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A Contribution to IEA EBC Annex 72

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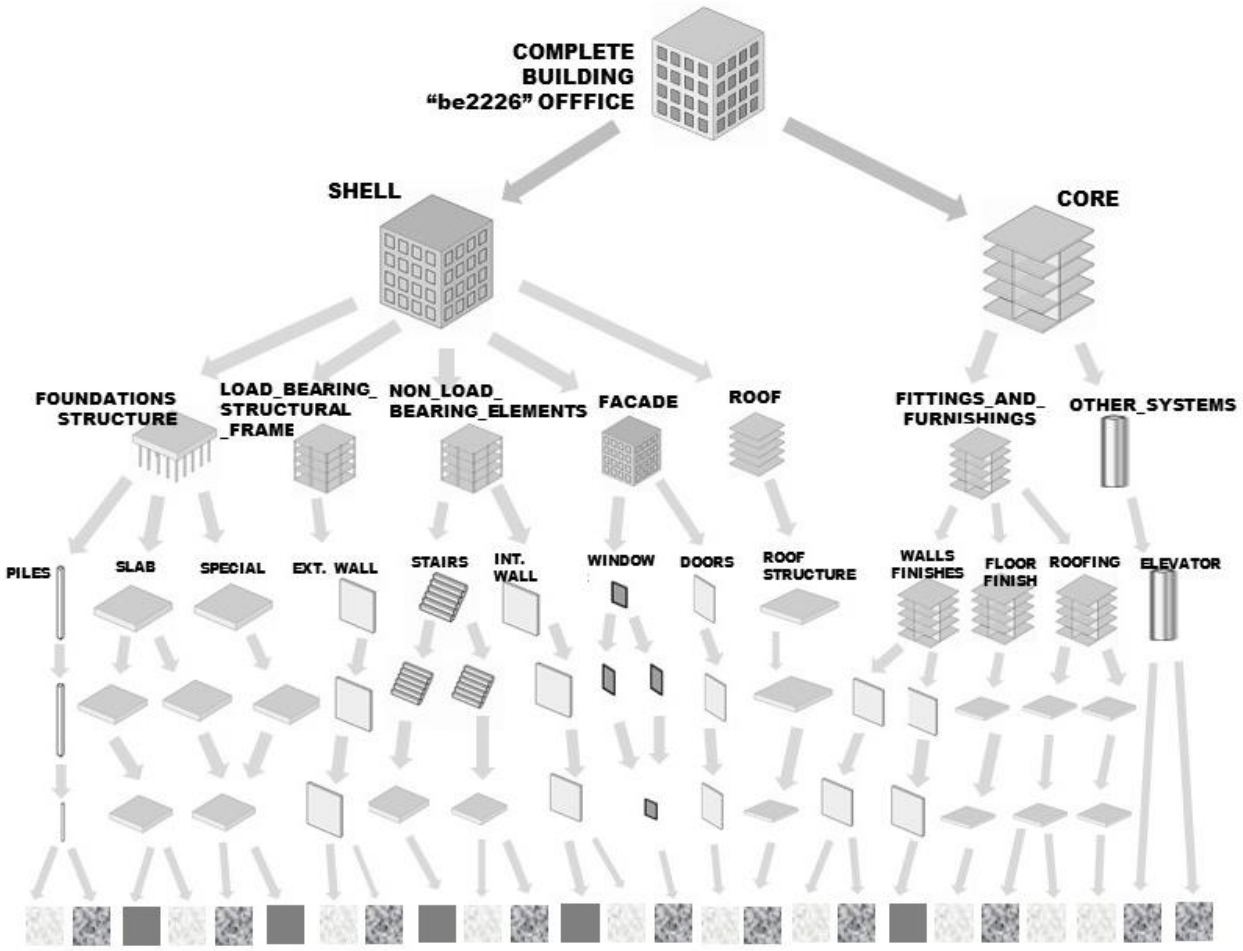

International Energy Agency

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Table of content

Abbreviations and glossary

Abbreviations	Meaning
BIM	Building Information Modelling
BOM	Bill of Materials
BOQ	Bill of Quantities
EIA	Environmental Impact Assessment
GHG	Green House Gases
LCA	Life Cycle Assessment
LCC	Life Cycle Costs
LCI	Life Cycle Inventory
LOD	Level of Development
LOG	Level of Geometry
LOI	Level of Information
CAD	Computer Aided Design
CED	Cumulative energy demand
CO_2eq	CO_2 equivalent
EE	Embodied Energy
EOL	End of life
EPD	Environmental Product Declaration
GFA	Gross Floor Area
GWP	Global Warming Potential
IEA	International Energy Agency
IEA-EBC	Energy in Buildings and Communities Programme of the IEA
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LC	Life Cycle
LCIA	Life Cycle Impact Assessment
LCCO_2	Life Cycle CO_2 equivalent
NZEB	Nearly zero energy building or nearly zero emissions building
NRE	Non-Renewable Energy (fossil, nuclear, wood from primary forests)
NRPE	Non-Renewable Primary Energy
OECD	Organization for Economic Co-operation and Development
PE	Primary Energy
RSL	Reference Service Life
RSP	Reference Study Period
ZEB	Zero Energy Building
ZEH	Zero Energy House
ST1	Annex 72 Subtask 1: Harmonised methodology guidelines

ST2	Annex 72 Subtask 2: Building assessment workflows and tools
ST3	Annex 72 Subtask 3: Case studies
ST4	Annex 72 Subtask 4: Building sector LCA databases
ST5	Annex 72 Subtask 5: Dissemination

Term	Definition
CO_2 Intensity	The total CO_2 emission embodied, per unit of a product or per consumer price of a product. [kg CO_2eq /unit of product or price]
CO_2eq	CO_2 equivalent - a unit of measurement that is based on the relative impact of a given gas on global warming (the so-called global warming potential). [kg CO_2eq]
Contractor	Synonym: Service provider
Clients	Synonyms: financer, building owner, tenant, user
Cradle	Where building materials start their life
Cradle to Gate	This boundary includes only the production stage of the building. Processes taken into account are: the extraction of raw materials, transport and manufacturing
Cradle to Site	Cradle to gate plus delivery to site of use.
Cradle to Handover	Cradle to site boundary plus the processes of construction and assembly on site
Cradle to End of Use	Cradle to handover boundary plus the processes of maintenance, repair, replacement and refurbishment, which constitute the recurrent energy. This boundary marks the end of first use of the building.
Cradle to Grave	Cradle to handover plus use stage, which includes the processes of maintenance, repair, replacement and refurbishment (production and installation of replacement products, disposal of replaced products) and the end-of-life stage, which includes the processes of demolition, transport, waste processing and disposal.
Embodied Energy	Embodied energy is the total amount of non-renewable primary energy required for all direct and indirect processes related to the creation of the building, its maintenance and end-of-life. In this sense, the forms of embodied energy consumption include the energy consumption for the initial stages, the recurrent processes and the end-of-life processes of the building. [MJ/reference unit/year of the RSP]
Embodied GHG emissions	Embodied GHG emissions is the cumulative quantity of greenhouse gases (CO_2, emissions methane, nitric oxide, and other global warming gases), which are produced during the direct and indirect processes related to the creation of the building, its maintenance and end-of-life. This is expressed as CO_2 equivalent that has the same greenhouse effect as the sum of GHG emissions. [kg-CO_2eq /reference unit/year of the RSP]
Energy Intensity	The total energy embodied, per unit of a product or per consumer price of a product. [MJ/unit of product or price]
Energy carrier	Substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes
Energy source	Source from which useful energy can be extracted or recovered either directly or by means of a conversion or transformation process

Gross Floor Area (GFA)	Gross Floor Area [m^2]. Total floor area inside the building external wall. GFA includes external wall, but excludes roof. GFA is measured from the exterior surfaces of the outside walls.
Global Warming Potential (GWP)	A relative measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is measured against CO_2eq which has a GWP of 1. The time scale should be 100-year.
Greenhouse gases (GHG)	They are identified in different IPCC reports
Input and Output Tables	The Input-Output Tables are systematically present and clarify all the economic activities being performed in a single country, showing how goods and services produced by a certain industry in a given year are distributed among the industry itself, other industries, households, etc., and presenting the results in a matrix format.
Input and Output Analysis	The use of national economic and energy and CO2 data in a model to derive national average embodied energy/CO2 data in a comprehensive framework.
LCA	Life Cycle Assessment
PE_{nr}	Primary Energy non-renewable. Nuclear Energy is included.
PE_t	Primary Energy total. Renewable + Non-renewable Primary Energy. Nuclear Energy includes in the Primary Energy total.
Project commissioning	Synonyms: project commissioners, authority, policy makers
RSP	Reference Study Period. Period over which the time-dependent characteristics of the object of assessment are analysed (EN15978:2011)
Sustainability and certification expert	Synonyms: consultant, auditor

Summary

The Life Cycle Assessment (LCA) technique applied to buildings involves the compilation and organization of a large amount of data. Thus, the systematic decomposition is considered a suitable practice to organise and classify building elements and materials. It is considered as a structure that can help to solve specific difficulties when completing the life cycle inventory, as well as allow to obtain reliable and transparent results. The present section provides an overview about the use of systematic building decomposition to conduct LCA to buildings, analyse the implications of taking such approach when integrating LCA in BIM and describe the results of a comparison among different national standards/guidelines that are used to conduct LCA for building decomposition. The study is based on the comparison of national classification systems/standards/guidelines used by twelve Annex participant countries. Moreover, as a common basis of comparison, the “be2226” reference office building was used as a case study to apply the different national standards/guidelines for building decomposition. Results shows that there are differences among the levels of decomposition, grouping and taxonomy principles. It allows us to identify the consequences of using such different systems/standards to conduct LCA, how these differences affect the LCI structures, the LCA databases and the communication of results. To conclude a set of recommendations and challenges based on these findings are proposed.

Keywords: Life Cycle Assessment; Building Information Modelling; Systematic Building Decomposition; Classification System.

Introduction

In the context of the application of LCA in buildings, the use of a systematic structure to decompose the building is needed for several purposes such as to simplify the processes of data collection and its organization (Cheng & Tong, 2017). It allows dividing or decomposing the building into a number of 'portions', 'component groups', 'elements', products, materials, typologies and fabricants (e.g., systems, parts, elements, components, materials or specific manufacturers) and should be performed following specific criteria or structure (Cheng & Tong, 2017; Soust-Verdaguer et al., 2020). For this purpose, a *taxonomy,* defined as 'a *system for naming and organizing things'* (Cambridge Dictionary, 2016) is a suitable term that can describe the main objective of this structure. The concepts of *taxonomy* and *classification systems* applied to buildings can provide a reliable description of the building, organise and relate the different parts, as well as a common reference to name the different systems, elements, and components, among others. It allows to describe and decompose the building elements for different purposes, such as cost estimation, library organization, and environmental assessment, among others.

In this context and based on the literature (Röck et al., 2018a; Shipra Singh Ahluwalia, 2008; Soust-Verdaguer et al., 2020) a variety of classification systems for the building decomposition are detected. Most of them are based on ISO 12006-2 Building Construction - Organization of Information about Construction Works - Part 2: Framework for Classification, which defines a global framework for the development of built environment classification systems (ISO, 2012a).

Objectives

The current report focuses on providing a basis for the understanding and the analysis of the topic. It starts from the definition and introduction of the main aspects related to the taxonomy and classification systems of buildings applied for the systematic building decomposition. The main section identifies and compares the different standards and guidelines that are used by the participating countries for that purpose, and is illustrated by a case study application to a reference building. The present report focuses on detecting the challenges, limitations, and opportunities for its implementation, as well as the current status on the integration national standards and guidelines for systematic building decomposition in BIM. Finally, its implications in on conducting an LCA with a focus on LCA-BIM coupling are analysed.

1. General Context

1.1 Systematic building decomposition to conduct building LCA

The application of systematic decomposition is needed to describe the building elements when conducting LCA, which allows one to identify possible levels of decomposition such as groups of elements, elements, components, products, materials, typologies, and manufacturers (see Figure 1) (Hoxha, 2015). In this vein, the systematic building decomposition in a comprehensible and standardized way according to national standards or guidelines is needed to provide results of building LCA studies at all levels of hierarchy (e.g., building, element, material). Also, though the use of a systematic building decomposition hierarchically conceived, the process of revising assessed components can be facilitated (Shipra Singh Ahluwalia, 2008). A systematic decomposition in a comprehensible and standardized way can also improve, among others, the overview of the completeness of the Life Cycle Inventory (LCI). Regarding the results communication, it also improves the understanding of hot spots for environmental impacts, when presented on various levels (per Life Cycle Stage, materials, elements, etc.). Moreover, the use of a systematic approach can support assessment at various design stages of the building (e.g., using element information early on and material level at a later stage) and supports consideration of uncertainties occurring on different hierarchical levels and at different design stages.

A study conducted by Cavalliere, Habert, Dell'Osso & Hollberg, (2019) investigated the potential of using a hierarchical systematic decomposition of the building, based on a classification system. It relates the design stages (in BIM) with the levels of hierarchy that organize the Bauteilkatalog (Holliger Consult, n.d.) which is based on the Swiss code (CRB, 2009) for the construction works classification system. Some of the advantages of using a classification system when conducting LCA are that it can support the comparability of results for both studies within one country and studies across different countries (one-time mapping of standardized decomposition systems enables comparison). It can also improve transparency in the communication of results in LCA, considering the existing differences in building classification systems. In the context of the IEA EBC Annex 72 (IEA EBC, 2017) project, a wide variety of classification systems applied in different countries to building decomposition were identified when conducting LCA (Soust-Verdaguer et al., 2020). The present chapter is focused on providing a general description of the standards and guidelines used for the systematic decomposition of buildings, mainly used in the Annex countries participants, as well as on comparing their main aspects and illustrating the relevance of their consideration when conducting building LCA.

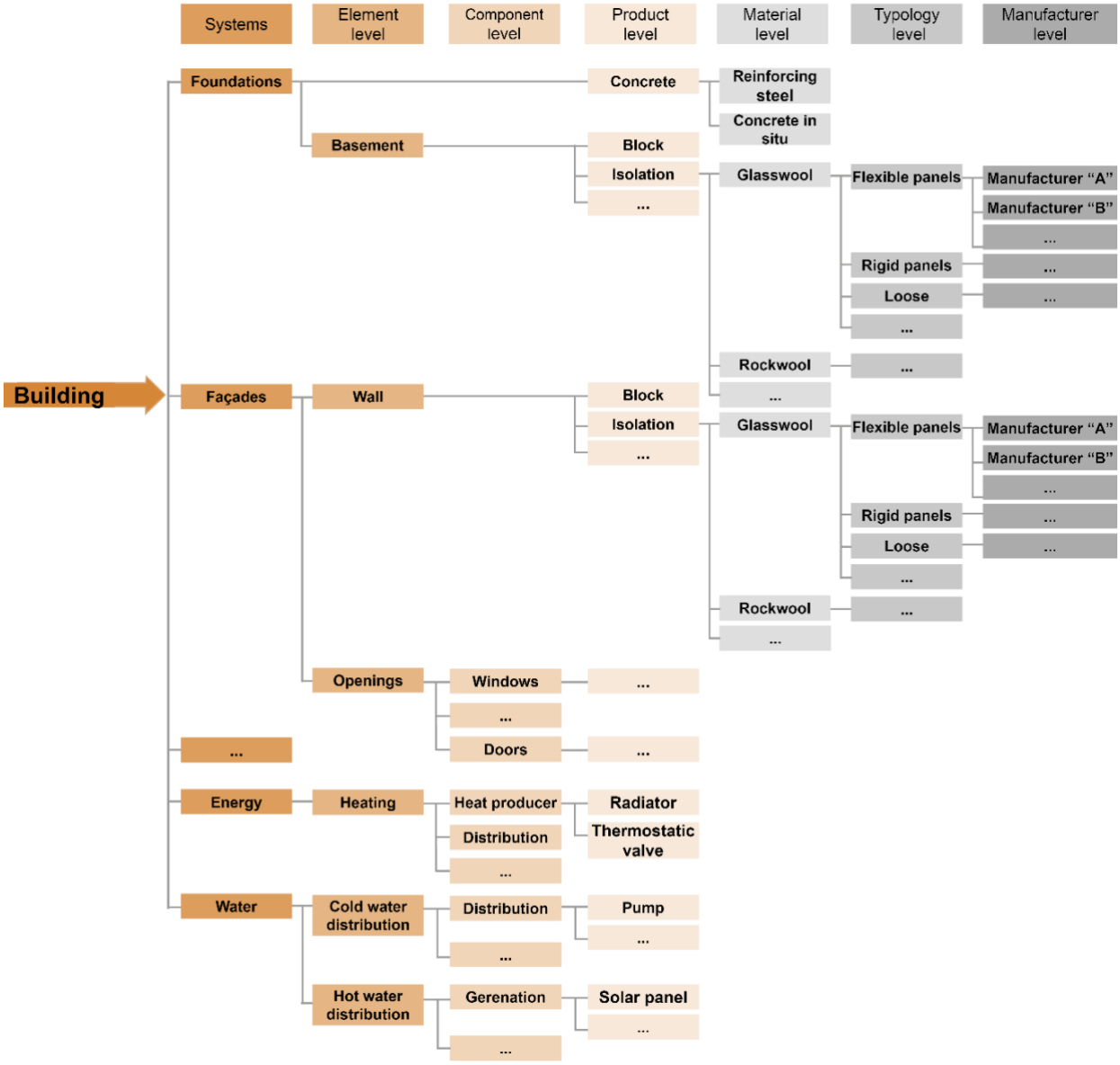


Figure 1: Example of the building decomposition for the building description when conducting LCA. (Source: Hoxha (Hoxha, 2015)

1.2 Systematic building decomposition and classification systems in BIM

The use of digital tools for designing and constructing buildings has changed over the last decades (Volk et al., 2014). Since the extensive use of building information modeling (BIM) tools to support design and construction is recognized, it has modified *"the way we deal with information in the construction sector, transferring the information contained in traditional documentation to ICT- handled data objects with attached information representing the construction complexes and entities, the spaces and the elements"* (International Construction Information Society, 2017). In this context, the integration of structures/tables focus on the description, organization, classification, and identification of objects in the digital tools as BIM is recognized as a challenge to deal with. This integration can provide, among others, a common language, a structure for building decomposition, and ways of managing information in a more uniform and transparent way (International Construction Information Society, 2017).
Additionally, one of the main utilities of the use of classification systems in BIM is the capability to integrate naming codes to organize and manage the building elements that compose the BIM model. The ICIS report on 'Classification, identification, and BIM' underscores that 'it *is important for modeling that the same object has the same code and name in the geometry and textual parts of the information model, so these two parts can integrate and be linked together'* and also 'the *challenge is that both building models and specifications are structured in a way that data will be able to be put on the lists in a coordinated manner'* (International Construction Information Society, 2017). This means that, depending on the level of object definition and needed specifications, from early stage design generic objects can be used followed by detailed objects at detailed stages. Thus, depending on the level of detail of the model and the level of detail of the LCA application, the amount and precision of the information and the levels of decomposition will increase.

For the building construction cost estimation, the application of LCC and environmental assessment to building, similarities on the modelled system structures are detected (Naneva et al., 2020) and demonstrated by the growing combination of both techniques in BIM (Bierer et al., 2015; Santos et al., 2019; Santos, Aguiar Costa, et al., 2020; Santos, Costa, et al., 2020). However, when comparing both methods performed in BIM, the level of maturity in the application of the cost estimation can be considered higher than for the environmental assessment based on LCA (International Construction Information Society, 2018a).

Otherwise, the use of BIM methodology to conduct LCA has been growing (Seyis, 2020; Soust-Verdaguer et al., 2017). Similar as the cost estimation the LCA requires to conduct an inventory, the quantification of the building elements, components, materials, products, and the use of classification systems to identify and organise this information. But, here unlike the cost estimation in BIM the LCA application in BIM, in some cases, lacks fluent workflows, specific databases, standardised or harmonised comprehension of the building elements, materials, products, components, as well as guarantees to obtain comparable results.

2. Problem statement and goal

In this chapter, we aim to provide a general description of the main concepts and criteria to the building decomposition, especially focus on conduction buildings LCA, its integration into design tools such as BIM methodology and the design workflow. Firstly, it includes a review of the main concepts and current standards in the field of taxonomy and classification systems applied to the construction works. Secondly, an overview of the use of systematic building decomposition to conduct LCA in the context of the Annex participants is presented. It discusses and compares them in theory, the main aspects of the classification systems to decompose building elements and its application in the context of digital design tools (such as BIM). Thirdly, a comparison in practice of the different standards/guidelines is performed by applying the case study to the 'be2226' reference building. Finally, challenges, open questions, and recommendations are proposed.

3. Building decomposition and classification main concepts

3.1 Taxonomy and classification systems

Given that systematic building decomposition implies the organization of the building elements, components and materials, etc., following certain criteria, the concepts of ***taxonomy*** and ***classification systems*** provide a valuable basis to the understanding of how this organization can be performed. In general terms, the taxonomy is considered as "*the science of classification*" (Encyclopedia Britannica, n.d.). It is conceived as a *"list of words that provides a classification of some larger topic"* (Inmon et al., 2019), and has originally been applied to plants and animals. Nowadays, the use of the term is being adopted by other disciplines. Generally, *w*hen a taxonomy is used, categories can be proposed within a classification depending on how relationships of similarities or relationships of interdependence are defined (Currás, 2010). Thus, it will be possible to establish a classification in a horizontal direction, and a hierarchy relation is used to establish a scale from greatest *to smallest, from superior to inferior* entity, which will give a sense of collectively and generality (Currás, 2010). Although, both concepts (taxonomy and classification) are closely related, slight differences are detected when considering the **taxonomy** and **classification system**. A **classification system** is a "*systematic arrangement in groups or categories according to established criteria*" (Merriam-Webster, 2020). A taxonomy can provide a structure and tags for the classification system. Classifying things is conceived as a technique to deal with complexity and organize content in a systematic way (ISO, 2013). Hence, regarding both concepts (taxonomy and classification systems), its definition and implications in the systematic building decomposition, the **classification systems** will be considered as a key concept for the systematic comprehension and analysis of the building parts and their relations. The following sections are focused on providing a general overview of the current standards and main concepts to expose a basis for the analysis of the **classification systems** and the standards/guidelines used for the building decomposition.

3.1.1 Review of International Standards of Classification Systems to Construction Works

The main standard related to the use of classification systems is the ISO 22274 (ISO, 2013), and its adaptation to the construction works is the ISO 12006-2 - Building Construction - Organization of Information about Construction Works - Part 2: Framework for Classification. It defines a global framework for the development of built environment classification systems (ISO, 2012a). The standard is focused on the scope definition of construction classification, defines the overall conceptual model, and points out relevant classification tables for the construction industry to use. The ISO 12006-2:2015 applies to the complete life cycle of construction works, including briefing, design, documentation, construction, operation and maintenance, and demolition (ISO, 2012a). The standard was revised in 2015 to, among other aims, "move it from the area of merely classifying document-oriented information to make it more BIM- and object-focused" (International Construction Information Society, 2017). Moreover, the ISO 12006-3:2007 - Building Construction - Organization of Information about Construction Works - Part 3: Framework for Object-Oriented Information, "enables classification systems, information models, object models and process models to be referenced from within a common framework" (ISO, 2012b). It provides the specification of a taxonomy model to define concepts by means of properties, to group concepts, and to define relationships between them, where objects, collections, and relationships are the basic entities of the model (ISO, 2012b). The standard is based on the statement that "the set of properties associated with an object provide the formal definition of the object as well as its typical behaviour" (ISO, 2012b). Overall, the standard proposes a general framework to use classification systems, object models, and object processes, specifically adapted to construction works.

Focusing on the general concepts that establish the ISO 12006-2 (ISO, 2012a) standards, the purpose of a classification system is to organize concepts and terms of a domain and provide a foundation for making distinction between objects. First, it is necessary to define the purpose of the classification, secondly the properties of interest, and finally the object can be organized according to the selected classes and properties (ISO, 2012a)**.** Considering that a class is a concept that refers to an object (ISO, 2012a), in classification, objects are grouped into different classes, where each class is a set composed of its members and determinate by properties. Attributes are concepts that represent an aspect or a singular property of an object (ISO, 2012a). In the BIM methodology an attribute is a "piece of data forming a partial description of an object or entity» (BSI, 2013), otherwise a property is a "unit of information that is dynamically defined as a particular entity instance" (ISO, 2020).

The classification allows to arrange in a hierarchy component classes (Jørgensen, 1998). There, the most general classes are at the higher levels and the most special classes are at the lower levels. A *level* is a set of classes with the same fineness or granularity (ISO, 2012a). The ISO 22274 (ISO, 2013) identify three types of classification tables: enumerative, faceted, and a combination of enumerative and faceted. Figure 2 illustrates the possible levels and relations that in general compose a classification system.

- ***Enumerative:*** *attempt to list all classes within their defined area of applicability* (ISO, 2012a).
- ***Faceted:*** *allows the assignment of multiple classification to an object* (ISO, 2012a).
- ***Combined:*** *a combination of both, in the higher levels of classification an enumerative approach can narrow down the areas of applicability of the individual classes to a manageable size, and at a lower level a faceted approach is applied to specify the nature of the concepts contained in the leaf classes of the classification system* (ISO, 2012a).

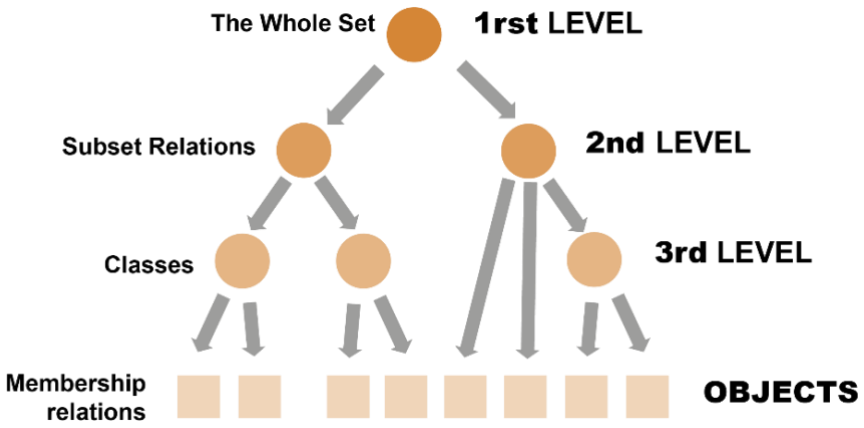


Figure 2: Structure of a classification system. (Source: based on ISO 12006-2 (ISO, 2012a) Building Construction).

