CIRCULAR BUILDINGS

Guideline for promoting circularity in Environmental Product Declarations

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Partners:

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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 promoting circularity in Environmental Product Declarations

Promotor

Associação Smart Waste Portugal

Partners

3drivers – Engenharia, Inovação e Ambiente, Lda.

Faculdade de Engenharia da Universidade do Porto

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PREAMBLE

The building sector accounted for 36% of final energy use and 39% of energy and process-related carbon dioxide emissions in 2018, 11% of which resulted from manufacturing building materials and products such as steel, cement and glass (IEA and UNEP 2020).

To assess the environmental impacts of the sector, standardized tools such as Environmental Product Declarations (EPD) are important, mainly at a product level. EPD were developed to improve the environmental performance of products and to allow the transparent comparison between them. An EPD is a standardized document for business-to-business communication of the environmental performance of a product throughout its life cycle.

This guideline provides an overview of the aim and scope of EPD for construction products, and it includes recommendations for integrating circularity measures in EPD in order to enhance the recovery, reuse and recycling of construction products, thereby reducing the associated environmental impacts.

This guideline is divided into two parts pertaining to different stakeholders: the first part is directed at manufacturers of building products and their consumers and provides more general background knowledge of EPD; the second part is directed at LCA practitioners who already have a working knowledge of EPD. Therefore, the second part includes a technical description of important topics in EPD regarding the promotion of circular construction.

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 creating Circular Materials Passports”.

PREÂMBULO

O setor da construção representou 36% da utilização final de energia e 39% das emissões de dióxido de carbono relacionadas com a energia e processos em 2018, 11% das quais resultaram do fabrico de materiais de construção e produtos como o aço, o cimento e o vidro (IEA and UNEP 2020).

Para avaliar os impactes ambientais do sector, ferramentas normalizadas como as Declarações Ambientais de Produto (DAP) são importantes, principalmente ao nível do produto. As DAP foram desenvolvidas para melhorar o desempenho ambiental de produtos e permitir uma comparação transparente entre os mesmos. Uma DAP é um documento normalizado para a comunicação *business-to-business* do desempenho ambiental de um produto ao longo do seu ciclo de vida.

Este guia fornece uma visão geral do objetivo e âmbito das DAP para produtos de construção e inclui recomendações para integrar medidas de circularidade nas DAP a fim de melhorar a recuperação, reutilização e reciclagem dos produtos de construção, reduzindo assim os impactes ambientais associados.

Este guia está dividido em duas partes referentes a diferentes intervenientes: a primeira parte é dirigida aos fabricantes de produtos de construção e aos seus consumidores e fornece um conhecimento mais geral das DAP; a segunda parte é dirigida aos profissionais de ACV que têm já um conhecimento operacional das DAP. Por conseguinte, a segunda parte inclui uma descrição técnica de tópicos importantes nas DAP relativamente à promoção da construção circular.

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 o "Guia para a criação de Passaportes de Materiais Circulares".

1 INTRODUCTION

1.1 CONTEXT

The construction sector has been repeatedly identified as a key sector to mitigate climate change. Commonly, the operational phase of buildings represents the highest contribution to a building's Life Cycle (LC) impacts (Azari and Abbasabadi 2018). The required energy, for heating, cooling, ventilation and domestic hot water, is usually summed up over the estimated building lifetime and expressed in energy or carbon. However, embodied impacts, which are the impacts related to the extraction and processing of raw materials and the manufacturing of a building product, are becoming increasingly important. This is because modern buildings are more energy efficient, thanks to an improved thermal performance of the building envelope. Energy-related impacts are also reducing, thanks to an increased share of renewable energy sources (Röck *et al.* 2020). This means the focus is no longer merely on energy and carbon but on required resources. Until now the construction sector underlies a linear model of "take, make, waste", meaning materials and products are intended for one time use only (Benachio *et al.* 2020). Over the last years, a paradigm shift has been taking place in order to adapt and apply the circular economy concept to the building sector, which could potentially lead to a reduced amount of required virgin materials and waste produced at the end-of-life of a building. However, while the potential of implementing closed loop strategies in the construction sector has been recognized across stakeholders, legal standards are still mostly missing on this topic. The creation and implementation of such standards is crucial for the promotion of the circular economy concept since they would provide guidance and enable a transparent and rigorous quantification of the recovery, reuse and recycling potential of materials.

Life Cycle Assessment (LCA) is a common quantitative method across sectors to analyze the environmental impacts related to the production, use and disposal of products or services. The following four steps are part of a standardized LCA: goal and scope definition; inventory analysis; impact assessment; and interpretation. LCA follows a modular approach, meaning that LC stages are divided as follows: A1-A3 Product stage; A4-A5 Construction process; B1-B7 Use; C1-C4 End of Life (EoL); and D Benefits and loads beyond the system boundary. A complete overview of LC stages can be seen in Figure 1.

Figure 1: Life cycle stages in line with EN 15804
Source: Adapted from EN 15804

The method is standardized internationally through ISO 14040 for the principles and framework of LCA (ISO/TC 207/SC5 2006a), and through ISO 14044 for LCA requirements and guidelines (ISO/TC 207/SC5 2006b). Specifically for construction, several standards were developed by the Technical Committee (TC) 350 of the European Committee for Standardization (CEN) (TC350/CEN). In addition, Type III environmental declarations, also known as Environmental Product Declarations (EPD), have been standardized. A core set of Product Category Rules (PCR) for developing EPD of construction products are standardized at the European level through EN 15804 “Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products” (CEN/TC 350 2019). Moreover, EN 15978 standardizes “Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method” (CEN/TC 350 2011b). These two standards follow the modular approach of LCA. An amendment to EN 15804 was released in October 2019. The aim of the A2 amendment is to align EN 15804 with the European Commission’s Product Environmental Footprint (PEF) method. Before the amendment’s release, only an accounting of the product module (LC stages A1-A3) was mandatory. Starting from July 2022, A2 will make it mandatory to also declare the EoL module (C1-C4) and the benefits and loads beyond the system boundary (D). All mandatory LC stages according to EN 15804 are shown, in green, in Figure 1, whereas non-mandatory stages are shown in grey.

Module D is used to estimate the reuse, recovery and recycling potential of a product, which is crucial to achieve a circular construction sector. Yet, calculating the benefits of module D is a complex procedure since it involves scenario analysis and requires making informed assumptions. The approach for end-of-life calculations in the revised standard EN 15804 is based on the PEF EoL formula that follows a 50:50 approach to allocate the benefits and loads equally between supplier and user of waste.

1.2 OBJECTIVES

The overarching objective of this document is to promote circular construction through an improved understanding of EPD and their integral opportunities to quantify and qualify circularity measures. The document is targeted at two different groups of interested stakeholders, with a varying level of EPD knowledge and interest:

- **Group i)** – includes the **manufacturers of building products and the consumers** of their products. Overall, this group has a more limited knowledge of EPD. Therefore, the part of the guideline that is directed at group i) aims at providing more general background information on EPD, thus raising awareness of and interest in EPD, which is the basis to consequently promote circular construction through this tool.
- **Group ii)** – refers to **LCA and sustainability practitioners** who are responsible for the execution of the environmental analysis and interpretation of results that are presented in EPD. This group has a high technical knowledge of EPD, thus the part of the guideline that is directed at group ii) aims to clarify methodological difficulties related to the integration of the end-of-life phase in EPD.

