 2 BUILDING ASPECT	TIER 3 BUILDING ASPECT	EXPECTED LIFESPAN
		- Drainage system	
	Other systems	- Lifts and escalators	20 years
		- Firefighting installations	30 years
		- Communication and security installations	15 years
		- Telecoms and data installations	15 years
EXTERNAL WORKS	Utilities	- Connections and diversions - Substations and equipment	30 years
	Landscaping	- Paving and other hard surfacing	25 years
		- Fencing, railings and walls	20 years
		- Drainage system	30 years

4.5 CIRCULARITY POTENTIAL

The third section of the Circular Material Passport describes the product's potential for reuse, recovery and recycling (Table 8).

Table 8: Input parameters of the third section of the Circular Material Passport – Circularity potential

PARAMETER	DESCRIPTION	TYPE OF PARAMETER
DESIGN FOR DISASSEMBLY	Characterizes the design for disassembly of the product in terms of (1) type of connection, (2) type of connection accessibility, (3) type of crossings, and (4) type of form containment.	Closed answer (checking box)
DISASSEMBLY INSTRUCTIONS	Provides additional information for the material or product disassembly at the end-of-life for quality assurance	Open answer (text)
QUANTITY	Indicates the weight of the product or of its components	Closed answer (number)
MATERIAL COMPOSITION	Estimates the material composition of the product or of its components in terms of (1) concrete, brick (stone), tiles and ceramics; (2) structural wood or other bio-based; (3) glass; (4) plastic; (5) bituminous mixtures; (6) metal; (7) insulation materials; (8) gypsum; or (9) mixture.	Closed answer (percentage) for a list of categories Possibility to indicate additional categories
MATERIAL INPUTS SOURCES	Estimates the percentage of the material input sources of the product or of its components in terms of (1) reused, (2) recycled, (3) biomass, or (4) virgin material.	Closed answer (percentage)
WASTE SCENARIOS	Estimates the quantities of the product or of its components sent to different waste scenarios, namely (1) reuse, (2) recycling, (3) energy recovery, (4) backfilling or other, or (5) landfill.	Closed answer (percentage)

4.5.1 Additional information on design for disassembly

In this section, the potential design for disassembly is characterized considering aspects such as the product's accessible connections and joining methods . Based on Cottafava and Ritzen (2021), four criteria are being considered: (1) type of connection, (2) type of connection accessibility, (3) type of crossings, and (4) type of form containment. A scoring system allows to quantify the ability to recover the product and to assess its future use in another building project. The system rating is from 0 to 1 (or 0 to 100%), where 1 represents the best disassembly performance and 0 indicates the weakest performance (product disassembly is impossible). The score can be interpreted as follows:

- It is only possible to recover the product while significantly damaging adjacent building components and destroying the product, i.e. value less than or equal to 0,1;
- It is only possible to recover the product while significantly damaging adjacent building components and components of the product, i.e. value greater than 0,1 and less than or equal to 0,2;
- It is only possible to recover the product while damaging adjacent building components and/or components of the product, i.e. value greater than 0,2 and less than or equal to 0,6;
- It is possible to recover the product while minimally damaging adjacent building components and/or components of the product, i.e. value greater than 0,6 and less than or equal to 0,8;
- It is possible to recover the product without damaging neither adjacent building components nor components of the product, i.e. value greater than 0,8 and less than or equal to 1,0.

Based on the scoring of the four indicators, the potential design for disassembly can be evaluated. Table 9 shows the subcategories and weights for the criteria (1) type of connection. Different categories from the literature (Schwede and Störl 2016; DGNB 2020; Cottafava and Ritzen 2021) were compared and merged for a refined set of sub-criteria. For more information on this comparative analysis please refer to Appendix A. The result is a detailed list of categories of connections that allows a specific classification of construction products regarding their potential design for disassembly.

