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Environmental profile of buildings

[update 2021]

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1. BUILDING MATERIALS METHODOLOGY

1.1. Why do we need a methodology for building materials?

Building materials generate environmental impacts at various life cycle stages: during the production of the materials (extraction, transport, manufacturing); during the construction phase (transport to the site and construction processes); during the use of the building (maintenance and replacement activities); and during the end-of-life phase (demolition, waste transport adn treatment). A typology study of the construction of Belgian houses showed that in the entire lifespan of a typical Belgian house built before 2001, building materials represent about ten to thirty percent of the total environmental impact (Allacker et al 2011, Allacker 2010). This relative share is expected to rise over the next decades as a consequence of the sharp decrease of energy-related impacts that will result from the construction and renovation to low-energy, passive or (nearly) zero-energy buildings. For this reason, it is essential to acquire a clear insight into the environmental performance of materials used in buildings and their building elements (hereinafter referred as: elements).

Decision-makers, i.e. architects, engineering consultants, contractors, building owners, project developers and policy makers, often lack the environmental information that is required for objective and transparent creation, selection or support of eco-friendly materials solutions. In addition, some manufacturers and distributors are unaware of the potential environmental impact that building materials have during their life cycle.

A quantitative assessment is therefore essential in order to identify and avoid these potential environmental impacts as early as the design stage. In an ideal world, next to the technical performance, costs and quality of building materials, design teams would in the design phase of an element – a floor, an external and/or internal wall, a flat and/or pitched roof – consider their life cycle environmental performance.

Therefore, the Public Waste Agency of Flanders (OVAM), together with the Service Public de Wallonie (SPW) and Brussels Environment took in 2014 the initiative to work towards the development of a common methodology to assess the environmental performance of buildings in Belgium. This methodology was later translated to a user-friendly online tool, called TOTEM (Tool to Optimise the Total Environmental impact of Materials), which was launched in February 2018. With TOTEM the 3 regional authorities want to provide a transparent tool which is adapted to the Belgian building context in terms of methods and scenarios, so building professionals and policy makers do not need to rely on foreign environmental assessment tools anymore.

1.2. What does the building materials methodology entail?

In the period covering February 2011 through August 2012, by order of the OVAM the project team comprising VITO, KU Leuven (Department of Architecture) and BBRI developed an expert calculation model (including an assessment framework called "*Milieugerelateerde Materiaalimpact van Gebouw(element)en*", or MMG for short) for the quantification of the environmental performance of elements. The model served as the basis for a limited database of 115 element variants that are representative for the Belgian construction sector (Servaes 2013). The expert calculation model has been further developed since 2013. The methodology has been updated to follow amendments within European standardisation and the developments regarding the European Product Environmental Footprint (PEF; EC 2013). Furthermore, the database has been extended to almost 500 element variants. The extension was also done as data input for the TOTEM tool launched in February 2018. Since October 2020, users can make use of specific environmental data from Belgian Environmental Product Declarations (B-EPDs) that have been provided by manufacturers via the federal Belgian EPD programme. With TOTEM, decision-makers have a user-friendly calculation tool which allows them to assess the environmental impact of their building (design) choices.

1.2.1. MMG assessment framework

The parameters and assumptions of the MMG assessment framework were selected after due consideration. A brief explanation of the choices can be found in this chapter. For a detailed description of the MMG assessment framework we refer to Chapter 2 “Assessment framework”.

1.2.1.1. Selection of environmental indicators

To stay in line with existing European initiatives in the field of environmental assessment of buildings and building products, the MMG assessment framework was developed taking into account the European LCA standards, submitted by CEN/TC 350, and the recommendations of the European “Institute for Environment and Sustainability” (JRC) regarding environmental indicators and impact assessment methods. Since October 2015 the CEN/TC 350 has been working on an alignment of the EN 15804 standards with the PEF methodology. This resulted in the second amendment of the standard, i.e. EN 15804:2012+A2:2019 (hereinafter referred as: EN 15804+A2).

Compared to the previous version, the number of mandatory environmental impact indicators in EN 15804+A2 was extended to cover a wider range of environmental issues. This new version includes 19 impact indicators which can be grouped in 12 main impact categories. In July 2021, the new set of indicators has been integrated in the MMG assessment framework and implemented in the TOTEM tool.

Since the update of 2021, the following 12 main environmental impact categories listed below are included in the MMG assessment framework. More details on the related 19 environmental impact indicators are included in section 2.5.

- Climate change
- Ozone depletion
- Acidification
- Eutrophication
- Photochemical ozone creation
- Depletion of abiotic resources
- Water use
- Particulate matter emissions
- Ionising radiation
- Eco-toxicity
- Human toxicity
- Land use

1.2.1.2. Data selection

To support environmental impact caculations, TOTEM provides a set of generic environmental data for building materials and components. These data are based on the Swiss ecoinvent database and were harmonised as much as possible to the Belgian context (see section 2.3.1).

Since 2020 TOTEM also includes specific environmental data from validated and verified B-EPDs. B-EPDs consist of data from building product manufacturers which are available on the Belgian market or can be used in buildings on the Belgian territory. These data are retrieved from the Belgian B-EPD database (see www.b-epd.be for more information on the B-EPD programme).

1.2.1.3. Aggregation to a single score

With the MMG assessment framework and TOTEM, it is possible to calculate one single score next to the nineteen individual environmental indicators. The single score allows users to make a decision-oriented selection of building solutions. In the context of the update to EN 15804+A2 in July 2021, it was decided to move from the previous monetisation approach and to apply the PEF weighting approach, mainly to align TOTEM as much as possible with the European developments on LCA. The PEF methodology calculates a single score by means of a normalisation step followed by a weighting step.

For each individual environmental indicator, the characterised values are first normalised by dividing them with their respective normalisation factors. These factors represent the yearly global impact per capita (e.g. the normalisation factor for climate change is $8.1 \cdot 10^3$ kg CO_2eq./person·year for reference year 2010) and allow to express all the results in a dimensionless unit.

In a second step, the normalised results are weighted by multiplying them by their respective weighting factors (e.g. the weighting factor for climate change is 21.06%) to reflect the perceived relative importance of the environmental impact categories considered. After weighting, the results of the different environmental indictors can be summed up to obtain a single overall score (expressed in milli-points in TOTEM). How the weighting factors were determined is explained in section 2.5.3.

1.2.2. How is the building materials methodology structured?

1.2.2.1. Hierarchical structure of TOTEM

TOTEM is built up according to a hierarchical structure and distinguishes four levels of analysis: building, element, component, and material (see figure 1) (Allacker 2010, Allacker et al. 2011). Each higher level is based on the previous level. Thus, a building is built up of a number of elements (such as floors, external walls, internal walls, roof, etc.), which in turn consist of several components (e.g. a masonry wall, an insulation layer). The components are again built up of different building materials (e.g. hollow bricks and mortar).

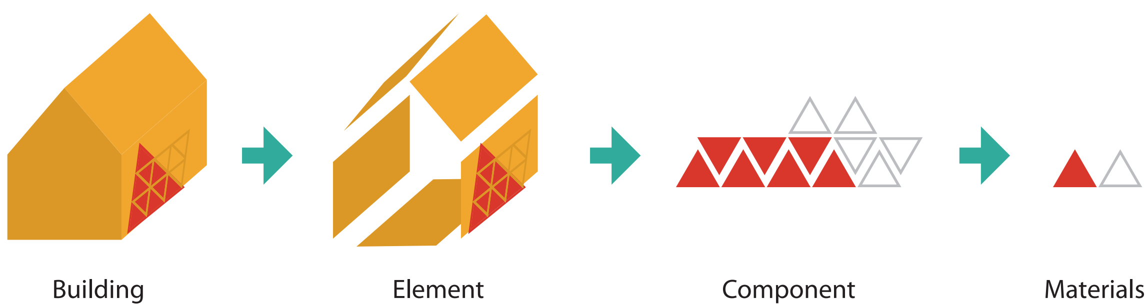

Figure 1: Illustration of the hierarchical structure of TOTEM and its four levels of analysis.

1.2.2.2. Three main databases

For the three lowest levels of the above-mentioned hierarchical structure – i.e. material, component and element levels – an extensive spreadsheet was created. The spreadsheet includes several databases containing input and output data that are used for calculating the environmental impact of the selected materials ("Database Materials"), components ("Database Components")[1] and elements ("Database Elements") (see figures 2 and 3; Allacker, 2010; Allacker et al., 2011). The element database is publicly accessible in TOTEM and users are allowed to change some parameters in these predefined elements (for example: adaptable thickness, lambda value or combining other components in an element). The component database is also accessible via the TOTEM library but limited to read-only and can to some extent be adapted by users when a component is applied in an element (see previous examples). The TOTEM library also includes a limited number of buildings as example. The score at building level is calculated based on the consituting elements.