2 GUIDELINES FOR PRODUCT MANUFACTURERS AND THEIR CLIENTS

2.1 DEFINITION

An Environmental Product Declaration (EPD), is a type III environmental declaration that includes information on the environmental impacts of products (ISO/TC 207/SC3 2006). An EPD declares impact categories such as global warming potential, ozone depletion potential, acidification of land and water, eutrophication, and several other important categories that influence our lives and the environmental quality of our planet.

The format of an EPD is standardized to ensure transparent and comparable information. It is intended for business to business (B2B) communication of LCA information of materials and products. An EPD needs to get verified by an independent third party, before it can be registered in an EPD programme, having a particular validity date defined.

There are numerous national EPD programs. An overview of available online EPD databases that are relevant for Europe can be seen in Appendix A. In Portugal, the national EPD program operator is called DAP Habitat, which has published 14 EPD up until August 2021 (for an overview please see Appendix B). So far, only one of the Portuguese EPD provides information for the EoL stage (DAP 001:2021). The Portuguese Product Category Rules, short "PCR", for construction products and services ("*Produtos e Serviços de Construção*"), which are required to ensure the production of high-quality EPD, are defined on behalf of DAP Habitat by Silvestre, Arroja and Almeida (DAP Habitat 2020). These standardized rules define how to collect and report the relevant information for the construction product category.

2.2 GENERATION OF AN EPD

The process of generating an EPD can be divided in multiple steps, each with a different entity responsible for it. An overview of this process, from data collection to published EPD, can be seen in Figure 2. The product manufacturer is responsible for collecting the necessary data. Usually, an external LCA practitioner who is hired for this purpose, specifies which data is needed and how it should be collected and organized. The LCA practitioner is also responsible for conducting the actual LCA, ensuring its compliance with the PCR, which includes the life cycle inventory, environmental impact assessment and the interpretation of the results of different impact categories. After the LCA is concluded, the manufacturer is responsible for the formulation of the textual data of the background report. Then, all the collected information, organized in accordance with the legal standards, is sent to a third party for verification. This third party should be an independent expert from the field. After the verification, the EPD gets published and included in the list of available EPD of the chosen EPD operator.

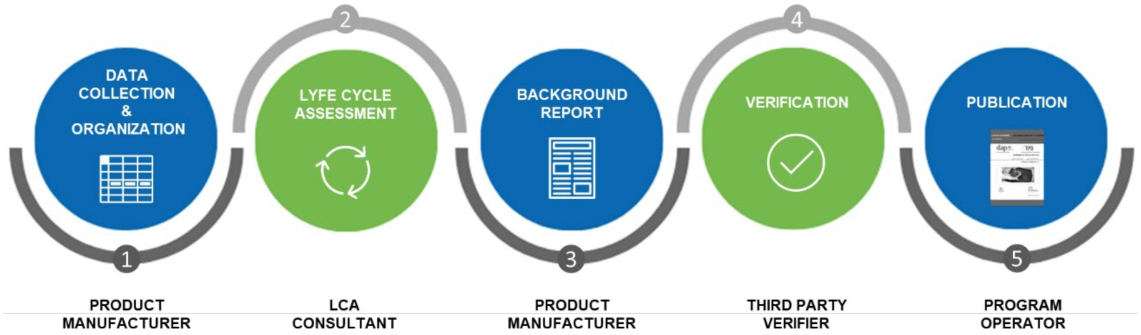

Figure 2: Step-by-step process certification for generating an EPD
Source: Adapted from OneClick LCA, 2021[1]

Currently fully automated EPD tools do not exist. This means that generating an EPD is a time consuming and cost intense process. However, commercial LCA software, such as SimaPro (PRé Consultants 2021) or Gabi (Sphera 2021), can simplify the process through their integrated databases and user interface. Moreover, commercial tools, like the OneClick LCA (Bionova) software, allow for a partially automated generation of EPD.

2.3 ADVANTAGES OF AN EPD

There are several reasons for manufacturers to get their product certified through an EPD, and for consumers to buy EPD-certified products:

- An EPD is a **comprehensive and standardized document** that includes all relevant environmental information of a product;
- Through the subdivision of LCA results into LC stages, the impacts of the product can be easily understood globally and per LC stage. In this way, it can help to **uncover improvement potential** in terms of environmental impacts, supply chain, and production costs, in any of the reported LC stages.
- Environmental sustainability is on the political agenda of Portugal and the European Commission. It is, therefore, important to produce and use environmentally-sound products. Having an EPD quantifies the environmental impact, hence **increasing the recognition** of the product among business clients and end users.
- Moreover, through an EPD, potential **environmental benefits** in terms of energy efficiency, selection of regenerative materials, or low-impact materials, can be quantified. It includes quantitative measures that **allow comparison** between similar products. However, it should be noted that an EPD must not state environmental superiority for a specific product.

[1] https://www.oneclicklca.com/simple-epd-guide/?utm_campaign=WEU%202020%20CAM%20EPD&utm_medium=cpc&utm_source=google&gclid=Cj0KCQjwi7yCBhDJARIsAMWFScPAfA1FYLDyIQJdYKoLic-kYe43Ihp_xgo1yk1xsaE1YnXCMjJ91MwaAhQ_EALw_wcB

2.4 GENERAL STRUCTURE OF AN EPD

The generic structure of an EPD is as follows:

1) Voluntary **cover page** including the name, image, date, EPD registration number etc. of the product;
2) **Program-related information** with a reference to the EPD system and a reference to the relevant PCR document upon which the EPD is based, date of publication and validity, geographical scope, further information such as relevant websites;
3) **Product-related information** about the product's name, manufacturer, description of its indented use and functional characteristics, statement of the functional (or declared unit);
4) **Content declaration** is a list of materials and chemical substances and summarized information regarding their environmental and hazardous properties (depending on the type of product, e.g. it is not appropriate for patented products);
5) **Environmental performance-related information** is the EPD's core that includes information about the use of resources and presents LCA-based environmental impacts, waste production and other environmental indicators, divided into different life cycle stages and given per functional (or declared) unit. EN 15804:2012 + A2:2019 makes the reporting of LC stages A1-A3, C and D, mandatory;
6) **Additional information** is not derived from the LCA-based calculation and can include various issues.

2.5 CIRCULARITY POTENTIAL IN EPD

Circularity, as referred to in circular economy or circular construction, describes the goal of closing material cycles by reusing, recycling and recovering materials. In LCA and EPD, module D includes the net benefits of secondary material, secondary fuel or recovered energy leaving the studied product system. In this way, module D identifies the "design for reuse, recycling and recovery" potential of construction by designating the potential benefits of avoided future use of primary materials and fuels while considering the loads associated with the recycling and recovery processes beyond the system boundary. Thus, the reporting of Module D has the potential to promote circular construction.