3.1.1.1 Part-of relations and type-of relations

The ISO 12006-2 (ISO, 2012a) standard establishs that a classification system, apart from a level order of specializations, has a level order of composition or composition structure. Figures 3 and 4 illustrate examples of the hierarchical principles of classification and composition.

Different types of relations are identified by the different characteristic properties (International Construction Information Society, 2017). The ISO 12006-2 (ISO, 2012a) identifies different types of relations depending on the hierarchy of the classes (classes and sub-classes).

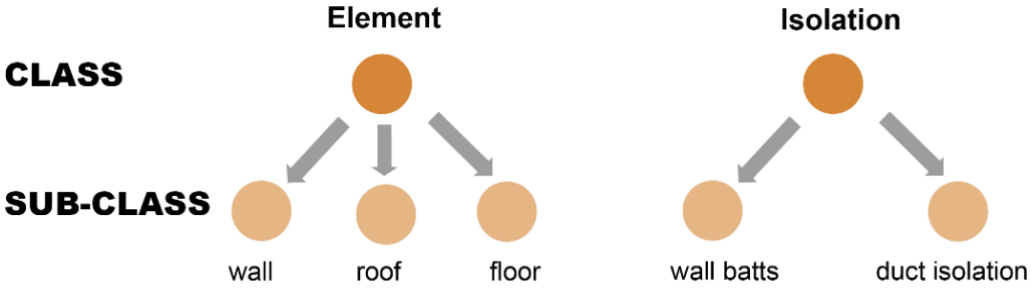


Figure 3: Classification hierarchy, subclasses are types of a superordinate class. (Source: ISO 12006-2 - Building Construction).

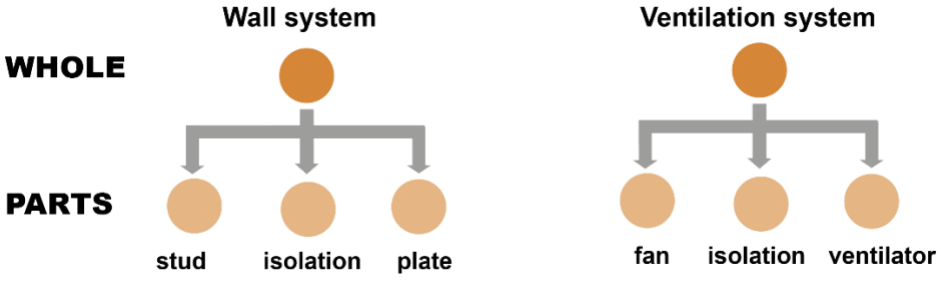


Figure 4: Composition hierarchy, subordinates are parts of a superordinate whole. (Source: ISO 12006-2 - Building Construction).

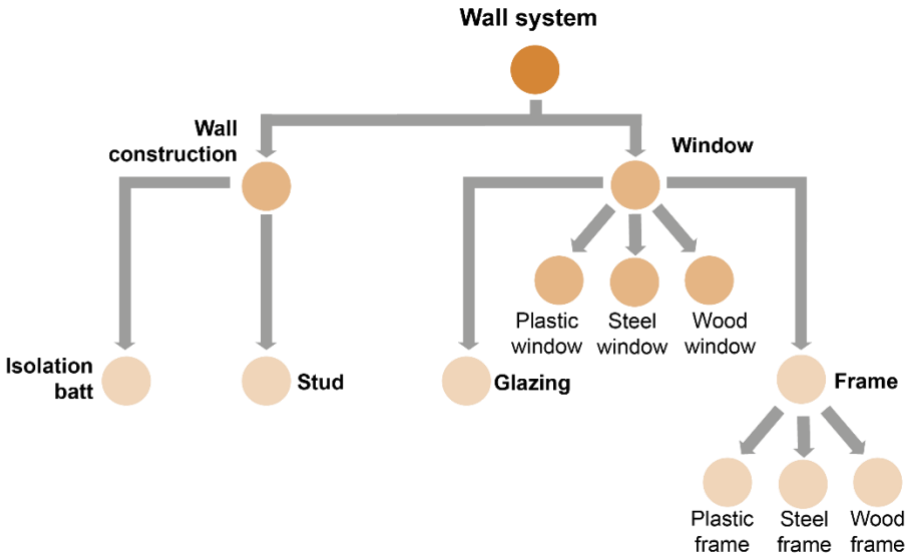


Figure 5: Combination of a composition and classification hierarchy. (Source: ISO 12006-2 - Building Construction).

In building construction, classification into subclass of a superordinate class can generally provide a horizontal decomposition or subdivision of elements (see Figure 3), and a vertical decomposition of elements (see Figure 4) generally allows classification of subordinate parts of a whole. However, horizontal decomposition can also be composed of a combination of both (Figure 5) at the lower vertical levels of decomposition.

3.1.1.2 Principles of specialization Part-of relations and type-of relations

The object of interest of the ISO 12006-2 (ISO, 2012a) standard is the “Construction Object”. For this object, four main classes are defined: 'Construction Resource', 'Construction Process', 'Construction Result', and 'Property / Characteristic' (ISO, 2012a). These classes are related in a generic process model which starts with 'Construction Resources', are used in 'Construction Processes' that will result in 'Construction Results', and all these objects have 'Properties / Characteristics' (Ekholm, 2005). The EXPRESS-G schema in Figure 5 illustrates the relations between the most generic classes.

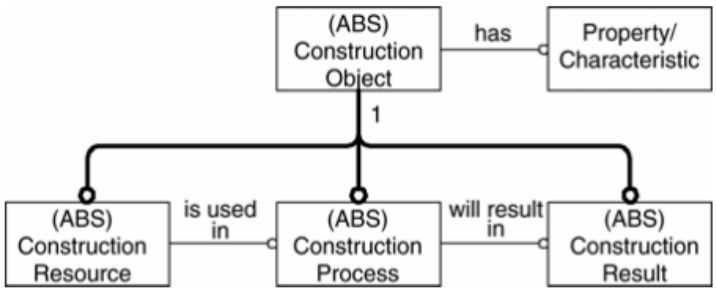


Figure 6: Main object classes and general relations between them. (Source: Ekholm et al. (Ekholm, 2005)).

However, the ISO 12006-2 (ISO, 2012a) standard does not specify any strict classification, recommends and suggests an example of specialization principles (Table 1) applied to the object classes (“Construction Resource”, “Construction Process”, “Construction Result”, and “Property/Characteristic”). Thus, classification table are the results of the application of *principle of specialization* to divide classes into subclasses (ISO, 2012a). In classification systems, there are specific tables to organize and classify elements (on a generic way), designed element (focus on the design stages for drawings and models), Work section/Work result/Production result (for calculation and execution), and Maintenance result (for operation purposes) (International Construction Information Society, 2017).

Table 1. Example of the principles of specialization applied to object classes (Source: ISO 12006-2 (ISO, 2012a))

Class	Classified by
Classes related to sources	
Construction Information	Content
Construction product	Function or form or material, or any combination of these
Construction agent	Discipline or role or any combination of these
Construction aid	Function or form or material, or any combination of these
Classes related to process	
Management	Management activity
Construction process	Construction activity or construction process lifecycle stage or any combination of these
Classes related to result	
Construction complex	Form or function or user activity or any combination of these
Construction entity	Form or function or user activity or any combination of these
Construction element	Form or function or user activity or any combination of these
Built space	Function or form or position, or any combination of these
Work result	Work activity and resources used
Classes related to property	
Construction properties	Property type

Hence, the use of standardized classification systems can support the organization of the information about the building and provide a systematic approach to the decomposition of the buildings, among the development of tables and data structures focus on a certain propose**.** Different stakeholders are interested in different properties depending on the information of interest and their purposes, thus, all classifications are based on characteristic properties (International Construction Information Society, 2017). In this vein, tables and data structures are used to organize different aspects of the building during its life cycle and focus on different purposes such as cost estimation, management and operating activities, among others.

3.2 Synthesis of the section

A taxonomy provides the order to the list of elements, and the *classification system* defines the relations (*part-of* and *type-of*) between those elements. According to the concepts mentioned above, a classification system can define vertical and horizontal orders for building decomposition. Thus, the vertical decomposition allows for the subdivision or classification of a system into subsystems using 'part-of' relations, while the horizontal decomposition allows the order of classes in subdivision determined by 'type-of' relations. Vertical levels and horizontal subdivision decomposition were used to compare and analyse a collection of national standards and guidelines for building decomposition (Soust-Verdaguer et al., 2020). Moreover, the *principles of specialization* also provide a purpose to the organization of the building parts and can also be considered as a key concept to be integrated in the analysis.

Given that the ISO standards do not provide a unique structure or table that should be used to conduct a systematic building decomposition, differences can be detected when analysing different country approaches. The general description of the main concepts and principles used in the definition of a taxonomy for buildings and classification systems provided by this chapter will be considered by the next chapter to compare and analyse different information structures based on standards and guidelines for building decomposition by the Annex participant countries.

4. Systematic Decomposition of Buildings according to National Standards/Guidelines

4.1 Overview of the state of play in the Annex countries

In the context of the IEA EBC Annex 72 when conduction LCA, different classification standards/ guidelines and tables for the building decomposition are used to organize the information of buildings. From an internal (within the IEA EBC Annex 72) survey requesting for contributors in this topic, turned out the following Annex participants: Austria, Belgium, Brazil, Canada, Czech Republic, France, Germany, Netherlands, New Zealand, Spain, Switzerland and UK.
Following, a summary of the structures and tables used by each country is presented in Table 2. It includes the name of the standard / guideline, which is based on, a brief description of the purpose of it use and Table 3 provide a graphical reference (Sankey diagram [1]) to illustrate their main characteristic. The complete version of the tables is included in Appendix I.
Table 2 and Table 3 provide an overview of the main aspects and characteristics of the standards / guidelines / tables, and a brief description of the parameters considered was presented including:

1. Country (use): Refers to the Annex participant country that is using a certain standard/guideline.
2. Name of classification system: If exist, refers to the name of the code, standards, or regulation of the classification system used for the building decomposition.
3. Main purpose: Refers to the main purpose for which it has been developed.
4. Data structure (Sankey diagram): Graphical reference of the data structure for the building decomposition. A general overview of the organization of the data structures including the scope, hierarchy order, and number of parts considered by each of the Annex countries participants.

[1] The Sankey diagrams were built with http://sankeymatic.com/build/.

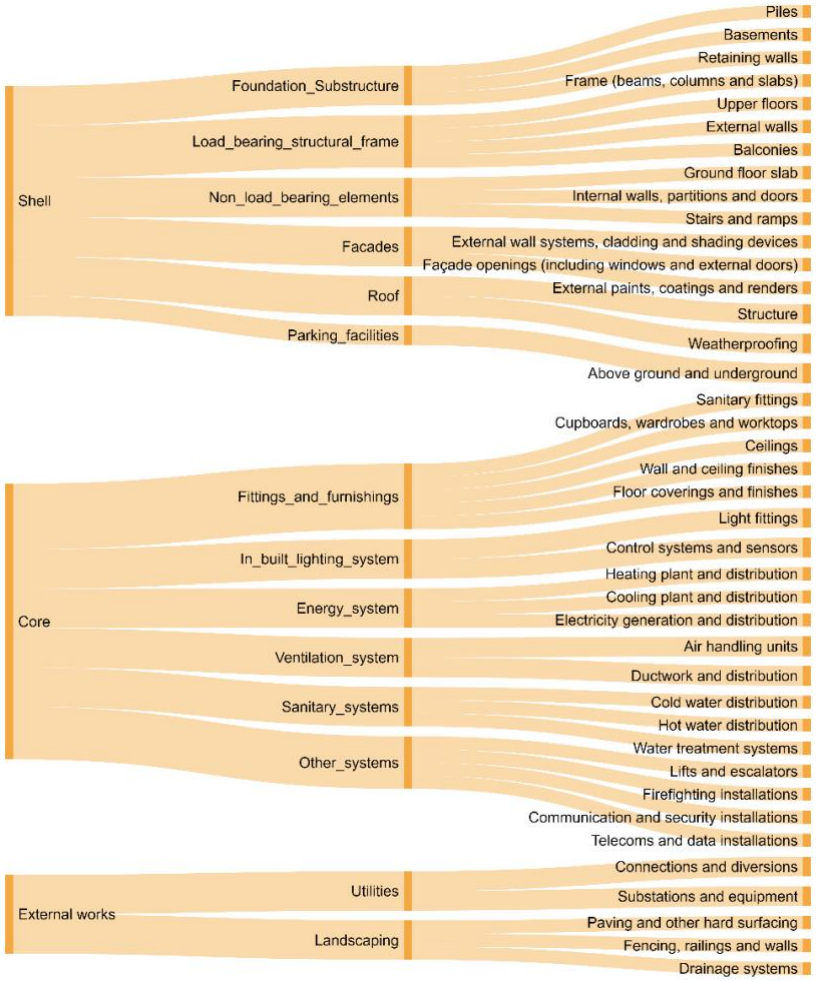
Table 2. National Classification and guidelines for building decomposition use to organise LCA information in Annex countries, including Austria, Belgium, Czech Republic, France, Germany, Netherlands, New Zealand, Spain, Switzerland and UK. (Source: Prepared by the authors based on (Afsari & Eastman, 2016) and on national regulation in classification systems).

Country	Standard or guideline based on	Main purpose
Austria	ÖNORM B1801 (ÖNORM, 2015b)	Building construction cost estimation and LCA data structure.
Belgium	BB/SfB plus (De Troyer, 2008)	Classification and coding system, building construction cost estimation and LCA data structure.
Brazil	ABNT NBR 15575 (NBR 15575-1: Edificações Habitacionais — Desempenho Parte 1: Requisitos Gerais, 2013)	Building performance (also suitable for construction cost estimation and LCA data structure)
Canada	UNIFORMAT II Elemental Classification (E1557-97) (Charette & Marshall, 1999)	Building specifications, cost estimating, cost analysis and (also LCA data structure)
Czech Republic	Not specified – *ad-hoc table*	LCA data structure
France	EQUER model (Polster et al., 1996)	LCA data structure and energy demand calculation
Germany	DIN 276 (DIN, 2008) DIN 18960 (Fröhlich & Fröhlich, 2010)	Building construction, cost estimation, (also LCA data structure).
The Netherlands	NL/SfB	Building construction, cost and LCA data structure
New Zealand	Uniclass 2015 (CPIc, 2015)	Building construction, cost estimation and LCA data structure.
Spain	CTE (CTE, 2006) (Spanish Building Technical Code) and *BCCA* (Andalusian Government, 2017)	Building construction, cost estimation, (also LCA data structure).
Switzerland	SN 506 511 (CRB, 2009)	Building construction, cost estimation and LCA data structure.
UK	SFCA (RICS & BCIS, 2012)	Building construction, cost estimation and LCA data structure.

Table 3. National Classification and guidelines for using the building decomposition to organise LCA information in Annex countries, including Austria, Belgium, Czech Republic, France, Germany, Netherlands, New Zealand, Spain, Switzerland and UK. (Source: Prepared by the authors based on (Afsari & Eastman, 2016) and on national regulation in classification systems)

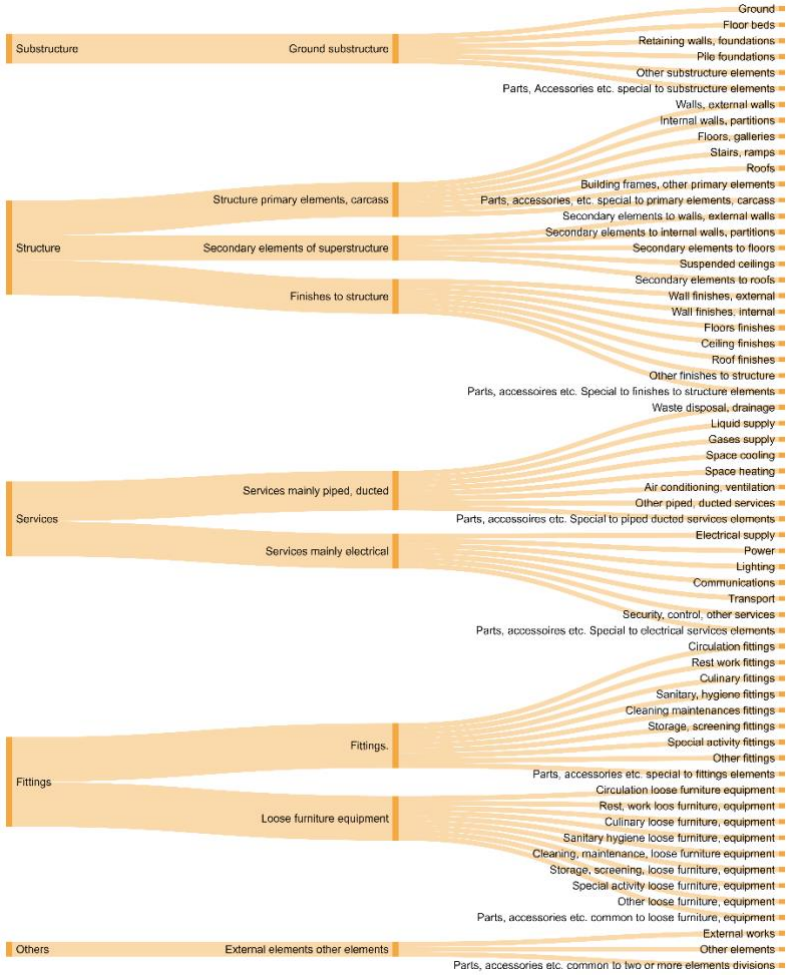
Austria (AT)

Building decomposition structure: (Ctrl+Click here to enlarge the image)



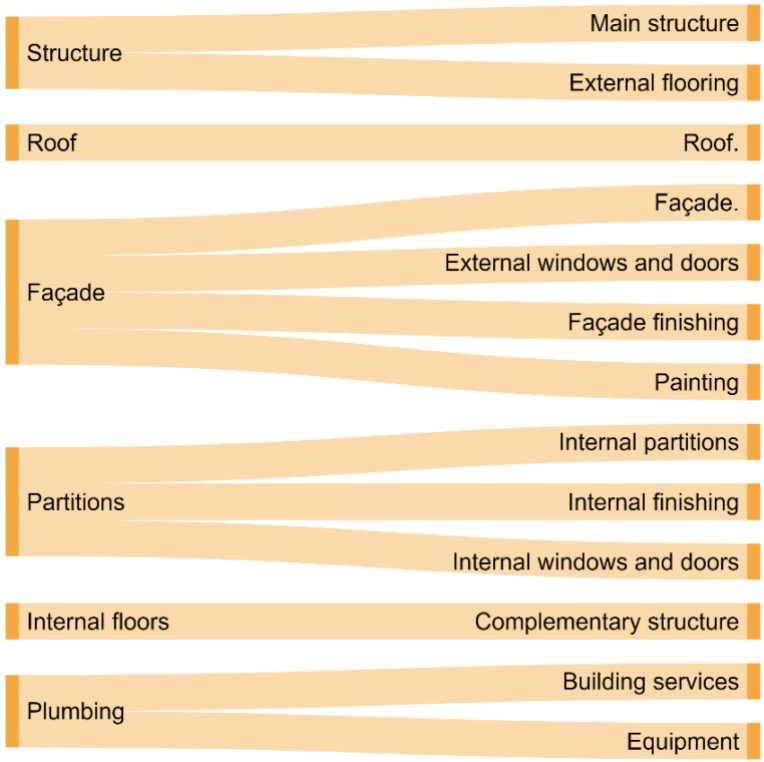
Belgium (BE)

Building decomposition structure: (Ctrl+Click here to enlarge the image)



Brazil (BZ)

Building decomposition structure: (Ctrl+Click here to enlarge the image)

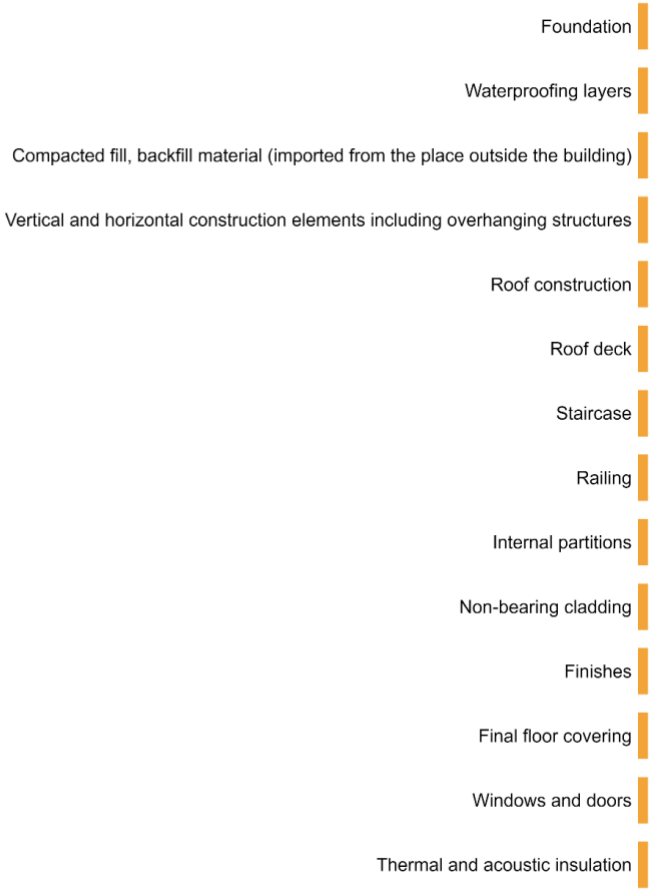


Canada (CA)

Building decomposition structure: (Ctrl+Click here to enlarge the image)

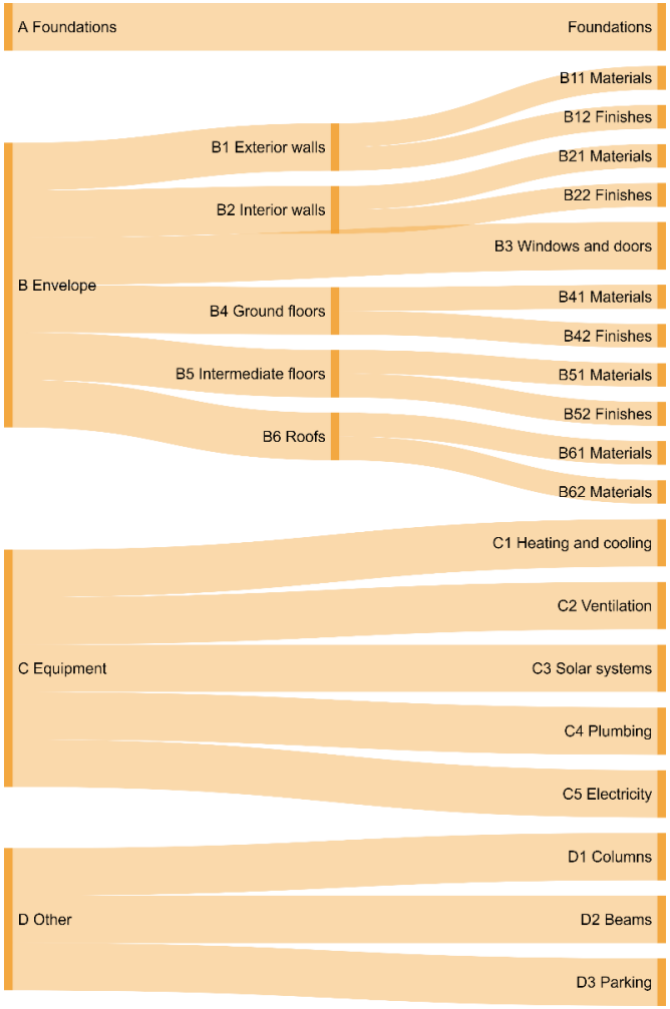
Czech Republic (CZ)

Building decomposition structure: (Ctrl+Click here to enlarge the image)



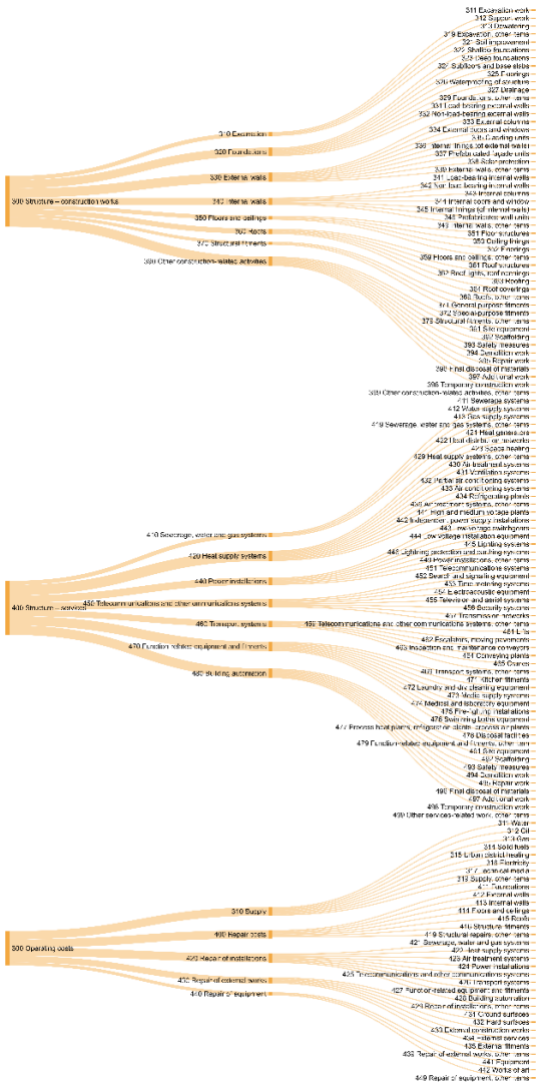
France (FR)