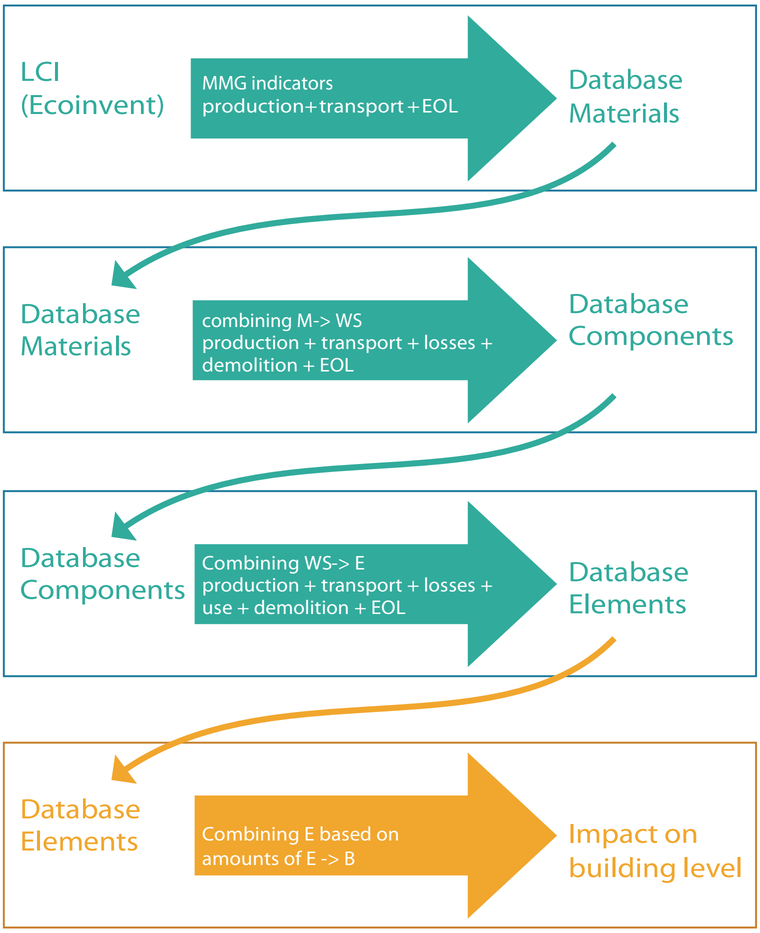

Figure 2: Overview of the three consecutive steps that successively create the databases at material, component and element level. The final calculation and visualisation of the results at building level constitutes a fourth step within TOTEM.

1 Components are called work sections in the TOTEM backend and MMG assessment framework.

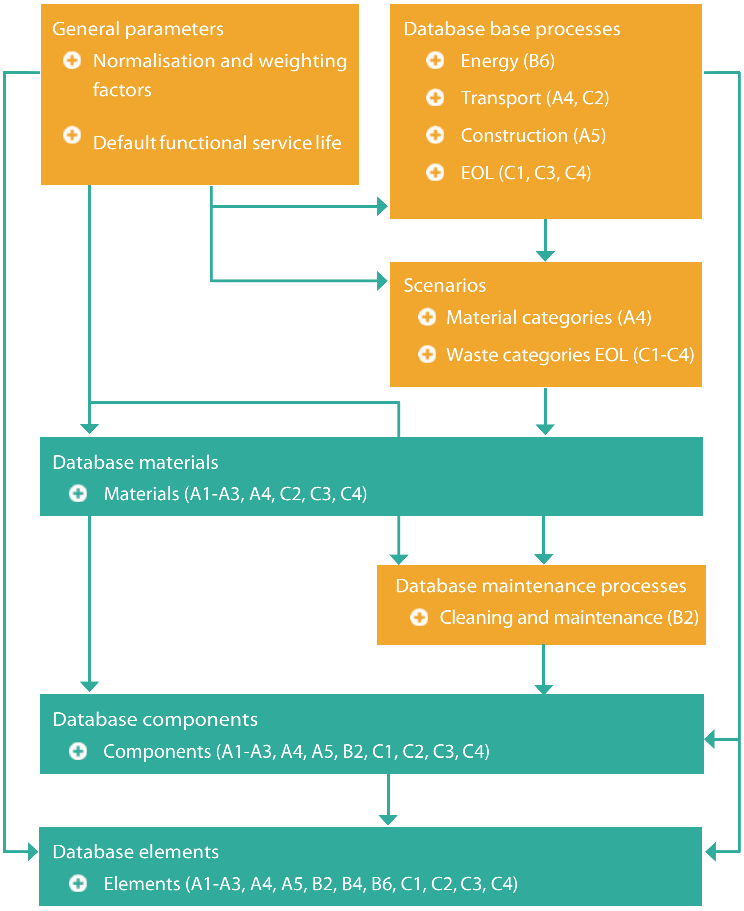

Figure 3: Overview of the structure of the TOTEM backend. The main databases at the three separate levels, i.e. the material , component and element databases are shown in green; the underlying databases, i.e. general parameters, base processes, scenarios and maintenance processes, are shown in orange.

1.2.3. What type of information is offered by the building materials methodology?

The integrated approach and modular structure of TOTEM generate a large amount of information, which can be used:

- either to obtain a detailed insight into the environmental profile of materials, components and elements[2], by using nineteen individual environmental indicators and taking into account all the separate life cycle stages; or
- to compare the environmental profiles of different element or building variants by using nineteen weighted indicators and/or one aggregated environmental score.

2 The lowest level of the results that can be exported from TOTEM is the element level. Only the relative contribution of the components within an element can be consulted in TOTEM.

It should be emphasised, however, that in order to take design decisions, the results of the environmental impact assessment must always be considered together with other building requirements, such as technical (e.g. fire and acoustic performance) and financial aspects (i.e. initial and periodical costs).

1.2.4. How reliable is the building materials methodology?

In the first MMG study, sensitivity analyses (based on the 115 element variants) have been carried out for the following aspects: building lifespan, transport scenarios, material losses during the construction process and end-of-life treatment.

The building lifespan is a very important assessment parameter. Based on Ammar and Longuet (1980) and Allacker (2010), a default lifespan of 60 years was considered in the MMG assessment framework. This default lifespan is currently a fixed parameter in the TOTEM tool. However, in future versions of the tool, it is recommended to allow users to make comparisons between different building life spans.

Furthermore, clear definition of the transport of building materials to – and from – the building site is essential. It is noted that logistics related to the transport of building materials can play a significant role in the priority sequence of element solutions, especially in the case of heavy and voluminous building materials (e.g. concrete), for which the type of transport (e.g. a small vs. a large lorry) and the distance between the manufacture/dealer and the building site may have a significant effect on the environmental impact.

Thirdly, it is important to limit any loss of material during the construction process. A variation in loss of material of 0 - 20% (a material loss of 5% is currently assumed in TOTEM) for all the types of materials however did not produce a significant difference between the aggregated environmental profiles.

Changing the end-of-life scenarios has a negligible effect on the aggregated environmental scores for the entire life cycle. The sensitivity analysis showed that transport – either or not through a sorting facility – to the final treatment plant and the type of waste treatment did not affect the weighted environmental impact of elements.

2. ASSESSMENT FRAMEWORK

2.1. Introduction

Calculation and clear communication of the environmental performance of materials used in buildings require a transparent methodological framework. In this chapter, we discuss in detail the assessment method underlying TOTEM. This method is in line with the European harmonised standards for the assessment of the environmental performance of buildings and building products, which have been developed by CEN/TC 350[3]:

- EN 15804+A2 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products (CEN 2019)
- EN 15978 Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method (CEN 2011)
- EN 15643 Sustainability of construction works – Framework for assessment of buildings and civil engineering works (CEN 2021)
- TR 15941 Sustainability of construction works – Environmental product declarations – Methodology for selection and use of generic data (CEN 2010)

Consequently, only the additions to, departures from and clarifications to these standards, as well as adopted values and scenarios that are specific to the model, are discussed here.

OVAM, Brussels Environment, SPW, and the authors of this study warn for any changes in standards or recommendations that would be in force after the publication of this brochure.

2.2. Objective and scope

The objective of the developed MMG assessment framework and TOTEM is to calculate the environmental impact of elements and buildings based both on individual environmental impact indicators and an aggregated score. This allows a better understanding of the environmental performance of building materials within the Belgian context, taking into account the entire life cycle of the building or element. Important methodological aspects related to the life cycle assessment are explained in the subsequent sections.

3 CEN/TC 350: Technical Committee on Sustainability (assessment) of construction works of the European normalisation centre (CEN).

2.2.1. Functional unit[4]

The orignal MMG assessment framework was intended primarily for assessments at element level[5]. The functional unit of planar elements (e.g. external walls, floors, roofs) is defined as 1 m² of the element as built in practice and that does not score identically for all possible performances. Within TOTEM also non-planar elements are included, such as beams, columns and sills, which are defined with a functional unit of 1 m. The advantage of this approach is that it allows to focus on one or more elements without having to design a complete building. A disadvantage of working only at the level of individual elements is that certain choices for one particular element can at times affect other elements (e.g. wider foundations are required for walls with thicker insulation layers), which can only be analysed at building level. In addition, depending on the lay-out of the building, the quantity of a particular element per m² of floor area can vary (e.g. m² of roof for an apartment block or a bungalow).

The “element method” was introduced as the first step towards the extension to the building level which has been implemented in the TOTEM tool. The functional unit at building level is 1 m² Gross Floor Area (GFA) of a whole building. This is calculated by dividing the sum of the total environment impact of all elements by the total m² GFA of the building.

The final comparison using functional units should also take into account the technical performances of the building/element, such as, among others, the related energy and acoustic performances. The main objective of this assessment method is, however, to compare the material-related environmental impact of various commonly used technical solutions. Consequently, such performances are not included in the definition of the functional unit. In order to be able to compare the building/element variants regarding their energy performance on an equivalent basis (and so avoid a situation of less insulated variants having a more favourable material-related environmental profile), their influence on the heating energy consumption is estimated separately using the equivalent degree-day method (see section 2.3.3).

4 In line with EN 15978:2011 §7.2 and EN 15804+A2 §6.3.2.

5 An element is a major physical part or system of a building, which consists of several components. Examples of elements are floors, roofs, walls, windows and technical services. Account is taken of the entire life cycle of an element in its particular application in the building.

2.2.2. Service life[6]

Specific requirements for the service life of the building are in most cases defined by the client. In the absence of such requirements, the assessment method uses a default reference service life of 60 years for dwellings, offices, schools and shops[7].

The average life expectancy of buildings is usually longer than 60 years, but it is assumed that after 60 years, the building will most likely be renovated so thoroughly that, apart from the structure, relatively few of the original materials will still be present[8]. Offices and shops are subject to major renovation even faster than dwellings, but the structural elements in principle tend to remain for at least 60 years, which explains why the same reference service life is assumed.