Moreover, the additional information section in EPD allows the creator of the EPD to include instructions that can help to recover, reuse, or recycle the product at its end-of-life.

2.6 IMPORTANT TERMS AND DEFINITIONS

This section presents a list of important terms and their definitions, related to the topic of circularity in buildings:

- **Allocation** –process that divides the input and/or output flows of a process to the product system under study in LCA. More specifically, according to ISO 14041 "*Where physical relationship (i.e. kg, m^2, m^3, etc.) cannot be established or used as the basis for allocation, the inputs should be allocated between the products and the functions in a way which reflects other relationships between them. For example, environmental input and output data might be allocated between co-products in proportion to the economic value of the products*";

- **Circular economy** – industrial model that aims at designing out waste, keeping products and materials in use during various use cycles, and regenerating natural systems;

- **Cut-off rules** – rules that define how much of the real system needs to be included in the LCA system model. Cut-off criteria describe which life cycle stages, activity types, specific processes and products and elementary flows are not relevant and therefore can be omitted from the LCA;

- **Declared unit** – used instead of a functional unit when only some of the LC phases are analysed instead of the whole LC, and/or when the exact product's function within the building is unknown;

- **EoL – End-of-life** phase in LCA refers to the modules C1 "Decommissioning/ Demolition", C2 "Transport to waste processing", C3 "Waste processing for reuse, recovery and recycling", C4 "Disposal";

- **End of waste** – state in which waste reaches the functional equivalence to replace primary material or fuel input in another product system and is, therefore, no longer considered waste. The associated benefits are beyond the system boundary and can be declared in module D;

- **Functional unit** – defined measure of the function of the studied product that allows comparison with other products in a fair way. It usually consists of a function, a quantity, a duration and a quality. See difference to declared unit;

- **GHG – Greenhouse gas** emissions trap heat in the atmosphere. Anthropogenic activities have been the cause for increased release of GHG emissions since the industrial revolution, which leads to an increase in global temperature. The most important ones, which are caused by the construction industry, are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O);

- **LCA – Life cycle assessment** is an ISO standardized methodology for the calculation of environmental impacts along the whole life cycle of a product from the extraction of raw material to the production or manufacturing of a product, its use stage, and its end-of-life;

- **LCI – Life cycle inventory** is the standardized second step of LCA. It refers to an inventory of input and output flows of a product system. The input flows include water, energy, and raw material, as well as emissions to land, air and water;

- **PCR – Product category rules** are necessary to define specific rules for products serving the same function and therefore allow making EPD comparable;

- **PEF – Product environmental footprint** is a methodology that is harmonized by the European Commission and intended for the calculation of the environmental footprint of products across sectors, including the construction sector. It incorporates life cycle thinking.

3 GUIDELINES FOR LCA PRACTICIONERS

3.1 NORMATIVE REFERENCES

The most important normative references for LCA are as follows:

- ISO 14040:2006 “Environmental management - Life cycle assessment - Principles and framework” (ISO/TC 207/SC5 2006a);
- ISO 14041:1998 “Environmental management - Life cycle assessment - Goal and scope definition and inventory analysis” (ISO/TC 207/SC5 1998);
- ISO 14044:2006 “Environmental management - Life cycle assessment - Requirements and guidelines” (ISO/TC 207/SC5 2006b).

The most important normative references for environmental declarations are as follows:

- ISO 14020 “Environmental labels and declarations. General principles” (ISO/TC 207/SC3 2000);
- ISO 14021 “Environmental labels and declarations – Self-declared environmental claims (Type II environmental labelling)” (ISO/TC 207/SC3 2016);
- ISO 14024 “Environmental labels and declarations. Environmental Labelling Type I. Principles and procedures” (ISO/TC 207/SC3 2018);
- ISO 14025 “Environmental labels and declarations – Type III environmental declarations – Principles and procedures” (ISO/TC 207/SC3 2006).

The most important normative references for EPD of construction products are as follows:

- ISO 21930 “Sustainability in building construction - Core rules for environmental declarations of construction products and services” (ISO/TC 59 2017);
- EN 15804:2012 + A2:2019 “Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products” (CEN/TC 350 2019);
- EN 15942:2011 “Sustainability of construction works – Environmental product declarations – communication format business-to-business” (CEN/TC 350 2011a);
- EN 15978:2011 “Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method” (CEN/TC 350 2011b).

Other important normative references and technical reports that are related to this guideline are:

- CEN/TR 16970:2016 “Sustainability of construction works – Guidance for the implementation of EN 15804” (CEN 2016)
- EN 16449:2014 “Wood and wood-based products – Calculation of the biogenic carbon content of wood and conversion to carbon dioxide” (CEN/TC 175 2014).

A hierarchy of the most important EPD standards can be seen in Figure 3.

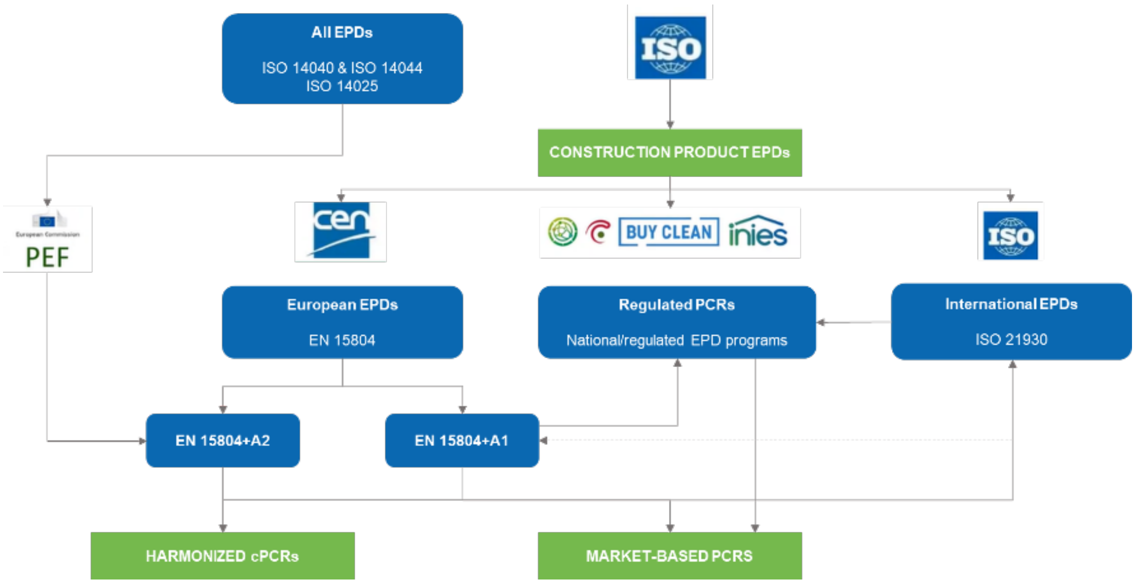

Figure 3: Hierarchy of standards and their importance EPD.
Source: Adapted from OneClickLCA, 2020