Table 9: Criteria "Type of connection"

1. TYPE OF CONNECTION	SUBCATEGORY	WEIGHT
Dry connection	Dry mechanical connection	1
	Click connection	1
	Velcro connection	1
	Magnetic connection	1
	Mortise	1
	Splicing	1
	Masonry	1
Connection with added element	Ferry connection	0.8
	Corner connections	0.8
	Screw connection	0.8
	Bolt and nut connection	0.8
Direct integral connection	Riveting	0.6
	Pin connection	0.6
	Nail connection	0.6
Soft chemical compound	Kit connection	0.2
	Foam connection	0.2
	Sealer	0.2

1. TYPE OF CONNECTION	SUBCATEGORY	WEIGHT
Hard chemical connection	Glue connection	0.1
	Pitch connection	0.1
	Weld connection	0.1
	Binder	0.1
	Cement bond	0.1
	Plastering	0.1
	Concrete pouring	0.1
	Chemical anchors	0.1
	Hard chemical connection	0.1

The three remaining criteria (2) type of connection accessibility, (3) type of crossings, and (4) type of form containment can be seen respectively in Table 10, Table 11 and Table 12.

Table 10: Criteria “Connection accessibility”

2. TYPE OF CONNECTION ACCESSIBILITY	WEIGHT
Freely accessible	1
Accessibility with additional actions that do not cause damage	0.8
Accessibility with additional actions with reparable damage	0.4
Not accessible irreparable damage to objects	0.1

Table 11: Criteria “Crossings”

3. TYPE OF CROSSINGS	WEIGHT
Modular zoning of objects	1
Crossings between one or more objects	0.4
Full integration of objects	0.1

Table 12: Criteria “Form containment”

4. TYPE OF FORM CONTAINMENT	WEIGHT
Open, no inclusions	1
Overlaps on one side	0.8
Closed on one side	0.2
Closed on several sides	0.1

4.5.2 Additional information on material composition

This section lists (an estimate) of the product’s material composition in percentage. To ensure a standardized inventory, a set of material types is provided. This set was adapted from the list of material types used in the Bill of Quantities in Level(s) to include all relevant types:

- (1) Concrete, brick (stone), tiles and ceramics; (2) Structural wood or other bio-based; (3) Glass; (4) Plastic; (5) Bituminous mixtures; (6) Metal; (7) Insulation materials; (8) Gypsum; (9) Mixture.

The material composition section in the CMP is linked to the performance score, which is calculated in the design for disassembly section. The smaller the disassembly performance score, the less likely it is to know the material composition at the product component level. In this case, it is important to estimate the material composition at the total product level. The total sum of the materials must amount to 100%.

4.5.3 Additional information on material input sources

There are four types of sources for the materials used in the product, which are provided in a pre-defined list in the passport:

- (1) % Reused; (2) % Recycled; (3) % Biomass; (4) % Virgin.

The definition of this parameter is only relevant for new building products, where the user is most likely to have information regarding the source of its materials. The total sum of the percentages of these four categories must amount to 100%.

4.5.4 Additional information on waste scenarios

In this section, the most likely waste scenario for the product or its components is selected from a list of operations (Figure 4):

- (1) Reuse, (2) Recycling, (3) Energy recovery, (4) Backfilling or other, (5) Landfill.

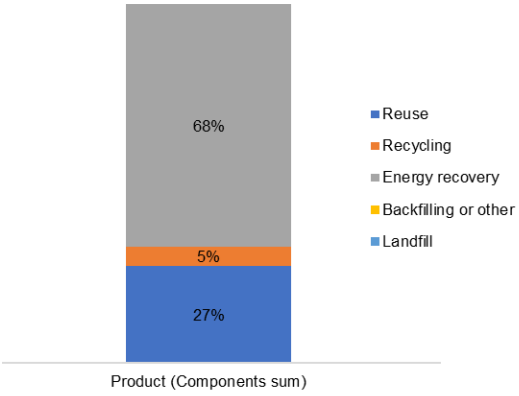

Figure 4: Example of a representation of the end-of-life scenario for a construction product

In the previous parameters, it was determined whether the waste scenario analysis should be performed at the product level (in case it cannot be separated into components) or at the component level.

The waste scenarios (1), (2), (3), (4) and (5) can therefore refer to the product level, if the whole product is being treated under the same respective scenario, or these scenarios can refer to the component level if different components of the product are treated under different waste scenarios. To give an example: a window is a product that consists of different components. Assuming that there are two main components: a PVC frame including a handle, and a double-glazing glass, each of these materials could be treated under

different end-of-life scenarios. Therefore, it is important to quantify the components and to assign a scenario for each of them, if not, one scenario for the whole window needs to be defined.