The fact that offices and shops tend to be renovated more quickly is, however, taken into account by applying a (much) shorter service life for the non-structural elements (e.g. non-loadbearing internal walls) and all finishes (e.g. false ceilings, floor coverings).

2.2.3. System boundaries[9]

In the European standards (CEN 2011, CEN 2019), the life cycle of a building is divided into several stages or modules (see Figure 4), each with clearly defined boundaries. The basic rule here is that an impact is assigned to the stage in which it occurs.

At times, the assessment method departs from these boundaries for practical reasons or else we have given our own interpretation due to a lack of clarity or contradictions in the standards. All additions, clarifications and departures with respect to these standards are described below.

6 In line with EN 15978:2011 §7.3.

7 Based, among others, on the service life used in conventional LCA tools.

8 The model assumes that materials are always replaced by the same material. The longer the reference service life, the more this assumption and hence the results will differ from reality. The probability is high that materials at the end of their service life will not be replaced by identical materials (due to changes in energy, acoustic or aesthetic requirements and to technological improvements).

9 In line with EN 15978:2011 §7.4 and EN 15804+A2 §6.3.5.

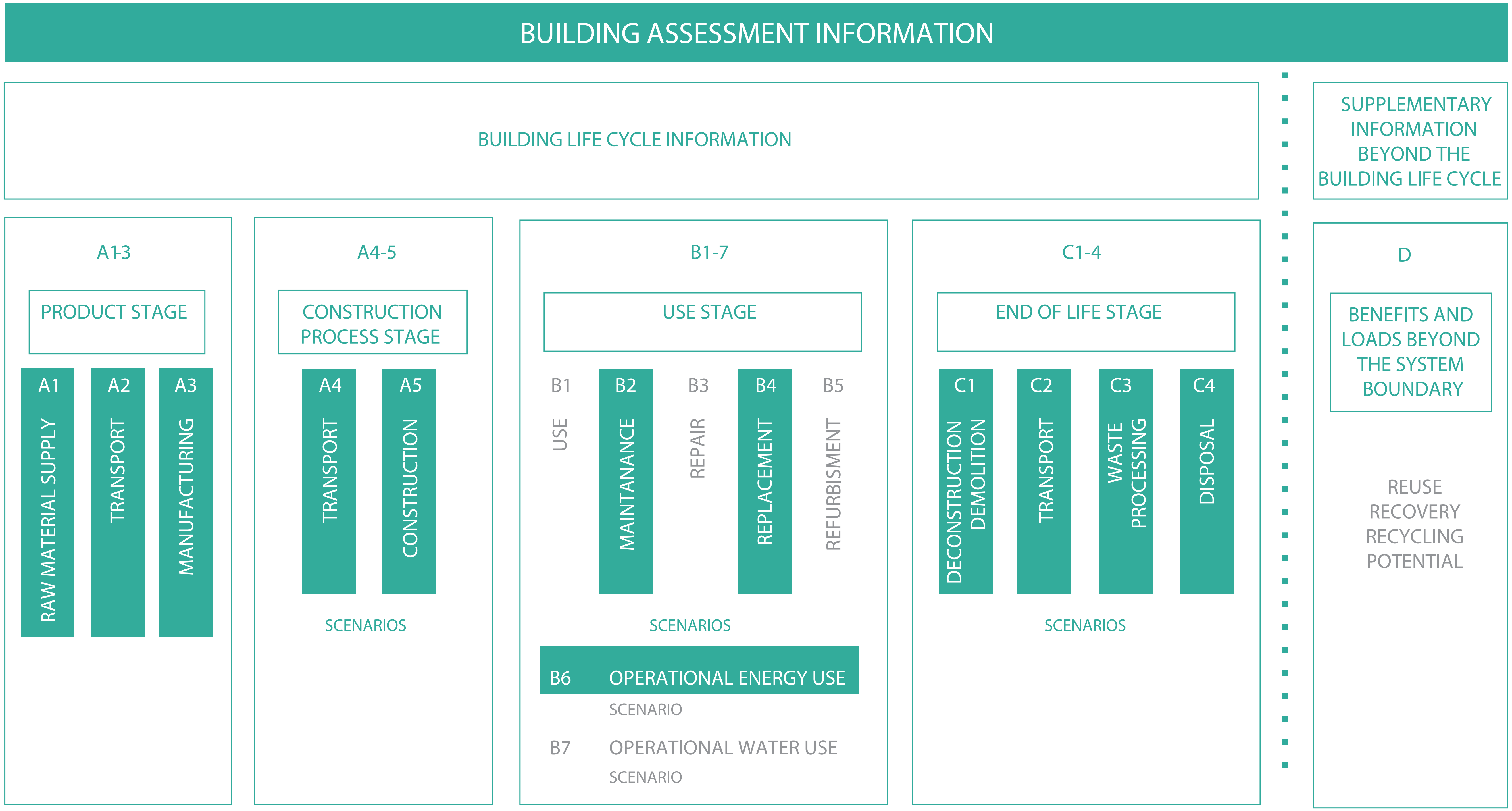

Figure 4: Overview of the life cycle stages and system boundaries within the European standard EN 15978:2011 (CEN 2011). The current version of TOTEM considers the modules coloured in green.

2.2.3.1. Product stage (modules A1-A3)[10]

In principle, the impact of the production of the packaging of the finished building product should be reported in the product stage. In the generic ecoinvent database, the impact of the packaging is not systematically included in the data records. As it is assumed that the impact of the packaging is rather limited, it was not separately modelled for the ecoinvent data records where it was missing.

For some raw materials where the import ratio is very significant, specific transport scenarios have been established for the import of these raw materials to Belgium (see 2.3.1). The impact of the import scenarios is considered as transport to the manufacturer (Module A2) followed by a final manufacturing step (Module A3) and not as transport to the building site (Module A4). This assumption deviates from the Belgian national supplement to the EN 15804 (NBN 2017), hereinafter called “B-PCR”, in which the conditions are determined for application of the EN 15804 in Belgium.

2.2.3.2. Construction process stage (modules A4-A5)[11]

The European standard EN 15978 § 7.4.3.1 states that the production-related impacts of capital goods (e.g. trucks) should be left out of consideration for the construction process stage (CEN 2011). This provision is not reflected, however, in the standard at product level (EN 15804+A2 § 6.3.5.3). Moreover, the latter explicitly states that all input and output processes for which data is available should be considered (see § 6.3.6) (CEN 2019). Consequently, the impacts of capital goods are taken into account in this particular stage[12].

Transport of building materials (A4)

While a fraction of materials is lost during transport from the factory to the building site (Module A4), for practical reasons all material losses are imputed in their entirety to the construction stage (Module A5, in total 5% see also section 1.2.4). In the absence of data, the transport of the construction equipment (cranes, concrete mixers, etc.) to the building site is left out of account.

10 According to EN 15804+A2 §6.2.2, the product stage includes raw material extraction and processing, processing of secondary material input (e.g. recycling processes), transport to the manufacturer and manufacturing, including provision of all materials, products and energy, as well as waste processing up to end-of-waste status or disposal of final residues during the product stage.

11 According to EN 15804+A2 §6.2.3, the construction process stage includes transport of the building products to the building site and installation into the building, including provision of all materials, products and energy, as well as processing up to the end-of-waste state or disposal of residues during the construction process stage.

12 For the other stages, the standards do not explicitly state whether the impact of the capital goods should or should not be considered. For this reason, the impact of capital goods is always included in the model as developed.

Building activities (A5)

Module A5 mainly includes the impact of building waste on the building site (e.g. production, transport and disposal of waste materials in the form of surpluses, trimmings, breakage, etc.) and only to a limited extent (if relevant) the impact of construction activities (e.g. excavation and electricity consumed for cellulose blowing).

The EOL processing of any packaging waste should also be considered in this module. However, as for the impact of the production of the packaging (see section 2.2.3.1), it is assumed to have a limited impact and is therefore not modelled separately for generic data.

2.2.3.3. Use stage (modules B1-B7)[13]

Cleaning and planned servicing related to preventative and regular maintenance are included in Module B2. Corrective, responsive or reactive maintenance actions that should be considered in Module B3 are excluded, as these are related to user-specific scenarios for which no default scenarios are available.

Refurbishment activities (Module B5) are not included in TOTEM yet, but will be in future versions. In the MMG expert calculation model Module B5 is also excluded, given that the analysis is carried out for elements and that refurbishment activities by definition[14] relate to a significant portion of the building.

With regard to the modules concerning the normal operational activities of the building (B6-B7: operational energy and water use), only the heating energy consumption is considered (see section 2.3.4).

13 According to EN 15804+A2 §6.2.4, the use stage, related to the building fabric, includes the use or application of the installed product, its maintenance, repairs, replacement and refurbishment, including provision and transport of all materials, products and related energy and water use, as well as waste processing up to the end-of-waste state or disposal of final residues during this part of the use stage. Also all impacts and aspects related to losses during this part of the use stage are included. On the other hand, the use stage, related to the operation of the building, includes operational energy use (due to heating and other technical installations) and operational water use (sanitary warm water), including provision and transport of all materials, products, as well as energy and water provisions, waste processing up to the end-of-waste status or disposal of final residues during this part of the usage stage.

14 Cf. EN 15804+A2 §6.3.5.4.2: B5-refurbishment: "These activities cover a concerted programme of maintenance, repair and/or replacement activity, across a significant part or whole section of the building".

2.2.3.4. End-of-life stage (modules C1-C4)[15]

In the case of waste incineration with energy recovery, there are two possibilities:

1. The waste incineration does not fulfil the criteria for energy valorisation[16] (EU 2008): in this case the impact of the incineration process (including the processing and transport of waste to the incinerator) is assigned fully to the building or element considered in the analysis (module C). The energy produced by the waste incinerators is thus free in terms of environmental impacts and is not included in the calculation (because all impacts are allocated to the building).
2. The waste incineration fulfils the criteria for energy valorisation[17] (EU 2008): in this case the impact of the incineration process falls outside the system boundaries. In other words, the impact is assigned to the energy produced and is therefore included in the energy mix.