3.2 PROMOTING CIRCULARITY THROUGH THE CORRECT CALCULATION OF MODULES C AND D

3.2.1 End of Life scenarios

The definition of an End of Life (EoL) scenario determines if and how emissions are modelled. The EoL scenario of a product is usually intertwined with the possible waste treatments of the materials it consists of. According to EN 15804 "*A scenario shall be realistic and representative of one of the most probable alternatives […]. Scenarios shall not include processes or procedures that are not in current use, or which have not been demonstrated to be practical […] If today's average is not available for the quantification of potential benefits or avoided loads, a conservative approach shall be used.*"

Anderson *et al.*(2019) divided the EoL scenarios into the following four possible types:

- **100% scenario** – where only one possibility is reported, for example, 100% of the product is sent to landfill;
- **Mixed scenario** – where one combination of possibilities is reported, for example, 50% of the product is sent to landfill, 25% is recycled and 25% is used for energy recovery. This type of reporting can be used to mirror the national reality of the typical EoL;
- **Multiple 100% scenarios** – where multiple, separate, 100% scenarios are reported;
- **Mixed and 100% scenarios** – where both, a 100% scenario and a mixed scenario based on the formed, is reported.

Providing multiple 100% scenarios can help to promote the circular use of products since this type of EoL reporting puts different waste categories and waste treatments in direct comparison. Therefore, it can highlight the comparable advantages of reusing or recycling paths. It should be noted that, in case a mixed scenario is declared, a 100% scenario should be reported additionally, according to CEN/TR 16970 (CEN 2016).

For a better judgment of the possible EoL scenarios, the understanding of waste categories and waste treatments is important. An overview of possible and recommendable waste categories based on the type of material can be seen in Table 1. Recommendable are scenarios that enable benefits beyond the system boundary (in module D) and, therefore, encourage a circular material cycle. The waste categories "fast decomposing" and "wood" are, in fact, subtypes of the material type "biomass". However, the characteristics of these two subtypes of biomass influence their waste treatment and are therefore shown in Table 1 as separate waste categories.

Table 1: Possible (o) and recommendable (x) waste categories by type of material

TYPE OF MATERIAL	WASTE CATEGORY				
	NO POTENTIAL	COMBUSTIBLE	RECYCLING/REUSE	FAST DECOMPOSING	WOOD
METAL	o		x		
NON-METALLIC MINERALS	o		x		
BIOMASS	o	x	x	o	o
FOSSIL FUEL	o	x	x		

In order to minimize the environmental and social aspects of waste, the hierarchy in Figure 4 shall be followed according to Directive 2008/98/EC on waste. This means that a **prevention of waste** is always the preferred option. This can be achieved either through **prolonging the lifetime** of the construction product, or by enabling its **recovery for direct reuse**. The latter is possible through anticipatory and high-quality design for disassembly (DfD). After, prevention of waste, different types of material recovery are preferred over the disposal of the material.

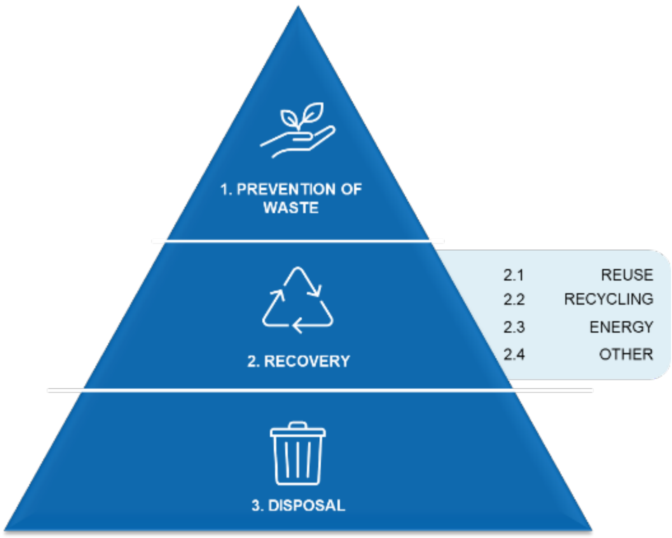

Figure 4: Waste hierarchy according to Directive 2008/98/EC

To be more precise, for building materials and products the following explanations can be considered:

- **2.1 Recovery – reuse:** of materials with minimal additional processing thanks to direct access to the product without quality loss;

- **2.2 Recovery – recycling:** consists of generating new products from waste materials. The recycling of most construction products is limited to a downcycle process, which leads to a lower value than that of the virgin material.
- **2.3 Recovery – energy recovery**: in a municipal incineration plant consists of incineration of waste and recovery of the heat generated by the material combustion process. The energy released from a material depends on its energy content. At the end, the thermal energy produced in the facility is assumed to be converted to electricity;
- **2.4 Recovery – backfilling:** refers to reclaiming suitable waste for usage in excavated areas or for engineering purposes in landscaping. It has to substitute other materials that are not waste and does not require additional processing;
- **3 Disposal – inert landfill:** for materials that do not release hazardous substances after building deconstruction. Normally, this waste treatment includes demolition materials that do not release GHG into the air;
- **3 Disposal – incineration**: that does not harm human health and the environment;
- **3 Disposal – other**.

Additionally, for organic materials, the following waste treatments can be recommended according to Pittau *et al.* (2018):

- **Recovery – methane:** in a composting facility where biogenic materials are treated to capture the produced methane during the biological decay process. It is possible to capture almost all of the produced methane and to reuse the bio-methane as a substitute for natural gas;
- **Disposal – sanitary landfill:** considered as temporary storage for reactive biogenic materials that cannot be recycled because they contain phenolic glue. Impacts from this waste treatment are usually high since organic materials release large amounts of methane during their decay.

A general framework for the choice of waste treatment depending on the waste category and the associated benefits beyond the system boundary can be found in Figure 5. This framework is based on the goal to maximize benefits in module D. For potential waste categories please refer to Table 1.

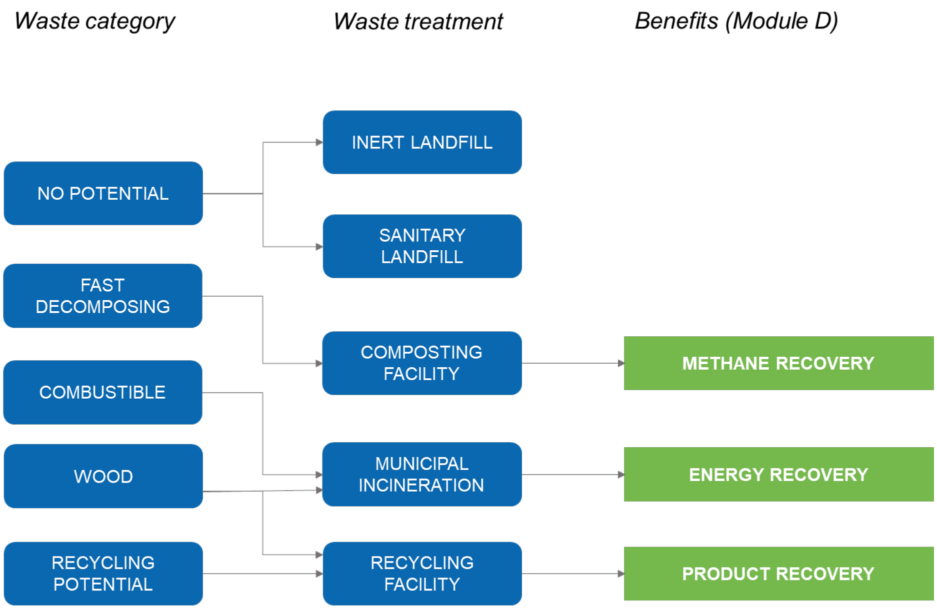

Figure 5: Recommended waste treatments depending on the waste category of a material and its associated benefits that need to be accounted for in module D