4.6 DATA SOURCES

This section identifies sources of standardized and reliable data for the creation of a CMP, which are required to accurately determine the circularity potential of construction products. The type, source and amount of data used in the making of a CMP define its validity and accuracy. A CMP resorts to two types of data, which are summarized in Figure 5.

Firstly, it is necessary to include specific characteristics of the material or product under study (functional unit including size, density, mechanical properties, etc.). This information should be primary data, meaning it should be sourced directly from the manufacturer, being characteristic of each product. Such information needs to either be collected manually from the manufacturer, or from an Environmental Product Declaration, in case it exists.

Secondly, informed assumptions that directly influence the circularity potential of the material or product are required. This includes the expected lifetime of the building and the product (in case the two diverge), the estimated ease of recovery, reuse, and recycling. This information underlies a subjective and project-specific analysis that should be well documented to ensure the transparency and robustness of the MP.

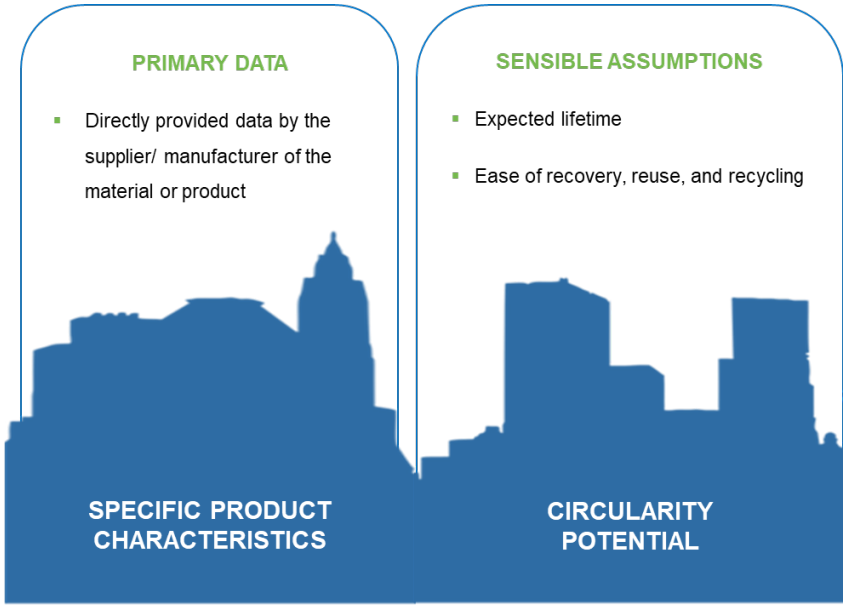

Figure 5: Data sources used for the creation of a MP

It needs to be noted that information provided directly by the manufacturer, e.g. regarding the material composition or mix design, production processes, or product functioning, can be sensitive information. If so, this information needs to be kept confidential and not be shared with the general public.

5 VERIFICATION AND VALIDITY OF CIRCULAR MATERIAL PASSPORTS

The lack of standardization and regulation will result in uncertainty regarding data quality in the material passports. A critical review process of the created Circular Material Passports is, therefore, required to ensure that:

- The methods used are consistent with the present guideline;
- The methods used are scientifically and technically valid;
- The data used is appropriate and reasonable;
- The result is transparent and consistent.

The critical review processes may be carried out by independent external experts in the sector or by a panel of interested parties.

6 IMPLEMENTATION AND FUTURE OUTLOOK

The present document is a guideline for the creation of CMP. This document is the first step towards promoting the use of this tool in a standardized manner in the construction sector. However, for a large scale use of this tool and for ensuring a level-playing field, regulations must be put in place by the competent authorities or through voluntary schemes by significant business associations, such as the European Construction Technology Platform (ECTP).

As indicated in previous sections, a set of CMP for products can be adapted to constitute a Building Materials Passport. The indicators provided by these Building Material Passports could have the potential to be used for public procurement, as well as to define building permit criteria and assessment.

Possible future strategic options for material passports include their integration with Building Information Modelling (BIM) and as a support tool for pre-demolition audits for identifying reusable and recyclable construction products and materials. The importance of policy development for the promotion of a standardized and regulated use of this tool needs to be highlighted.