In both cases, all the benefits of energy recovery (i.e. the avoided impacts of e.g. the Belgian electricity mix or the production of heat from gas) should be estimated in module D. However the impact of module D is currently not included in TOTEM (see section 2.2.3.5)

2.2.3.5. Benefits and loads beyond the system boundaries (module D)

Since the second amendment of the EN 15804, Module D is a mandatory information module and the end-of-life formulae provided in Annex D of the EN 15804+A2 should be used to calculate the net impacts in module D (CEN 2019). The provided formulae and normative guidelines however are still subject to interpretation. Therefore module D has not yet been implemented in TOTEM but will be integrated in future versions.

2.3. Scenarios for defining the building life cycle[18]

Within the environmental assessment of buildings or elements, a number of scenarios (e.g. concerning transport) and, in certain cases, default values (e.g. concerning the service life of components) need to be established. Scenarios that are specific to the present assessment method are given below. The default values for the service life, the type and frequency of cleaning, maintenance and replacement of components and elements are technical data that are based on various literature sources (BCIS 2006; Jacobs et al. 2005; Ten Hagen & Stam 2000; SBR 1998; Perret 1995; den Hollander et al. 1993; Pasman et al. 1993; CSTC et al. 1991; WTCB et al. 2011).

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15 According to EN 15804+A2 §6.2.6, the end-of-life stage includes deconstruction and demolition of the building/element, transport to waste processing (either or not via a sorting plant), waste processing for reuse, recovery and/or recycling and disposal (incineration or landfill), including provision of all transport, provision of materials, products and related energy and water use.

16 According to EN 15804+A2 § 7.2.4.4, NOTE 4: waste incineration with utilisation of energy where the thermal energy efficiency rate is:
≥ 0.60 for installations licensed before 1 January 2009,
≥ 0.65 for installations licensed after 31 December 2008.

17 Various interpretations are possible in case of waste incineration with utilisation of energy.

18 In line with EN 15978:2011 §8.

2.3.1. Scenarios for the product stage (A1-A3)[19]

Next to the specific data from Belgian Environmental Product Declarations (B-EPDs)[20], TOTEM provides a set of generic environmental data for building materials and components based on the Swiss ecoinvent database.

To ensure geographical representativeness for the Belgian context, preference is given to ecoinvent processes that are representative for Western Europe[21]. When no Western European processes are available in the ecoinvent database, Swiss (or global) data records are adapted by replacing the energy flows (i.e. electricity and heat), water flows and material processing by European corresponding processes[22]. These adaptations are only done for the flows included in the production of the analysed product. The energy, water and material processing related flows in the underlying processes (e.g. production of raw materials used in the production process) are not modified to the Western European version. A sensitivity analysis revealed that harmonisation of the underlying processes has no significant influence on the results (Spirinckx 2009).

For raw materials where the import ratio is very significant, specific scenarios have been established for the transport of the raw materials to Belgium. Based on these scenarios, specific processes can then be created for the imported versions of these products. This applies to the following products:

- Bluestone/natural stone plates from Asia (Delem & Spirinckx 2009):
  - 580 km transport by heavy truck from quarry to port in Asia,
  - 19500 km transport by sea-going ship to the Port of Antwerp.
- Timber: in this case, average transport scenarios have been prepared for several large groups (see Table 1). These scenarios are based on the average transport distances from the main countries of origin and their share on the Belgian market (cf. weighted average). Note that the number of kilometres is calculated per m^3 of sawn timber. For the portion of tropical timber transported as roundwood (logs), the necessary conversion factors have been applied (i.e. 2 m^3 roundwood for 1 m^3 of sawn timber) (Delem & Spirinckx 2009).

19 In line with EN 15978:2011 §8.4.

20 www.b-epd.be.

21 We have opted for Western European processes because for most product groups no Belgian data is available and because a certain proportion of products on the Belgian market is imported with mainly only the last production process step happening in Belgium. The latter is based upon an input-output analysis of the Belgian construction sector.

22 For energy consumption during the construction process stage (e.g. blowing of cellulose) and the use stage, we have, however, opted for Belgian-specific processes, e.g. Belgian electricity mix.

In the previous version of MMG with ecoinvent 2.2 LCI data, the transport processes within the production processes were also replaced by a representative Western-European version. However with the introduction of market and transformation processes in ecoinvent 3 and by selecting the transformation process for the generic LCI data, the replacement of transport processes is not needed anymore.

	Heavy truck [km]	Sea-going ship [km]	Barge, inland waterways [km]	Train [km]
Hardwood (42% local, 58% import)				
Local production[a]	125			
Imported tropical timber	350[b]	9900[c]	225	20
Imported non-tropical timber[d]	1280	1010	/	/
Belgian mix[e]	360	2100	45	40
Softwood (60% local, 40% import)				
Local production	50			
Imported softwood[f]	740	1400	/	130
Belgian mix	450	830		75

Table 1: Transport scenarios for different groups of wood.

a Transport from forest to sawmill
b Transport from forest to foreign port
c Weighted average transport distance from foreign ports to Port of Antwerp
d Is partly by truck and partly by truck and boat (including truck transport to the port)
e Average transport based on share of different countries of origin (including local production) on the Belgian market
f Transport from forest in foreign country to distributor in Belgium.

Finally within the first MMG study, for a limited number of products containing a portion of secondary raw materials (steel, glass wool, cellular glass, cellulose, MDF, OSB, concrete and others), it was examined whether the percentage of secondary raw materials adopted on a default basis in the ecoinvent processes differs from Belgian practice. Also the check was made whether the system boundaries and allocation rules for recycling and co-products applied in the ecoinvent LCI data are consistent with the principles of EN 15804 and the established MMG assessment method.

On this basis, it was decided to adapt the product data for concrete to the Belgian practice. In the ecoinvent database, concrete is produced from CEM I cement. In Belgium, however, furnace cement (CEM III A) is commonly used for poured concrete. Therefore, for poured concrete, in the standard ecoinvent process CEM I is replaced for 10% by CEM III B and for 55% by CEM III A[23]. For precast concrete products the default ecoinvent process is used (CEM I-based concrete), because furnace cement is rarely used for this application (due to the need for rapid stripping of precast products from their formwork).

23 Sales of furnace cement in Belgium = 2302 kt, deliveries for ready-mixed concrete + deliveries to construction sites + in the trade = 3522 kt. 2302/3522=0.65 (Febelcem 2008).

2.3.2. Scenarios for the construction process stage (A4-A5)[24]

The construction process stage mainly consists of the transport of building materials from factory to building site, as well as a standard % of construction waste that is produced on the building site. A limited number of construction activities (e.g. excavation, energy-related processes, and specific emissions at the construction site) are also included in Module A5.

2.3.2.1. Scenario for the transport of materials from factory to building site

Means of transport and distances

For the transport of construction materials from factory to building site default transport scenarios have been defined for main product groups (see Table 3 on the next page). For each product group or material category, average transport distances and means of transport have been determined according to whether the product is transported directly from the factory to the site, or from the factory to an intermediate supplier and from there to the building site. The figures are based on the default transport scenarios of the B-PCR (NBN 2017).

Load factor

For the calculation of the environmental impacts associated with the transport of materials or waste, we have used the default LCI data from ecoinvent. The LCI data in ecoinvent are given per tkm for different vehicle types (LCI data for carrying 1 ton over a distance of 1 km with a particular vehicle) and were calculated based on average European load factors (see Table 2).

Lorry size class [tons]	Average load factor [tons]	Gross vehicle weight [tons]
3.5-7.5	0.98	4.98
7.5-16	3.29	9.29
16-32	5.79	15.79
>32	15.96	29.96

Table 2: Load factors and gross vehicle weights assumed for calculating the environmental impact per tonne-kilometre for different means of transport (ecoinvent 2019).

24 In line with EN 15978:2011 §8.5.

Product group/ Material category	Transport route		Means of transport from							Average transport distance from		
	% directly from factory to site	% via an inter-mediary supplier	factory to site			factory to supplier	supplier to site			factory to site [km]	factory to supplier [km]	supplier to site [km]
			Lorry 16-32 ton (EURO 5)	Lorry 7.5-16 ton (EURO 5)	Lorry 3.5-7.5 ton (EURO 5)	Lorry >32 ton (EURO 5)	Lorry 16-32 ton (EURO 5)	Lorry 7.5-16 ton (EURO 5)	Lorry 3.5-7.5 ton (EURO 5)			
Bulk materials for structural work (e.g. cement, sand, gravel, ...)	75%	25%	100%	0%	0%	100%	90%	10%	0%	100	100	35
Poured concrete	100%	0%	100%	0%	0%	n/a	n/a	n/a	n/a	100	100	35
Prefabricated products for structural work (e.g. beams, columns, ...)	100%	0%	100%	0%	0%	100%	100%	0%	0%	100	100	35
Loose products (e.g. blocks, bricks, roof tiles, plasterboard, ...)	40%	60%	100%	0%	0%	100%	85%	15%	0%	100	100	35
Insulation	40%	60%	100%	0%	0%	100%	85%	15%	0%	100	100	35
Finishing products: floor coverings (e.g. carpet, linoleum, ceramic tiles, ...)	10%	90%	90%	10%	0%	100%	90%	10%	0%	100	100	35
Finishing products: plasters (e.g. gypsum plaster, external plaster, ...)	40%	60%	50%	50%	0%	100%	50%	50%	0%	100	100	35
Finishing products: cabinet work (e.g. window frames, stairs, ...)	90%	10%	50%	45%	5%	100%	40%	50%	10%	100	100	35
Finishing products: paints and varnishes	10%	90%	0%	100%	0%	100%	0%	80%	20%	100	100	35
Installations (e.g. heating boiler, radiators, ventilation, ...)	0%	100%	n/a	n/a	n/a	100%	0%	80%	20%	100	100	35

Table 3: Default scenarios for the transport of building materials from factory to building site (NBN 2017).