3.2.2 The Circular Footprint Formula

The revised EN15804 + A2 (CEN/TC 350 2019) provides a more complete, albeit more complex, methodology for calculating module D. The method for calculating end-of-life impacts in the amended EN 15804 is based on PEF's EoL Circular Footprint Formula (Mirzaie *et al.* 2020). The formula includes allocation factors. The calculation rules for the exact method are provided in annex D of EN 15804+A2.

For module C, the formula makes the sum of impacts related to:

- waste processing for material recovery to be recycled or reused;
- waste processing for energy recovery, i.e. to become a secondary fuel;
- waste processing and incineration for energy recovery from waste in an installation with efficiency greater than 60% and the impacts from waste processing and incineration for the thermal treatment of waste in an installation with efficiency lower than 60%;
- landfilling.

For module D, the formula makes the sum of loads and benefits related to the export of:

- secondary materials;
- secondary fuels;
- energy as a result of waste incineration;
- energy as a result of landfilling.

3.3 COMMON MISTAKES

CEN TR16970:2017 (CEN 2016), the guidance document for EN 15804, states that "*as soon as a construction product leaves the factory gate the assessment is based on scenarios and assumptions: the fate of the product in the building chain will depend on locations, types of transport, […] and waste handling.*

The manufacturer cannot control these processes completely. An assessment thus requires scenarios to be specified for each module, i.e. for modules […] C and […] D."

Hereafter a description of common mistakes in the modelling of scenarios for modules C and D. There are no universal solutions to those modelling challenges. However, this guideline provides insight into common mistakes and suggests pathways how to avoid them.

3.3.1 Definition of system boundaries

The end-of-waste state describes when a formerly considered waste material is considered as a secondary material that can be used as input in another system. Therefore, this concept is crucial for circular buildings. The construction product system under study reaches the EoL system boundary when outputs of the system, for example materials or product elements, reach the end-of-waste state. A common problem related to end-of-waste state is its regional variance due to market and demand differences, or the fact that the secondary material may not be commonly used in some regions (Anderson *et al.* 2019). Figure 6 provides a generalized sketch of the end-of-waste state. For more details please refer to Silvestre *et al.* (2014). A decision-tree for the end-of-waste system boundary can be found in Annex B of EN 15804:2012 + A2:2019. Potential benefits and loads beyond the end-of-waste state are credited in module D.

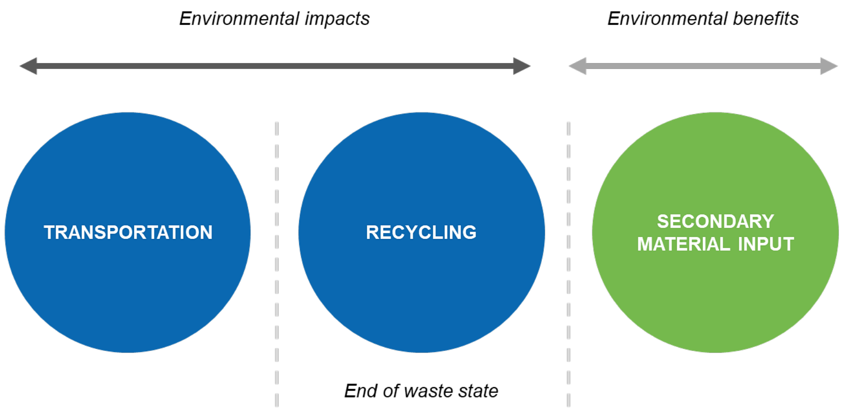

Figure 6: End of waste state according to the alternative
Source: Adapted from Silvestre *et al*. (2014)

3.3.2 Manufacturing energy

Additional information allows to provide scenarios for manufacturing energy. This is important considering that the European Union has committed to becoming carbon neutral by 2050 (EC 2019). One important variable on the way to carbon neutrality is the transition of energy grids towards renewable sources. Therefore, the "additional information" section should be used to provide scenarios that allow adjusting the impact of manufacturing energy, due to a changing energy mix towards renewable sources. The "Transition Pathway Explorer" (EU Calculator: Trade-offs and pathways towards sustainable and low-carbon European Societies 2019) is a useful online tool to project different national pathways for the transition of the energy grid.

When providing a manufacturing energy scenario, the following scenario parameters and information should be provided:

- Electricity data source and quality;
- Electricity in emission per kWh (e.g. CO_2 equivalents per kWh);
- District heating data source and quality;
- District heating in emission per kWh (e.g. CO_2 equivalents per kWh).

3.3.3 Transport modelling

In the EoL stage, transport is included in C2. There are various sources of uncertainty for the modelling of transport-related impacts, which should be avoided for an accurate estimate of total impacts and therefore for allowing to compare EoL scenarios:

- **Type of vehicle:** the technological advancement of the car industry, for example from combustion to electric engine could be included as a scenario in the “additional information” section;
- **Vehicle capacity:** usually the weight of material (e.g. in tons) is used as the determining factor to calculate when a transport vehicle is fully loaded. However, for lightweight materials, such as thermal insulation, the maximum volume should be used instead of weight;
- **Fuel consumption:** depends on the actual load of the vehicle. Moreover, related to the type of vehicle, the actual fuel consumption can vary significantly;
- **Route:** often when performing an LCA, as needed for an EPD, it is unknown where the origin and destination of the transport route is. Moreover, empty returns of the transport vehicle should not be forgotten in the estimate of transport-related impacts.

When providing a transport scenario, the following scenario parameters and information should be provided:

- Assumed vehicle type, its capacity and fuel consumption;
- Specific transport emissions per ton-km (e.g. CO_2 equivalents per ton-km);
- Average transport distance in km;
- Transport capacity utilization in %;
- Bulk density of transported products in kg/m^3.

3.3.4 Biogenic carbon

Bio-based construction is a trending topic with high hopes on its potential for mitigating climate change. In France, for example, starting from 2022, all new public buildings need to be constructed with a minimum 50% of bio-based materials (Almeida 2020).

Construction products that contain any type of biomass, such as timber or straw, can be credited for the carbon sequestration of the plant: When plants grow, they extract CO_2 from the atmosphere and store it as carbon in their biomass. Calculation rules for the biogenic carbon content of biomass can be found in EN 16449:2014 (CEN/TC 175 2014). In EN 15804+A2, the Global Warming Potential category is split into four different reported categories:

- Climate change – total sum of subcategories;
- Climate change – fossil;
- Climate change – biogenic;
- Climate change – land use and land use changes.