Building decomposition structure: (Ctrl+Click here to enlarge the image)



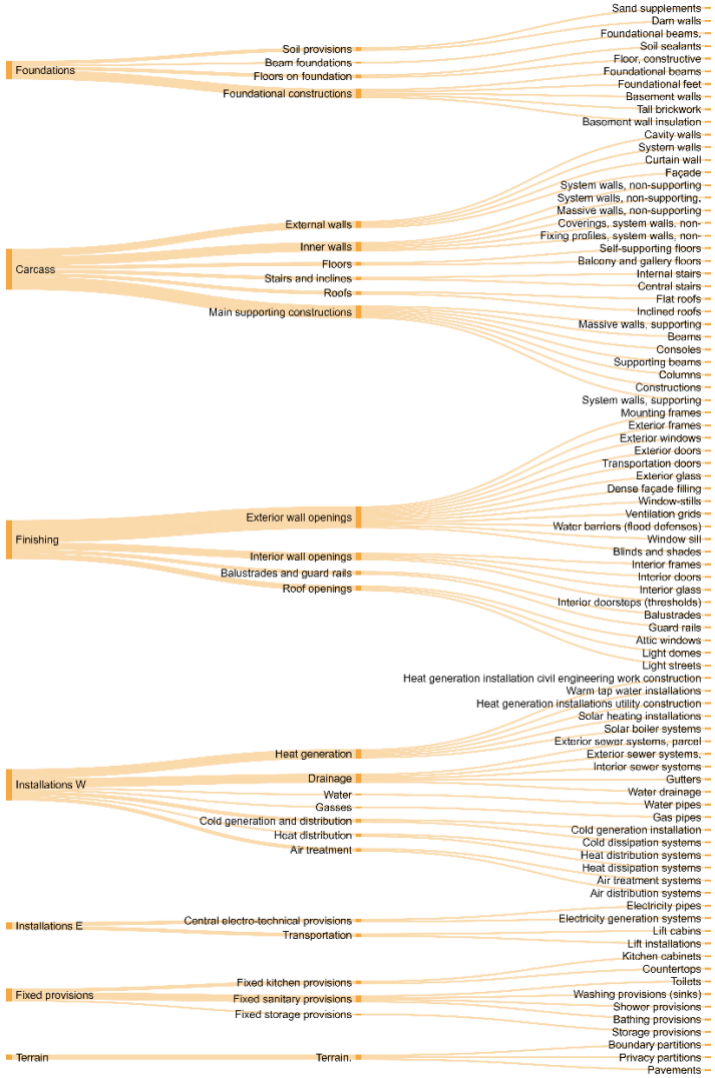
Germany (DE)

Building decomposition structure: (Ctrl+Click here to enlarge the image)



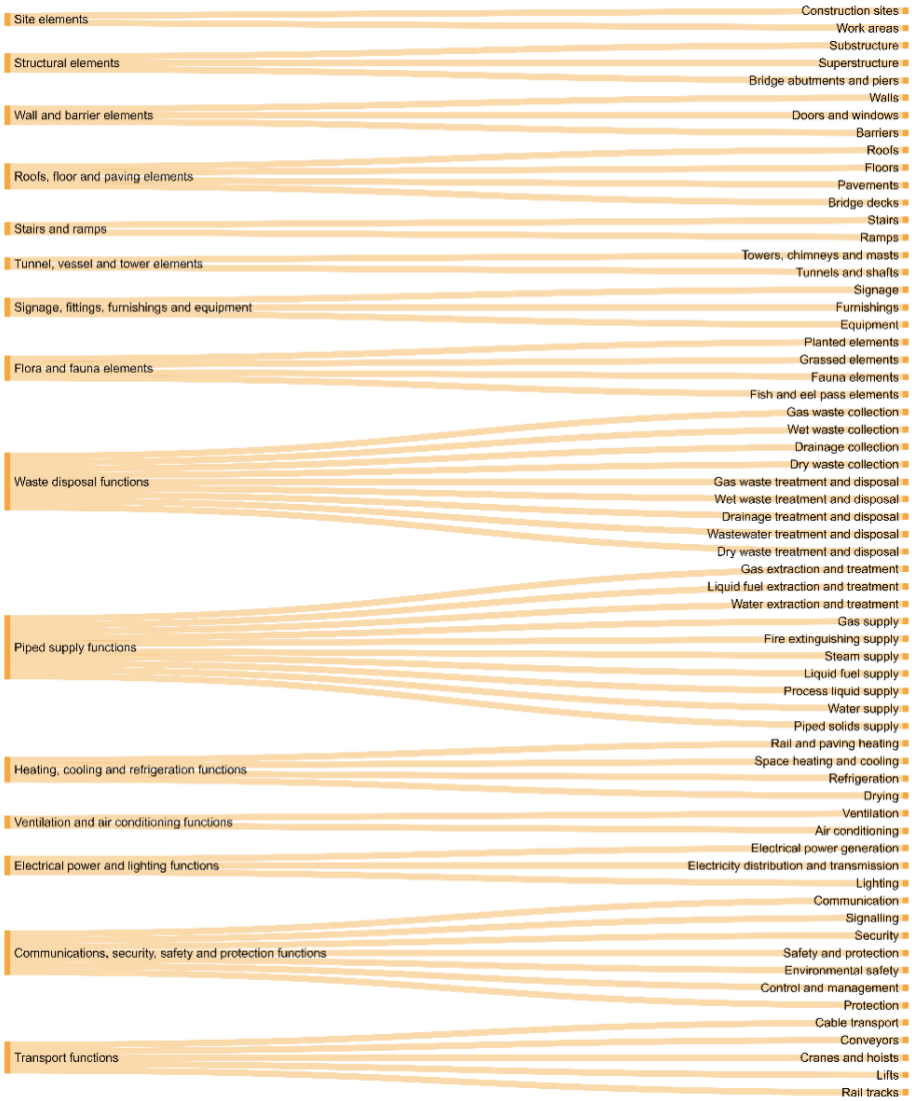
Netherlands (NL)

Building decomposition structure: (Ctrl+Click here to enlarge the image)



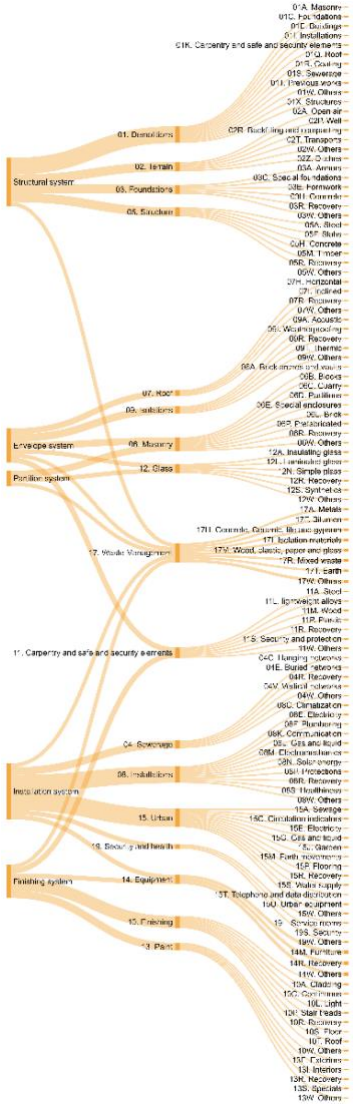
New Zealand (NZ)

Building decomposition structure: (Ctrl+Click here to enlarge the image)



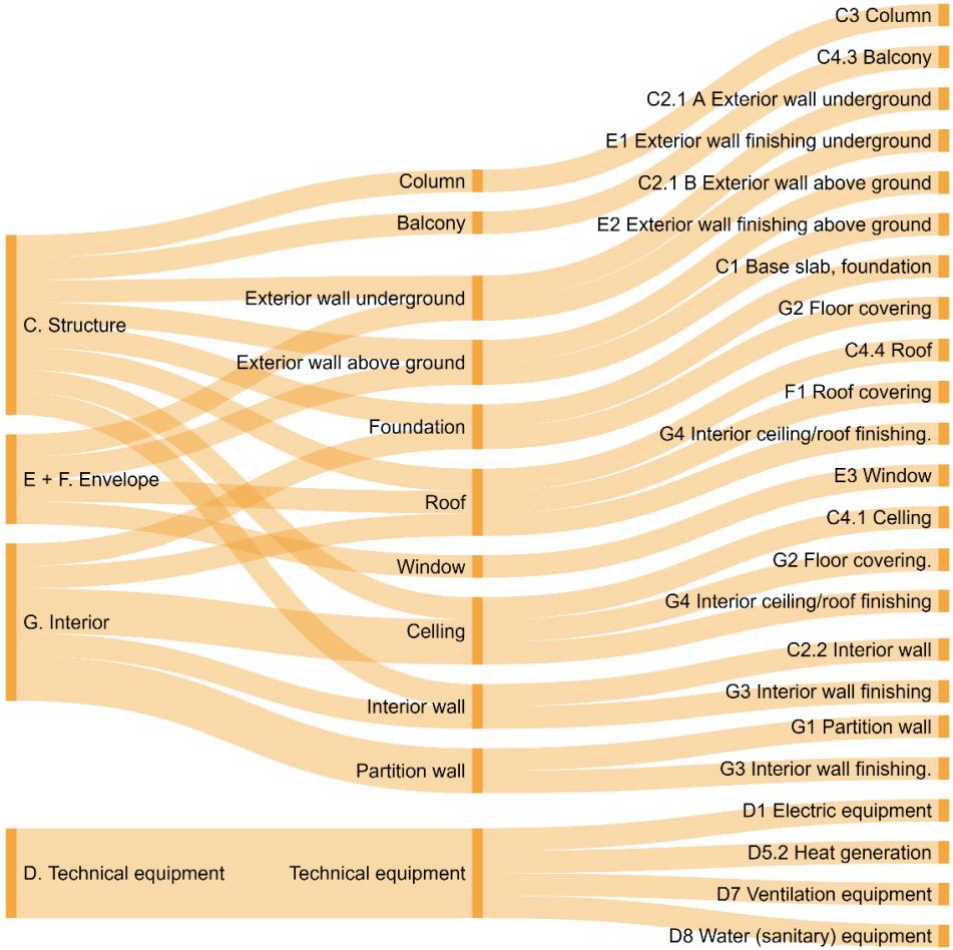
Spain (ES)

Building decomposition structure: (Ctrl+Click here to enlarge the image)



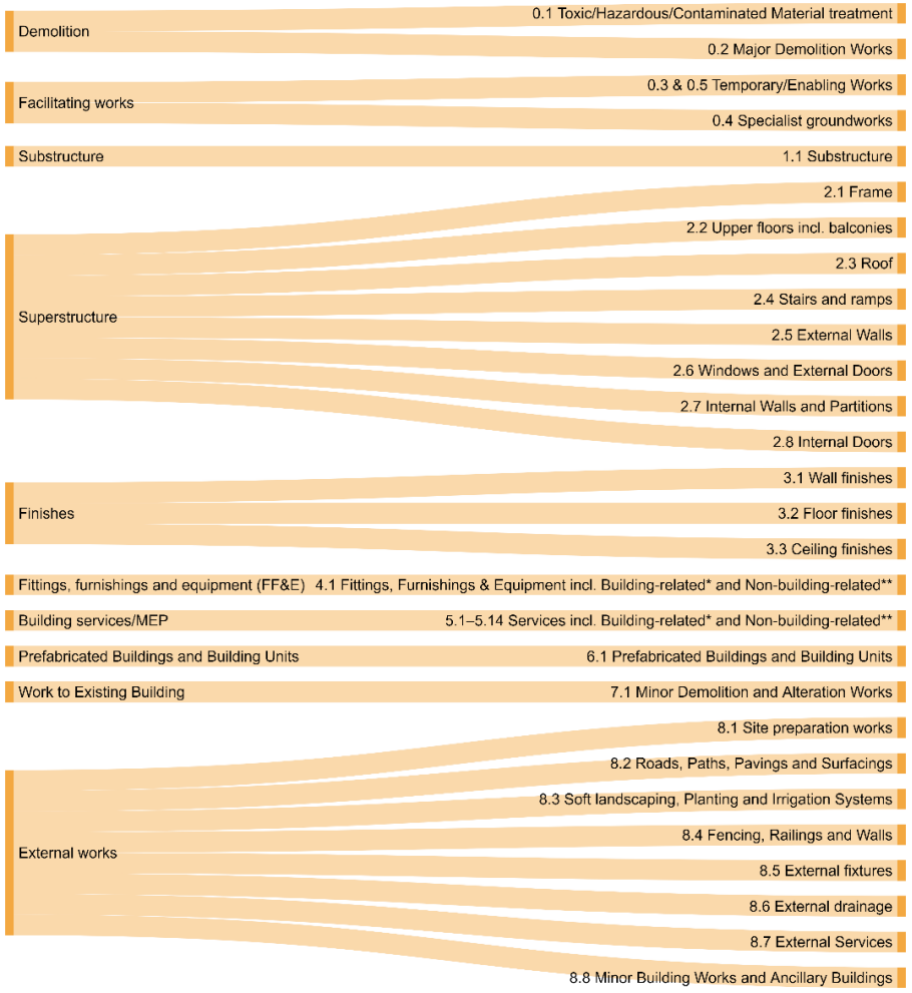
Switzerland (CH)

Building decomposition structure:
Extract of the data structure applied in (Cavalliere et al., 2019). *(Ctrl+Click here to enlarge the image)*



United Kingdom (UK)

Building decomposition structure: (Ctrl+Click here to enlarge the image)



Notice that the structures used for building decomposition are generally composed by tables based on national standards for building construction cost estimations (e.g. UK, Germany, Switzerland). In several cases, the structures belong to guidelines based on national standards to organize building parts/elements (e.g. Belgium). Other countries (e.g. France, and the Czech Republic) proposed a specific structure for the application of LCA.
Table 2 and especially Table 3 provide evidence of the heterogeneity of the different data structures used by each country. Therefore, the following section is focused on analysing and comparing the detected differences, based on the main concepts defined in Section 4.

4.2 Methods

The comparative analysis of the structures/tables/guidelines for building decomposition used by the Annex participant aims to:

- Analyse and categorize their main differences, regarding:
  - the **Vertical and Horizontal orders** to decompose the building (previously defined in Section 3.1.1.1.), (included in Section 5.3.1).
  - the main **principles of specialization** (previously defined in Section 4.1.2., Table 1), (included in Section 5.3.1).
- Analyse their implications to conduct LCA in BIM, regarding:
  - an overview of the existing classification systems for systematic building decomposition in BIM (included in Section 5.3.2).
  - the analysis of the design stages of buildings (early and detail) in BIM, (included in Section 5.3.3).

Hence, the objective of Section 5.3.1 is to characterize the main differences on the organization of the building parts and the principles and purpose of their grouping. Sections 5.3.2 and 5.3.3 are focused on the discussion of the integration of systematic building decomposition in the context of design tools.

4.3 Results and Discussion

4.3.1 Analysis of levels of decomposition and principles of specialization

This section presents from a conceptual point of view, the characterization of the differences on the structures/guidelines and tables used for systematic building decomposition, involving the following aspects:

– *Levels of decomposition:* Refers to the number or levels in which each structure/guideline and table decompose the building parts.

1. **Vertical LEVELS** (vertical order) **- COMPOSITION PRINCIPLE (Figure 3 and 4):** This principle is generally based on the use of a structure to relate the parts of a whole (building). For example, considering the structure, a vertical level of decomposition can include columns, slabs, and beams, among others. The use of a hierarchical structure to define different levels of decomposition is generally based on a first level that **i**nvolves the complete building up to the division into materials/products.

2. **Horizontal SUBDIVISION** (horizontal order) - **CLASS PRINCIPLE** (Figure 3 and 4): The horizontal level generally refers to different classes and sub-classes of systems/categories /elements/objects, for example, focus on the function, materiality, etc.

– *Principles of Specialization:* These principles can provide support to the organization of the information about the building and generate a systematic approach to the decomposition of the buildings, among the development of tables and data structures focus on a certain propose **to a certain stakeholder.**

– *Taxonomy and naming codes:* Refers to the rules and convention codes used for naming the building parts.

The results of Table 3 evidence the heterogeneity of the different structures analysed. This could be due to the differences in the purpose of the classification of building elements, the criteria to organize the building elements (principle of specialization) and the naming codes (taxonomy principles). Some of the national structures for building decomposition were based on national standards for cost estimation such as the Swiss SN 506 511(CRB, 2009). Others organize building elements of the LCI such as in the France case. Thus, from the analysis of **Tables 2, 3, and 4** several findings can be extracted:

– **Levels of decomposition:** Most of case studies (such as Austria, Belgium, Germany, Netherlands, New Zealand, Switzerland, Spain and UK) integrate at least three or four vertical levels of decomposition (from the complete building level to elemental level): a first level that integrates the general classification of the building systems or categories, a second level composed by a classification of group of elements, a third level composed by an elemental classification, and a fourth level that integrates a material/product classification. However, major differences have been detected in the horizontal sub-divisions. These differences can have consequences on the LCI completeness and the LCA results, which are analysed in depth in **Section 6** by a case study application**.**

  When evaluating the level definition, differences in the scope are detected. Table 4 shows the differences on the organization of the elements (groups) and the number of elements considered, which also affect the subsequent sub-elements, components, products and materials. For example, considering the building decomposition at vertical level 1 (first classification criteria), it was detected that national regulations do not considered the same number of building groups of elements, and their sub-sequential elements/sub-elements/materials and products.

  The obtained results show that the tables used for implementing the systematic building decomposition at the vertical level are mostly limited to the classification of the building parts up to the elemental decomposition. Thus, none of the tables provide detailed specifications of the more detailed vertical levels of decomposition (such as material, typology, or manufacture levels), introduced by Hoxha (Hoxha, 2015) as the highest levels of specification to describe the building parts when conducting LCA. Several exceptions are the Spanish data structure (Andalusian Government, 2017), Belgian (De Troyer, 2008), Canadian (Charette & Marshall, 1999), French (Centre Efficacité énergétique des Systèmes de Mines ParisTech, n.d.), and Switzerland that includes several specifications about the organization of the sub-element or/and material level. For example, Switzerland uses for defining the material level the KBOB (“KBOB. Okobilanzdaten im Baubereich”, n.d.) list of materials. The Spanish data structure (Andalusian Government, 2017) (developed for the cost estimation dataset and also to organise the cost estimation database) provides a complete description of the systems and processes that comprise building construction, including a description of the elements, subelement, materials, products, machinery, and labour, according to the regional technical characteristics (more detailed information is included in Appendix I). This approach can provide a complete dataset and increase transparency when conducting the detailed modelling of construction (A5), replacement (B4) or deconstruction modules

(C1), due to the fact that allows to organize the specific information about the building parts (e.g., energy consumption for installation of the items).

Despite the heterogeneity in the number of the horizontal sub-divisions (from 9 to 32 at the vertical level 2), the results show (see Table 3) that several groups of elements have been generally considered. These are foundations, façade, roofs, floors, partitions (related items coloured orange in Table 4). Hence, the main differences are related to their conception, organization, and to the number of type-of relations considered. For example, Uniformat standard (Charette & Marshall, 1999) (Canada) defines three element types in the group of foundations ("Standard Foundations", "Special Foundations", "Slab on Grade"), while the German standard (DIN, 2008) defines eight types ("321 Soil improvement", "322 Shallow foundations", "323 Deep foundations", "324 Subfloors and base slabs", "325 Floorings", "326 Waterproofing of structure", "327 Drainage", and "329 Foundations, other items").

– **Principle of Specialization:** Table 4 evidences that most of the structures for the building decomposition that organize the object classes related to "Construction elements" (based on Table 1 ISO 12006-2 (ISO, 2012a) examples), focus on the main class "Construction Result" (ISO, 2012a). Notice that in almost all data structures, an *elemental decomposition of the building* has been performed. However, several differences on the organization and hierarchization of the "Construction elements" are identified. For example, the French structure considered finishes at vertical level 3, and the Dutch structure integrates a category for "finishes" at vertical level 1. However, other object classes are considered, in addition to the 'Construction elements'. Germany, for example, declared the use of tables/structures to organize information about use stages, close to object classes related to 'Management activity' (see Table 1). The UK and Spain also include object classes related to 'construction aids' (such as 'Demolition' UK or 'Ground breaking' Spain).

  Moreover, the results also show that some of the analysed examples combine an *element classification* (relating to the elements that compose the building) with a classification into *system* approach (relating to the systems that compose the building) (see Figure 7). This means that some countries first perform a *classification into systems* and then a *classification of element* (e.g., Spain (Andalusian Government, 2017) first recognises the "Finishing system" and then the elements (such as external wall, ceiling, etc.) that include the finishing). In this vein, the Uniclass 2015 (CPIc, 2015) standard is the unique standard for the classification system that explicitly provides a set of classification tables focused on different purposes (systems, elements, among others). The elemental classification / decomposition generally allows to identify the most relevant elements that compose the building, such as the structure, exterior walls, partitions, etc. It also can help to track an item from the elemental to the material level (e.g., alkyd paint (material level) _paint layer (sub-element) _exterior wall 2 (element level)). In contrast, the system classification can help to group by their function the main systems that compose the building. The limitation of that approach is that the possibilities of tracking a material by the element and sub-element which belongs to, can be not possible. This means that once similar materials are identified, they can be grouped without specifying the specific element and sub-element that it came from.

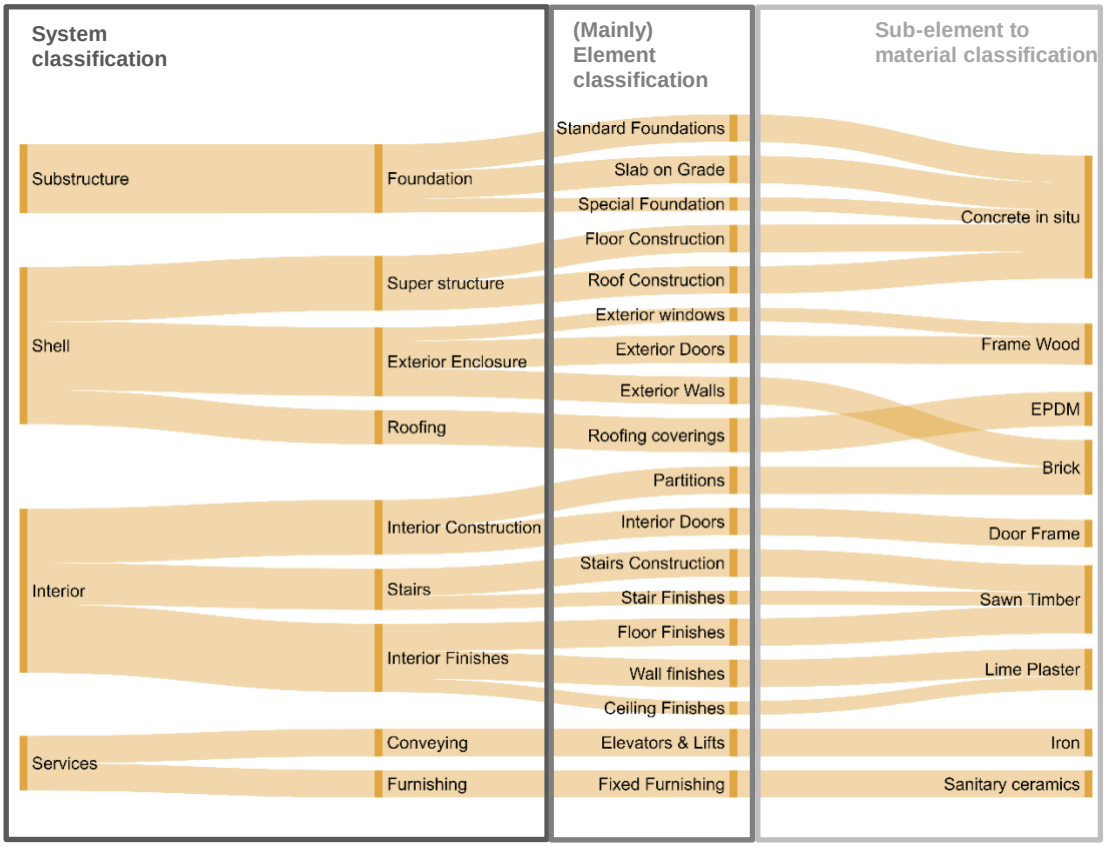


Figure 7. Example of the system and elemental approaches based on a selection of items of the Uniformat II standard. (Source: Prepared by authors)

For example, the finishing material for the walls (e.g. lime plaster interior) can be grouped together without specifying which type of wall it belongs to (interior or exterior). Notice that a classification system should allow to identify all the elements that compose the building and describe the main characteristics of those systems that transversally involve the building elements (e.g., finishing, waterproofing layers).

– **Taxonomy and naming codes:** Several differences have been noticed in naming codes and conventions, which follow different criteria on the taxonomy and organization of the different levels of decomposition. These could be due to differences in translation or meaning definition related to each country or region. For example, similar terms are used to describe similar items such as 'Shell' (Austria and Canada), 'Carcass' (The Netherlands and Belgium) and 'Envelope' (France, Spain, and Switzerland). The differences can also be related to the regional technical characteristics of each country and the traditions and technologies of building construction.

  The obtained results show that several standards provide detailed rules for introducing the naming codes when tagging elements, sub-elements and materials (e.g., Spain), while other standards or guidelines (e.g., France) introduce a less rigorous rules. Notice that the use of naming conventions and tags can provide a useful reference when tracking and organizing the data for implementing LCA and especially in BIM.

