Applying EU Level(s) framework indicators to improve circularity: A case study

Conference Paper

Author(s):
Honic-Eser, Meliha; De Wolf, Catherine

Publication date:
2023-06

Permanent link:
https://doi.org/10.3929/ethz-b-000640033

Originally published in:
IOP Conference Series: Earth and Environmental Science 1196(1), https://doi.org/10.1088/1755-1315/1196/1/012041

Funding acknowledgement:
21-2 FEL-06 - Framework for a blockchain technology based Circular Economy Platform in the AEC-industry (ETHZ)

IOP Conf. Series: Earth and Environmental Science 1196 (2023) 012041 doi:10.1088/1755-1315/1196/1/012041

Applying EU Level(s) framework indicators to improve circularity: A case study

M Honic and C De Wolf

ETH Zurich, Stefano-Franscini-Platz 5, 8093 Zurich, Switzerland

mhonic@ethz.ch

Abstract. The construction industry is the main consumer of raw materials and simultaneously responsible for 36% of solid waste in the EU, wherefore the implementation of a circular economy in the industry is urgently needed. The European Commission developed the Level(s) framework to help measure the environmental impact and improve the circularity of buildings. Yet applying the framework's indicators with the provided templates is a challenging task due to the comprehensive nature and size of EU documents and the lack of clarity on how to use the templates. This paper applies Indicators 2.1 (Bill of quantities, materials, and lifespans) and 2.2 (Construction and demolition waste and materials) to a case study to provide a better understanding of using them in practice. The findings will help actors throughout the whole value chain to implement required information into their building models for assessing and improving circularity in their buildings.

1. Introduction

The transition from a linear economy to a circular economy has been recognized as one of the main solutions to avoid waste caused in the construction industry, which is responsible for ~36% of solid waste in the EU [1], 60% of the world's raw materials extraction [2] and ~40% of energy-related greenhouse gas emissions [3]. Due to the lack of consideration of waste reduction or reuse potential in the design stage of buildings, 50% of construction and demolition waste is created during the end-of-life stage [4]. Reducing raw materials extraction and waste generation can be achieved by increasing reuse and recycling rates of materials within existing buildings to enable a circular economy.

The European Union is supporting the realization of a circular economy in the architecture, engineering, and construction industry in the "Circular economy action plan", which views secondary raw materials as valuable resources for recycling and reuse (European Commission, 2022). The European Commission has proposed the Level(s) "common framework of core sustainability indicators for office and residential buildings" to better standardize measurements and provide a general language for sustainability of buildings. The Level(s) framework consists of six overarching macro-objectives which cover topics of energy, material use, waste, water and indoor air quality [5].

The open-source Level(s) framework was developed by the Joint Research Centre for sustainable buildings, based on comprehensive research efforts by the industry and the public sector. A report was introduced by the Joint Research Centre explaining how to use the framework [5]. Furthermore, an e-learning platform (EU Academy) [6] was set up as well as Excel templates and an online Calculation and Assessment Tool (CAT) [7] were provided to assist users in applying it to their buildings. However, understanding the content of the indicators as well as deriving the required information to enable their use is a challenging task due to the multiple sources of information and the complexity of the publications explaining the framework [5], [8], [9]. Moreover, calculating the indicators by using the provided Excel templates is challenging and requires input by several experts.

This paper documents a case in which two Level(s) indicators (2.1 “Bill of quantities, materials and lifespans” and 2.2 “Construction and demolition waste and materials”, both part of the macro-objective “resource efficient and circular material life cycles”) were applied on a residential building design in Vienna. After a background section about the Level(s) framework, the “Materials and Methods” section introduces the case study and the application of the two indicators. The results on the construction and demolition waste of the building show the quantities of materials that can likely be reused, and the discussion demonstrates the complexity and difficulty in applying the indicators.

2. Background

2.1. The Level(s) framework

The voluntary Level(s) framework consists of 16 core indicators of sustainability that can be applied to building projects in order to measure, report and improve their environmental performance. The framework is divided into three levels, which cover all project phases of a building. Level 1 is used in the conceptualization stage to set qualitative objectives. Level 2 is applied at the detailed design and construction stage to evaluate quantitative performance of a building. Level 3 is used in the as-built stage to assess and monitor performance in terms of sustainability after completion [10]. The indicators can be applied on each Level (1, 2 or 3). The macro-objective targeted in this paper is “Resource efficient and circular material life cycles”, which aims to optimize the building design, support circular flows, extend long-term material utility, and reduce environmental impacts. The macro-objective contains four indicators to assess the impacts of material use, namely Indicator 2.1 “Bill of quantities, materials and lifespans”, Indicator 2.2 “Construction and demolition waste and materials”, Indicator 2.3 “Design for adaptability and renovation” and Indicator 2.4 “Design for deconstruction”. Indicators 2.1 and 2.2 in particular were applied to direct the focus of this paper to construction and demolition waste.