This allows and encourages to account for biogenic carbon. However, there are still unresolved issues related to the accounting of biogenic carbon. Particularly, for bio-based construction products, closing the loop of the biomass cycle is crucial. When the plant is cut or harvested, and transformed into a building product, then the carbon is moved into this product, and subsequently into a building, as well. When biomass degrades or combusts then the biogenic carbon is released to the air as CO_2, CO or CH_4. Until today, there is no consensus in the LCA community regarding how to account for biogenic carbon uptake and release. There are four main approaches, which are illustrated in Figure 7.

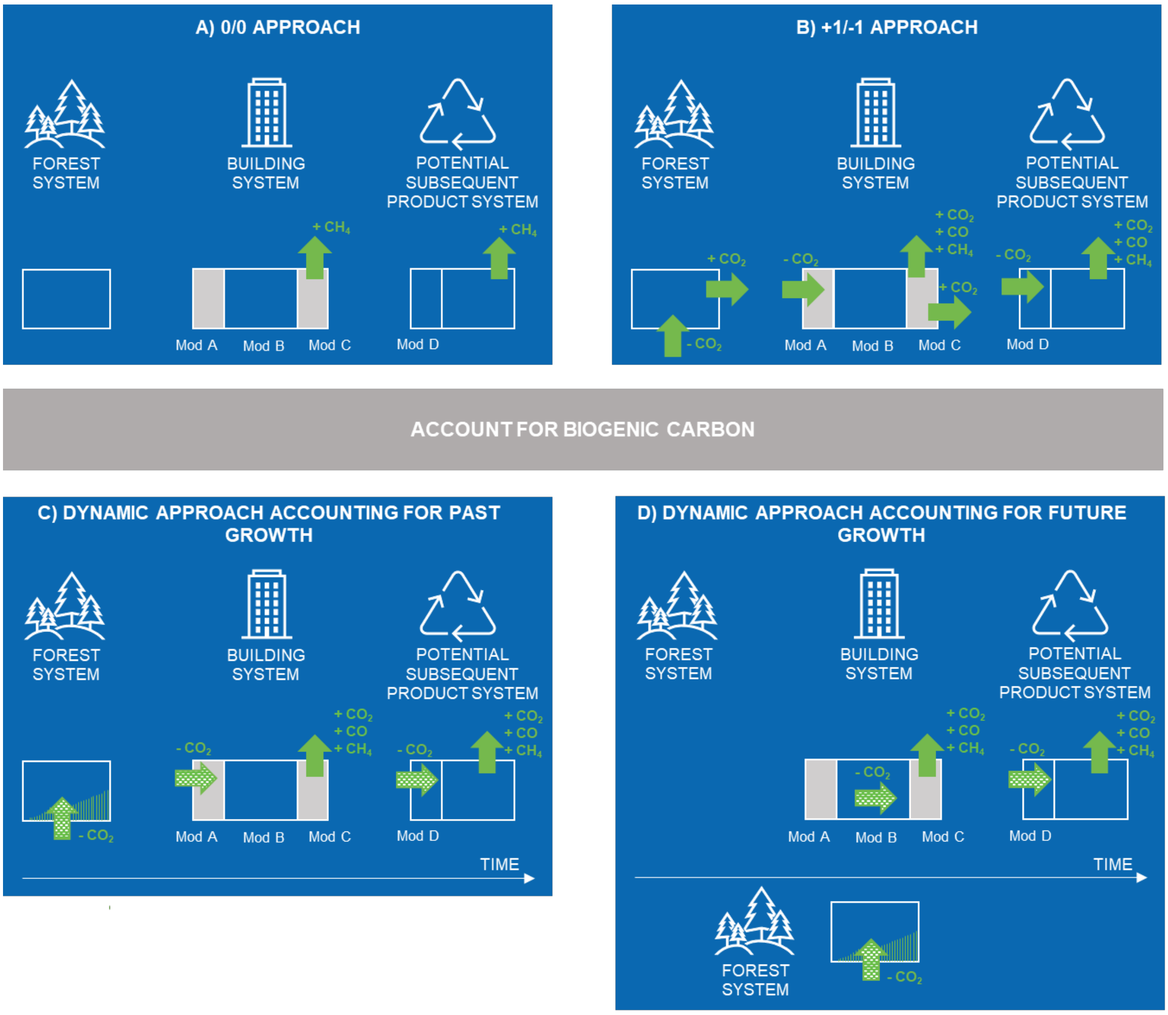

Figure 7: Overview of approaches to account for biogenic carbon uptake and release
Source: Adapted from Hoxha *et al.* (2020)

Assuming that the product is incinerated at its EoL, then the sequestered carbon is released back to the atmosphere. Approach a), the 0/0 approach, also referred to as the carbon neutral approach, incorporates that idea and does not consider carbon uptake (0) and release (0). Approach b), the -1/+1 approach, tracks the biogenic carbon flows along the product's LC and balances them to zero over the LC. This approach assumes that the original carbon uptake during the plant's growth (-1) is equally released at its EoL or transferred to another system (+1).

Currently, approaches a) and b) are most commonly used. Yet, the temporal aspect of the carbon release, and the rotation period of the plant (for example trees take decades while wheat straw only takes one year to regrow) play an important role. There are two approaches (c and d) that allow for accounting of these temporal aspects. While c) credits the carbon uptake of the actual plant that is cut or harvested and, therefore, refers to the past plant growth, approach d) estimates and credits the future carbon uptake of the plant that will replace the cut/harvested plant.

It was shown by Hoxha *et al.* (2020) that approach d) is the most robust and transparent. This guideline follows the same recommendation of approach d) for the calculation of carbon uptake and release of bio-based construction products.

3.4 PROMOTING CIRCULARITY IN EPD'S "ADDITIONAL INFORMATION"

As described, starting from 2022, it will be mandatory to include modules C and D in new EPD. Therefore, at a minimum, a basic analysis of the end-of-life phase, and potential loads and benefits beyond the system boundary are required in new EPD. However, to promote circular construction and circular buildings by enabling the increased recovery, reuse, and recycling of materials, it is recommended to include further information on the product system in the section "Additional information" of an EPD (please refer to 2.4).