2.3.2.2. Scenario for material losses during the construction process stage[25]

During the construction process stage a fraction of the materials is always lost (e.g. during storage or cutting to size). The extent of the loss is, however, largely dependent on the nature of the construction (e.g. size, type or how far it is designed with standard sizes), the product group (e.g. materials with limited service life, custom manufactured materials or materials needing to be cut to size on-site), the care with which materials are handled, etc[26]. In the absence of detailed data for each material and each application, but also for practical reasons, a global add-on of 5% has been applied in the model regardless of the product group.

2.3.3. Scenarios regarding the number of replacements and maintenance during the use stage (B4 + B2)[27]

When the service life of components is shorter than the service life of the building in which they are used, replacements will be necessary in order to guarantee the technical and functional performance of the building. The number of replacements of a component over the service life of the building is obtained by dividing the service life of the building by the service life of the component and reducing this result by 1 (the initial installation). Where the result is an integer, this is the number of replacements of the component. For example, for a window with a service life of 30 years and a building with a service life of 60 years, the number of replacements is equal to (60/30)-1, which corresponds to 1 replacement (at year 30).

It can also happen, however, that the result of this calculation is not an integer. For example, if the service life of the window would be 25 years instead of 30. The number of replacements becomes (60/25)-1=1.4. In this case, there are two possible approaches: either the window is replaced after 25 years and after 50 years or it can be assumed that the owner will no longer replace the windows after 50 years because this is too close to the end of the service life of the building for such a (large) investment.

To ensure an unambiguous approach, the concept of a "suspension period" is introduced. The suspension period is defined as the minimum number of years separeting the intervention from another intervention. The following rules are applied:

- If the intervention is required for safety or comfort reasons, the suspension period is 1, which means that the intervention will always occur, even if the remaining expected service life is one year.
- If the intervention is required for aesthetic reasons only (mainly finishes), a suspension period equal to half the frequency of the occurence is considered by default. For example, interior plastering has a replacement frequency of 40 years and a suspension period of 20 years (40/2). In the case of a (fictive) building service life of 50 years, the plaster will not be replaced after 40 years as the remaining service life (10 years) is shorter than the suspension period.

25 In line with EN 15978:2011 §9.3.1.

26 Depending on the type of building and construction materials, the weight percentage of the quantities purchased per project usually varies between 1 and 10% (FVSB 1997).

27 In line with EN 15978:2011 §9.3.3.

This principle of suspension period is applied in a hierarchical way:

- How long before the end of life of a building, “elements” will still be replaced;
- How long before the end of life of an element, “components” will still be replaced;
- How long before the end of life of a component, a “big maintenance” will still be organised (a “big maintenance” will never happen in the year of the end of the life of the concerning component, element or building);
- How long before the organisation of a big maintenance, a “small maintenance” will still be organised (a "small maintenance” will never happen in a year when a big maintenance is done or at the end of life of the concerning component, element or building).

2.3.4. Scenarios for operational energy use during the use stage (B6)[28]

In the current version of TOTEM a simplified approach based on the Equivalent Heating Degree Days (EHDD) method has been implemented to calculate the operational energy use for heating due to transmission losses and ventilation losses. This approach is particularly appropriate for the early design stages as most input data for an Energy Performance of Buildings (EPB) calculation are still lacking. In a future version of TOTEM a more detailed approach based on input from the EPB software will be included.

2.3.4.1. Heating energy use at building level

For the analysis at building level, the environmental impact of the yearly heating energy use resulting from both transmission losses through the building skin and ventilation losses is estimated via the following formula:

yearly environmental impact of heating energy use at building level =

$$(U_m \times S + V \times n_{tot} \times 0.36) \times DD_{eq} \div (\eta_{distribution} \times \eta_{emission} \times \eta_{control}) \times EI_{heat}$$

With:

- U_m = the average heat transfer coefficient in W/m²K;
- *S* = the heat loss surface of the building in m²;
- *V* = the heated volume of the building in m³;
- n_{tot} = the total air change per hour in h^{-1}, calculated by taking the sum of the air changes resulting from the controlled ventilation (n_{vent}) and (uncontrolled) air infiltration (n_{inf}) which are calculated in accordance with the calculation method for the primary energy use of residential units (Flemish Government 2017). For the air infiltration rate, the default value of 12 m³/h·m² is assumed;

28 In line with EN 15978:2011 §8.6.5.

- DD_{eq} = 1200 equivalent degree-days[29] (Allacker 2010) multiplied with ((24×60×60)/10⁶) to convert days into seconds and joules into mega joules;
- $\eta_{distribution}$ = a distribution efficiency of 0.95, based on a distribution length between 2 and 20 m of an individual central heating system (VEA 2013);
- $\eta_{emission}$ = an emission efficiency of 0.96, based on a situation in which radiators and floor heating is used for heat emission (VEA 2013);
- $\eta_{control}$ = a control efficiency of 0.94, based on a heating control system with a room thermostat, thermostatic valves and no outdoor temperature sensor (VEA 2013);
- EI_{heat} = the environmental impact of heat produced by a condensing modulating natural gas boiler (<100 kW) with a production efficiency (with reference to the lower heating value) of 102% (Villigen and Uster 2007).

For the electricity consumption of the condensing modulating natural gas boiler, the Belgian electricity mix is used (i.e. ecoinvent process: "Electricity, low voltage {BE}| market for | Alloc Rec, U"). Ecoinvent does not offer any Belgian process for natural gas from a low pressure distribution network, but this is constructed by taking the available Swiss data record "Natural gas, low pressure {CH}| market for | Alloc Rec, U", and replacing the underlying Swiss processes by corresponding Belgian processes.

2.3.4.2. Heating energy use at element level

For the analysis at element level, only the heating energy use due to transmission losses is taken into account. This is calculated with the following formula:

yearly environmental impact of heating energy use at element level =

$$U_{EL} \times S_{EL} \times DD_{eq} \div (\eta_{distribution} \times \eta_{emission} \times \eta_{control}) \times EI_{heat}$$

With:

- U_{EL} = the heat transfer coefficient of the building element in W/m²K;
- S_{EL} = the surface area of the element in m².

2.3.5. Scenarios regarding the end-of-life stage of building materials (C1-C4)

2.3.5.1. Scenario for deconstruction and demolition

Given that deconstruction often consists exclusively of manual operations, there are no environmental impacts attributed to the non-destructive removal of building materials. Demolition processes are however associated with consumption of energy and emissions. The composition of the materials and the method of connecting with other materials/components determined the type of demolition process to be applied (Doka 2009).

29 The lower the K-value of a building, the lower the number of equivalent degree-days. 1200 equivalent degree-days correspond to a well-insulated dwelling and an average indoor temperature of 18°C.

2.3.5.2. Basis for the transport and final disposal of construction and demolition waste

With the exception of soil, all construction and demolition waste, whether or not sorted on site, is transported from the building/demolition site to a sorting facility/ collection point (e.g. metal dealer or crusher) and from there it is eventually further dispatched to recycling, reuse facility, incineration, energy recovery or landfill. This assumption and the end-of-life scenarios per waste cateory as given in Table 4 (on page 30 and 31) are based on the B-PCR (NBN 2017).

For materials that are going to be recycled, the boundary between the current life cycle and the next life cycle (i.e. material incorporating secondary raw materials) corresponds to the point where the materials are considered no longer as waste but as a secondary raw material (i.e. where the end-of-waste status reached)[30]. For all materials that are recycled or reused, the default assumption is that the "end-of-waste" status is attained at the exit gate of the sorting facility or collection point. The fact is that based on the available information, the precise point at which waste turns into secondary raw materials is difficult to determine for each separate product. The consequence of this assumption is that the impact up to and including the sorting facility (or for the stony fraction up to and including the crusher) is allocated to the waste producing product, but that all subsequent impacts (i.e. of transport from the sorting facility to the recycling facility and the impact of the recycling process itself) for these fractions lie outside the system boundaries and are therefore allocated to the material for which the secondary materials are used[31]. The environmental impact of sorting on the site is neglected.

Based on the B-PCR, the following processes are taken into account when modelling the sorting of materials in a sorting facility (i.e. the fraction not sorted on the site itself):

- Electricity use (Belgian low voltage electricity mix) for mechanical sorting processes:
    - Sorting plant without a crusher: 0.0022 kWh/kg material (for materials sorted out prior to the crusher (e.g. mineral wool ,boards, ...) or causing no resistance in crushing (e.g. paints);
    - Sorting plant with a crusher: 0.0037 kWh/kg material (e.g. concrete materials);
- Diesel for loading and unloading waste: 5.9 MJ diesel burned in a hydraulic digger/ m^3 bulk volume of waste[32]
- Sorting plant infrastructure including land occupation and transformation and energy for administrative facilities: 1×10^{-10} plant/kg material (NBN 2017).

Given that fuel consumption for loading and unloading depends on the density of the material, a different sorting process is modelled per waste type.

30 In line with EN 15804+A2 §6.3.5.5.

31 An advantage here is that the chosen system boundaries match those used in putting together the ecoinvent database. This avoids the risk of double counting or failing to factor in certain impacts.

32 As an approximation, the bulk density of waste can be calculated as 0.9 x material density.

The general modelling of the waste processing stage (after demolition or dismantling for replacement) is shown schematically in Figure 5. By way of illustration, in Figure 6, Figure 7 and Figure 8 we also give the specific modelling for concrete, metals and aerated autoclaved concrete.