Table 4. Number of vertical levels of decomposition and horizontal sub-divisions. A detailed description of the building element type is provided in the Appendix I. (Source: Prepared by authors)

Number of V- H- Levels*	Country code AT	BE	BR	CA	CH[1]	CZ	DE	ES	FR	NL	NZ	UK
1	**3** Shell, Core, External works	**5** Substructure Structure Services Fittings Others	**6 Systems:** Structure Internal floors Façade Partitions Roof Plumbing	**4 Major Group Elements** A Substructure, B Shell, C Interiors, D Services	**3 Categories:** Structure Envelope Interior	Not specified	**2 Systems:** 300 Structure construction works, 400 Structure – services **300 Operating costs**	**5[2] Systems:** Structure; Envelope; Partitions; Finishing; Air conditioning and installations	**4 Systems/ Categories:** A Foundations; B Envelope; C Equipment D Other	**5 Category/System**: Foundations, Carcass, Finishing, Finishes; Installations E	**1** EE_Elements and functions	**4** Category/Systems 1 Substructure 2 Superstructure 3 Finishes Fittings, furnishings and equipment (FF&E) 4 Building services/MEP
2	**14 Building parts:** 1. Foundation Substructure 2. Load bearing structural frame 3. Non load bearing elements 4. Facades 5. Roof 6. Parking facilities 7. Fittings and furnishings 8. In built lighting system 9. Energy system 10. Ventilation system 11. Sanitary systems 12. Other systems 13. Utilities 14. Landscaping	**9 Elements Definition:** 1. Ground substructure 2. Structure primary elements, carcass 3. Secondary elements of superstructure 4. Finishes to structure 5. Services mainly piped, ducted 6. Services mainly electrical 7. Fittings 8. Loose furniture equipment 9. External elements other elements.	**14 Building parts:** 1.Main structure; 2.Complementary structure; 3.Façade; 4.Internal partitions; 5.Roof; 6.Internal finishing; 7.Façade finishing; 8.External flooring; 9.Painting; 10. Waterproof system; 11. External windows and doors; 12. Internal windows and doors; 13. Building services; 14. Equipment	**17 Group of Elements:** 1. Foundation 2. Basement construction 3. Super structure 4. Exterior Enclosure 5. Roofing 6. Interior Construction 7. Stairs 8. Interior Finishes 9. Conveying 10. Plumbing 11. HVAC 12. Fire Protection 13. Electrical 14. Equipment 15. Furnishing 16. Special Construction 17. Service Building Demolition	**16 Building elements:** 1. Foundation 2. Exterior wall 3. Interior wall 4. Pillars 5. Floors 6. Stairs and Ramps 7. Balcony 8. Roof 9. Technical equipment 10. Exterior Window and doors 11. Partitions, doors 12. Fixed equipment 13. Ceiling 14. Special Technical equipment 15. Outdoor equipment 16. Furniture equipment	**14 Building parts** 1. Foundation 2. Waterproofing layers 3. Vertical and horizontal construction elements 3. Roof construction 4. Roof deck 5. Staircase 6. Internal partitions 7. Non-bearing cladding 8. Finishes 9. Final floor covering 10. Windows and doors	**21 Building group of elements/process:** **300 Structure – construction works** 310 Excavation 320 Foundations 330 External walls 340 Internal walls 350 Floors and ceilings 360 Roofs 370 Structural fitments 390 Other construction-related activities **400 Structure – services** 410 Sewerage, water and gas systems 420 Heat supply systems 440 Power installations 450 Telecommunications and other communications systems 460 Transport systems 470 Function-related equipment and fitments 480 Building automation 490 Other services-related work **300 Operating costs** 310 Supply 400 Repair costs 420 Repair of installations 430 Repair of external works 440 Repair of equipment	**18[3] Building group of elements/process:** 01. Demolitions 02. Terrain 03. Foundations 04. Sewerage 05. Structure 06. Masonry 07. Roof 08. Installations 09. Isolations 10. Finishing 11. Carpentry and safe and security elements 12. Glass 13. Paint 14. Equipment 15. Urban 17.Waste Management 19.Security and health	**14 Building parts:** B1 Exterior walls B2 Interior walls B3 Windows and doors B4 Ground floors B5 Intermediate floors B6 Roofs C1 Heating and cooling C2 Ventilation C3 Solar systems C4 Plumbing C5 Electricity D1 Columns D2 Beams D3 Parking	**32 Groups of Elements:** 1. Soil provisions 2. Floors on foundation 3. Foundational constructions 4. Beam foundations 5. External walls 6. Inner walls 7. Floors 8. Stairs and inclines 9. Roofs 10. Main supporting constructions 11. Exterior wall openings 12. Interior wall openings 13. Balustrades and guard rails 14. Roof openings 15. Exterior wall finishes 16. Interior wall finishes 17. Floor finishes 18. Ceiling finishes 19. Roof finishes 20. Heat generation 21. Drainage 22. Water 23. Gasses 24. Cold generation and 25. distribution 26. Heat distribution 27. Air treatment 28. Central electro-technical provisions 29. Transportation 30. Fixed kitchen provisions 31. Fixed sanitary provisions 32. Fixed storage provisions 33. Terrain	**15 EF_Elements** 1.Site elements 2.Structural elements 3.Wall and barrier elements 4.Roofs, floor and paving elements 5.Stairs and ramps 6.Tunnel, vessel and tower elements 7.Signage, fittings, furnishings and equipment 8.Flora and fauna elements 9.Waste disposal functions 10. Piped supply functions 11. Heating, cooling and refrigeration functions 12. Ventilation and air conditioning functions 13. Electrical power and lighting functions 14. Communications, security, safety and protection functions 15. Transport functions	**28 Building elements** 0.1 Toxic/Hazardous/Contaminated Material treatment 0.2 Major Demolition Works 0.3 & 0.5 Temporary/Enabling Works 0.4 Specialist groundworks 1.1 Substructure 2.1 Frame 2.2 Upper floors incl. balconies 2.3 Roof 2.4 Stairs and ramps 2.5 External Walls 2.6 Windows and External Doors 2.7 Internal Walls and Partitions 2.8 Internal Doors 3.1 Wall finishes 3.2 Floor finishes 3.3 Ceiling finishes 4.1 Fittings, Furnishings & Equipment incl. Building-related* and Non-building-related** 5.1–5.14 Services incl. Building-related* and Non-building-related** 6.1 Prefabricated Buildings and Building Units 7.1 Minor Demolition and Alteration Works 8.1 Site preparation works 8.2 Roads, Paths, Pavings and Surfacings 8.3 Soft landscaping, Planting and Irrigation Systems 8.4 Fencing, Railings and Walls 8.5 External fixtures 8.6 External drainage 8.7 External Services 8.8 Minor Building Works and Ancillary Buildings
3	**41 Building elements type**	**61 Element/process type**	-	**57 Individual Elements**	**58 Building elements type (also called "Building components")**	-	**142 Element/process type**	**115 Elements/process type**	**10 Sub-elements/materials**	**111 Building elements type**	**66 Building elements type**	Not specified
4	-	A brief description of the sub-elements, materials, products sub-division is given. Detailed descriptions is provided in the document (De Troyer, 2008).	-	A brief description of the sub-elements, materials, products sub-division is given. Detailed descriptions is provided in the document (Charette & Marshall, 1999).	Here is used the KBOB list (*KBOB. Okobilanzdaten Im Baubereich*, n.d.).	-	-	A definition and description of default sub-elements, materials, products, machinery and labour is given. Detailed descriptions is provided in the BBCA document (Andalusian Government, 2017).	-	-	-	-

* Number of Vertical Levels of decomposition. ** Number of Horizontal Levels of decomposition. 1 The listed items comprise a selection of the most relevant items for the purpose of systematic building decomposition. 1 Based on CTE (CTE, 2006) (Spanish Building Technical Code) primary classification. 3 Based on BBCA (Andalusian Government, 2017)Classification.

4.3.2 Systematic Building Decomposition in the context of digital design tools - BIM and LCA

In current practice, the systematic building decomposition in the context of digital design tools is supported by using *classification systems,* which allows (among others) to insert naming codes/tags and list elements in the BIM model. Two of the most used BIM software -Autodesk Revit (Revit, 2021) and AchiCad (GRAPHISOFT, 2017)- allows to integrate many classification systems in the BIM model in an easy and user-friendly way (included in the default configuration of the software or by a downloadable add-in or packaged). Autodesk Revit (Revit, 2021), for example, integrates *Autodesk Classification Manager for Revit* (Autodesk Revit, n.d.) an add-in that allows to integrate UniFormat (Charette & Marshall, 1999), MasterFormat, OmniClass (International Organization for Standardization (ISO) et al., n.d.), Uniclass, or a custom database classification system to the BIM model. Archicad (GRAPHISOFT, 2017), for example, integrates a 'BIM Content' that can be imported from its web page. Actually, the available national classification systems are the followings (updated to 19/08/2020) : Önorm 6241-2 (AT), Uniclass 2015 (UK), Uniclass 2 (UK), CAWS, SFG20, RICS NRM 1, RICS NRM 3, NBS Create, MasterFormat, OmniClass (International Organization for Standardization (ISO) et al., n.d.), ASTM UniFormat II (US) (Charette & Marshall, 1999), 2010 CSI UniFormat (US), NATSPEC, CCS, BIM7AA, Rumsfunktionskoder - CC001_001_001, Rumsfunktion - CD002_001_001, Funktionskoder Regionservice -CD001_001_004, BIMTypeCode, NS 3451 – Beygningsdelstabell, TALO 2000 Hankenimikkeistö, TALO 2000 Building Component Classification, SINAPI, NL/SfB (NL), EcoQuestor, STABU-Element, BB/SfB (BE), VMSW, GuBIMclass (ES).

Table 5 introduces the list of existing classification systems and shows if the standard is used by the Annex participant country for implementing LCA. Notice that several standards integrated in ArchiCAD (Classification manager) are mainly focused on the BIM methodology than on the definition of classification systems for construction works, such as the ÖNORM B 6241-2 (ÖNORM, 2015a) “Digital structure documentation - Part 2: Building Information Modelling (BIM) - Level 3-iBIM”.

An automatic workflow between the classification system and the BIM model can reduce effort when integrating LCA in the BIM workflow. The current situation towards the integration of the classification system in the most used BIM commercial software shows that just the most popular classification systems (e.g., Master Format, Uniformat) are included in the automatic workflow of the software, that can be to the fact that the some of the BIM software have adapted their capabilities to the national requirements (e.g., Revit to United States of America).

Moreover, Table 5 also shows that the integration of the classification system into the BIM automatic workflow is still scarce in the context of the Annex participant countries. The most frequently used BIM software have not yet included at all the possibility to have an automatic workflow between the different national classification system used for LCA purpose and the BIM model.

Table 5. Integration of classification systems (tables) in BIM. Source based on: Classification system and its use in Autodesk (Autodesk Revit, n.d.) and BIM content for ArchiCAD (GRAPHISOFT, 2017).

Revit		
Classification system	**Country of origin**	**Annex participant in practice**
UniFormat (Charette & Marshall, 1999)	US	Canada
MasterFormat	US	-
OmniClass (International Organization for Standardization (ISO) et al., n.d.)	US	-
Uniclass	UK	New Zealand
a custom database classification system	-	-
ArchiCAD		
2010 CSI UniFormat	US	-
BB/SfB	BE	Belgium
BIM7AA	DK	-
BIMTypeCode	SE	-
CAWS	UK	-
CCS	DK	-
CCTB	BE	-
EcoQuestor	NL	-
Funktionskoder Regionservice - CD001_001_004	SE	-
GuBIMclass	ES	-
MasterFormat	US	-
NATSPEC	AU	-
NBS Create	UK	
NL/SfB	NL	NL
NS 3451 – Beygningsdelstabell	NO	-
OmniClass [18]	US	-
ÖNORM B 6241-2	AT	-
RICS NRM 1	UK	UK
RICS NRM 3	UK	-
Rumsfunktion - CD002_001_001	SE	-
Rumsfunktionskoder	SE	-
SFG20	UK	-
SINAPI	BZ	-
STABU-Element	NL	-
TALO 2000 Building Component Classification	FI	-
TALO 2000 Hankenimikkeistö	FI	-
Uniclass 2	UK	-
Uniclass 2015	UK	New Zealand
UniFormat (Charette & Marshall, 1999)	US	Canada
VMSW	BE	-

Previous studies provide evidence that one of the most important application of the classification systems into current BIM workflow is for cost estimation (International Construction Information Society, 2018b). Thus, could it be possible to transfer the lessons learnt for implementing it for LCA purposes? Currently, the use of the classification systems (designed focused on cost planning) for conducting cost estimation (International Construction Information Society, 2018b) and LCA (Cavalliere et al., 2019; Naneva et al., 2020; Röck et al., 2018b) in BIM is growing, and the Swiss context is an example of that. For cost estimation, two possible approaches are identified: the “component-oriented” and BIM compatible with the e-BKP (CRB, 2009) and the “execution-oriented” compatible with the BKP classification (International Construction Information Society, 2018b). The “elemental” or “component-oriented” approach is considered a suitable method to calculate the total costs of building works (International Construction Information Society, 2018a) and the sustainable assessment (Lützkendorf, 2019). This approach is also more compatible with the BIM workflow (analysed in detail in Section 6) than the “execution-oriented” approach.

The process requires among others, the quantification and the use of classification systems to identify and organise the building elements that compose the building. Performing a classification and identification coding of objects provides better possibilities for securing that everything has been properly included (International Construction Information Society, 2017).

In BIM, which is the generic classification of building elements that compose a model? The IFC Version 4.1.0.0 scheme (buildingSMART, 2020) (interoperable BIM format) propose an element classification that distinguish the physically existent objects given by the *IfcElement* entity (buildingSMART, 2020). The *IfcElement* entity cover the abstract supertypes of:
IfcBuildingElement, *IfcFurnishingElement, IfcElectricalElement, IfcDistributionElement, IfcTransportElement , IfcEquipmentElement, IfcFeatureElement, IfcElementAssembly, IfcVirtualElement.*

The *IfcBuildingElement* entity cover the major functional part of a building and comprise all elements that are primarily part of the construction of a building, its structural and space separating system, which are all physically existent and tangible things (buildingSMART, 2020). The *IfcBuildingElement* entity covers the abstract supertypes of:
IfcBuildingElementProxy, IfcCovering, IfcBeam, IfcColumn, IfcCurtainWall, IfcDoor, IfcMember, IfcRailing, IfcRamp, IfcRampFlight, IfcWall, IfcSlab, IfcStairFlight, IfcWindow, IfcStair,
IfcRoof, IfcPile, IfcFooting, IfcBuildingElementComponent, IfcPlate.

The IFC element classification recognises the following physical building parts: Covering, Roof, Column, Curtain wall, Door, Railing, Ramp, Ramp flight, Wall, Slab, Stair, Window, Roof, Pile, Footing, Plate. The element classification also covers the furnishing, electrical elements, distribution element, transport element, equipment, element assembly, and virtual elements.

4.3.3 Systematic Building Decomposition to conduct LCA during building design stages in BIM

In BIM, multiple levels of object definition are needed during the building's design stages. At early design stage, generic objects are used to compose the model. At detailed design stage the amount of information about the objects increase, but the object (e.g. a door) will still be the object, changes are detected in the granularity and precision of the object information (International Construction Information Society, 2017). Based on previous research (Santos et al., 2019) related to the integration of BIM and LCA in the design stages, two milestones or stages to conduct the LCA are identified: **the early design and the detail stage. At the Early design stage**: general LOD/LOG up to 200, element definition (lower modelling precision, use of generic objects). **At the detail design stage:** general LOD/LOG upper than 300, product/material definition (higher element modelling precision and product/material definition). The **element definition** relates to the geometry definition of the building elements, which could correspond to an up to 200 LOD/LOG. At this level the layers of the building elements are not at all defined. The **product/material definition** referes to an upper level of detail of the information about the building elements, where the layers and specific materials are already defined (at least 300 LOD/LOG).

As well as during the modelling process in BIM, in building decomposition the granularity of the data structure can increase as well as the number of vertical levels of decomposition. This means that generally the higher number of vertical levels, the greater number of building elements, building sub-elements, products and materials are identified. However, modelling tools not always allows to manage objects/materials/components/products at the same level of decomposition as the structures for building decomposition (International Construction Information Society, 2017).

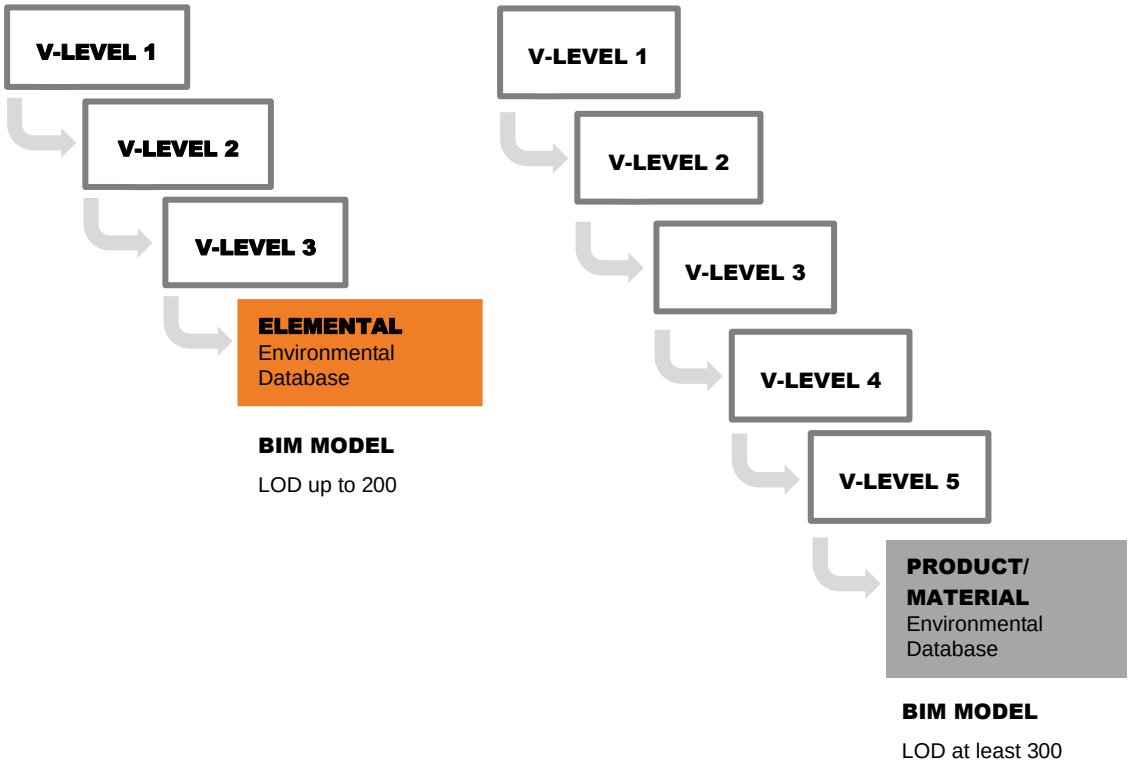
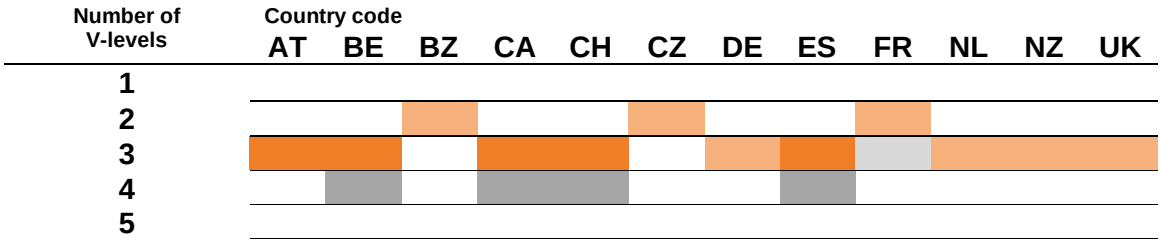


Figure 8. Example of the V-Level correlation with the environmental databases structure.

Figure 8 gives an example of the possible correlation between the vertical levels of decomposition, the environmental (LCA) database structure, the LOD/LOG/LOI of the BIM model, and design stage of the building. There, two possible design stages are considered: early and detail. These stages are ideally defined by two possible decomposition "milestones": i) **the elemental classification** (for early design) and ii) the **product/material classification** (for detail design). Thus, are the early and detailed LCA related to a specific elemental or product/material level of decomposition? Regarding the studied structures, the elemental classification can probably be performed at the vertical-levels 2/3 approx., which means that the environmental impact calculation can be ideally performed by using a BIM model with an up to 200 LOD (LOG/LOI), and an environmental database which integrates an elemental decomposition structure (e.g. Bauteilkatalog (Holliger Consult, n.d.)). The product/material classification (for detail design) can be performed following the elemental classification but increasing the granularity of data. Considering the studied structures, the product/material classification (for detail design) can probably be performed at the V-levels 3/5 approx., which means that the environmental impact calculation can be ideally performed by using a at least 300 LOD (LOG/LOI) BIM model and an environmental database which integrates a material/product structure (e.g. EPD database, or KBOB (*KBOB. Okobilanzdaten Im Baubereich*, n.d.)). Following, Table 7 introduce an overview of these aspects in the context of the Annex participants.

Table 7. Differences on vertical and horizonal level definition and the correlation with the design stages. (Source: Prepared by the authors based on national standards and guidelines for building decomposition to conduct LCA)



References: Number of Vertical Levels of decomposition

Orange (dark and light): early design stage / Grey (dark and light): detailed design stage

The obtained results confirm that the criteria to perform the elemental decomposition of the building is heterogeneous. Considering that the elemental classification (needed at the early design stages), is the decomposition of the building parts into items such as pillars, beams, roof, floor, external walls, windows, doors, balconies, etc. some data structure combine different levels of disaggregation. For example, Austrian structure combines group of elements such as "Foundations_Substructure" and "Load bearing structural frame" at level 2, where is contained the element "External walls" (level 3) while the German structure includes at level 2 a group of elements called "External walls" as well as "Foundations". Also, the decomposition regarding the number of elements considered can be different, for example the German structure includes 9 categories for decomposing the "external walls" group (331 Load-bearing external walls, 332 Non-load-bearing external walls, 333 External columns, 334 External doors and windows, 335 Cladding units, 336 Internal linings (of external walls), 337 Prefabricated façade units, 338 Solar protection, 339 External walls, other items), while the Dutch structure includes a group of elements called "External walls" at level 2 and at level 3 includes a type-of classification of that element into "Cavity walls", "System walls", "Curtain wall", "Façade". Due to that fact the rules for identifying the elemental decomposition and the definition of the vertical level are diverse, the Table 7 use two different colors for identifying the elemental classification level, the orange is used to indicate the cases that clearly fit into the above-mentioned criteria and the light orange is used for indicating the cases that partially perform it. Reading the sub-elemental and material decomposition (needed at the detailed design stages), similar difficulties are detected.

In general, Table 7 provide evidence of the differences in the granularity of the building decomposition structures (elemental or product/material decomposition) used by the Annex country participants to conduct early or detail LCA. Those differences can affect the data structure for the building decomposition not only to organize the LCI, but also the data set of databases and other needed data sources for implementing the LCA. Moreover, regarding the evolution of the building definition through the design stages, several standards that combines the decomposition into *system* and into *elements* approaches do not always integrate a hierarchical approach in the building elemental decomposition of all the building elements. It means that for example, the "Internal walls finishing" are not included in the internal wall's category, they are grouped in other category called "Finishing" (e.g., Austrian standard).

4.4 Synthes of the section

Difference along the national standards and guidelines used for the systematic building decomposition are detected. Thus, along the analysis and discussion of results can be extracted that:

- -The differences affect the levels of vertical decomposition and mainly the horizontal sub-divisions.
- The principles of specialization of the structures are generally based on the class (defined by the ISO 12006-2 (ISO, 2012a) standard) “Construction Result”, and provide in several cases a combination of decomposition into elements and system of the building.
- The integration of the classification systems in the current workflow in BIM (default configuration of the most used BIM software) is still scarce and depend on the level of maturity (or popularity) of the BIM implementation.
- The elemental and subsequent vertical decomposition of the building parts do not fulfill the same criteria and rules. These differences can affect among others the organization of the environmental databases when considering the LCA application at design stages (early and detail).
- Given that one of the detected difficulties in comparing the systems was the heterogeneities and differences in the standards / guidelines to building decomposition, the following chapter is focus on comparing them based on a case study. Therefore, we aim to illustrate the scope and implications of using a systematic building decomposition when conducting LCA.

5. Case study Be2226 building: building decomposition and their implications to conduct a LCA

5.1 Brief description of the case study reference building

The reference building “be2226” (see Figure 9) office building is located in Lustenau (Austria). Previously used as a reference building to compare national LCA methods in the IEA EBC Annex 72 ST 1 Activity 1.2 and reported in (Frischknecht et al., 2019). The present comparison started by using the same template information developed for (Frischknecht et al., 2019) to apply different national classification systems and standards/guidelines for the building decomposition and organize the building information. The template comprehends the building element types presented in Table 8, including: foundation, external walls, floor structure, roof structure, stairs, flooring, roofing, windows, doors and building services (see also Appendix II).

Figure 9. External view of the be2226 reference building. (Source: IEA EBC Annex 72. ST 1 Activity 1.2).

Table 8. Overall building structure, elements with respective sub-elements and materials (Source: IEA EBC Annex 72. ST 1 Activity 1.2).