TERMS AND DEFINITIONS

TERM	SOURCE	DEFINITION
BUILDING COMPONENT	Donatello *et al.* (2021)	A construction product manufactured as a distinct unit to serve a specific function or functions
CIRCULAR ECONOMY	Ellen MacArthur Foundation (2015a, 2015b)	Global economic model that decouples economic growth and development from the consumption of finite resources
CONSTRUCTION AND DEMOLITION WASTE	Directive 2008/98/EC (European Parliament and the Council of the European Union 2008)	Waste generated by construction and demolition activities
DEMOLITION	Donatello *et al.* (2021)	Removal by destructive methods
DISASSEMBLY	Dodd *et al*. (2021a)	The non-destructive taking-apart of a construction works or constructed asset into constituent materials or components
MAINTENANCE	Dodd *et al.* (2021b)	Combination of all technical and associated administrative actions during the service life to retain a building or an assembled system in a state in which it can perform its required functions
RECOVERY	Directive 2008/98/EC (European Parliament and the Council of the European Union 2008)	Any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. Annex II sets out a non-exhaustive list of recovery operations
RECYCLING	Directive 2008/98/EC (European Parliament and the Council of the European Union 2008)	Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations
RENOVATION	Donatello *et al.* (2021)	Work that involves the structural alteration of buildings, the substantial replacement of main services or finishes and/or substantial changed used of floor space whilst at the same time including associated redecoration and repair works on the one hand and related to the new building on the other
REUSE	Directive 2008/98/EC (European Parliament and the Council of the European Union 2008)	Any operation by which products or components that are not waste are used again for the same purpose for which they were conceived
SERVICE LIFE	Ellen MacArthur Foundation (2015a, 2015b)	Period of time after installation during which a building or an assembled system meets or exceeds the technical requirements and functional requirements
WASTE	Directive 2008/98/EC (European Parliament and the Council of the European Union 2008)	any substance or object which the holder discards or intends or is required to discard

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APPENDIX A – COMPARISON OF "TYPE OF CONNECTION" CRITERIA

The compared criteria shown below are taken from Cottafava and Ritzen (2021), the German Green Building Council's (DGNB) methodology for calculating criterion TEC1.6 "ease of recovery and recycling. Documentation" that is recommended by Level(s) for the indicator 2.4 "design for deconstruction", and from Schwede and Störl (2016). The colour coding used in the tables identifies similar criteria across the three references.

Schwede and Störl (2016)
Type
Mechanical joinery
Bolted connection
Screwed connection
Nailed connection
Binders
Sealer
Glue
Welding

DGNB TEC 1.6 (Level(s) indicator 2.4)	
Type	*Score*
Glued	Quality L1
Riveting	QL1
Welding	QL1
Plastering	QL1
Screwed	QL2
Nailing	QL2
Mortise	QL2
Splicing	QL2
Pin connection	QL2
Masonry	QL2
Concrete pouring	QL1

Cottafava and Ritzen (2021)		
Type	*Score*	
Dry connection	1	Dry connection
Click connection	1	
Velcro connection	1	
Magnetic connection	1	
Ferry connection	0.8	Connection with added element
Corner connections	0.8	
Screw connection	0.8	
Bolt and nut connection	0.8	
Pin connection	0.6	Direct integral connection
Nail connection	0.6	
Kit connection	0.2	Soft chemical compound

Foam connection	0.2	
Glue connection	0.1	Hard chemical connection
Pitch connection	0.1	
Weld connection	0.1	
Cement bond	0.1	
Chemical anchors	0.1	
Hard chemical connection	0.1	

The comparison leads to an adapted and synthesized set of criteria, which can be seen in the table below. This criteria set is proposed in this guide to provide additional information on the type of connection (as explained in section 4.5.1).

Type	**Redefined for this guide MP**	
Dry connection	Dry connection	1
Click connection		
Mortise		
Splicing		
Masonry		
Ferry connection	Connection with added element	0.8
Bolt and nut connection		
Screw connection		
Screwed		
Riveting	Direct integral	0.6
Pin connection		
Nail connection		
Nailing		
Pin connection		
Kit connection	Soft chemical compound	0.2
Foam connection		
Glue connection	Hard chemical compound	0.1
Glued		
Weld connection		
Welding		
Cement bond		
Plastering		
Concrete pouring		

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Iceland
Liechtenstein
Norway grants

CIRCULAR BUILDINGS