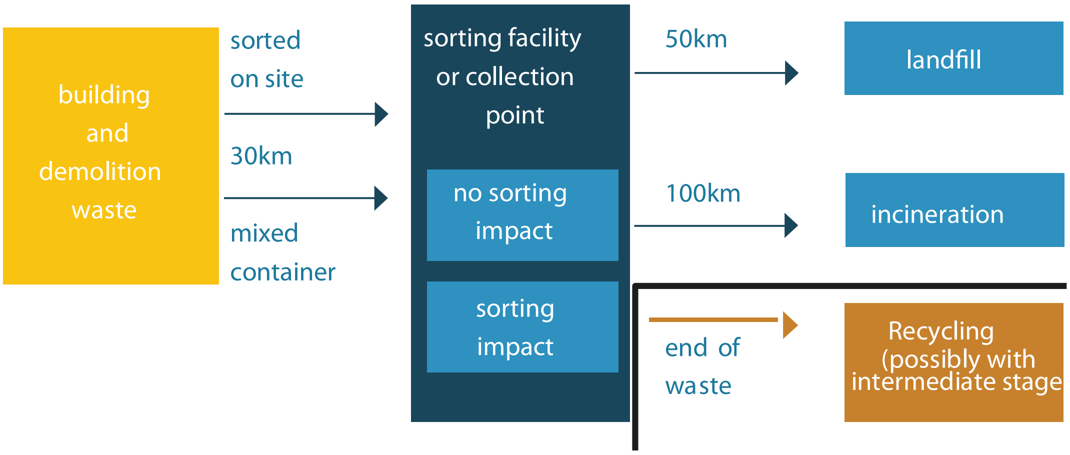

Figure 5: General modelling of waste processing after deconstruction or demolition. Impacts falling within the system boundaries are shown in blue and impacts outside the system boundaries are shown in orange.

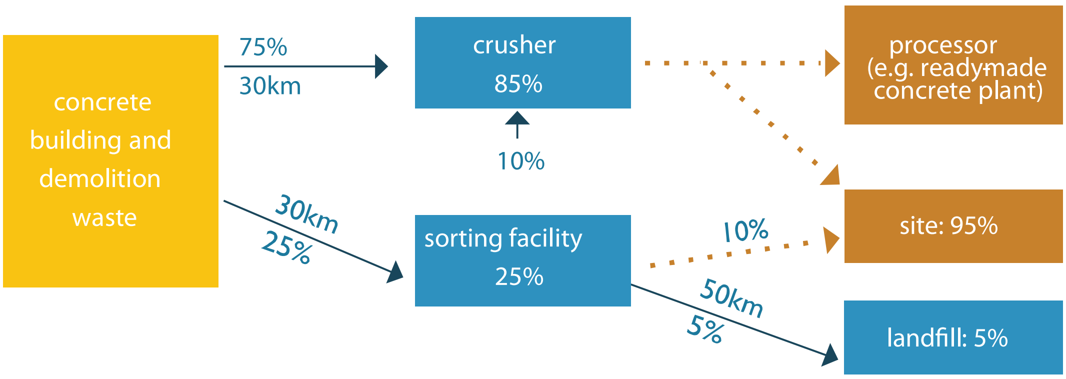

Figure 6: Specific modelling for concrete construction and demolition waste. 75% of concrete waste is sorted on site and then goes directly to a crusher, while the remaining 25% goes to a sorting facility. 10% of the inert waste that passes via a sorting facility, after sorting goes directly to a building site or a processor (sieve sand), but 10% still needs to be crushed after the sorting process for use as a secondary raw material. Transport between crusher and sorting facility in principle lies within the system boundaries, but is, however, neglected. In practice, some sorting facilities crush the rubble themselves (using their own or a mobile crusher). In this way transport between crusher and sorting facility is relatively limited (also in distance) (Jacobs et al 2005). Impacts falling within the system boundaries are shown in blue and impacts outside the system boundaries are shown in orange.

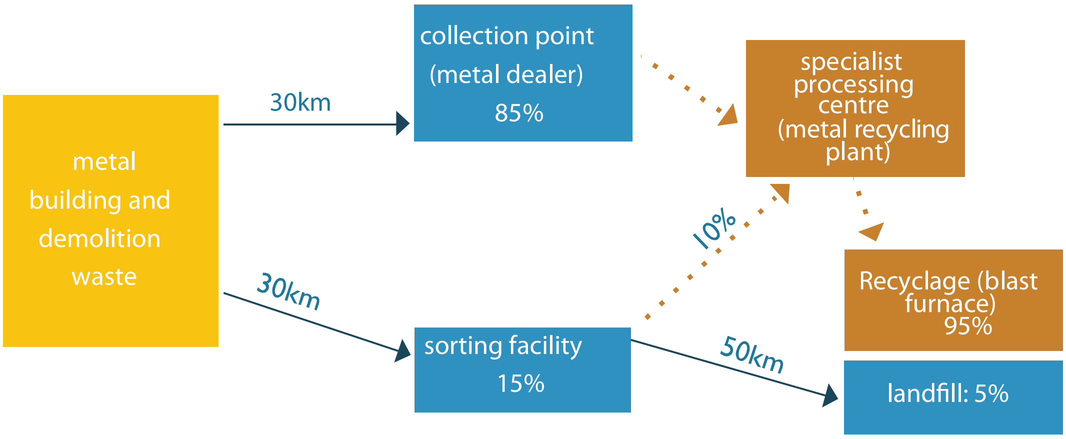

Figure 7: Specific modelling for metallic building and demolition waste. 85% of the metal waste is sorted on the building site and 15% is mechanically sorted in a sorting facility. While in reality the end-of-waste status should probably be situated on the far side of the specialised processing centre, by convention it is located at the gate of the collection point or sorting facility. Note that part of the 85% sorted on the building site may still end up passing through a sorting facility. But since in this case there is no further need for mechanical sorting, for the sake of clarity it is classified under "collection point".

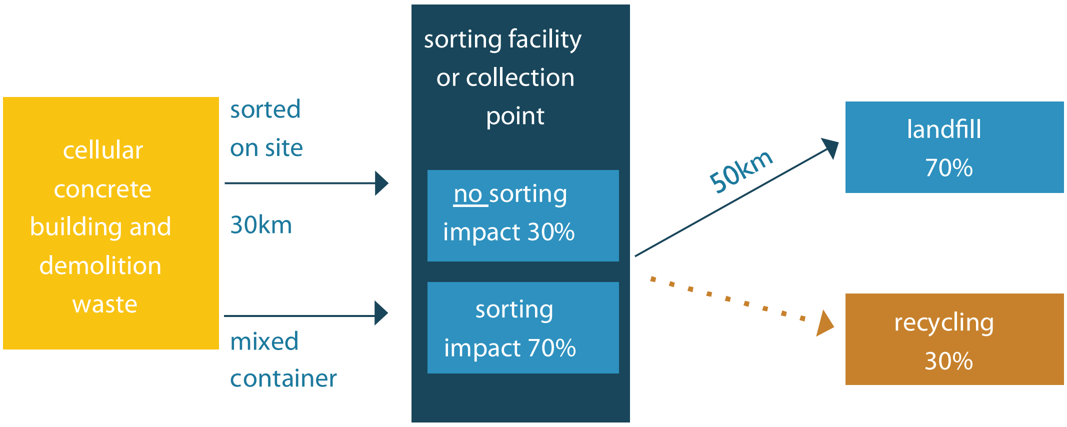

Figure 8: Specific modelling for aerated autoclaved concrete waste from construction and demolition activities. 30% of the aerated autoclaved concrete waste is sorted directly on the building site, while the rest is mechanically sorted in a sorting facility. For the portion sorted on the building site, the collection point can be a sorting facility or a storage site, where the contractor groups his waste and then takes it directly to the recycling facility. While in reality, the end-of-waste status ought to be attained at the latter facility, by convention it is located at the gate of the sorting facility (or collection point).

In the absence of clear data on the efficiency of Belgian incinerators and in the spirit of the principles of the European Waste Framework Directive (EU 2008), it is assumed by convention that the impact of the incineration of construction and demolition waste falls within the considered system boundaries.

Consequently, the environmental damage is assigned entirely to the material incinerated and not to the energy produced.

2.3.5.3. Transport of construction and demolition waste

Based on the B-PCR, the following default scenario is used for the transport of construction and demolition waste:

Transport distances:

- From demolition site to sorting facility or collection point: 30 km
- From collection point or sorting facility to landfill: 50 km
- From collection point or sorting facility to incinerator: 100 km

Means of transport:

- 100% with lorry 16-32 ton (EURO 5)

2.3.5.4. Final processing of construction and demolition waste

Table 4 gives the assumed destination, as well as the proportion of waste sorted directly at the building site (% by weight) of the 37 different waste categories which are based on the default end-of-life scenarios of the B-PCR (NBN 2017).

2.3.6. Scenarios regarding existing, reused and demolished components

In the current version of TOTEM, it is possible to indicate whether a component is newly built, existing, reused or demolished. The impact of the different statuses is explained in the subsequent sections.

2.3.6.1. Existing components in a refurbishment project

When modelling an element in TOTEM, it is possible to indicate whether a component already exists. In that case, only the environmental impact linked to the use stage (module B) and end-of-life (module C) will be taken into account for its application in a building over a full service life of 60 years. E.g. in case a component is originally built in 1980 and the component is retained without any alterations nor relocations after a building refurbishment realised in 2021, only the environmental impact of the existing component over a period of 60 years for cleaning, maintenance, replacement, and end-of-life is considered. The impacts due to production (module A) will be zero for the existing component.

2.3.6.2. Reused components within the project or from outside the project

In addition to existing components, components can also be modelled as reused after disassembly from a previous use. This could be reused "in situ" meaning that the reused component is re-installed in the same project after being disassembled, thus without the need of transport from another place to the construction site. In this case, the environmental impact of the installation process (module A5), use stage (module B) and end-of-life (module C) will be considered for its application in a building over a full service life of 60 years.

The other possibility is to indicate that a components is reused "ex situ" meaning that the component is installed in the considered project after being disassembled from another project, thus transported from another place to the construction site. In that case, the environmental impact of the transport (Module A4), installation process (module A5), use stage (module B) and end-of-life (module C) will be taken into account for its application in a building over a full service life of 60 years.