Building element Type	Building Element
Foundation	FN01_Structural foundation, driven piles new, d42.0
	FN02_Structural foundation, slab-on-grade slab, reinf. Concrete, 25.0
	FN03_Structural foundation, special
	FC01_Perimeter insulation (slab-on-grade)
External walls	EW01_Exterior wall, outer brick + plaster, 40.5
	EW02_Exterior wall, brick attica, 38.0
Floor structure	FS01_Floor structure, upper floors, concrete slab+plaster, 24.5
Roof structure	RS01_Roof structure, concrete slab, 24.0
Stairs	ST01_Stair primary, concrete, w100.0
	ST02_Stair secondary, wood, w100.0
Internal walls	IW01_Interior wall, brick + plaster 27.0
	IW02_Interior wall, brick + plaster 17.0
	IW03_Interior wall, brick+plaster, 12.0
Flooring	FL01_Floor finish, ground floor, 29.5
	FL02_Floor finish, upper floors, 14.5
Roofing	RF01_Roofing, sealing+insulation+foil+gravel, 36.0
Windows	WE01_Windows exterior, ground floor, incl. side panel
	WE02_Windows exterior, upper floors, incl. side panel
Doors	DE01_Door exterior, ground floor, incl. side panel
	DI01_Door interior, wooden door + frame
	DI02_Door interior, glass door (modelled as wall), 5.5
	DI03_Door interior, wooden door + frame
Building services	SA01_Sanitary equipment
	EL01_Elevator

5.2 Methods

The office building “be2226” [24] was used to illustrate the differences and similarities in the organization of building parts, and to analyse the implications of using those national standards/guidelines to organize the building information relevant for LCA, including the organization of the Life Cycle Inventory (LCI), LCA databases and results communication (Soust-Verdaguer et al., 2020). We also analysed the implications of integrating these standards/guidelines into BIM for LCA purposes. The objective of using this reference building lies in the fact that the LCI was automatically extracted from the BIM model. Thus, the LCA calculation procedure was based on the automatic bill of material quantities from the BIM model (Frischknecht et al., 2019), that enables to discuss the implications of using a systematic building decomposition to conduct building LCA in BIM.

The case study used a common template to identify the basis of the elements and materials that composes the building. Then by using the different standards and guidelines for the systematic building decomposition it is numbered the quantity of mayor element groups considered, the quantity of groups of elements, the quantity of element types, the specific element, sub-elements and materials. Depending on the granularity, levels and subdivision that the standard or guidelines propose are defined the number of items contained in the Table 9.

Here, a comparative analysis of the national standards and guidelines for building decomposition and their implications to conduct LCA, considering the be2226 building case study, was conducted regarding:

- The life cycle inventory and the communication of results (data structure and grouping principles)
- The reference service life definition (at which level and which group/element/product etc.)

5.3 Results and Discussion

The presented results are founded on the **tables and data structures** obtained from conducting the building decomposition by using the national standard/guidelines to the reference building “be2226.”

5.3.1 Tables and data structures

The decomposition of the building parts into vertical levels and horizontal sub-division, was discussed in accordance with the ISO principles for classification and composition. There, the vertical decomposition allows the subdivision or classification of a system into sub-systems using ‘part-of’ relations, while the horizontal decomposition allows the order of classes in sub-division determined by ‘type-of’ relations (Soust-Verdaguer et al., 2020) (see Figure 10). The different national standards and guidelines for systematic building decomposition were compared considering the vertical levels and horizontal sub-division decomposition.

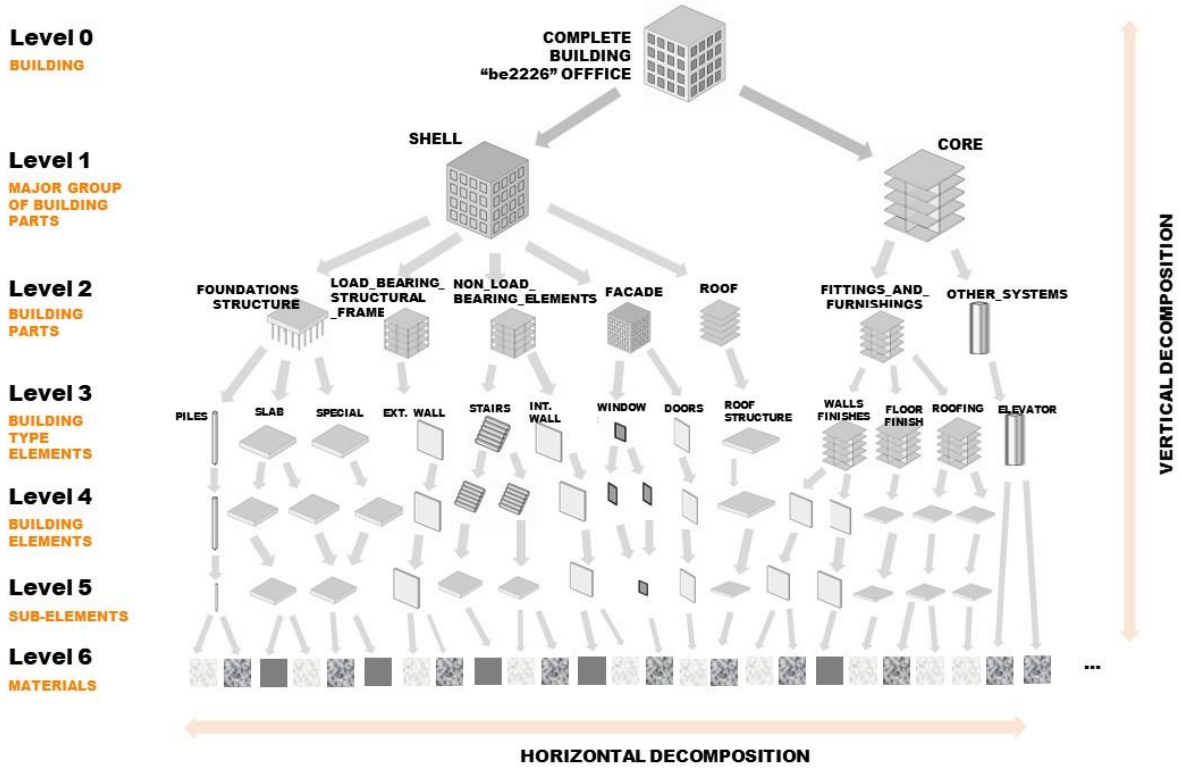


Figure 10. Scheme of the systematic building decomposition of the be2226 reference building following the Austrian ÖNORM B 1801-1 (ÖNORM, 2015b). (Source: based on (Soust-Verdaguer et al., 2020) and prepared by authors based on the Austrian standard Austrian ÖNORM B 1801-1 (ÖNORM, 2015b)).

The tables and data structures summarize the number of levels of vertical decomposition and sub-divisions of horizontal decomposition, that are used to organize ‘part-of’ (vertical) and ‘type-of’ (horizontal) relations of the reference building “be2226” (Soust-Verdaguer et al., 2020). The Appendix II includes the detailed results and the data sources to develop Table 9.

Table 9. Number of vertical levels of decomposition and horizontal sub-divisions. (Source: Prepared by the authors based on national regulation in construction and LCA application to buildings)

Nr of V-levels*	Country code											
	AT	**BE**	**BR**	**CA**	**CH**	**CZ**	**DE**	**ES**	**FR**	**NL**	**NZ**	**UK**
1	2 Shell, Core	3 Structure, Substructure and Services	6 Systems/elements: Structure Internal floors Façade Partitions Roof Plumbing	4 Major Group Elements A Substructure, B Shell, C Interiors, D Services	4 Categories: C- Structure E- Envelope G- Interior. F- Roof D- Technical equipment	Not specified	2 Systems: 300 Structure construction works, 400 Structure – services	5[1] Systems: Structure; Envelope; Partitions; Finishing; Air conditioning and installations	3 Systems/ Categories: A Foundations; B Envelope; C Others	6 Category/System Foundations, Carcass, Finishing, Finishes; Installations E Fixed provisions	1 EE_Elements and functions	5 Category/Systems 1 Substructure 2 Superstructure 3 Finishes 4 Fittings, furnishings and equipment (FF&E) 5 Building services/MEP
2	7 Building parts: Foundation Substructure; Load bearing structural frame; Non load bearing elements, Facades; Roof, Fittings and furnishings, Other_system s	6 Group of Elements: 1.Ground substructure 2.Structure primary elements, carcass 3.Secondary elements of superstructure 4.Finishes to structure 5. Services mainly electrical 6.Loose furniture equipment	14 Building parts: Main structure; Complementary structure; Façade; Internal partitions; Roof; Internal finishing; Façade finishing; External flooring; Painting; Waterproof system; External windows and doors; Internal windows and doors; Building services; Equipment	8 Group of Elements A10 Foundations; B10 Superstructure B20 Exterior Closure; B30 Roofing C10 Interior Construction; C20 Staircases C30 Interior Finishes Conveying E20 Furnishings	10 Building elements: 1. Foundation 2. Stairs 3. Exterior wall above ground 4. Window 5. Floor 6. Roof 7. Interior wall 8. Ceiling 9. Technical equipment 10.Sanitary equipment	14 Building parts Foundation Waterproofing layers Vertical and horizontal construction elements Roof construction Roof deck Staircase Internal partitions Non-bearing cladding Finishes Final floor covering Windows and doors	8 Building parts: 320 Foundations, 330 External walls; 340 Internal walls; 350 Floor and ceilings. 360 Roofs; 370 Structural fitments; 460 Transport systems	9[2] Group of Elements: 03. Foundations 05. Structure 06. Masonry 07. Roof 08. Installations 09. Isolations 10. Finishing 11. Carpentry and safe and security elements 12. Glass	9 Building parts: A Foundations; B1 Exterior walls B2 Interior walls B3 Windows and doors B4 Ground floors B5 Intermediate floors B6 Roofs C Sanitary Equipment Transports	16 Groups of Elements: Floors on foundation; Foundational construction; External walls; Inner walls; Floors; Stairs and inclines; Roofs Main supporting construction; Exterior wall openings; Interior wall openings; Exterior wall finishes; Interior wall finishes; Floor finishes; Ceiling finishes; Roof finishes; Transportation	6 EF_ Structural elements Wall and barrier elements Roofs, floor and paving elements Stairs and ramps Signage, fittings, furnishings and equipment Transport functions	13 Groups of Elements: 1.1 Substructure 2.2 Upper floors incl. balconies 2.3 Roof 2.4 Stairs and ramps 2.5 External Walls 2.6 Windows and External Doors 2.7 Internal Walls and Partitions 2.8 Internal Doors 3.1 Wall finishes 3.2 Floor finishes 3.3 Ceiling finishes 4.1 Fittings, Furnishings & Equipment 5.1–5.14 Services incl. Building-related
3	16 Building elements type	18 Building elements type	-	18 Individual Elements	16 Building components	Not specified	16 Elements type	12 Building elements type	47 Materials	25 Building elements type	10 Building elements type	24 Building elements
4	26 Building elements	33 Building elements	-	52 Sub-elements	72 Materials	Not specified	27 Building elements	20 Building Element	-	31 Building elements	21 Building elements	42 Sub-elements
5	45 Building sub-elements	54 Sub-elements	-	69 Materials	-	Not specified	58 Sub-elements	53[2] Material	-	50 Sub-elements	48 Sub-elements	59 Materials
6	67 Materials	73 Materials	-		-	-	73 Materials	-	-	70 Materials	73 Materials	-

Number of H - subdivisions**

* Number of Vertical Levels of decomposition. ** Number of Horizontal subdivisions of decomposition. [1] Based on CTE (CTE, 2006) (Spanish Building Technical Code) primary classification. [2] Based on BBCA (Andalusian Government, 2017) Classification.

5.3.2 Table structures: number of levels of decomposition

The template inventory (included in Appendix II) was organised by a hierarchical structure that provides an elemental classification (including piles, slabs, etc..), a sub-elemental classification (including concrete for foundation, etc.), and a material classification (including concrete in situ, reinforcing steel, etc), which leads to three vertical levels of decomposition. The information contained in the template does not recognise specific manufacturer for the materials; thus, this information is not included in the structures for building decomposition of the reference building which is also a limitation of the present study.
The structure is organised according to the material quantity take-off that was automatically extracted from the BIM model. Thus, the structure allows to track the materials and sub-materials that integrates each building element.

Table 10. Part of the template inventory (complete version in Appendix II). (Source: IEA EBC Annex 72. ST1 Activity 1.2)

Building Element	**Sub-element**	**Material**
FN01_Structural foundation, driven piles new, d42.0	Concrete Foundation Pilar	Concrete In Situ
		Reinforcing Steel

Regarding the obtained results, most standards or guidelines recommend integrating at least six vertical levels of decomposition (from the complete building level (level 0) to the material level (level 6). Generally, a first level was identified that provides a rough classification of the building, by identifying the main systems of major group of elements regarding their function (e.g., structure, envelope), the second level comprised a classification of the group of elements (e.g. foundation), a third level included an elemental type classification (e.g. external wall), a fourth level composed an elemental specific classification (for example by identifying the different type of external walls), a fifth level integrated a sub-elemental classification (for example by identifying the layers that composed the different type of external walls), and a sixth level that integrated a material classification process (for example by identifying the specific materials and products that composed the different layers of each type of external walls). For the case study ("be2226" reference building), the maximum number of materials extracted from the template inventory was 73, which corresponds to the decomposition of 24 building specific elements (included in the BIM model) into 54 sub-elements, and finally into 73 materials (Soust-Verdaguer et al., 2020). The account of elements/sub-elements and materials was performed by tracking the elemental and sub-elemental that the material belong to. For example, the material "Concrete In Situ" is considered as the building material that belongs to the sub-element "Concrete Foundation Pilar", and the building element "FN01_Structural foundation, driven piles new, d42.0", and was considered different as the material "Concrete In Situ" that belongs to the sub-element "Concrete Foundation Slab", and the building element "FN02_Structural foundation, slab-on-grade slab, reinf. Concrete, 25.0".

Obtained results provide evidence of the differences in terms the organization of the first vertical level of the elements or systems classification (Table 9). Probably, the major differences were detected at the first level, which affected the rest of the building decomposition. For example, the Austrian standard can be used to consider two major groups (Core and Shell), while the Swiss and Spanish codes respectively take into account four categories (Structure, Technical equipment, Envelope, Interior) or five systems (Structure; Envelope; Partitions; Finishing; Air conditioning and installations) (Soust-Verdaguer et al., 2020).
Results shows that in most of the analysed cases, the levels of desegregation and grouping principles from vertical levels 1–3 depended on the structure that was defined by the standard/guideline for building decomposition (Soust-Verdaguer et al., 2020). The decomposition at the subsequent levels (levels 4–6), mainly depended on the building characteristics and the granularity of the BIM model, i.e., the variety of element types/sub-elements and materials. Therefore, the results demonstrate that the organization of the higher levels of decomposition (from element to material) were not carefully described in the on the

standards and guidelines, their organization were mainly a consequence of the elemental building decomposition.
Moreover, the main differences between the number of elements, sub-elements and materials considered are related to the decomposition of *system* and *element* approaches. The combination of both allows can produce deviations/disparity for example when considering finishing materials and products that could be performed by grouping type of materials (such as lime plaster interior for walls) or by grouping type of element (such as external wall, internal wall).

5.3.3 Table structures: grouping principles and naming codes

Differences in naming codes and conventions, following different criteria on the taxonomy and organization of the different levels of decomposition were also detected (Soust-Verdaguer et al., 2020). As abovementioned in section 5.3.1, could be partly due to translation or local construction culture and meanings.

5.3.4 Implications regarding aspects of LCA

The results show differences in the organization of the building parts, the granularity or precision in the building decomposition, the sub-divisions and the levels of decomposition of the standards /guidelines across the use of the different systems/standards for building decomposition when conducting LCA (Soust-Verdaguer et al., 2020). There, various aspects are involved, such as the structure of the LCI, LCA databases, communication of results and the consideration of the service life.

5.3.4.1 Implications in the life cycle inventory (data structure) and communication of results

A standardized structure for organizing and grouping the building parts, potentially affects the ability to verify the LCI completeness. It means that, the more detailed and hierarchically organized the LCI is, the easier it is to identify the building parts/elements/sub-elements/materials (Soust-Verdaguer et al., 2020).
One of the consequences of using one or other standard for the systematic building decomposition, is that differences in the number of tagged materials or elements included in the LCI can be detected. For example, Table 9 shows that the number of tagged materials for Austria was 67 and for France was 47. It means that the way that elements, sub-elements and material are organized can affect the number of tagged building materials, and the possibility of tracking elements and building systems.
In the communication of results, the relevance of performing a systematic building decomposition affects the ability to detect hotspots and the optimization of the environmental performance by modifying building parts/elements/sub-elements/materials. An adequate balance between completeness and utility should be considered. Thus, the more levels of vertical and horizontal decomposition are used, the more accurate building decomposition process can be carried out, but this approach also increases the complexity of the data structure, which is a significant drawback (Soust-Verdaguer et al., 2020).

5.3.4.2 Implications in the service life consideration

The service life definition of the building systems, group of elements, elements, components, product and material is a relevant aspect when conducting building LCA. There, the structure for the building decomposition plays an important role, because it affects among others the comparability of results.
Table 11 summarize the obtained results for the service life consideration included in the IEA EBC Annex 72 ST 1 Activity 1.2. The activity comprised a basis template building decomposition structure where each country declared the years of service life assumed to conduct the LCA of the reference building “be2226”.
Based on the obtained results, the most considered systems/elements/materials were substructure, external and internal walls. For those systems/elements the building service life (in years) was heterogeneously considered, except for the **Substructure system**. There, most countries considered 50 or 60 years and a similar granularity of the data structure (including “Foundations”, “Basement walls”, and “Ground floor construction”). Also, the same number of years were assumed for all the building elements that compose the **Substructure system.** In contrast, the **Building services system** was one of the most

heterogeneous, because of the neglection the system in the system boundaries of the LCA or because of the differences in the years of service life (from 15 to 50). Regarding the **Finishes,** differences has been detected, among which the definition of the service life depending on the building materials (e.g., Belgium and the Netherlands).

In sum, the obtained results provide evidence that the consideration of the building service life has similar or compatible elemental decomposition structures, that can be compared. Similar trends in the consideration and assumption have been detected in most countries. There, the **Substructure and structure systems** (external walls, frames, internal walls (supporting), roof, stairs and ramps) mostly assumed the same number service life years (around 50 or 60 years). While other systems such as the finishes provide evidence of the differences in the service life assumptions and its decomposition, which can depend among others, on the regional regulations related or the materials and construction characteristics.

Table 11. Summary of the obtained results for the service life consideration based on the IEA EBC Annex 72 ST 1 Activity 1.2. (Source: IEA EBC Annex 72 ST1 Activity 1.2.)

Building element	AT	BE	BR	CA	CZ	CH	DE	ES	FR	NL	NZ	UK
Substructure												
Foundations	60	60	50	60	60	60	50	50	50	1000	>60	60
Basement walls	-	60	50	60	60	60	50	50	50	1000	>60	-
Ground floor construction	60	60	50	60	60	60	50	50	50	1000	>60	-
Superstructure												
External walls												
External walls (below ground)	-	60	50	60	60	60	50	50	50	1000	>60	60
External walls (above ground)	100	60	50	60	60	60	50	50	50	15-75	>60	60
Frames (pillars and beams)	-	60	-	60	-	60	N/A	N/A	50	1000	>60	60
External doors	30	30	20	60	30	30	35	25	30	1000	60	40
Windows	30	30	20	21	30	30	30	25	30	1000	60	40
Internal walls												
internal wall construction (supporting)	100	60	50	60	60	60	50	50	50	-	60	60
partition wall and doors (non-supporting)	30	30	20	60	30	30-60	50	25	30	-	60	30
Floors (structural)	50	60	8	60	60	60	50	50	50	-	60	60
Ceilings	80	60	50	60	60	60	40	50	50	1000	30	60
Roof structural construction	60	60	50	60	60	60	50	50	50	75	60	30
Stairs and ramps (structural)	70	60	50	60	60	60	50	50	50	50	60	-
Building Services												
Water system	-	20	20	N/A	30	-		N/I	50	75	N/D	-
Sewage system	-	20	20	N/A	30	-	no	25	50	50	N/D	-
Electrical system	-	20	20	N/A	30	30	no	N/I	50	50	N/D	-
Heating system (heat producer)	-	20	-	N/A	20	20	N/A	N/I	20	15-30	N/D	-
Heating system (heat distribution)	-	20	-	N/A	30	30	N/A	N/I	50	30-50	N/D	-
Cooling system	-	20	20	N/A	30	-	N/A	N/I	20	-	N/D	-
Ventilation system	-	20	-	N/A	30	30	no	N/I	20	25-35	N/D	-
Conveying system	-	20	13	N/A	-	-	25	25		-	N/D	40
Data system	-	20	20	N/A	-	-	no	N/I		-	N/D	-
Fire protection system	-	20	20	N/A	-	-	no	N/I		-	N/D	-
Finishes												
External finishes walls (below ground)	60	60	50	60	60	60	N/A	50	50	-	>60	-
External finishes walls (above ground)												
external coating	30	40	20	60	40	40	N/A	50	10	-	8	30
external thermal insulation (compact facade)	-	DM	20	60	30	30	N/A	50	50	75	N/D	30
facade cladding (ventilated)	-	20-40 DM	20	60	40	40		50	50	75	N/D	30
facade system	-	DM	40	60	40	40	N/A	50	50	75	50 - 60	30
External finishes roof (below ground)	-		50		60	60	N/A	50	50	-	N/D	30
External finishes roof (above ground)												
roof cladding - flat roof	30	DM	13	30	30	30	40	50	50	30	15 - 25	30
roof cladding - inclined roof	-	DM	13	N/A	40	40	N/A	50	50	40	30 - 60	30
Internal finishes (walls, floors)	30	DM	13	25-60	30	30	N/A	25	10	15-40 DM	60	25
Furniture	-	N/I	-	-	-	-	N/A	N/I		-	N/D	-

Fixed Furniture	-	N/I	-	-	-	-	N/A	N/I		-	N/D	-
External												
Balcony	-	N/I	50	N/A	40	40	N/A	N/I	50	75 DM	N/D	-
Vegetation	-	N/I	-	-	-	-	N/A	N/I		-	N/A	-
Pavements	-	N/I	-	-	-	-	no	N/I	50	-	N/A	-

N/A: not applicable, N/D: No data, N/I: not included; DM: depending on type of material

5.3.5 Implications for design phases in design tools (BIM)

One of the most relevant implications of integrating LCA into BIM is that it can reduce efforts to conduct the bill of material quantities (Soust-Verdaguer et al., 2016), through the automatic material take-off. Thus, a systematic building decomposition specific rules can be useful to organize the material take-off of the building elements/objects. However, in BIM methodology multiple levels of object definition are needed during the design development process and also the precision of the modelling also changes during the design process (Soust-Verdaguer et al., 2020).

The results of this study confirm that the organization of the building elements/objects differed, and especially their hierarchy also differed (Soust-Verdaguer et al., 2020). For example, the French table used for building decomposition defines that the elements of the “Exterior walls” contains the finishing materials (e.g., “B Envelope”→ “B1 Exterior walls”→“B12 Finishes”) in the “Envelope” system. Nevertheless, the Austrian standard considered the internal wall finishes as part of a separate group called “Wall and ceiling finishes” (e.g., “Core (fittings, furnishings and services)”→ “Fittings_and_furnishings” → “Wall and ceiling finishes”). This means that, the information about the object (e.g. “finish materials”) was hierarchically grouped in the French table based on a principle associated with the object itself (e.g.“Interior walls”), while the Austrian standard treated the object as a new sub-system (e.g., “Core (fittings, furnishings and services)”) that contained all the building finishing (such as “Sanitary fittings, Ceilings, Wall and ceiling finishes, Floor coverings and finishes”) (Soust-Verdaguer et al., 2020). Moreover, for organizing other systems and elements/objects such as the structure or the external walls, similar differences were also detected. Thus, no matter which standards/guidelines are considered to be the most appropriate, our results indicate that the decomposition or desegregation level of the building elements/objects needs to mirror the way that the objects are organized in the model, especially when considering the different design phase in BIM and their hierarchical organization (Soust-Verdaguer et al., 2020). This approach can reduce efforts on identifying hotspots and developing strategies to reduce impacts at design stages. Moreover, most of countries that mainly based the decomposition on the *elemental approach*, include the maximum number of building materials (73). If this approach is combined with the *system* decomposition approach can provide more guarantees (improving the traceability and transparency) when organizing the LCI and the communication of results in LCA. It can help for example to identify hotspots by building systems, building elements, building materials and a combination of all. For example, when considering the finishing system, it should be also possible to decomposed it into the building elements that compose the system (e.g., external walls finishing type 1, internal walls finishing type 1, floor finishing type 1).

5.4 Synthes of the section

Twelve national standards were compared by applying to a reference building and illustrating the implications of the findings regarding aspects of the LCA.

- The results confirmed the above-mentioned tendencies related to the differences on the number and organization of the levels of decomposition, which affected the completeness and the organization of the LCI (such as the number of elements, materials, etc.) and the organization of the LCA results.

- The detected differences also affected the consideration of the element service life (life spam) and the elemental decomposition.

Based on the obtained results, the following section presents the final discussion of the topic, the detected challenges and provide recommendations.

1. Challenges and recommendations

The present work demonstrates that one of the major benefits of using a systematic approach to the building decomposition is that it provides transparency and guaranty to obtain a traceable and comprehensive organization of the building elements, sub-elements and materials. It means that depending on the granularity of the needed information about the building, for different purposes in the LCA (hots spots identification, communication of results, etc.), the organization of the information (e.g., the number of elements and how they are grouped) can be easily recognized. The conducted overview of the different national standards used for the systematic building decomposition provide evidence of the heterogeneity in the organization and grouping principles of the building information structures for implementing the LCA, supporting the relevance of using and communicating which standards or guideline was used. Moreover, we detected the existence of challenges related to the interoperability, translation and harmonization of available standards and guidelines for systematic building decomposition to conduct LCA. Consequently, we conclude that (at least at the moment) it cannot be possible, in the short term, to define one harmonized information structure to the systematic building decomposition for implementing the LCA, due to the great heterogeneity and the strong connection of these structures with national or regional datasets and databases (e.g., environmental impacts databases) for implementing the LCA (e.g., KBOB). However, in the long term, the possibility of defining a common reference or harmonized standard can be addressed. Two great tendencies are detected when analyzing the different standards and guidelines, the first one provides a decomposition based on the recognition of the main systems (system approach) and the second is more focused on the classification of the building elements (elemental approach) based on their function. Both approaches are needed and provide a valid structure for the building decomposition. Most of the standards and guidelines are based on a combination of both, except the Uniclass 2015 standard (CPIc, 2015) that explicit it and provide one table for each approach. Regarding the implementation of LCA in BIM, and the integration of systematic building decomposition into BIM methodology, on the one hand, the elemental approach can be more compatible with the BIM workflow that the *system* approach, because it allows to track and identify the hierarchical decomposition of the building including elements, sub-elements and, materials and products. On the other hand, the *system* approach allows to obtain a global overview of the systems, but limited capability to track and identify specific elements, sub-elements and materials of the building. In sum, both approaches are complementary regarding the scale and complexity of the building, design stage that is implemented the LCA and scope of the study.