3.4.1 Circularity Indicator

The calculation of circularity indicators is on the rise. Even though there is no standardized method and there is no designated section for circularity indicators in EPD, it could be useful to include such indicators in the "additional information" section. The Ellen MacArthur Foundation (2015a) developed a methodology for the calculation of a material circularity indicator (MCI), considering the amount of virgin material, the amount of unrecoverable waste, and the lifetime of the product. It depends on a "Linear Flow Index" (LFI) that is the amount of virgin material that ends as waste, and on a utility function (U) that refers to, among other characteristics, the durability and usage intensity of a product. For more information on LFI and U please refer to the documentation by the Ellen MacArthur Foundation (2015b, pt. Annex C and D). The formula can be seen in Equation (1):

$$(1)\quad MCI = 1 - LFI * U(x)$$

Efforts have been made regarding the scale-up of the MCI to express the circularity of a building. Cottafava and Ritzen (2021) propose a simplified building circularity indicator (BCI) as shown in Equation (2):

$$(2)\quad BCI = \frac{1}{N} * \sum_{j=1}^{J} LK_j * M_j * MCI_j * \left(\frac{\sum_{i=1}^{n} F_{i,j}}{n}\right)$$

Where *N* is a normalization factor, *J* is the total considered number of building components in a building, *LK* is a weighting factors for the different layers of a building, *M* is the mass of a component, n is the number of DfD criteria, and $F_{i,j}$ is the assigned weight for the design criteria i for the product j.

3.4.2 Disassembly for recovery, reuse and recycling

The criteria for potential disassembly for recovery, reuse and recycling, simplified "design for disassembly" (DfD), are detailed technical criteria that allow quantifying how easy or difficult it is to access a product in the finished building. A well-known reference for the detailed definition of these criteria is Durmisevic (2006). However, the criteria defined by Durmisevic is complex since it covers eight different aspects of design for disassembly of building configuration that require advanced technical knowledge. To improve the practicality, Alba Concepts subsequently developed a simplified version of DfD criteria, later adopted by Cottafava and Ritzen (2021), with only four different types of criteria: "type of connection", "accessibility of connection", "crossings", and "form containment". The criteria are weighed on a scale from 0 to 1. Each criterion has a weight assigned and consists of a set of sub-criteria (see Appendix C for the complete list of criteria and sub-criteria). The criteria can be considered as weights that need to be multiplied with another factor, such as material quantity or emissions, to express the disassembly potential of a product non-dimensionless. The information taken for the definition and application of these criteria was taken from Cottafava and Ritzen (2021), DGNB (2020) and van Schaik (2019).

Instructions regarding the potential disassembly of buildings and their elements are important to enable recovery, reuse, and recycling of the material. The “additional information” section of an EPD can be used to provide such instructions. Hereafter, a list of suggestions based on the above-mentioned four criteria for potential disassembly:

Type of connection:

- Specify what type it is and which tools and processes are required to dissolve the connection;
- Indicate the quality level of the material (product) after the connection is dissolved, i.e. is it intact, or does it require additional processing before it can enter its second life cycle;

Accessibility of connection:

- Specify potential areas of application for the product;
- Describe the immediate product’s environment after installation in the building;

Crossings:

- Describe the zoning of the product after installation in the building, e.g. modular installation versus a full integration with neighbouring elements;

Form containment:

- Describe the immediate product’s environment after installation in the building, e.g. are there inclusions or overlaps, if so on how many sides of the installed product.

Hereafter a small practical example of the quantification of the potential design for disassembly for a typical window with a PVC frame and double-glazing. Figure 8 shows the schematic drawing of the window and a detail of the double-glazing.

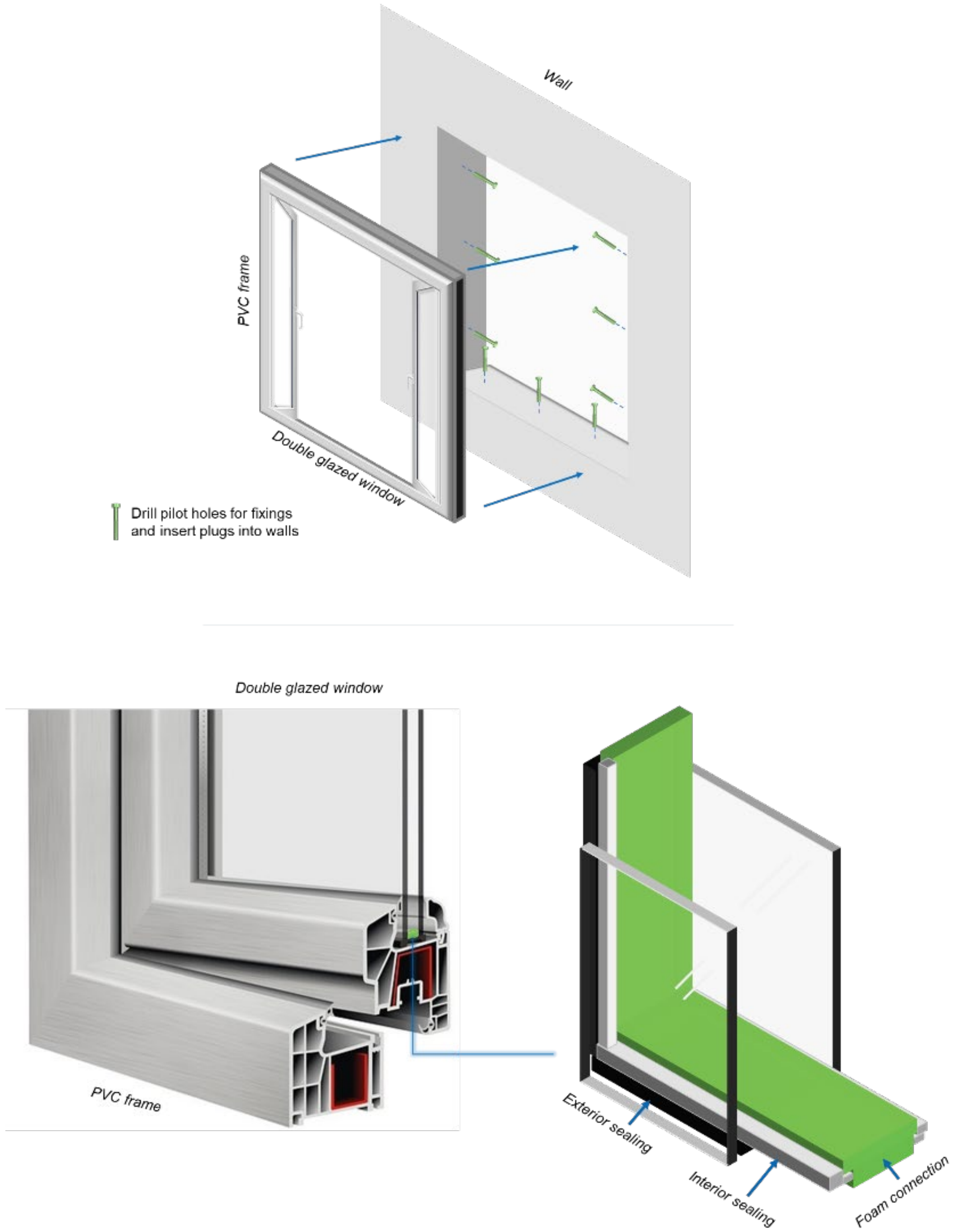

Figure 8 - Schematic drawing of the window and a detail of the double glazing

The example is based on Cottafava *et al*. (2020) and uses the embodied energy of the window measured in Giga Joule (GJ) as a multiplier. Table 2 shows the quantification of DfD for the illustrated window. The embodied energy refers to LC stages A1 to A3 (as described in Figure 1) for each element, i.e. the frame and the glass. The values shown for embodied energy in Table 2 are only for exemplifying purposes. Depending on the window type, size and location these values can significantly change. Each criterion is weighted equally (i.e. each criterion contributes 25% to the total average disassembly potential).