2.2. Indicators 2.1 and 2.2

The two indicators focused on in this paper assess the environmental performance at the design and construction stage (Level 2 of the framework). Indicator 2.1, “Bill of quantities, materials and lifespans”, delivers a breakdown by material type for the time of construction and for the lifetime as well as a simplified estimate for construction waste. (“Time of construction” means the time when the building is constructed, whereas “lifetime” includes the required replacements of building elements within the entire lifetime of the building. The indicator creates a “bill of quantities” to assess the total mass of the building and each material type embedded, for the construction and the entire lifetime of a building. For the construction phase, material waste (materials that are delivered to the construction site but not used) and over-ordering rates (too much of a material is ordered) for each material are taken into account to estimate construction waste. The simplified estimation is enriched with more accurate results from Indicator 2.2. Furthermore, assumed waste types are used to identify the amount of inert waste (not contaminated by harmful substances, e.g., uncontaminated concrete), non-hazardous waste (containing a limited concentration of harmful substances, e.g., metals) and hazardous waste (containing harmful substances, e.g., asbestos). Building elements are sorted according to three tiers, each of which contain several categories. Tier 1 includes the categories of shell (e.g., roof, facades and foundations), core (e.g., fittings and furnishings, sanitary systems, ventilation systems) and external works (e.g., utilities and landscaping).

Indicator 2.1 serves as input for Indicator 2.2, “Construction and demolition waste and materials”, which calculates the amount of construction and demolition waste for the entire building as well as delivers a breakdown by material type. The waste is then split into the following categories (end-of-life-scenarios) for both construction and demolition waste: reuse, recycling, material recovery (backfill), energy recovery, and disposal (inert, non-hazardous, or hazardous). Each category is then assigned a waste code (e.g., 17 02 01 for reuse of an element/material). Indicator 2.2 provides two scenarios for construction and demolition waste: the probable outcome and the best outcome. Indicator 2.2 also assesses the landfill costs of construction and demolition waste. Landfill unit costs are provided for each type of waste disposal (inert, non-hazardous and hazardous waste at 10, 70, and 275 €/tonne, respectively).

3. Materials and Methods

3.1. Case study

A residential building design from previous research [11], which was planned to be located in the second district of Vienna, was used as a case for implementing Indicators 2.1 and 2.2. In the previous study, a method from the Austrian Institute of Building and Ecology [12] was used on the same building design to calculate the recycling potential of the building. Exterior walls, roof, ceilings, and windows were the building elements used for assessments in the previous research and in this paper to enable a comparison of the results and to avoid errors.

The method for the current study was based on the element areas [m^2] retrieved from the Building Information Model (BIM) and the list of elements with the material layer composition of each element. The building was modelled in BIM-software (Figure 1) with a Level of Development (LOD) of 300, meaning that material layers were assigned to each building element. The residential building was supposed to be designed with sustainable and lightweight materials. Accordingly, the load-bearing elements, most of the insulation materials (except e.g., the roof insulation) and window frames are made of timber. For the building elements, material layer compositions were obtained from the database dataholz [13], which provides material layer compositions (incl. material thicknesses) of timber.

Figure 1. BIM of the case study

3.2. Application of Indicators 2.1 and 2.2 on the case study

Figure 2 displays the workflow for compiling information for Indicator 2.1 and calculations for Indicator 2.2. For both indicators, the Excel templates provided by Level(s) were used to conduct the assessments. As the ease of use of the templates needs to be improved, Level(s) also provides a more user-friendly CAT tool. However, due to the lack of transparency on the indicators in this tool, this paper focused on the Excel templates.

The templates consist of mandatory (green) and optional (yellow) cells to be filled out, as well as resulting values (red). The unit and conversion factors were defined in the template. For the case study, volume [m^3] was defined as the “unit” and density [kg/m^3] as the “conversion factor” to calculate the “bill of quantities (number of units)” property in the template. The building floor area [m^2], material types, densities [kg/m^3], volumes [m^3] and lifetime [a] were required as input information for Indicator 2.1.