The study also provides evidence of the limits of the building decomposition hierarchy structure which come up to material level, thus, when introducing the circularity principles in the construction sector the integration of information about material flows (e.g. raw materials, manufacturing process, etc.) became necessary. The approach can be relevant regarding the concepts of “material passport” (*BAMB. Materials Passports*, 2019) and “building and material inventories” (Leibniz Institute of Ecological Urban and Regional Development & Karlsruhe Institute of Technology, 2020), and especially to support decisions related to the replacement of components and the deconstruction of existing buildings (Lützkendorf, 2019) (potential of reuse, recycling).

The present work confirms that considering different national standards used for the systematic building decomposition, the highest vertical level of desegregation (from sub-element to manufacturer level) are less described and include limited rules for their organization. That fact provide evidence that further developments should be performed, in order to improve comparability and transparency when conducting LCA, especially at detailed design stages. Also, further harmonization could be performed related to the building definition at different design stages and the building decomposition. There, a possible path to solve it could be to define a common elemental decomposition structure (adapted to the different national standards and guidelines), in order to identify those elements that should be defined at early design stages and those elements and systems that should be defined at detailed design stages.
Thus, when considering the analyzed standards and guidelines for systematic decomposition, and building elements classification used in BIM (IFC), the building decomposition at the element level can comprise the following items:

Element level decomposition	**Sub-element and Material level decomposition**
Substructure and superstructure	
Foundations	Main sub-element and materials
Basement	Main sub-element and materials
External walls	Main sub-element and materials (including external wall finishes)
Pillars (columns)	Main sub-element and materials
Beams	Main sub-element and materials
Doors (interior and exterior)	Main sub-element and materials
Windows (interior and exterior)	Main sub-element and materials
Internal wall	Main sub-element and materials (including internal wall finishes)
Floors (slabs)	Main sub-element and materials (including finishes)
Ceilings	Main sub-element and materials (including finishes)
Roof	Main sub-element and materials (including finishes)
Stairs	Main sub-element and materials
Ramps	Main sub-element and materials
Exterior and equipment	
Furniture, equipment, and outdoor equipment (e.g. Vegetation, Pavements)	Main sub-element and materials
Building services	
Water, Sewage, and gas system	Main sub-element and materials
Electrical/Power/Lighting system	Main sub-element and materials
HVAC system	Main sub-element and materials
Communication/Telecommunications/Data and Fire protection system	Main sub-element and materials

The element level (at early design stage) can include a general classification of the building elements regarding their main function in the building. At detailed stages the number of building elements can be higher than at the early stage because other secondary elements (e.g. sealing and joining elements) are integrated in the model and LCA inventory. Hence, at the sub-element and material level the decomposition can include (at least) the main sub-elements and materials that are composing the elements (a consequence of the element classification).

The case study application to the reference building confirmed the detected tendencies when comparing the national standards and guidelines to perform a systematic building decomposition. It also illustrates the scope and implications of the differences when conducting LCA.
To conclude, opportunities are detected over the integration of classification systems to perform the systematic decomposition in BIM for cost estimation proposes. There, the maturity and level of

development of the datasets and databases is higher than in the LCA. Also, in some cases such as the Spanish standard (e.g., BCCA) the use of predefined dataset for describing the materials, products, machinery and labor around an element can provide more transparency to the LCA application (especially for example when detailed modelling A5, B4 and C1 modules).

Therefore, several conclusions and recommendations are drafted:

- To use, whenever possible, a classification system **based on hierarchical grouping principles**, and allows to identify the main systems and elements that compose the building which improves transparency on LCA application and support during the design stages.
- To promote the **compatibility** of structures for systematic building decomposition with environmental, economic, etc. datasets and databases, that enables to improve the interoperability of data during design stages of buildings.
- To **promote** the use of structures for systematic building decomposition that allows a whole life cycle classification, based on the ISO 12006-2(ISO, 2012a) principle of object classes ("Construction Resource", "Construction Process", "Construction Result", and "Property/Characteristic").
- Special care should be paid when comparing different countries LCA, where the use of the same standard and guidelines for building decomposition should be implemented to provide a fair case study comparison.

Some recommendations related to the BIM workflow:

- To promote the **development** of packages or add-ins or encourage the integration in the default configuration of the BIM software, of the most frequently used classification systems for LCA application.
- To integrate the lessons learnt from the cost estimation/LCC workflow in BIM, based on the **element-oriented approach**, which can help to increase the use of classification systems to conduct LCA in BIM.

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3. Appendix I. Examples of Systematic Building decomposition based on national standards/guidelines

Table 1. Example of Systematic Building Decomposition- Austria (Source: based on the ÖNORM B1801 (ÖNORM, 2015b))

Building parts	Related building elements
Shell	
Foundation_Substructure	Piles
	Basements
	Retaining walls
Load_bearing_structural_frame	Frame (beams, columns and slabs)
	Upper floors
	External walls
	Balconies
Non_load_bearing_elements	Ground floor slab
	Internal walls, partitions and doors
	Stairs and ramps
Façades	External wall systems, cladding and shading devices
	Façade openings (including windows and external doors)
	External paints, coatings and renders
Roof	Structure
	Weatherproofing
Parking_facilities	Above ground and underground (within the curtilage of the building and servicing the building occupiers)
Core (fittings, furnishings and services)	
Fittings_and_furnishings	Sanitary fittings
	Cupboards, wardrobes and worktops (where provided in residential property)
	Ceilings
	Wall and ceiling finishes
	Floor coverings and finishes
In_built_lighting_system	Light fittings
	Control systems and sensors
Energy_system	Heating plant and distribution
	Cooling plant and distribution
	Electricity generation and distribution
Ventilation_system	Air handling units
	Ductwork and distribution
Sanitary_systems	Cold water distribution
	Hot water distribution

	Water treatment systems
	Drainage system
Other_systems	Lifts and escalators
	Firefighting installations
	Communication and security installations
	Telecoms and data installations
External works	
Utilities	Connections and diversions
	Substations and equipment
Landscaping	Paving and other hard surfacing
	Fencing, railings and walls
	Drainage systems

Table 2. Example of Systematic of Building Decomposition. Summary of the classification Structure of the BCCA- Spain (including level 2 and level 3) – (Source: Banco de Costes de la Construcción de Andalucía- Spain (Andalusian Government, 2017))

"Chapter"	"Sub-chapter"
01. Demolitions	01A. Masonry
	01C. Foundations
	01E. Buildings
	01I. Installations
	01K. Carpentry and safe and security elements
	01Q. Roof
	01R. Coating
	01S. Sewerage
	01T. Previous works
	01W. Others
	01X. Structures
02. Terrain	02A. Open air
	02P. Well
	02R. Backfilling and compacting
	02T. Transports
	02W. Others
	02Z. Ditches
03. Foundations	03A. Armors
	03C. Special foundations
	03E. Formwork
	03H. Concrete
	03R. Recovery
	03W. Others
04. Sewerage	04C. Hanging networks
	04E. Buried networks
	04R. Recovery
	04V. Vertical networks
	04W. Others
05. Structure	05A. Steel
	05F. Slabs
	05H. Concrete
	05M. Timber
	05R. Recovery
	05W. Others
06. Masonry	06A. Brick arches and vaults
	06B. Blocks
	06C. Cuarry
	06D. Partitions
	06E. Special enclosures
	06L. Brick
	06P. Prefabricated
	06R. Recovery
	06W. Others
07. Roof	07H. Horizontal
	07I. Inclined
	07R. Recovery
	07W. Others

08. Installations	08C. Climatization
	08E. Electricity
	08F. Plombering
	08K. Communication
	08L. Gas and liquid
	08M. Electromechanics
	08N. Solar energy
	08P. Protections
	08R. Recovery
	08S. Healthiness
	08W. Others
09. Isolations	09A. Acoustic
	09I. Weatherproofing
	09R. Recovery
	09T. Thermic
	09W. Others
10. Finishing	10A. Cladding
	10C. Continuous
	10L. Light
	10P. stair treads
	10R. Recovery
	10S. Floor
	10T. Roof
	10W. Others
11. Carpentry and safe and security elements	11A. Steel
	11L. lightweight alloys
	11M. Wood
	11P. Plastic
	11R. Recovery
	11S. Security and protection
	11W. Others
12. Glass	12A. Insulating glass
	12L. Laminated glass
	12N. Simple glass
	12R. Recovery
	12S. Synthetics
	12W. Others
13. Paint	13E. Exteriors
	13I. Interiors
	13R. Recovery
	13S. Specials
	13W. Others
14. Equipment	14M. Furniture
	14R. Recovery
	14W. Others
15. Urban	15A. Sewage
	15C. Circulation indicators
	15E. Electricity
	15G. Gas and liquid
	15J. Garden
	15M. Earth movements
	15P. Flooring
	15R. Recovery
	15S. Water supply
	15T. Telephone and data distribution
	15U. Urban equipment
	15W. Others
17. Waste Management	17A. Metals
	17F. Bitumen
	17H. Concrete, Ceramic, tile and gypsum
	17I. Isolation materials
	17M. Wood, plastic, paper and glass
	17R. Mixed waste
	17T. Earth
	17W. Others

19. Security and health	19L. Service rooms
	19S. Security
	19W. Others

Table 3. Example of Systematic Building Decomposition- Germany (Source: Building LCA DGNB based on DIN 276 (DIN, 2008))

300 Structure – construction works	310 Excavation	311 Excavation work
		312 Support work
		313 Dewatering
		319 Excavation, other items
	320 Foundations	321 Soil improvement
		322 Shallow foundations
		323 Deep foundations
		324 Subfloors and base slabs
		325 Floorings
		326 Waterproofing of structure
		327 Drainage
		329 Foundations, other items
	330 External walls	331 Load-bearing external walls
		332 Non-load-bearing external walls
		333 External columns
		334 External doors and windows
		335 Cladding units
		336 Internal linings (of external walls)
		337 Prefabricated façade units
		338 Solar protection
		339 External walls, other items
	340 Internal walls	341 Load-bearing internal walls
		342 Non-load-bearing internal walls
		343 Internal columns
		344 Internal doors and window
		345 Internal linings (of internal walls)
		346 Prefabricated wall units
		349 Internal walls, other items
	350 Floors and ceilings	351 Floor structures
		352 Floorings
		353 Ceiling linings
		359 Floors and ceilings, other items
	360 Roofs	361 Roof structures
		362 Roof lights, roof openings
		363 Roofing
		364 Roof coverings
		369 Roofs, other items
	370 Structural fitments	371 General purpose fitments
		372 Special-purpose fitments
		379 Structural fitments, other items
	390 Other construction-related activities	391 Site equipment
		392 Scaffolding
		393 Safety measures

		394 Demolition work
		395 Repair work
		396 Final disposal of materials
		397 Additional work
		398 Temporary construction work
		399 Other construction-related activities, other items
400 Structure – services	410 Sewerage, water and gas systems	411 Sewerage systems
		412 Water supply systems
		413 Gas supply systems
		419 Sewerage, water and gas systems, other items
	420 Heat supply systems	421 Heat generators
		422 Heat distribution networks
		423 Space heating
		429 Heat supply systems, other items
		430 Air treatment systems
		431 Ventilation systems
		432 Partial air conditioning systems
		433 Air conditioning systems
		434 Refrigerating plants
		439 Air treatment systems, other items
	440 Power installations	441 High and medium voltage plants
		442 Independent power supply installations
		443 Low-voltage switchgears
		444 Low voltage installation equipment
		445 Lighting systems
		446 Lightning protection and earthing systems
		449 Power installations, other items
	450 Telecommunications and other communications systems	451 Telecommunications systems
		452 Search and signalling equipment
		453 Time metering systems
		454 Electroacoustic equipment
		455 Television and aerial systems
		456 Security systems
		457 Transmission networks
		459 Telecommunications and other communications systems, other items
	460 Transport systems	461 Lifts
		462 Escalators, moving pavements
		463 Inspection and maintenance conveyors
		464 Conveying plants
		465 Cranes
		469 Transport systems, other items

	470 Function-related equipment and fitments	471 Kitchen fitments
		472 Laundry and dry cleaning equipment
		473 Media supply systems
		474 Medical and laboratory equipment
		475 Fire-fighting installations
		476 Swimming baths equipment
		477 Process heat plants, refrigeration plants, process air plants
		478 Disposal facilities
		479 Function-related equipment and fitments, other item
	480 Building automation	481 Automated systems
		482 Control cabinets
		483 Management and operator facilities
		484 Room control systems
		485 Transmission networks
		489 Building automation, other items
	490 Other services-related work	491 Site equipment
		492 Scaffolding
		493 Safety measures
		494 Demolition work
		495 Repair work
		496 Final disposal of materials
		497 Additional work
		498 Temporary construction work
		499 Other services-related work, other items
NKG base on DIN 18960		
300 Operating costs		
	310 Supply	311 Water
		312 Oil
		313 Gas
		314 Solid fuels
		315 Urban district heating
		316 Electricity
		317 Technical media
		319 Supply, other items
	400 Repair costs	410 Structural repairs
		411 Foundations
		412 External walls
		413 Internal walls
		414 Floors and ceilings
		415 Roofs
		416 Structural fitments
		419 Structural repairs, other items
	420 Repair of installations	421 Sewerage, water and gas systems
		422 Heat supply systems
		423 Air treatment systems

		424 Power installations
		425 Telecommunications and other communications systems
		426 Transport systems
		427 Function-related equipment and fitments
		428 Building automation
		429 Repair of installations, other items
	430 Repair of external works	431 Ground surfaces
		432 Hard surfaces
		433 External construction works
		434 External services
		435 External fitments
		439 Repair of external works, other items
	440 Repair of equipment	441 Equipment
		442 Works of art
		449 Repair of equipment, other items

Table 4. Example of Systematic Building Decomposition- Switzerland. (Source: Selection of items prepared by the authors based on e-BKP-H SN 506 511 (CRB, 2009))

Level 1	Level 2	Level 3
Construction Category	Architectural element	Component according to BKP-H
C- Structure	Foundation	C1 Base slab, foundation
	Exterior wall	C2.1 A Exterior wall under ground
		C2.1 B Exterior wall above ground
	Interior wall	C2.2 Interior wall
	Pillars	C3 Pillars
	Floors	C 4.1 Floors
	Stairs and Ramps	C 4.2 Stairs and ramps
	Balcony	C4.3 Balcony
	Roof	C4.4 Roof
	Others	C5 Additional services to the structural work
D- Installations	Technical equipment	D1 Electric equipment
		D2 Building automation
		D3 Security
		D4 Fire protection
		D5 Heat generation
		D5.3 / D5.4 Heat distribution and delivery
		D6 Refrigeration
		D7 Ventilation
		D8 Water distribution installations, gas and compressed air
		D9 Transport
E- Envelope	Wall under ground	E1 Exterior wall finishing under ground
	Facade	E2 Exterior wall finishing above ground
	Exterior Window and doors	E3.1 Window
		E3.2 Doors
F- Roof	Roof	F1 Roof covering
		F2 Additional elements in roof
G- Interior	Partitions, doors	G1 Partition wall
		G 1.2 Movable partitions
		G 1.3 Interior windows
		G 1.4 Interior doors
		G 1.5 Blackout blinds
	Floor	G2 Floor covering

	Walls	G3 Interior wall finishing
		G4 Interior ceiling/roof finishing
	Fixed equipment	G5 Fixed equipment
		G6 Additional services to interior fittings
	Exterior wall under ground	G2 Floor covering
	Ceiling	G4 Interior ceiling/roof finishing
H- Installations specials	Special Technical equipment	H1 Production facilities and laboratories
		H2 Industrial kitchens
		H3 Laundries, cleaning facilities
		H4 Hospital facilities
		H5 Training facilities and culture
		H6 Sports and leisure facilities
		H7 Other specific installations
I Buildings Surroundings	Outdoor equipment	I1 Outdoor Facilities
		I3 Green spaces
		I4 Hard surfaces
		I5 Protective devices, outside
		I6 Installations, outdoors
		I7 Furniture and machinery, outdoors
J- Furnishings, decoration	Furniture equipment	J1 Furniture
		J2 Small elements
		J3 Textile
		J4 Work of art

Table 5. Example of Systematic Building Decomposition- France (Source:Equer model (Centre Efficacité énergétique des Systèmes de Mines ParisTech, n.d.))

Level 1	Level 2	Level 3
A Foundations		
B Envelope	B1 Exterior walls	B11 Materials
		B12 Finishes
	B2 Interior walls	B21 Materials
		B22 Finishes
	B3 Windows and doors	
	B4 Ground floors	B41 Materials
		B42 Finishes
	B5 Intermediate floors	B51 Materials
		B52 Finishes
	B6 Roofs	B61 Materials
		B62 Finishes
C Equipment	C1 Heating and cooling	
	C2 Ventilation	
	C3 Solar systems	
	C4 Plumbing	
	C5 Electricity	
D Other	D1 Columns	
	D2 Beams	
	D3 Parking	

Table 6. Example of Systematic Building Decomposition- Czech Republic (Source: Provided by the authors)

Level 1
Foundation
Waterproofing layers
Compacted fill, backfill material (imported from the place outside the building)
Vertical and horizontal construction elements including overhanging structures
Roof construction
Roof deck
Staircase
Railing
Internal partitions
Non-bearing cladding
Finishes
Final floor covering
Windows and doors
Thermal and acoustic insulation

Table 7. Example of Systematic Building Decomposition- the Netherlands (Source: Provided by the authors based on (Stichting Bouwkwaliteit, 2014)).

Level 1	Level 2	Level 3
Foundations	Soil provisions	Sand supplements
		Dam walls
	Floors on foundation	Soil sealants
		Floor, constructive
	Foundational constructions	Foundational beams
		Foundational feet
		Basement walls
		Tall brickwork
		Basement wall insulation
	Beam foundations	Foundational beams
Carcass	External walls	Cavity walls
		System walls
		Curtain wall
		Façade
	Inner walls	System walls, non-supporting
		System walls, non-supporting, moveable
		Massive walls, non-supporting
		Coverings, system walls, non-supporting
		Fixing profiles, system walls, non-supporting
	Floors	Self-supporting floors
		Balcony and gallery floors
	Stairs and inclines	Internal stairs
		Central stairs
	Roofs	Flat roofs
		Inclined roofs
	Main supporting constructions	Massive walls, supporting
		Beams
		Consoles
		Supporting beams
		Columns
		Constructions
		System walls, supporting
Finishing	Exterior wall openings	mounting frames
		Exterior frames
		Exterior windows
		Exterior doors
		Transportation doors
		Exterior glass
		Dense façade filling

		Window-stills
		Ventilation grids
		Water barriers (flood defenses)
		Window sill
		Blinds and shades
	Interior wall openings	Interior frames
		Interior doors
		Interior glass
		Interior doorsteps (thresholds)
	Balustrades and guard rails	Balustrades
		Guard rails
	Roof openings	Attic windows
		Light domes
		Light streets
Finishes	Exterior wall finishes	Cavity walls
		Coverings
		Finishing layers
		Insulation layers
	Interior wall finishes	Coverings
		Finishing layers
	Floor finishes	Screed floors
		Finishing layers
		Insulation layers
	Ceiling finishes	Lowered ceilings
		Finishing layers
		Coverings and grids, lowered ceilings
		Fixing profiles, lowered ceilings
	Roof finishes	Coverings, outside
		Water barriers (flood defenses)
		Flat roof covering
		Inclined roof covering
		Finishing layers
		Insulation layers, flat roof
		Insulation layers, inclined roof
Installations W	Heat generation	Heat generation installation civil engineering work construction
		Warm faucet water installations
		Heat generation installations utility construction
		Solar heating installations
		Solar boiler systems
	Drainage	Exterior sewer systems, parcel
		Exterior sewer systems, neighbourhood
		Interior sewer systems
		Gutters
		Water drainage
	Water	Water pipes
	Gasses	Gas pipes
	Cold generation and distribution	Cold generation installation
		Cold dissipation systems
	Heat distribution	Heat distribution systems
		Heat dissipation systems
	Air treatment	Air treatment systems
		Air distribution systems
Installations E	Central electro-technical provisions	Electricity pipes
		Electricity generation systems
	Transportation	Lift cabins
		Lift installations
Fixed provisions	Fixed kitchen provisions	Kitchen cabinets
		Countertops
	Fixed sanitary provisions	Toilets
		Washing provisions (sinks)
		Shower provisions
		Bathing provisions
	Fixed storage provisions	Storage provisions

Terrain	Terrain	Boundary partitions
		Privacy partitions
		Pavements

Table 8. Example of Systematic Building Decomposition- New Zealand (Source Uniclass 2015 (CPIc, 2015))

Level 1	Level 2
Site elements	Construction sites
	Work areas
Structural elements	Substructure
	Superstructure
	Bridge abutments and piers
Wall and barrier elements	Walls
	Doors and windows
	Barriers
Roofs, floor and paving elements	Roofs
	Floors
	Pavements
	Bridge decks
Stairs and ramps	Stairs
	Ramps
Tunnel, vessel and tower elements	Vessels and trenches
	Towers, chimneys and masts
	Tunnels and shafts
Signage, fittings, furnishings and equipment	Signage
	Fittings
	Furnishings
	Equipment
Flora and fauna elements	Planted elements
	Grassed elements
	Fauna elements
	Fish and eel pass elements
Waste disposal functions	Gas waste collection
	Wet waste collection
	Drainage collection
	Dry waste collection
	Gas waste treatment and disposal
	Wet waste treatment and disposal
	Drainage treatment and disposal
	Wastewater treatment and disposal
	Dry waste treatment and disposal
Piped supply functions	Gas extraction and treatment
	Liquid fuel extraction and treatment
	Water extraction and treatment
	Gas supply
	Fire extinguishing supply
	Steam supply
	Liquid fuel supply
	Process liquid supply
	Water supply
	Piped solids supply
Heating, cooling and refrigeration functions	Rail and paving heating
	Space heating and cooling
	Refrigeration
	Drying
Ventilation and air conditioning functions	Ventilation
	Air conditioning
Electrical power and lighting functions	Electrical power generation
	Electricity distribution and transmission
	Lighting
Communications, security, safety and protection functions	Communication
	Signalling
	Security
	Safety and protection
	Environmental safety
	Control and management

	Protection
	Communication
Transport functions	Cable transport
	Conveyors
	Cranes and hoists
	Lifts
	Rail tracks

Table 9. Example of Systematic Building Decomposition- Belgium (Source: BB/SfB)

Level 1	Level 2	Level 3
Substructure	Ground substructure	Ground
		Floor beds
		Retaining walls, foundations
		Pile foundations
		Other substructure elements
		Parts, Accessories etc. special to substructure elements
Structure	Structure primary elements, carcass	Walls, external walls
		Internal walls, partitions
		Floors, galleries
		Stairs, ramps
		Roofs
		Building frames, other primary elements
		Parts, accessories, etc. special to primary elements, carcass
	Secondary elements of superstructure	Secondary elements to walls, external walls.
		Secondary elements to internal walls, partitions
		Secondary elements to floors
		Suspended ceilings
		Secondary elements to roofs
	Finishes to structure	Wall finishes, external
		Wall finishes, internal
		Floors finishes
		Ceiling finishes
		Roof finishes
		Other finishes to structure
		Parts, accessoires etc. Special to finishes to structure elements
Services	Services mainly piped, ducted	Waste disposal, drainage
		Liquid supply
		Gases supply
		Space cooling
		Space heating
		Air conditioning, ventilation
		Other piped, ducted services
		Parts, accessoires etc. Special to piped ducted services elements
	Services mainly electrical	Electrical supply
		Power
		Lighting
		Communications
		Transport
		Security, control, other services
		Parts, accessoires etc. Special to electrical services elements
Fittings	Fittings	Circulation fittings
		Rest work fittings
		Culinary fittings
		Sanitary, hygiene fittings
		Cleaning maintenances fittings
		Storage, screening fittings
		Special activity fittings

		Other fittings
		Parts, accessories etc. special to fittings elements
	Loose furniture equipment	Circulation loose furniture equipment
		Rest, work loos furniture, equipment
		Culinary loose furniture, equipment
		Sanitary hygiene loose furniture, equipment
		Cleaning, maintenance, loose furniture equipment
		Storage, screening, loose furniture, equipment
		Special activity loose furniture, equipment
		Other loose furniture, equipment
		Parts, accessories etc. common to loose furniture, equipment
Others	External elements other elements.	External works
		Other elements
		Parts, accessories etc. common to two or more elements divisions

Table 10. Example of Systematic Building Decomposition- UK (Source: Prepared by the authors based on the report Whole life carbon assessment for the built environment (RICS, 2018) and the BCIS SFCA (RICS & BCIS, 2012))

	Building part/Element group	Building element
	Demolition	0.1 Toxic/Hazardous/Contaminated Material treatment
		0.2 Major Demolition Works
0	Facilitating works	0.3 & 0.5 Temporary/Enabling Works
		0.4 Specialist groundworks
1	Substructure	1.1 Substructure
2	Superstructure	2.1 Frame
		2.2 Upper floors incl. balconies
		2.3 Roof
		2.4 Stairs and ramps
2	Superstructure	2.5 External Walls
		2.6 Windows and External Doors
2	Superstructure	2.7 Internal Walls and Partitions
		2.8 Internal Doors
3	Finishes	3.1 Wall finishes
		3.2 Floor finishes
		3.3 Ceiling finishes
4	Fittings, furnishings and equipment (FF&E)	4.1 Fittings, Furnishings & Equipment incl. Building-related* and Non-building-related**
5	Building services/MEP	5.1–5.14 Services incl. Building-related* and Non-building-related**
6	Prefabricated Buildings and Building Units	6.1 Prefabricated Buildings and Building Units
7	Work to Existing Building	7.1 Minor Demolition and Alteration Works
8	External works	8.1 Site preparation works
		8.2 Roads, Paths, Pavings and Surfacings
		8.3 Soft landscaping, Planting and Irrigation Systems
		8.4 Fencing, Railings and Walls
		8.5 External fixtures
		8.6 External drainage
		8.7 External Services
		8.8 Minor Building Works and Ancillary Buildings

* Building-related items: Building-integrated technical systems and furniture, fittings and fixtures built into the fabric. Building-related MEP and FF&E typically include the items classified under Shell and core and Category A fit-out. ** Non-building-related items: Loose furniture, fittings and other technical equipment like desks, chairs, computers, refrigerators, etc. Such items are usually part of Category B fit-out.