Table 2: Example of the Design for Disassembly analysis for a window

Source: Cottafava *et al.* (2020)

CRITERIA	PVC FRAME EMBODIED ENERGY 400 GJ		DOUBLE GLAZING EMBODIED ENERGY 50 GJ	
	SUB-CRITERIA	WEIGHT	SUB-CRITERIA	WEIGHT
Type of connection	Connection with added elements	0.8	Soft chemical compound	0.2
Accessibility of connection	Accessibility with additional actions with reparable damage	0.8	Freely accessible	1.0
Crossings	Modular zoning of objects	1.0	Modular zoning of objects	1.0
Form containment	Open, no inclusions	1.0	Closed on several sides	0.1
DISASSEMBLY POTENTIAL		**0.9**		**0.575**

This means that the window's potential design for disassembly amounts to:

$$DfD_{Window} = \frac{(0.8 + 0.8 + 1.0 + 1.0)}{4} * 400\ GJ + \frac{(0.2 + 1.0 + 1.0 + 0.1)}{4} * 50\ GJ = 389\ GJ$$

In other words, by recovering the window, 389 GJ of its initial embodied energy of 450 GJ, or roughly 86%, can be recovered. The remaining 14% are destined to be treated as waste. As described in section 3.2.1, this could be done through energy recovery, backfilling, incineration or landfill for final disposal.

3.4.3 Improvement of maintenance

As described in section 3.2.1 (End of Life scenarios), preventing waste should always be the preferred option. High quality and timely maintenance can enable a prolonged lifetime and, therefore, prevent waste. For that reason, it is important to provide information in an EPD on the correct maintenance to increase a product's lifespan. The "additional information" section of an EPD can be used to provide such information. More specifically, details on the proper use of the product, key parts of the product that determine its durability, and instructions for a proper maintenance and service of the product, should be included here. This information can then enable optimized life cycle management. It should be noted that the key stakeholders for life cycle management are facility managers since they plan and oversee maintenance tasks. Therefore, the additional information in an EPD on life cycle management should contain information that, in its content and form, is useful to a facility manager. For this purpose, it should provide information on how to gather, store, process, and present product data in Building Information Models (BIM). Moreover, it should do that considering the standardization of Industry Foundation Classes (IFC): a standardized, digital description of the built asset industry that is defined in ISO 16739-1 (ISO/TC 59/SC13 2018). Targeting additional information towards facility managers in that manner allows for an optimized long-term planning of maintenance works.

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APPENDIX A – OVERVIEW OF ONLINE EPD DATA SOURCES

Data source	**Country**	**Developer/ provider**	**Data format**	**Building materials**	**Building products**	**Building services**	**Chemicals**	**Construction materials**	**Construction products**	**Energy**	**Furniture and Packaging**	**HVAC**	**Multi-purpose**	**Services**	**Waste**
Bau EPD	Austria	The Bau EPD GmbH	PDF						x						
CENIA	Czech Republic	Czech Environmental Information Agency	PDF						x						
DAP construcción	Spain	CAATEEB, Agenda de la construcción sostenible	PDF						x						
EcoPlatform EPD	Europe	Eco Platforn	PDF						x						
EPD Danmark	Denmark	Danish Technological Institute	PDF						x						
EPD Ireland	Ireland	Irish Green Building Council	PDF	x	x	x									
EPD Italy	Italy	EPD Italy	PDF						x						
EPD Norge	Norway	The Norwegian EPD Foundation	PDF	x			x			x	x				
EUCoMDat	Europe	The EPD registry	PDF, ILCD+EPD						x						
GreenBookLive	Europe	BRE Global	PDF						x						
IBU	Germany	German Institute for Construction and Environment	PDF, XML	x	x	x									
INIES	France	Alliance HQE-GBC	PDF						x	x		x		x	
ITB EPD	Poland	Polish Building Research Institute	PDF						x						
RTS EPD	Finland	Building Information Foundation	PDF						x						
The International EPD System	Internation al	EPD International	PDF, ILCD+EPD						x				x		
TurCoMDat	Turkey	Metsims Sustainability Consulting, SÜRATAM, The EPD registry	PDF, XML, ILCD+EPD					x		x					x
UK CoMDat	UK	Metsims Sustainability Consulting, UK Ecolabel Center, The EPD registry	PDF, XML, ILCD+EPD					x	x						

APPENDIX B – OVERVIEW OF AVAILABLE PORTUGUESE EPD FROM DAP HABITAT

Specific product	***Material***	***Indicator***	***FU***	***Link***
Grés Porcelânico Gres Panaria	Porcelain stoneware tiles	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1-A5, B1-B7, C1-C4, D	1 m^2	Link
Argex – Argila expandida	(Lightweight) concrete aggregate, thermal insulation material	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1, A2, A3	1 m^3	Link
Agregado Siderúrgico Inerte Megasa	Base layer exterior pavements	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1, A2, A3	1 ton	Link
Lã de rocha Termolan	Thermal insulation	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1, A2, A3	1 m^2	Link
Monoporosa Pavigrés	Interior walls coating	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1, A2, A3	1 kg	Link
Grés vidrado Pavigrés	Interior floor and wall covering	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1, A2, A3	1 kg	Link
Grés porcelânico Pavigrés	Interior floor and wall covering	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1, A2, A3	1 kg	Link
Agregado leve de argila expandida LECA	Concrete aggregate, thermal insulation material	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1, A2, A3	1 m^3	Link
Granulado de cortiça expandida Amorim	Thermal insulation material	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1, A2, A3	1 m^3	Link
Aglomerado de cortiça expandida (ICB) Amorim	Thermal insulation	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1, A2, A3	1 m^3	Link
Sistema weber.therm natura Weber Saint-Gobain	ETICS with cork	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1, A2, A3	1 m^2	Link
Weber.rev Naturkal Saint-Gobain Weber	Lime-based mineral coating	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1, A2, A3	1 kg	Link
Weber.therm kal Saint-Gobain Weber	Adhesive and coating mortar	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1, A2, A3	1 kg	Link
Aglomerado de cortiça expandida (ICB) Sofalca	Thermal insulation	GWP, ODP, AP, EP, POCP, ADP, PE-NRe for LC stages A1, A2, A3	1 m^3	Link

Note: Information retrieved on August 2021

APPENDIX C – DESIGN FOR DISASSEMBLY CRITERIA

There are four types of design for disassembly criteria that can be seen in the tables below. The definitions of criteria are taken from different sources to obtain a complete set (Schwede and Störl 2016; DGNB 2020; Cottafava and Ritzen 2021). Moreover, the weighting was adapted for the Circular Buildings project. For more information please refer to the Circular Buildings - Guideline for creating Circular Materials Passports.

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
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

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

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

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

CIRCULAR
BUILDINGS

Iceland
Liechtenstein
Norway grants