For the case study, the building floor area [m^2] was obtained from the BIM and the densities [kg/m^3], volumes [m^3] and lifetimes [a] from the existing list of elements. The total mass [kg] of each layer were calculated automatically in the template. One section of the completed template is presented in Section of the Indicator 2.1 template applied on the exterior wall, which shows application of Indicator 2.1 on an exterior wall of the case study. The tier 1, 2 and 3 building elements were defined for each element and the associated material layers. The material types (e.g., wood, glass, plastic) were defined in the template based on the material layers from the list of elements. Thereby, e.g., cross laminated was categorized as wood, as shown in Table 1. The materials were weighted according to their contents (e.g., a window is 10% timber frame and 90% glass panel). Accordingly, the breakdown by material type (in tonnes and percentage for each material) was assessed automatically. The cost assessment is optional and was not conducted due to lack of data on the costs. No changes were made to the assumed wastage/ over-ordering rate in the template since no data was available. The waste type and waste code of each material type are given in the template and the simplified estimate for construction waste was conducted automatically. After all required information was entered, the results were generated automatically in the template to supply the bill of quantities and materials for the construction and the lifetime as well as the simplified estimate for construction waste.

The template for Indicator 2.2 relies on information from Indicator 2.1. One section of the completed template is displayed in Table 2. In particular, the tier 1 and 2 elements, mass of each material layer, material type, estimated wastage rate, waste type and the waste code for each material type were obtained from Indicator 2.1. To calculate the construction waste, possible outcomes (end-of-life scenarios) are provided in the template. For each material the best possible and most probable outcome was chosen from, among others, the following possible outcomes: reuse of over-ordering element/ material or of construction waste, recycling, recovery as backfill/landscaping, waste to energy plant, incineration plant and landfill (inert, non-hazardous, hazardous). For demolition waste, the outcomes range from reuse (on-site or off-site) to recycling, material recovery as backfill/landscaping, energy recovery through delivering waste to energy plants, thermal destruction by incineration and landfill (inert, non-hazardous, hazardous).