Table 11. Example of Systematic Building Decomposition– Canada (UNIFORMAT II) (Source: Prepared by the authors based on UNIFORMAT II (Charette & Marshall, 1999))

Level 1	Level 2	Level 3

Major Group of Element	Group of Elements	Individual elements
Substructure	Foundation	Standard Foundations
		Special Foundations
		Slab on Grade
	Basement construction	Basement Excavation
		Basement Walls
Shell	Super structure	Floor Construction
		Roof Construction
	Exterior Enclosure	Exterior Walls
		Exterior windows
		Exterior Doors
	Roofing	Roofing coverings
		Roof Openings
Interior	Interior Construction	Partitions
		Interior Doors
		Fittings
	Stairs	Stairs Construction
		Stair Finishes
	Interior Finishes	Wall finishes
		Floor Finishes
		Ceiling Finishes
Services	Conveying	Elevators & Lifts
		Escalators &Moving Walks
		Other Covering Systems
	Plumbing	Plumbing Fixtures
		Domestic Water Distribution
		Sanitary Waste
		Rain Water Drainage
		Other Plumbing Systems
Equipment & Furnishing	HVAC	Energy Supply
		Heat Generating Systems
		Cooling Generating Systems
		Distribution Systems
		Terminal & Package Units
		Controls &Instrumentation
		Systems Testing & Balancing
		Other HVAC Systems &Equipment
	Fire Protection	Sprinklers
		Standpipes
		Fire Protection Specialities
		Other Fire Protection Systems
	Electrical	Electrical Service & Distribution
		Light and Branch Wiring
		Communication &Security
		Other Equipment
	Equipment	Commercial Equipment
		Institutional Equipment
		Vehicular Equipment
		Other Equipment
	Furnishing	Fixed Furnishing
		Movable Furnishings
Special Construction & Demolition	Special Construction	Special Structure
		Integrated Construction
		Special Construction Systems
		Special facilities
		Special Control and Instrumentation
	Service Building Demolition	Building Elements Demolition
		Hazardous Components Abatement

Table 12. Example of Building Decomposition– Brazil (Source: Prepared by authors based on ABNT NBR 15575 (NBR 15575-1: Edificações Habitacionais — Desempenho Parte 1: Requisitos Gerais, 2013))

Level 1	Level 2
Major Group of Element	Group of Elements
Structure	Main structure;

	External flooring;
Roof	Roof;
	Waterproof system;
Façade	Façade;
	External windows and doors;
	Façade finishing;
	Painting;
Partitions	Internal partitions;
	Internal finishing;
	Internal windows and doors;
Internal floors	Complementary structure;
Plumbing	Building services;
	Equipment

4. Appendix II. Results of the Systematic Building decomposition of the “be2226” reference building using different national standards/guidelines

Table 1. Basis initial template

Element level data (L1)	Sub-element (L2)	Material level data (L3)	
Level 1: Building element	Level 2: Sub-element (workblock/layer)	Level 3: Material	Nr
FN01_Structural foundation, driven piles new, d42.0			
	Concrete Foundation Pilar		
	Concrete Foundation Pilar	Concrete In Situ	1
	Concrete Foundation Pilar	Reinforcing Steel	2
FN02_Structural foundation, slab-on-grade slab, reinf. Concrete, 25.0			
	Concrete Foundation Slab	Concrete In Situ	3
	Concrete Foundation Slab	Reinforcing Steel	4
FN03_Structural foundation, special		---	
	Concrete Foundation Slab		
	Concrete Foundation Slab	Concrete In Situ	5
	Concrete Foundation Slab	Reinforcing Steel	6
FC01_Perimeter insulation (slab-on-grade)			
	Perimeter Insulation	XPS	7
EW01_Exterior wall, brick + plaster, 83.0			
	Lime Plaster Exterior	Lime Plaster	8
	Brick wall Insulating	Brick	9
	Brick wall Insulating	Cement Mortar	10
	Mortar Layer	Cement Mortar	11
	Brick wall Structural	Brick	12
	Brick wall Structural	Cement Mortar	13
	Lime Plaster Interior		
	Lime Plaster Interior	Lime Plaster	14
EW02_Exterior wall, brick attica, 38.0			
	Brick wall Insulating	Brick	15
	Brick wall Insulating	Cement Mortar	16
	Lime Plaster Interior	Lime Plaster	17
FS01_Floor structure, upper floors, concrete slab+plaster, 24.5			
	Concrete Floor	Concrete In Situ	18
	Concrete Floor	Reinforcing Steel	19
	Plaster Ceiling	Lime Plaster	20
RS01_Roof structure, concrete slab, 24.0			
	Concrete Roof	Concrete In Situ	21
	Concrete Roof	Reinforcing Steel	22

	Plaster Ceiling	Lime Plaster	23
ST01_Stair primary, concrete, w100.0			
	Stair Steps	Concrete Prefab	24
ST02_Stair secondary, wood, w100.0			
	Stair Steps	Sawn Timber	25
IW01_Interior wall, brick + plaster, 27.0			
	Brick wall Interior	Brick	26
	Brick wall Interior	Cement Mortar	27
	Lime Plaster Interior	Lime Plaster	28
IW02_Interior wall, brick + plaster, 17.0			
	Brick wall Interior	Brick	29
	Brick wall Interior	Cement Mortar	30
	Lime Plaster Interior	Lime Plaster	31
IW03_Interior wall, brick+plaster, 12.0			
	Brick wall Interior	Brick	32
	Brick wall Interior	Cement Mortar	33
	Lime Plaster Interior	Lime Plaster	34
FL01_Floor finish, ground floor, 29.5			
	Screed	Anhydrite Floor	35
	Sealing Floor	PVC foil	36
	Acoustic Insulation Floor	Rockwool	37
	Sawn Timber	Sawn Timber	38
	Sawn Timber	Sawn Timber	39
	Double Flooring System	Double flooring system	40
FL02_Floor finish, upper floors, 14.5			
	Screed	Anhydrite Floor	41
	Sealing Floor	PVC foil	42
	Acoustic Insulation Floor	Rockwool	43
	Wood	Plywood	44
	Wood	Sawn Timber	45
RF01_Roofing, sealing+insulation+foil+gravel, 36.0			
	Roof Sealing	EPDM	46
	Insulation Roof XPS	XPS	47
	Roof Sealing	PVC foil	48
	Gravel Roof	Gravel	49
WE01_Windows exterior, ground floor, incl. side panel, 405.0x185.0			
	Window Glazing	Glazing Triple	50
	Window Frame	Frame Wood	51
	Window Ventilation Panel	Plywood	52
	Window Ventilation Panel	Vacuum Insulation Panel	53
WE02_Windows exterior, upper floors, incl. side panel, 295.0x185.0			
	Window Glazing	Glazing Triple	54
	Window Frame	Frame Wood	55
	Window Ventilation Panel	Plywood	56
	Window Ventilation Panel	Vacuum Insulation Panel	57
DE01_Door exterior, ground floor, incl. side panel, 405.0x185.0			
	Door Exterior Frame	Frame Wood	58
	Door Exterior Panel	Plywood	59
	Door Exterior Panel	Vacuum Insulation Panel	60

DI01_Door interior, wooden door + frame, 310.0x90.0			
	Door Interior Frame	Door Frame	61
	Door Interior Panel	Plywood	62
DI02_Door interior, glass door frameless 5.5 (modelled as wall), 310.0x180.0cm			
	Door Interior Panel	Glazing Double	63
DI03_Door interior, wooden door + frame, 290.0x90.0			
	Door Interior Frame	Door Frame	64
	Door Interior Panel	Plywood	65
SA01_Sanitary equipment			
	Toilets	SanitaryCeramics	66
	Basins	SanitaryCeramics	67
EL01_Elevator			
	Elevator	Aluminium	68
	Elevator	Cast Iron	69
	Elevator	Copper	70
	Elevator	Steel	71
	Elevator	Polyethylene	72
	Elevator	Electronics	73
24 Elements	37 Sub-elemnets	73 Materials	

Table 2. Example of Systematic Building Decomposition- Austria (Source: Prepared by the authors based on the ÖNORM B1801 (ÖNORM, 2015b))

Building parts	Related building elements				
Shell (substructure and superstructure)					
Building part	Building element type	Building element (specific)	Sub-element	Material	Nr
Foundation_Substructure	Piles	1. Pilar	1.1 Concrete Foundation Pilar	1.1.1 Concrete In Situ	1
				1.1.2 Reinforcing Steel	2
	Basements	2. Foundation Slab	2.1 Concrete Foundation Slab	2.2.1 Concrete In Situ	3
				2.1.2 Reinforcing Steel	4
			2.2 Concrete Foundation Slab_special	2.2.1 Concrete In Situ	5
				2.2.2 Reinforcing Steel	6
		3. Perimeter Insulation	3.1 Perimeter Insulation	3. XPS	7
Load_bearing_structural_frame	Upper floors	4. Floor structure, upper floors	4.1 Concrete Floor	4.1.1 Concrete In Situ	8
				4.1.2 Reinforcing Steel	9
	External walls	5. Exterior wall	1. Exterior wall, brick + plaster, 83.0	1.1 Lime Plaster Brick	10
				1.2 Cement Mortar	11
				1.3 Cement Mortar	12
				1.4 Brick	13
				1.5 Cement Mortar	14
				1.6 Lime Plaster	15
			2. Exterior wall, brick attica, 38.0	2.1 Brick 2.2 Cement Mortar 2.3 Lime Plaster	16 17 18
Non_load_bearing_elements	Internal walls, partitions and doors	6. Interior wall, brick + plaster	6.1 Brick wall Interior	6.1.1 Brick	19
				6.1.2 Cement Mortar	20
		7. Interior wall, brick + plaster	7.1 Brick wall Interior	7.1.1 Brick	21
				7.1.2 Cement Mortar	22
		8. Interior wall, brick+plaster	8.1 Brick wall Interior	8.1.1 Brick	23
				8.1.2 Cement Mortar	24
		9. Door exterior, ground floor,	9.1 Door Exterior Frame	9.1.1 Frame Wood	25
			9.2 Door Exterior Panel	9.2.1 Plywood	26
				9.2.2 Vacuum Insulation Panel	27
		10. Door interior, wooden door + frame,	10.1 Door Exterior Frame	10.1.1 Door Frame	28
			10.2. Door Exterior Panel	10.2.1 Plywood	29
		11. Door interior, glass door	11.1. Door Exterior Panel	11.1.1 Glazing Double	30
		12. Door interior, wooden door + frame	12.1 Door Exterior Frame	12.1.1 Door Frame	31
			12.2. Door Exterior Panel	12.2.1 Plywood	32
	Stairs and ramps	14. Stair primary, concrete	14.1 Stair Steps	14.1.1 Concrete Prefab	33
		15. Stair secondary, wood	15.1 Stair Steps	15.1.1 Sawn Timber	34
Facades	Façade openings (including windows and external doors)	16. Windows exterior ground floor,	16.1. Window Glazing	16.1.1. Glazing Triple	35
			16.2 Window Frame	16.2.1 Frame Wood Plywood	36
			16.3 Window Ventilation Panel	16.3.1 Vacuum Insulation Panel	37

		17. Windows exterior, upper floors,	17.1. Window Glazing 17.2 Window Frame 17.3 Window Ventilation Panel	17.1.1. Glazing Triple 17.2.1 Frame Wood Plywood 17.3.1 Vacuum Insulation Panel	38 39 40
Roof	Structure	18. Roof structure, concrete slab,	18.1 Concrete Roof	18.1.1 Concrete In Situ	41
				18.1.2 Reinforcing Steel	42
	Weatherproofing	19. Roofing	19.1 Roof Sealing	19.1.1 EPDM	43
			19.2 Insulation Roof XPS	19.2.1 XPS	44
			19.3 Roof Sealing	19.3.1 PVC foil	45
			19.4 Gravel Roof	19.4.1 Gravel	46
Core (fittings, furnishings and services)					
Fittings_and_ furnishings	Sanitary fittings	20. Toilets	20.1 Toilets	20.1.1 Sanitary Ceramics	47
		21. Basins	21.1 Basins	21.1.1 Sanitary Ceramics	48
	Wall and ceiling finishes	22. Wall finishes 23. Ceiling finishes	22.1 Lime Plaster Interior	22.1.1. Lime Plaster	49
			23.1. Plaster Ceiling	23.1.1 Lime Plaster	50
	Floor coverings and finishes	24. Floor finish, ground floor	24.1 Screed	24.1.1 Anhydrite Floor	51
			24.2 Sealing Floor	24.2.1 PVC foil	52
			24.3 Acoustic Insulation Floor	24.3.1 Rockwool	53
			24.4 Sawn Timber	24.4.1 Sawn Timber	54
			24.5 Sawn Timber	24.5.1 Sawn Timber	55
			24.6 Double Flooring System	24.6.1 Double Flooring System	56
		25. Floor finish, upper floors,	25.1 Screed	25.1.1 Anhydrite Floor	57
			25.2 Sealing Floor	25.2.1 PVC foil	58
			25.3 Acoustic Insulation Floor	25.2.3 Rockwool	59
			25.4 Wood	25.2.4 Plywood	60
			25.5 Wood	25.2.5 Sawn Timber	61
55Other_systems	Lifts and escalators	26. Elevator	26.1. Elevator	26.1.1 Aluminium	62
				26.1.2. Cast Iron	63
				26.1.3. Copper	64
				26.1.4 Steel	65
				26.1.5 Polyethylene	66
				26.1.6 Electronics	67

Table 3. Example of Systematic Building Decomposition. Summary of Classification Structure of BCCA- Spain – (Source: Prepared by the authors based on Banco de Costes de la Construcción de Andalucía- Spain)

"Chapter"	"Sub-chapter"	Element	Material	Nr
03. Foundations				
	03C. Special foundations	03CPS. Concrete Foundation Pilar	03CPS.	
			Concrete In Situ	1
			Reinforcing Steel	2
	03H. Concrete	03HAL. Concrete Foundation Slab	03HAL.	
			Concrete In Situ	3
			Reinforcing Steel	4
05. Structure	05F. Slabs	05F. Slabs Floor structure	05F.	
			Concrete In Situ	5
			Reinforcing Steel	6
	05H. Concrete	05H. Roof structure	05H.	
			Concrete In Situ	7
			Reinforcing Steel	8
06. Masonry	06D. Partitions	06DSS. Brick wall Interior	06DSS.	
			Brick	9
			Cement Mortar	10
	06L. Brick	06LEM. Brick wall Structural	06LEM	

			Lime Plaster	11
			Brick	12
			Cement Mortar	13
			Cement Mortar	14
			Brick	15
			Cement Mortar	16
07. Roof	07H. Horizontal	07HNW Roofing	07HNW00009	
			EPDM	17
			XPS	18
			PVC foil	19
			Gravel	20
08. Installations	08F. Plumbing	08FSI. Toilet 08FSL. Bassin	08FSI. Toilet	21
			08FSL. Bassin	22
	08MA. Elevators	08MAA. Elevators	08MAA. Elevators	
			Electronics	23
09. Isolations	09T. Thermal	Slab-on-grade Perimeter Insulation	XPS	24
10. Finishing	10C. Continuous	10CEE Exterior wall – 10CEE Interior wall -	10CEE Lime Plaster Interior	25
	10S. Floor	10SCW Floor, ground floor and upper floor	10SCW Floor, ground floor	
			Anhydrite Floor	26
			PVC foil	27
			Rockwool	28
			Sawn Timber	29
			Sawn Timber	30
			Double flooring system	31
			10SCW Floor finish, upper floors,	
			Anhydrite Floor	32
			PVC foil	33
			Rockwool	34
			Plywood	35
			Sawn Timber	36
	10T. Roof	10CGG. Wood Roof	10CGG. Plaster Ceiling	37
11. Carpentry and safe and security elements	11M. Wood	11MPP. Wood door, ground floor and upper floors	11MPP Door Frame ground floor	38
			11MPP Door Frame wooden door + frame	39
			11MPP. Door Frame wooden door + frame	40
			11MWW. Plywood	41
			11MWW. Plywood	42
			11MWW. Vacuum Insulation Panel	43
		11MVP. Wood window, ground floor and upper floors	11MVP. Frame Wood ground floor	44
			11MWW Plywood	45
			11MWW Vacuum Insulation Panel	46
			11MVP Frame Wood upper floor	47
			11MWW. Plywood	48
			11MWW Vacuum Insulation Panel	49
	11SE. Stairs.	11SEV. Stairs.	11SEV Concrete Stairs.	50
			11SEV Sawn Timber Stairs	51
12. Glass	12W. Others	12LSR. Windows exterior, ground floor and upper floor.	12LSR. Glazing Triple	52
		12ACT. Door interior	12LSR. Glazing Double	53

Table 4. Example of Systematic Building Decomposition- Germany (Source: Prepared by the authors based on Building LCA DGNB based on DIN 276 (DIN, 2008))

300 Structure – construction works						
	320 Foundations	323 Deep foundations		Concrete Foundation	Concrete In Situ	1

			Structural foundation, driven piles	Pilar	Reinforcing Steel	2
		324 Subfloors and base slabs	Structural foundation, slab-on-grade slab	Concrete Foundation Slab	Concrete In Situ	3
					Reinforcing Steel	4
			Structural foundation, special	Concrete Foundation Slab	Concrete In Situ	5
					Reinforcing Steel	6
		326 Waterproofing of structure	Perimeter Insulation	Perimeter Insulation	XPS	7
	330 External walls	331 Load-bearing external walls	Exterior wall, brick + plaster	Lime Plaster Exterior	Lime Plaster	8
				Brick wall Insulating	Brick	9
					Cement Mortar	10
				Mortar Layer	Cement Mortar	11
				Brick wall Structural	Brick	12
					Cement Mortar	13
				Lime Plaster Interior	Lime Plaster	14
			Exterior wall, brick attica,	Brick wall Insulating	Brick	15
					Cement Mortar	16
				Lime Plaster Interior	Lime Plaster	17
		334 External doors and windows	Windows exterior, ground floor,	Window Glazing	Glazing Triple	18
				Window Frame	Frame Wood	19
				Window Ventilation Panel	Plywood	20
					Vacuum Insulation Panel	21
			Windows exterior, upper floors	Window Glazing	Glazing Triple	22
				Window Frame	Frame Wood	23
				Window Ventilation Panel	Plywood	24
					Vacuum Insulation Panel	25
			Door exterior, ground floor	Door Exterior Frame	Frame Wood	26
				Door Exterior Panel	Plywood	27
					Vacuum Insulation Panel	28
	340 Internal walls	341 Load-bearing internal walls	Interior wall, brick + plaster	Brick wall Interior	Brick	29
					Cement Mortar	30
				Lime Plaster Interior	Lime Plaster	31
			Interior wall, brick + plaster	Brick wall Interior	Brick	32
					Cement Mortar	33
				Lime Plaster Interior	Lime Plaster	34
			Interior wall, brick + plaster	Brick wall Interior	Brick	35
					Cement Mortar	36
				Lime Plaster Interior	Lime Plaste	37
		344 Internal doors and window	Door interior, wooden	Door Interior Frame	Door Frame	38
				Door Interior Panel	Plywood	39

			door + frame			
			Door interior, glass door frameless	Door Interior Panel	Glazing Double	40
			Door interior, wooden door + frame	Door Interior Frame	Door Frame	41
				Door Interior Panel	Plywood	42
	350 Floors and ceilings	351 Floor structures	Floor structure, upper floors, concrete	Concrete Floor	Concrete In Situ	43
					Reinforcing Steel	44
		352 Floorings	Floor finish, ground floor	Screed	Anhydrite Floor	45
				Sealing Floor	PVC foil	46
				Acoustic Insulation Floor	Rockwool	47
				Sawn Timber	Sawn Timber	48
				Sawn Timber	Sawn Timber	49
				Double Flooring System	Double flooring system	50
			Floor finish, upper floors	Screed	Anhydrite Floor	51
				Sealing Floor	PVC foil	52
				Acoustic Insulation	Rockwool	53
				Floor	Plywood	54
				Wood	Sawn Timber	55
				Wood		
		353 Ceiling linings	Floor	Plaster Ceiling	Lime Plaster	56
	360 Roofs	361 Roof structures	Roof structure, concrete slab	Concrete Roof	Concrete In Situ	57
					Reinforcing Steel	58
		363 Roofing	Roofing	Roof Sealing	EPDM	59
				Insulation Roof XPS	XPS	60
				Roof Sealing	PVC foil	61
				Gravel Roof	Gravel	62
		369 Roofs, other items	Roof interior finish	Plaster Ceiling	Lime Plaster	63
	370 Structural fitments	379 Structural fitments, other items	Stair primary, concrete	Stair Steps	Concrete Prefab	64
			Stair secondary, wood	Stair Steps	Sawn Timber	65
400 Structure – services	410 Sewerage, water and gas systems	412 Water supply systems	Sanitary equipment	Toilets	Sanitary Ceramics	66
				Basins	Sanitary Ceramics	67

	460 Transport systems	461 Lifts	Elevator	Elevator	Aluminium	68
					Cast Iron	69
					Copper	70
					Steel	71
					Polyethylene	72
					Electronics	73

Table 5. Example of Systematic Building Decomposition- Switzerland (Source: Selection of the main elements and process prepared by the authors based on e-BKP-H SN 506 511 (CRB, 2009)).

Level 1	Level 2	Level 3			Material	Nr
Construction Category	Architectural element	Component according to BKP-H	Element	Sub-element		
C- Structure	Foundation	C1 Base slab, foundation	Piles	Concrete Foundation Slab	Concrete In Situ	1
					Reinforcing Steel	2
C- Structure			Slab	Concrete Foundation Slab	Concrete In Situ	3
					Reinforcing Steel	4
C- Structure			Structural foundation, special	Concrete Foundation Slab	Concrete In Situ	5
					Reinforcing Steel	
C- Structure			Perimeter insulation	Perimeter Insulation	XPS	6
C- Structure	Stairs	C 4.2 Stairs	Stair primary, concrete,	Stair Steps	Concrete Prefab	7
C- Structure			Stair secondary, wood	Stair Steps	Sawn Timber	8
C- Structure	Exterior wall above ground	C2.1B Exterior wall above ground	Exterior wall, brick + plaster	Brick wall Insulating	Brick	9
					Cement Mortar	10
				Mortar Layer	Cement Mortar	11
				Brick wall Structural	Brick	12
					Cement Mortar	13
C- Structure			Exterior wall, brick attica,	Brick wall Insulating	Brick	14
					Cement Mortar	14
E- Envelope		E2 Exterior wall finishing above ground	Exterior wall	Lime Plaster Exterior	Lime Plaster	15
			Exterior wall	Lime Plaster Exterior	Lime Plaster	16
C- Structure	Interior wall	C2.2 Interior wall	Interior wall	Brick wall Interior	Brick	17
					Cement Mortar	18
C- Structure			Interior wall	Brick wall Interior	Brick	19
					Cement Mortar	20
			Interior wall	Brick wall Interior	Brick	22
					Cement Mortar	23
G- Interior		G3 Interior wall finishing	Interior wall	Lime Plaster Interior	Lime Plaster	24
			Interior wall	Lime Plaster Interior	Lime Plaster	25
			Interior wall	Lime Plaster Interior	Lime Plaster	26
E- Envelope	Window and doors	E3.1 Window	Windows exterior, ground floor,	Window Glazing	Glazing Triple	27
				Window Frame	Frame Wood	28
				Window Ventilation Panel	Plywood	29
					Vacuum Insulation Panel	30
E- Envelope			Windows exterior, upper floors	Window Glazing	Glazing Triple	31
				Window Frame	Frame Wood	32
				Window Ventilation Panel	Plywood	33
					Vacuum Insulation Panel	34
E- Envelope		E3.2 Doors	Door exterior	Door Exterior Frame	Frame Wood	35
				Door Exterior Panel	Plywood	36

					Vacuum Insulation Panel	37
G- Interior	Doors	G 1.4 Door interior	Door interior	Door Interior Panel	Glazing Double	38
			Door interior	Door Exterior Frame	Frame Wood	39
				Door Exterior Panel	Plywood	40
					Vacuum Insulation Panel	41
			Door interior	Door Exterior Frame	Frame Wood	42
				Door Exterior Panel	Plywood	43
					Vacuum Insulation Panel	44
C- Structure	Floor	C4.1 Floor		Concrete Floor	Concrete In Situ	45
					Reinforcing Steel	46
C- Structure	Roof	C4.4 Roof	Roof	Concrete Roof	Concrete In Situ	47
					Reinforcing Steel	48
G- Interior	Ceiling	G4 Interior ceiling/roof finishing	Roof	Plaster Ceiling	Lime Plaster	49
F- Roof		F1 Roof covering	Roofing	Roof Sealing	EPDM	50
				Insulation Roof XPS	XPS	51
				Roof Sealing	PVC foil	52
				Gravel Roof	Gravel	53
G- Interior		G2 Floor covering	Floor finish, ground floor	Screed	Anhydrite Floor	54
				Sealing Floor	PVC foil	55
				Acoustic Insulation Floor	Rockwool	56
				Sawn Timber	Sawn Timber	57
				Sawn Timber	Sawn Timber	58
				Double Flooring System	Double flooring system	59
			Floor finish, upper floors	Screed	Anhydrite Floor	60
				Sealing Floor	PVC foil	61
				Acoustic Insulation Floor	Rockwool	62
				Wood	Plywood	63
				Wood	Sawn Timber	64
D-Technical equipment	Technical equipment	D 9.1 Transport installations	Elevator	Elevator	Aluminium	65
					Cast Iron	66
					Copper	67
					Steel	68
					Polyethylene	69
					Electronics	70
G- Interior	Sanitary equipment	G 5.6 Accessories	Sanitary equipment	Toilets	Sanitary Ceramics	71
				Basins	Sanitary Ceramics	72

Table 6. Example of Systematic Building Decomposition- France (Source: Prepared by the authors based on Equer model (Centre Efficacité énergétique des Systèmes de Mines ParisTech, n.d.)