2.3.6.3. Demolition of existing components in a refurbishment project

The status "demolished" allows to model existing components which are demolished in the context of a refurbishment. In that case, the environmental impact from the demolition, waste transport, waste processing and disposal is taken into account and reported in the before use stage (module A)

Main category	Waste category	Landfill	Incineration[a]	Reuse	Recycling	Sorted on building site[b]
Stony & glass	Bricks, roof tiles	5%	0%	0%	95%	75%
	Bulk materials (e.g. sand, gravel, expanded clay grains)	5%	0%	95%	0%	90%
	Concrete	5%	0%	0%	95%	75%
	Flat glass	5%	0%	0%	95%	70%
	Other stony waste (e.g. tiles, natural stone, slates, sand-lime blocks)	5%	0%	0%	95%	75%
	Porcelain and ceramics (e.g. toilet, bath, washbasin)	15%	0%	0%	85%	75%
Wood	Chemically treated, impregnated wood (e.g. railway sleepers, wood used for carports, outdoor playsets, garden screens)	0%	100%	0%	0%	40%
	Composite wood products (e.g. fibreboards (like plywood, chipboard, OSB, MDF), veneer, laminate)	0%	95%	0%	5%	40%
	Surface treated, solid wood (e.g. painted or varnished (like window frames, solid parquet))	0%	85%	0%	15%	40%
	Untreated, uncontaminated wood (e.g. roofs, structures, formworks, auxiliary timber)	0%	25%	0%	75%	40%
Metals	Metals: iron, steel, non-ferro (copper, brass, aluminium, lead, zinc, tin)	5%	0%	0%	95%	85%
Packaging (on construction site)[c]	EPS packaging	10%	30%	0%	60%	50%
	Pallets	0%	40%	20%	40%	50%
	Paper and cardboard packaging	0%	5%	0%	95%	50%
	Plastic films packaging	5%	60%	0%	35%	50%
Insulation materials	Mineral insulation materials (e.g. stone wool, glass wool)	50%	50%	0%	0%	0%
	Organic insulation materials (e.g. vegetable fibres (like wood, coconut, hemp, flax), cellulose (in bulk or blankets), sheep wool, cork (in bulk or boards))	5%	95%	0%	0%	0%
	Synthetic insulation materials (e.g. polyurethane (PUR), polyisocyanurate (PIR), extruded polystyrene (XPS), phenolic foam, expanded polystyrene (EPS))	5%	95%	0%	0%	0%
Fibre cement products	Fibre cement products (e.g. fibre cement slabs or slates)	100%	0%	0%	0%	75%

Table 4: Waste scenarios for the 37 waste categories considered in the B-PCR (NBN 2017).

a Destination of the waste by product group (% by weight calculated on the total amount of waste per product group: e.g. 5% of brick waste is landfilled and 95% is recycled).

b This represents the percentage (by mass) of the waste that is sorted directly at the building site. The remaining share is removed from the construction/demolition site in a mixed container and subsequently mechanically sorted (at sorting facility), e.g. 30% of cellular concrete waste is sorted directly on site and 70% is removed, mixed in with other wastes.

c As already mentioned, EOL processing of packaging materials is not considered, as it is assumed that the majority of generic data records does not include packaging.

Main category	Waste category	Landfill	Incineration[a]	Reuse	Recycling	Sorted on building site[b]
Gypsum elements	Gypsum elements (e.g. gypsum blocks, gypsum (fibre/plaster)boards)	80%	0%	0%	20%	50%
Aerated / cellular concrete	Aerated autoclaved concrete (e.g. elements, blocks)	70%	0%	0%	30%	30%
Bitumen	Bitumen (e.g. bituminous roofing, vapour barrier, waterproofing membrane)	85%	5%	0%	10%	0%
Polyolefins (PP, PE)	Polyolefins (PP, PE) (e.g. kraft paper or polyethylene (PE) vapour barrier, ducts), excluding packaging	10%	85%	0%	5%	0%
Elastomers	Elastomers (e.g. EPDM roofing)	90%	0%	0%	10%	0%
PVC	PVC cabling (e.g. electric cables and wire insulation)	10%	40%	0%	50%	0%
	PVC pipes (e.g. for sewerage)[c]	10%	30%	0%	50%	0%
	PVC profiles (e.g. window frames)	10%	45%	0%	45%	0%
	PVC sheets (e.g. PVC roofing, waterproofing membranes (like for swimming pools))	20%	65%	0%	15%	0%
Supple flooring	Supple flooring (e.g. linoleum, fixed carpet, vinyl)	0%	95%	0%	5%	0%
Finishing layers[d]	Finishing layer fixed to stony waste (e.g. plaster (like gypsum plaster, calcareous plaster, loam plaster), paint, coatings, adhesives)	5%	0%	0%	95%[e]	0%
	Finishing layer fixed to wood, plastic or metal (e.g. paint, coatings, adhesives)	0%	100%[f]	0%	0%	0%
Remaining waste	Combustible remaining waste	0%	100%	0%	0%	0%
	Non-combustible remaining waste	100%	0%	0%	0%	75%
Other hazardous waste	Aerosols and kits (e.g. PU foam, silicones)	0%	100%	0%	0%	100%
	Asbestos (bounded, unbounded)	100%	0%	0%	0%	100%
	Fluorescent lamps	30%	0%	0%	70%	100%
	Liquid construction site waste (e.g. paints, adhesives, resins, form mould oil, white spirit)	0%	75%	0%	25%	100%

Continuation of Table 4: Waste scenarios for the 37 waste categories considered in MMG based on the B-PCR (NBN 2017).

a Destination of the waste by product group (% by weight calculated on the total amount of waste per product group: e.g. 5% of brick waste is landfilled and 95% is recycled).

b This represents the percentage (by mass) of the waste that is sorted directly at the building site. The remaining share is removed from the construction/demolition site in a mixed container and subsequently mechanically sorted (at sorting facility), e.g. 30% of cellular concrete waste is sorted directly on site and 70% is removed, mixed in with other wastes.

c 10% remains in the ground, which is why the columns does not sum to 100%

d Regards a relative small amount of material that is fixed to other materials.

e The finishing layer follows the same route as its carrier (e.g. concrete, brick). Thus the finishing layer will be recycled together with the debris when the carrier is crushed into granulates (open loop recycling). It needs to be mentioned that gypsum plaster is a hampering substance which decreases the quality of the stony fraction (cf. B-PCR).

f The finishing layer follows the same route as its carrier. A finishing layer on wood will end up with the powder fraction of the crushed wood, which will be incinerated. Recycling of metals happens at high temperatures so in practice the finishing layer is also incinerated (cf. B-PCR).

2.4. Life cycle inventory: data collection[33]

2.4.1. Data quality and data sources generic product data[34]

The generic data is taken from the Swiss ecoinvent database (version 3.6). This choice was based on the following criteria:

- Completeness: over 13.300 LCI datasets, i.e. processes, available including various building materials.
- Transparency: for all data in the database, detailed reports are available with all necessary background information.
- Adaptability/modularity: underlying processes are almost always visible (e.g. electricity use for production) and can be adjusted as desired. Furthermore, the LCI data for production (cradle to gate), transport and waste processing all exist separately in the database, so that processes can be combined according to scenarios that are representative of the Belgian context.
- Reliability: data are all checked before being entered in the database. Availability of information relating to the uncertainty of the data.
- Regularly updated (version 3.6 was released in 2019).
- Availability of data representative for Western Europe and Belgium: the ecoinvent database mainly contains data representative of Western Europe or Switzerland, and some specific Belgian processes (e.g. electricity mix). Where only Swiss data are available, the non-aggregated data can be relatively easily adapted to the Belgian context (see section 2.3.1).

In accordance with EN 15804+A2 § 6.3.8 regarding data quality requirements, the time period over which the environmental impacts are assessed is 100 years. However, the standard also states that "a longer time period shall be used if relevant". MMG/TOTEM deviates from this latter point, as the relevance of a longer time period is not the same for all processes and impact categories. Therefore all long term emissions have been excluded for the transparency and not to further complicate the calculations.

2.4.2. Data quality and data sources specific product data

Since October 2020, users can also use specific environmental data from B-EPDs that have been provided by manufacturers via the federal Belgian EPD programme and allowed by manufacturers for integration in TOTEM. The data quality of the integrated B-EPDs is covered by the mandatory verification process of the B-EPD programme (www.b-epd.be).

33 In line with EN 15978:2011 §9.4.

34 In line with EN 15978:2011 §9.4.2, EN 15804+A2 §6.3.7 and TR 15941:2010.

2.5. Life cycle impact assessment[35]

During the Life Cycle Impact Assessment (LCIA) of an LCA, the significance of potential environmental impacts is assessed based on the results of the Life Cycle Inventory analysis (LCI). For this, the inventory data are associated with specific environmental impacts. In this way, the overall environmental impact of a building/element is given on the basis of an environmental profile.

2.5.1. Selection procedure

Determining the particular environmental profile calls for a substantiated selection of both the environmental impact indicators and the associated impact assessment methods. For this selection the CEN/TC 350 standard EN 15804+A2 is followed in order to stay in line with the existing European initiatives in the field of environmental assessment of buildings and building products and to support integration of specific B-EPD data in TOTEM.

Besides individual environmental impact scores, the results are also communicated, at the request of the 3 regional authorities, in the form of an aggregated environmental impact score. As explained further in this chapter, the proposed weighting (since July 2021) is based on the PEF weighting approach developed by the JRC (Sala et al 2018). The CEN/TC 350 standards do not consider weighting nor aggregation.

The 3 regional authorities and the authors of this study warn for any changes in standards or recommendations that would be in force after this writing (December 2021).