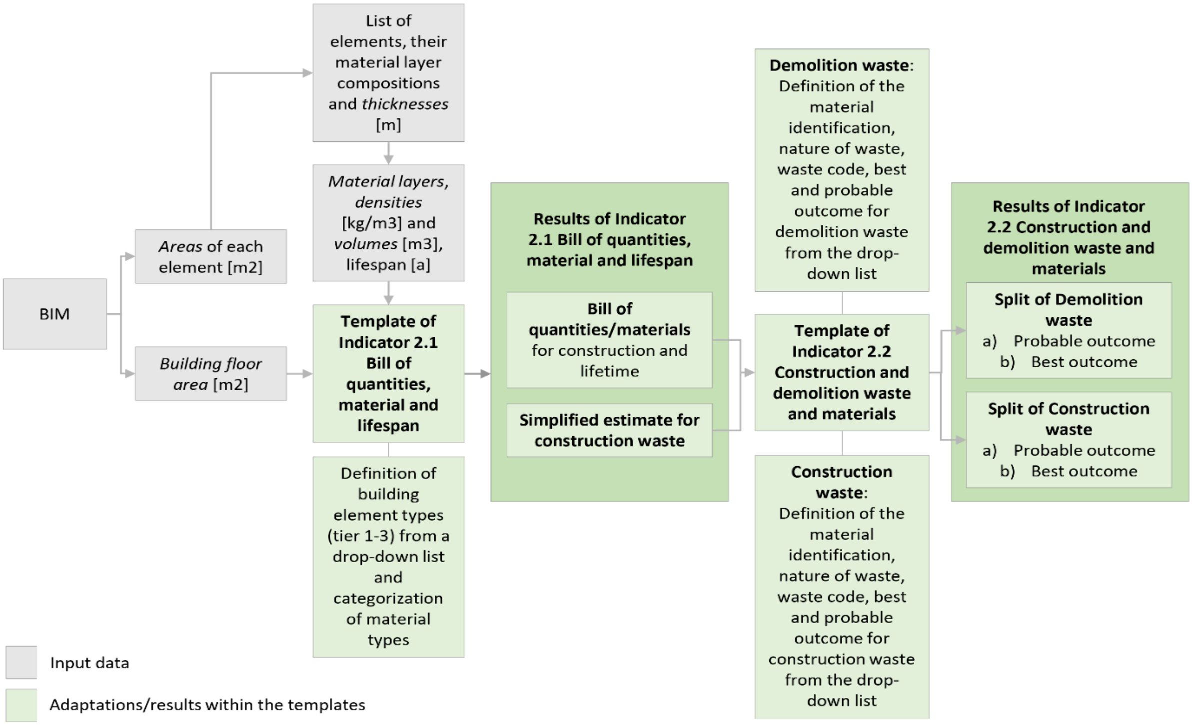


Figure 2. Workflow and information required to apply Indicators 2.1 and 2.2

As decision support for defining the potential outcome of each material according to the provided options, the method of the previous research was used, which was based on the Austrian Institute for Building and Ecology (IBO). In the IBO method, three end-of-life scenarios are considered: reuse/recycling, incineration, or disposal, whereby the reuse/recycling option is the favorable option and incineration the option that should be avoided. Furthermore, grades from 1 to 5 are assigned to each material which reflect the possible end-of-life options. Grade 1 stands for reuse; incineration of a pure material with a high thermal value; or disposal as inert waste landfill. Grade 2 materials can be recycled with very low effort; are not completely pure materials which can be incinerated and have a high thermal value; or are materials to be disposed with construction waste without contamination. Materials with grade 3 are contaminated recycling materials which can be disassembled only with high effort; materials with a medium thermal value or consisting of a small amount of metal or halogen; or materials with a low number of non-mineral components. Materials with grade 4 are either down-cyclable, consist of a high amount of nitrogen or other non-mineral components, or are made of gypsum-based mineral material with a high amount of non-mineral contaminations. Grade 5 is assigned to materials which cannot be recycled; have a high metal and halogen content; or are a compound of organic and mineral components or contaminated metals accrued as part of the construction waste. (Rock wool is categorized as hazardous waste in Austria, even though it does not contain any harmful materials.) Since only a few rock wool manufacturers recycle their own products, the probable outcome for rock wool was assumed as hazardous waste landfill, so the waste code 17 06 05 was applied. The best outcome for rock wool was defined as offsite recycling. Accordingly, as an example for this case study, if a material was assigned the grade 1 (e.g., cross location laminated timber), it was assumed that the material or element could be reused. Apart from that, the of the specific element or material was considered when defining the outcomes. For demolition waste, e.g., the outcome of a cladding material after the lifetime was defined as energy recovery.

Table 1. Section of the Indicator 2.1 template applied to the exterior wall

Tier 1 building element	Tier 2 building element	Tier 3 building element	Optional further description of the product	Bill of Quantities (number of units)	Unit	Conversion factor (kg/unit)	TOTAL (kg)
Shell	Facades	External wall systems, cladding and shading devices	Laminated wood	45.53	m^3	440	20033.12
Shell	Facades	External wall systems, cladding and shading devices	Sawn timber	7.59	m^3	540	4097.68
Shell	Facades	External wall systems, cladding and shading devices	Wood fiberboard	41.74	m^3	250	10433.92
Shell	Facades	External wall systems, cladding and shading devices	Wood fiberboared insulation	379.42	m^3	160	60706.42
Shell	Load-bearing structural frame	External walls	Cross laminated timber	180.22	m^3	440	79297.77
Shell	Facades	External wall systems, cladding and shading devices	Sawn timber	11.38	m^3	540	6146.53
Shell	Facades	External wall systems, cladding and shading devices	Rock wool	102.44	m^3	33	3380.59
Shell	Facades	External wall systems, cladding and shading devices	Plasterboard	47.43	m^3	850	40312.86

Table 2. Section of the Indicator 2.2 template applied on the exterior wall - construction waste (CW)

Tier 1 building element	Description of material/ element	Optional further description of the product	Bill of quantities (kg)	Estimated wastage (CW) rate (%)	Estimated CW (kg)	Nature of waste	List of waste code	Best outcome for CW	Probable outcome for CW
Shell	Wood	Laminated wood	20033.12	20.0%	4006.62	Non-haz	17 02 01	Reuse of CW (preparation for)	Reuse of CW (preparation for)
Shell	Wood	Sawn timber	4097.68	20.0%	819.54	Non-haz	17 02 01	Reuse of CW (preparation for)	Reuse of CW (preparation for)
Shell	Wood	Wood fiberboard	10433.92	20.0%	2086.78	Non-haz	17 02 01	Reuse of CW (preparation for)	Offsite recycling
Shell	Wood	Wood fiberboard insulation	60706.42	20.0%	12141.28	Non-haz	17 02 01	Reuse of CW (preparation for)	Waste to energy plant
Shell	Wood	Cross laminated timber	79297.77	20.0%	15859.55	Non-haz	17 02 01	Reuse of CW (preparation for)	Reuse of CW (preparation for)
Shell	Wood	Sawn timber	6146.53	20.0%	1229.31	Non-haz	17 02 01	Reuse of CW (preparation for)	Reuse of CW (preparation for)
Shell	Insulation materials	Rock wool	3380.59	20.0%	676.12	Hazardous	17 06 05	Offsite recycling	Hazardous waste landfill
Shell	Gypsum-based materials	Plasterboard	40312.86	22.5%	9070.39	Non-haz	17 08 02	Reuse of CW (preparation for)	Offsite recycling