Level 1	Level 2	Level 3	Nr
Building part /system	Element	Material	
A Foundations		Concrete In Situ	1
		Reinforcing Steel	2
		XPS	3
B Envelope	B1 Exterior walls	B11 Materials	
		Lime Plaster	4
		Brick	5
		Cement Mortar	6
		B12 Finishes	
		Lime Plaster	7
	B2 Interior walls	B21 Materials	
		Brick	8
		Cement Mortar	9
		B22 Finishes	

		Lime Plaster	10
	B3 Windows and doors	Glazing Triple	11
		Frame Wood	12
		Plywood	13
		Vacuum Insulation Panel	14
		Door Frame	15
		Glazing Double	16
		Plywood	17
	B4 Ground floors	B41 Materials	
		Concrete In Situ	18
		Reinforcing Steel	19
		Lime Plaster	20
		B42 Finishes	
		Anhydrite Floor	21
		PVC foil	22
		Rockwool	23
		Sawn Timber	24
		Double flooring system	25
		Plywood	26
	B5 Intermediate floors	B51 Materials	
		Concrete In Situ	27
		Reinforcing Steel	28
		Lime Plaster	29
		B52 Finishes	
		Anhydrite Floor	30
		PVC foil	31
		Rockwool	32
		Plywood	33
	B6 Roofs	B61 Materials	
		Concrete In Situ	34
		Reinforcing Steel	35
		EPDM	36
		XPS	37
		PVC foil	38
		B62 Finishes	
		Lime Plaster	39
Others	Sanitary equipment	Sanitary Ceramics	40
		Sanitary Ceramics	41
	Elevator	Aluminium	42
		Cast Iron	43
		Copper	44
		Steel	45
		Polyethylene	46
		Electronics	47

Table 7. Example of Systematic Building Decomposition- Belgium (Source: Prepared by the authors based on BB/SfB (De Troyer, 2008))

Level 1	Level 2	Level 3	Element type	Sub-element type	Material	Nr
Substructure	Ground substructure	Floor beds	Structural foundation, slab-on-grade slab	Concrete Foundation Pilar	Concrete In Situ	1
					Reinforcing Steel	2
		Pile foundations	Structural foundation, driven piles new, d42.0	Concrete Foundation Slab	Concrete In Situ	3
					Reinforcing Steel	4
		Other substructure elements	Structural foundation, special	Concrete Foundation Slab	Concrete In Situ	5
					Reinforcing Steel	6
		Parts, Accessories etc. special to substructure elements	Perimeter Insulation	Perimeter Insulation	XPS	7
				Brick wall Insulating	Brick	8

Structure	Structure primary elements, carcass	Walls, external walls	Exterior wall, brick + plaster		Cement Mortar	9
				Mortar Layer	Cement Mortar	10
				Brick wall Structural	Brick	11
					Cement Mortar	12
			Exterior wall, brick + plaster	Brick wall Insulating	Brick	13
					Cement Mortar	14
		Internal walls, partitions	Interior wall,	Brick wall Interior	Brick Cement Mortar	15
						16
			Interior wall,	Brick wall Interior	Brick Cement Mortar	17
						18
			Interior wall,	Brick wall Interior	Brick Cement Mortar	19
						20
		Floors, galleries	Floor structure,	Concrete Floor	Concrete In Situ	21
					Reinforcing Steel	22
		Stairs, ramps	Stair primary, concrete	Stair Steps	Concrete Prefab	23
			Stair secondary, wood,	Stair Steps	Sawn Timber	24
		Roofs	Roof structure,	Concrete Roof	Concrete In Situ	25
					Reinforcing Steel	26
	Secondary elements of superstructure	Secondary elements to walls, external walls.	Windows exterior, ground floor	Window Glazing	Glazing Triple	27
				Window Frame	Frame Wood	28
				Window Ventilation Panel	Plywood	29
					Vacuum Insulation Panel	30
			Windows exterior, upper floors	Window Glazing	Glazing Triple	31
				Window Frame	Frame Wood	32
				Window Ventilation Panel	Plywood	33
					Vacuum Insulation Panel	34
			Door exterior, ground floor,	Door Exterior Frame	Frame Wood	35
				Door Exterior Panel	Plywood	36
					Vacuum Insulation Panel	37
		Secondary elements to internal walls, partitions	Door interior	Door Interior Frame	Door Frame	38
				Door Interior Panel	Plywood	39
			Door interior	Door Interior Panel	Glazing Double	40
			Door interior	Door Interior Frame	Door Frame	41
				Door Interior Panel	Plywood	42
	Finishes to structure	Wall finishes, external	Exterior wall	Lime Plaster Exterior	Lime Plaster	43
			Exterior wall	Lime Plaster Exterior	Lime Plaster	44
		Wall finishes, internal	Exterior wall	Lime Plaster Interior	Lime Plaster	45
			Exterior wall	Lime Plaster Interior	Lime Plaster	46
			Interior wall	Lime Plaster Interior	Lime Plaster	47
			Interior wall	Lime Plaster Interior	Lime Plaster	48
			Interior wall	Lime Plaster Interior	Lime Plaster	49
		Roof finishes	Roof finishes	Roof Sealing	EPDM	50
				Insulation Roof XPS	XPS	51
				Roof Sealing	PVC foil	52
				Gravel Roof	Gravel	53
		Ceiling finishes	Roof	Plaster Ceiling	Lime Plaster	54
		Floors finishes	Floor finish, ground floor	Screed	Anhydrite Floor	55
				Sealing Floor	PVC foil	56
				Acoustic Insulation Floor	Rockwool	57
				Sawn Timber	Sawn Timber	58
				Sawn Timber	Sawn Timber	59
				Double Flooring System	Double flooring system	60
			Floor finish, upper floors	Screed	Anhydrite Floor	61
				Sealing Floor	PVC foil	62
				Acoustic Insulation Floor	Rockwool	63

				Wood	Plywood	64
				Wood	Sawn Timber	65
Services	Services mainly electrical	Transport	Elevator	Elevator	Aluminium	66
					Cast Iron	67
					Copper	68
					Steel	69
					Polyethylene	70
					Electronics	71
	Loose furniture equipment	Sanitary hygiene loose furniture, equipment	Toilets	Toilets	Sanitary Ceramics	72
			Basins	Basins	Sanitary Ceramics	73

Table 8. Example of Systematic Building Decomposition- UK (Source: Prepared by the authors based on the report Whole life carbon assessment for the built environment (RICS, 2018) and the BCIS SFCA (RICS & BCIS, 2012))

	Building part/Element group	Building element		Sub element	Material	Nr
1	Substructure	1.1 Substructure	Structural foundation, slab-on-grade slab	Concrete Foundation Slab	Concrete In Situ	1
					Reinforcing Steel	2
			Structural foundation, special	Concrete Foundation Slab	Concrete In Situ	3
					Reinforcing Steel	4
			Structural foundation, driven piles	Concrete Foundation Pilar	Concrete In Situ	5
					Reinforcing Steel	6
			Perimeter Insulation	Perimeter Insulation	XPS	7
2	Superstructure	2.2 Upper floors incl. balconies	Floor structure, upper floors	Concrete Floor	Concrete In Situ	8
					Reinforcing Steel	9
		2.3 Roof	Roof structure, concrete slab	Concrete Roof	Concrete In Situ	10
					Reinforcing Steel	11
		2.4 Stairs and ramps	Stair primary, concrete,	Stair Steps	Concrete Prefab	12
			Stair secondary, wood,	Stair Steps	Sawn Timber	13
2	Superstructure	2.5 External Walls	Exterior wall, brick + plaster	Brick wall Insulating	Brick	14
					Cement Mortar	15
				Mortar Layer	Cement Mortar	16
				Brick wall Structural	Brick	17
					Cement Mortar	18
			Exterior wall, brick attica,	Brick wall Insulating	Brick	19
					Cement Mortar	20
		2.6 Windows and External Doors	Windows exterior, ground floor	Window Glazing	Glazing Triple	21
				Window Frame	Frame Wood	22
				Window Ventilation Panel	Plywood	23
					Vacuum Insulation Panel	24
			Windows exterior, upper floors	Window Glazing	Glazing Triple	25
				Window Frame	Frame Wood	26
				Window Ventilation Panel	Plywood	27
					Vacuum Insulation Panel	28
2	Superstructure	2.7 Internal Walls and Partitions	Interior wall, brick + plaster	Brick wall Interior	Brick	29
					Cement Mortar	30

			Interior wall, brick + plaster	Brick wall Interior	Brick Cement Mortar	31
						32
		2.8 Internal Doors	Door interior, wooden door + frame,	Door Interior Frame Door Interior Panel	Door Frame Plywood	33
						34
			Door interior, glass door frameless	Door Interior Panel	Glazing Double	35
			Door interior, wooden door + frame	Door Interior Frame	Door Frame	36
				Door Interior Panel	Plywood	37
3	Finishes	3.1 Wall finishes	Interior	Lime Plaster Interior	Lime Plaster	38
			Exterior	Lime Plaster Exterior	Lime Plaster	39
		3.2 Floor finishes	Floor finish, ground floor	Screed	Anhydrite Floor	40
				Sealing Floor	PVC foil	41
				Acoustic Insulation Floor	Rockwool	42
				Sawn Timber	Sawn Timber	43
				Sawn Timber	Sawn Timber	44
				Double Flooring System	Double flooring system	45
			Floor finish, upper floors	Screed	Anhydrite Floor	46
				Sealing Floor	PVC foil	47
				Acoustic Insulation Floor	Rockwool	48
				Wood	Plywood	49
				Wood	Sawn Timber	50
		3.3 Ceiling finishes	Floor and roof	Plaster Ceiling	Lime Plaster	51
4	Fittings, furnishings and equipment (FF&E)	4.1 Fittings, Furnishings & Equipment incl. Building-related* and Non-building-related**	Sanitary equipment	Toilets	Sanitary Ceramics	52
				Basins	Sanitary Ceramics	53
5	Building services/MEP	5.1–5.14 Services incl. Building-related* and Non-building-related**	Elevator	Elevator	Aluminium	54
					Cast Iron	55
					Copper	56
					Steel	57
					Polyethylene	58
					Electronics	59
* Building-related items: Building-integrated technical systems and furniture, fittings and fixtures built into the fabric. Building-related MEP and FF&E typically include the items classified under Shell and core and Category A fit-out. ** Non-building-related items: Loose furniture, fittings and other technical equipment like desks, chairs, computers, refrigerators, etc. Such items are usually part of Category B fit-out.						
Not included						
RF01_Roofing, sealing+insulation+foil+gravel, 36.0				Roof Sealing	EPDM	
				Roof Sealing	XPS	
				Insulation Roof XPS	PVC foil	
				Gravel Roof	Gravel	

Table 9. Example of Systematic Building Decomposition- the Netherlands (Source: Prepared by the authors based on (Stichting Bouwkwaliteit, 2014))

Level 1	Level 2	Level 3	Level 4	Sub element	Material	Nr
	Floors on foundation	Soil sealants				
		Floor, constructive	Structural foundation, slab-	Concrete Foundation Slab	Concrete In Situ	1
					Reinforcing Steel	2

			on-grade slab			
			Structural foundation, special	Concrete Foundation Slab	Concrete In Situ	3
					Reinforcing Steel	4
	Foundational constructions	Foundational feet	Structural foundation, driven piles	Concrete Foundation Pilar	Concrete In Situ	5
					Reinforcing Steel	6
		Basement wall insulation	Perimeter Insulation	Perimeter Insulation	XPS	7
Carcass	External walls	Façade	Exterior wall, brick + plaster	Lime Plaster Exterior	Lime Plaster	8
				Brick wall Insulating	Brick	9
					Cement Mortar	10
				Mortar Layer	Cement Mortar	11
				Brick wall Structural	Brick	12
					Cement Mortar	13
			Exterior wall, brick	Brick wall Insulating	Brick	14
				Lime Plaster Interior	Cement Mortar	15
	Inner walls	System walls, non-supporting	Interior wall, brick + plaster	Brick wall Interior	Brick	16
					Cement Mortar	17
			Interior wall, brick + plaster	Brick wall Interior	Brick	18
					Cement Mortar	19
			Interior wall, brick + plaster	Brick wall Interior	Brick	20
					Cement Mortar	21
	Floors	Self-supporting floors	Floor structure, upper floors	Concrete Floor	Concrete In Situ	22
					Reinforcing Steel	23
	Stairs and inclines	Internal stairs	Stair secondary, wood,	Stair Steps	Sawn Timber	24
		Central stairs	Stair primary, concrete	Stair Steps	Concrete Prefab	25
	Roofs	Flat roofs	Roof structure, concrete slab	Concrete Roof	Concrete In Situ	26
					Reinforcing Steel	27
Finishing	Exterior wall openings	Exterior windows	Windows exterior, ground floor	Window Glazing	Glazing Triple	28
				Window Frame	Frame Wood	29
				Window Ventilation Panel	Plywood	30
					Vacuum Insulation Panel	31
			Windows exterior, upper floors,	Window Glazing	Glazing Triple	32
				Window Frame	Frame Wood	33
				Window Ventilation Panel	Plywood	34
					Vacuum Insulation Panel	35
		Exterior doors	Door exterior, ground floor	Door Exterior Frame	Frame Wood	36
				Door Exterior Panel	Plywood	37
					Vacuum Insulation Panel	38
	Interior wall openings	Interior doors	Door interior, wooden door	Door Interior Frame	Door Frame	39
				Door Interior Panel	Plywood	40
			Door interior, wooden door + frame	Door Interior Frame	Door Frame	41
				Door Interior Panel	Plywood	42
		Interior glass	Door interior, glass door	Door Interior Panel	Glazing Double	43
Finishes	Exterior wall finishes	Finishing layers	Exterior wall		Lime Plaster	44
	Interior wall finishes	Finishing layers	Interior wall		Lime Plaster	45
	Floor finishes	Finishing layers	Floor finish, ground floor	Screed	Anhydrite Floor	46
				Sealing Floor	PVC foil	47
				Sawn Timber	Sawn Timber	48
				Sawn Timber	Sawn Timber	49
				Double Flooring System	Double flooring system	50
			Floor finish, upper floors	Screed	Anhydrite Floor	51
				Sealing Floor	PVC foil	52
				Wood	Plywood	53
				Wood	Sawn Timber	54

		Insulation layers	Floor finish	Acoustic Insulation Floor	Rockwool	55
	Ceiling finishes	Finishing layers	Roof	Plaster Ceiling	Lime Plaster	56
	Roof finishes	Water barriers (flood defenses)	Roofing	Roof Sealing	EPDM	57
					PVC foil	59
		Finishing layers	Roofing	Gravel Roof	Gravel	60
		Insulation layers, flat roof	Roofing	Insulation Roof XPS	XPS	61
Installations E	Transportation	Lift cabins	Elevator	Elevator	Aluminium	62
					Cast Iron	63
					Copper	64
					Steel	65
					Polyethylene	66
		Lift installations			Electronics	67
Fixed provisions	Fixed sanitary provisions	Toilets	Toilet	Toilet	Sanitary Ceramics	68
		Washing provisions (sinks)	Basin	Basin	Sanitary Ceramics	69

Table 10. Example of Systematic Building Decomposition- Czech Republic (Source: Prepared by authors)

Level 1	Nr
Foundation	1
Waterproofing layers	2
Compacted fill, backfill material (imported from the place outside the building)	3
Vertical and horizontal construction elements including overhanging structures	4
Roof construction	5
Roof deck	6
Staircase	7
Internal partitions	8
Non-bearing cladding	9
Finishes	10
Final floor covering	11
Windows and doors	12
Thermal and acoustic insulation	13

Table 11. Example of Systematic Building Decomposition- Uniclass 2015- New Zealand (Source: Prepared by authors based on Uniclass 2015)

Code	Group	Sub gr.	Title	Element	Sub element	Material	Nr
EF_20	20		Structural elements				
EF_20_05	20	05	Substructure	Structural foundation, driven piles new	Concrete Foundation Pilar	Concrete In Situ	1
						Reinforcing Steel	2
				Structural foundation, slab-on-grade slab,	Concrete Foundation Slab	Concrete In Situ	3
						Reinforcing Steel	4
				Structural foundation, special	Concrete Foundation Slab	Concrete In Situ	5
						Reinforcing Steel	6
EF_20_10	20	10	Superstructure	Floor structure, upper floors, concrete	Concrete Floor	Concrete In Situ	7
						Reinforcing Steel	8
				Roof structure, concrete slab,	Concrete Roof	Concrete In Situ	9
						Reinforcing Steel	10
				Perimeter insulation slab-on-grade	Perimeter insulation	XPS	11

EF_25	25		Wall and barrier elements				
EF_25_10	25	10	Walls	Exterior wall, brick + plaster, 83.0	Lime Plaster Exterior	Lime Plaster	12
					Brick wall Insulating	Brick	13
						Cement Mortar	14
					Mortar Layer	Cement Mortar	15
					Brick wall Structural	Brick	16
						Cement Mortar	17
					Lime Plaster Interior	Lime Plaster	18
				Exterior wall, brick attica, 38.0	Brick wall Insulating	Brick	
						Cement Mortar	19
					Lime Plaster Interior	Lime Plaster	20
							21
				Interior wall, brick + plaster	Brick wall Interior	Brick	22
						Cement Mortar	23
					Lime Plaster Interior	Lime Plaster	24
				Interior wall, brick + plaster	Brick wall Interior	Brick	25
						Cement Mortar	26
					Lime Plaster Interior	Lime Plaster	27
				Interior wall, brick+ plaster	Brick wall Interior	Brick	28
						Cement Mortar	29
					Lime Plaster Interior	Lime Plaster	30
EF_25_30	25	30	Doors and windows	Door	Door exterior, ground floor	Frame Wood	31
						Plywood	32
						Vacuum Insulation Panel	33
					Door interior, wooden door + frame	Door Frame	34
						Plywood	35
					Door interior, glass door frameless	Glazing Double	36
					Door interior, wooden door + frame	Door Frame	37
						Plywood	38
				Window	Windows exterior, ground floor,	Glazing Triple	39
						Frame Wood	40
						Plywood	41
						Vacuum Insulation Panel	42
					Windows exterior, upper floors,	Glazing Triple	43
						Frame Wood	44
						Plywood	45
						Vacuum Insulation Panel	46
EF_30	30		Roofs, floor and paving elements				
EF_30_10	30	10	Roofs	Roof structure, concrete slab	Plaster Ceiling	Lime Plaster	47
				Roofing, sealing+insulation+foil+gravel	Roof Sealing	EPDM	48
					Insulation Roof XPS	XPS	49
					Roof Sealing	PVC foil	50

					Gravel Roof	Gravel	51
EF_30_20	30	20	Floors	Floor structure, upper floors, concrete	Plaster Ceiling	Lime Plaster	52
EF_30_60	30	60	Pavements	Floor finish, ground floor	Sealing Floor	Anhydrite Floor	53
						PVC foil	54
					Acoustic Insulation Floor	Rockwool	55
					Sawn Timber	Sawn Timber	56
					Sawn Timber	Sawn Timber	57
					Double Flooring System	Double flooring system	58
				Floor finish, upper floors	Screed	Anhydrite Floor	59
					Sealing Floor	PVC foil	60
					Acoustic Insulation Floor	Rockwool	61
					Wood	Plywood	62
					Wood	Sawn Timber	63
EF_35	35		Stairs and ramps				
EF_35_10	35	10	Stairs	Stair Steps	Stair Steps Concrete	Concrete Prefab	64
					Stair Steps Timber	Sawn Timber	65
EF_40	40		Signage, fittings, furnishings and equipment	Toilets	Toilets	Sanitary Ceramics	66
					Basins	Sanitary Ceramics	67
EF_80	80		Transport functions				
EF_80_50	80	50	Lifts	Elevator	Elevator	Aluminium	68
						Cast Iron	69
						Copper	70
						Steel	71
						Polyethylene	72
						Electronics	73

Table 12. Example of Systematic Building Decomposition– Canada (UNIFORMAT II) (Source: Prepared by the authors based on UNIFORMAT II (Charette & Marshall, 1999))

Level 1	Level 2	Level 3	Element	Sub-element	Material	Nr
Major Group of Element	Group of Elements	Individual elements				
Substructure	Foundation	Standard Foundations	Structural foundation, driven piles	Concrete Foundation Pilar	Concrete In Situ	1
					Reinforcing Steel	2
		Special Foundations	Structural foundation, special	Concrete Foundation Slab	Concrete In Situ	3
					Reinforcing Steel	4
		Slab on Grade	Structural foundation, slab-on-grade slab	Concrete Foundation Slab	Concrete In Situ	5
					Reinforcing Steel	6
			Perimeter insulation (slab-on-grade)	Perimeter insulation	XPS	7
Shell	Super structure	Floor Construction	Floor structure, upper floors,	Concrete Floor	Concrete In Situ	8
					Reinforcing Steel	9

		Roof Construction	Roof structure, concrete slab	Concrete Roof	Concrete In Situ	10
					Reinforcing Steel	11
	Exterior Enclosure	Exterior Walls	Exterior wall, brick + plaster	Lime Plaster Exterior	Lime Plaster	12
				Brick wall Insulating	Brick	13
					Cement Mortar	14
				Mortar Layer	Cement Mortar	15
				Brick wall Structural	Brick	16
					Cement Mortar	17
			Exterior wall, brick + plaster	Brick wall Insulating	Brick	18
					Cement Mortar	19
		Exterior windows	Windows exterior, ground floor	Window Glazing	Glazing Triple	20
				Window Frame	Frame Wood	21
				Window Ventilation Panel	Plywood	22
					Vacuum Insulation Panel	23
			Windows exterior, upper floors	Window Glazing	Glazing Triple	24
				Window Frame	Frame Wood	25
				Window Ventilation Panel	Plywood	26
					Vacuum Insulation Panel	27
		Exterior Doors	Door exterior, ground floor,	Door Exterior Frame	Frame Wood	28
				Door Exterior Panel	Plywood	29
					Vacuum Insulation Panel	30
	Roofing	Roofing coverings	Roofing	Roof Sealing	EPDM	31
				Insulation Roof XPS	XPS	32
				Roof Sealing	PVC foil	33
				Gravel Roof	Gravel	34
Interior	Interior Construction	Partitions	Interior wall, brick + plaster	Brick wall Interior	Brick	35
					Cement Mortar	36
			Interior wall, brick + plaster	Brick wall Interior	Brick	37
					Cement Mortar	38
			Interior wall, brick + plaster	Brick wall Interior Lime Plaster Interior	Brick	40
					Cement Mortar	41
		Interior Doors	Door interior, wooden door + frame,	Door Interior Frame	Door Frame	42
				Door Interior Panel	Plywood	43
			Door interior, wooden door + frame,	Door Interior Panel	Glazing Double	44
			Door interior, wooden door + frame	Door Interior Frame	Door Frame	45
				Door Interior Panel	Plywood	46
	Stairs	Stairs Construction	Stair Steps	Stair Steps	Concrete Prefab	47
		Stair Finishes	Stair Steps	Stair Steps	Sawn Timber	48
	Interior Finishes	Wall finishes	Walls	Lime Plaster Interior	Lime Plaster	49
		Floor Finishes	Floor finish, ground floor	Screed	Anhydrite Floor	50
				Sealing Floor	PVC foil	51
				Acoustic Insulation Floor	Rockwool	52
				Sawn Timber	Sawn Timber	53
				Sawn Timber	Sawn Timber	54
				Double Flooring System	Double flooring system	55
			Floor finish, upper floors	Screed	Anhydrite Floor	56
				Sealing Floor	PVC foil	57
				Acoustic Insulation Floor	Rockwool	58
				Wood	Plywood	59
				Wood	Sawn Timber	60

		Ceiling Finishes	Roof and floor	Plaster Ceiling	Lime Plaster	61
Services	Conveying	Elevators & Lifts	Elevator	Elevator	Aluminium	62
					Cast Iron	63
					Copper	64
					Steel	65
					Polyethylene	66
					Electronics	67
	Furnishing	Fixed Furnishing	Toilets	Toilets	Sanitary Ceramics	68
			Basins	Basins	Sanitary Ceramics	69

Table 13. Example of Systematic Building Decomposition– Brazil (Source: Prepared by authors based on ABNT NBR 15575 (NBR 15575-1: Edificações Habitacionais — Desempenho Parte 1: Requisitos Gerais, 2013))

Level 1	Level 2
Major Group of Element	Group of Elements
Structure	Main structure;
	External flooring;
Roof	Roof;
	Waterproof system;
Façade	Façade;
	External windows and doors;
	Façade finishing;
	Painting;
Partitions	Internal partitions;
	Internal finishing;
	Internal windows and doors;
Internal floors	Complementary structure;
Plumbing	Building services;
	Equipment