2.5.2. Assessment of individual environmental impact scores

Since October 2015 the CEN/TC 350 has been working on an alignment of the EN 15804 standards with the PEF methodology. This resulted in the second amendment of the standard, i.e. EN 15804+A2. Compared to the previous version, the number of mandatory environmental impact indicators in EN 15804+A2 was extended to cover a wider range of environmental issues. This new version includes 19 impact indicators which can be grouped in 12 main impact categories. In July 2021, the new set of indicators has been integrated in the MMG assessment framework and implemented in the TOTEM tool. An overview of the environmental impact categories, impact indicators and impact assessment methods is given in Table 5 on the next page.

35 In line with EN 15978:2011 §11.

Main environmental impact category	Environmental impact indicator	Unit	Model impact method
Climate change	Climate change - total[a]	kg CO_2 eq.	Baseline model of 100 years of the IPCC based on IPCC 2013
	Climate change - fossil	kg CO_2 eq.	Baseline model of 100 years of the IPCC based on IPCC 2013
	Climate change - biogenic	kg CO_2 eq.	Baseline model of 100 years of the IPCC based on IPCC 2013
	Climate change - land use and land use change	kg CO_2 eq.	Baseline model of 100 years of the IPCC based on IPCC 2013
Ozone depletion	Ozone depletion	kg CFC 11 eq.	Steady-state ODPs, WMO 2014
Acidification	Acidification	mol H+ eq.	Accumulated Exceedance, Seppälä et al. 2006, Posch et al., 2008
Eutrophication	Eutrophication - aquatic freshwater	kg P eq.	EUTREND model, Struijs et al., 2009b, as implemented in ReCiPe
	Eutrophication - aquatic marine	kg N eq.	EUTREND model, Struijs et al., 2009b, as implemented in ReCiPe
	Eutrophication - terrestrial	mol N eq.	Accumulated Exceedance, Seppälä et al. 2006, Posch et al., 2008
Photochemical ozone formation	Photochemical ozone formation	kg NMVOC eq.	LOTOS-EUROS ,Van Zelm et al., 2008, as applied in ReCiPe
Depletion of abiotic resources	Depletion of abiotic resources - minerals and metals	kg Sb eq.	CML 2002, Guinée et al., 2002, and van Oers et al. 2002.
	Depletion of abiotic resources - fossil fuels	MJ, net calorific value	CML 2002, Guinée et al., 2002, and van Oers et al. 2002.
Water use	Water use	m^3 world eq. deprived	Available WAter REmaining (AWARE) Boulay et al., 2016
Particulate matter	Particulate matter emissions	Disease incidence	SETAC-UNEP, Fantke et al. 2016
Ionizing radiation	Ionizing radiation - human health	kBq U235 eq.	Human health effect model as developed by Dreicer et al. 1995 update by Frischknecht et al., 2000
Eco-toxicity	Eco-toxicity - freshwater	CTUe	Usetox version 2 until the modified USEtox model is available from EC-JRC
Human toxicity	Human toxicity - cancer effect	CTUh	Usetox version 2 until the modified USEtox model is available from EC-JRC
	Human toxicity - non-cancer effects	CTUh	Usetox version 2 until the modified USEtox model is available from EC-JRC
Land use	Land use related impacts/soil quality	dimensionless	Soil quality index based on LANCA

Table 5: Overview of the environmental impact indicators including the units and environmental impact assessment methods (CEN 2019).

a The total climate change is the sum of: fossil, biogenic and land use and land use change climate change.

2.5.3. Assessment of the aggregated environmental score

The intention of assessing the environmental performance of buildings, that is to simplify the identification and selection of environmentally friendly materials and components, calls for an unambiguous decision model. A multiplicity of individual impact scores is rarely a good basis for decision-making. For this reason and at the request of the 3 regional authorities, the possibility is offered of viewing the environmental profile of a building (element) via an aggregated score.

In the context of the update of EN 15804+A2, it was decided to move from the previous monetisation approach and to apply the PEF weighting approach, mainly to align TOTEM as much as possible with the European developments on LCA.

The PEF weighting approach consists of two steps:

1. Normalisation: the characterised values are normalised by dividing them with normalisation factors that are expressed as impact per capita per year (based on a global value in reference year 2010). TOTEM applies the normalisation factors proposed by the European Platform on Life Cycle Assessment (EPLCA 2019).
2. Weighting: the normalised values are weighted by multiplying them with weighting factors (see box below) to reflect the perceived relative importance of the environmental impact categories considered. TOTEM applies the weighting factors by Sala et al (2018).

Table 6 provides an overview of the normalisation and weighting factors. After normalisation and weighting the scores can be aggregated to one single score. The unit of the single score in TOTEM is given in dimensionless milli-points (mPt). In the results tables of TOTEM an "aggregation factor" per impact indicator is given based on the combination of the normalisation and weighting factors of PEF. These aggregation factors are calculated by multiplying the inverse of each normalisation factor with its corresponding weighting factor and 1000 for the conversion from Pt to mPt (e.g. the aggregation factor of the indicator climate change is 0.02601 ((1 ÷ 8.10E+03) × 0.2106 × 1000).

PEF weighting factors

The weighting factors proposed by the JRC (Sala et al 2018) are calculated based on a combination of three weighting sets:

1. **a panel weighting set derived from a public survey (accounted for 25%),**
2. **a panel weighting set derived from a survey among LCA experts (accounted for 25%), and**
3. **a hybrid approach combining evidence-based criteria (e.g. spread, time span, reversibility of impacts…) and expert judgement (accounted for 50%).**

To account for the robustness of the impact indicators, a correction factor (on a scale from 0.1 to 1) is then applied on the weighting factors to decrease the importance of impact categories with a low robustness.

Environmental impact indicator	Unit	Normalisation factor [unit/ person·year] (EPLCA 2019)	Weighting factor [%] (Sala et al 2018)
Climate change - total[a]	kg CO_2 eq.	8.10E+03	21.06
Climate change - fossil	kg CO_2 eq.	-	-
Climate change - biogenic	kg CO_2 eq.	-	-
Climate change - land use and land use change	kg CO_2 eq.	-	-
Ozone depletion	kg CFC 11 eq.	5.36E-02	6.31
Acidification	mol H^+ eq.	5.56E+01	6.20
Eutrophication aquatic freshwater	kg P eq.	1.61E+00	2.80
Eutrophication aquatic marine	kg N eq.	1.95E+01	2.96
Eutrophication terrestrial	mol N eq.	1.77E+02	3.71
Photochemical ozone formation	kg NMVOC eq.	4.06E+01	4.78
Depletion of abiotic resources - minerals and metals	kg Sb eq.	6.36E-02	7.55
Depletion of abiotic resources - fossil fuels	MJ, net calorific value	6.50E+04	8.32
Water use	m^3 world eq. deprived	1.15E+04	8.51
Particulate matter emissions	Disease incidence	5.95E-04	8.96
Ionizing radiation, human health	kBq U235 eq.	4.22E+03	5.01
Eco-toxicity (freshwater)	CTUe	4.27E+04	1.92
Human toxicity, cancer effect	CTUh	1.69E-05	2.13
Human toxicity, non-cancer effects	CTUh	2.30E-04	1.84
Land use related impacts/ Soil quality	dimensionless	8.19E+05	7.94

Table 6: Overview of the normalisation and weighting factors of the environmental impact indicators.

a The total climate change is the sum of: fossil, biogenic and land use and land use change climate change.

2.6. Synthesis

The described MMG assessment method is characterised as follows:

Integrated approach:

- So as to have a comprehensive picture of the environmental profile of materials, components and elements (and higher), the entire life cycle has been taken into account (cf. "cradle-to-grave" LCA).
- Similarly, an extensive range of environmental indicators is implemented (19 at individual level, 16 at weighted value level and 1 at aggregated level) based on the principles of life cycle assessment (LCA) and recent European standards and frameworks.
- For this we have selected environmental indicators, for which the contribution to specific environmental impacts is assessed on a quantitative and scientifically founded basis.
- The different assessment levels (based on individual, weighted or aggregated scores) allow the detailed underpinning of the environmental profile of components, elements, and buildings, as well as decision-making, for example when comparing different variants of elements or buildings. In this way the assessment method is available to various players, from producers and industry organisations to users/developers, designers, contractors and environmental public authorities.
- In the first instance we have used an extensive database of generic LCIs, harmonised as far as possible to the Belgian building context. Complementary to this, this assessment method permits the use of manufacturer and sector-specific LCI data by integrating B-EPDs in TOTEM.
- Realistic scenarios have been taken into account for the transport of materials and components to the building site and to the EOL processing site, for the type of EOL processing and for the service life of the building.

Modular structure:

- The underlying environmental data are compiled by life cycle stage and can be viewed separately (cf. EN 15804+A2).
- The underlying environmental data are hierarchically arranged: i.e. material – component – element – building…
- Environmental scores are viewed on 3 levels: by individual indicator, by weighted value indicator and also as aggregated single score.

Extendable/adjustable:

- The transparent reporting of the assessment method (and the modelling thereof) makes room for future modifications or extensions by third parties. In this way, with better understanding of environmental effects, changes in standards and construction practices, etc., improved underlying LCI data and scenarios, as well as weighting methods can be integrated into the assessment method.
- To obtain better construction-related insights, the assessment method can also be extended to district level.

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Summary
Since February 2018 the online tool TOTEM (Tool to Optimise the Total Environmental impact of Materials) can be used by building professionals to acquire an insight into the Environmental Performance of Materials used in Buildings and Building Elements (in Dutch: MMG: *Milieugerelateerde Materiaalprestatie van Gebouw(element)en*). With TOTEM it is possible to assess and communicate about the environmental performance of buildings and elements in a uniform and neutral way, adatped specifically to the Belgian building context. This publication offers an open and transparent presentation of the MMG assessment framework, the underlying methodology of TOTEM, and is an updated version of the publication dd March 2013. Although the presented building materials methodology is far from final, it is a dynamic assessment framework (and web tool) that will be fine-tuned and extended in the future. In that context, this publication should be perceived as a communication tool to facilitate the dialogue with stakeholders (architects, material producers, building owners) in the future.

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