4. Results

4.1. Indicator 2.1

The bill of quantities of Indicator 2.1 assesses the masses for both the construction and the lifetime, whereby the replacement cycles of materials and elements are accumulated (see Table 3). The building from the case study has a predicted total mass of ~1694 tonnes for the time of construction. Wood accounts around half of the total mass and at the same time is the material with the highest share, mainly because the load-bearing elements are made of cross-laminated timber. The share of concrete, brick, tile, natural stone, and ceramics is ~37%. Gypsum, which was used due to fire protection reasons, has also a high mass and accounts for ~11%. The total masses over the whole lifetime of the building, amount to ~2548 tonnes. It is remarkable that the share of concrete, brick, tile, natural stone, and ceramic exceeds the total mass of wood. This is mainly caused by the required replacements of screed concrete. Furthermore, the amount of glass rises significantly due to the required substitution of the windows.

Table 3. Bill of quantities for construction and lifetime

	Material total for construction (t)	Material total for construction (%)	Material total for lifetime (t)	Material total for lifetime (%)
Concrete, brick, tile, natural stone, ceramic	623.25	36.78%	995.71	39.1%
Wood	747.38	44.11%	971.66	38.1%
Glass	100.30	5.92%	250.74	9.8%
Plastic	5.77	0.34%	14.35	0.6%
Bituminous mixtures	4.83	0.29%	9.66	0.4%
Metals	0.00	0.00%	0.00	0.0%
Insulation materials	24.18	1.43%	48.35	1.9%
Gypsum	188.61	11.13%	257.52	10.1%
Mixed	0.00	0.00%	0.00	0.0%
Electrical and electronic equipment	0.00	0.00%	0.00	0.0%
Total	1694.32	100.0%	2547.99	100.0%

4.2. Indicator 2.2

The results of Indicator 2.2 are divided into two parts: construction waste (including over-ordering waste) and demolition waste. For both, the split into reusable, recyclable and recoverable (material and energy recovery) materials as well as materials to be disposed is calculated. The optional over-ordering rate was not considered in this Indicator.

Figure 3 shows the probable and best outcomes of the construction waste. The probable outcome shows that ~42% of construction waste will likely be reused, ~33 % recycled, ~0.1% material recovered, ~23.1% energy recovered and ~1.4% disposed. The best possible outcome shows that ~87% of the built-in materials and elements could be reused and ~13% recycled. Figure 4 displays the demolition waste divided into the probable and the best outcomes. The probable outcome accounts for ~33% reuse (material + element), ~40% recycling, 4% material recovery (backfill), 9% energy recovery and 14% disposal. In the best outcome scenario, ~48% of waste could be reused (material + element) and 52% recycled.

Figure 3. Split of construction waste

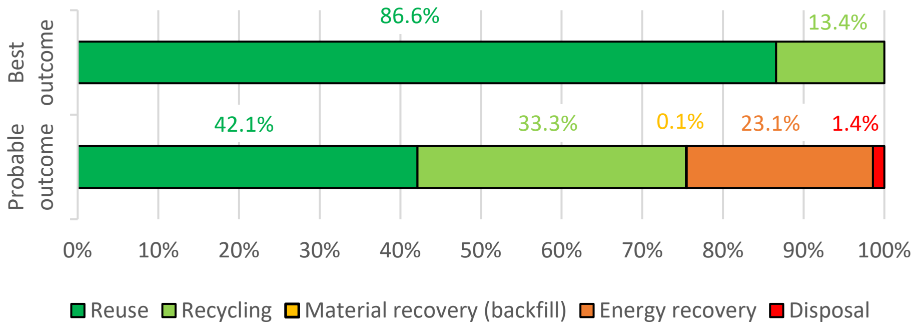
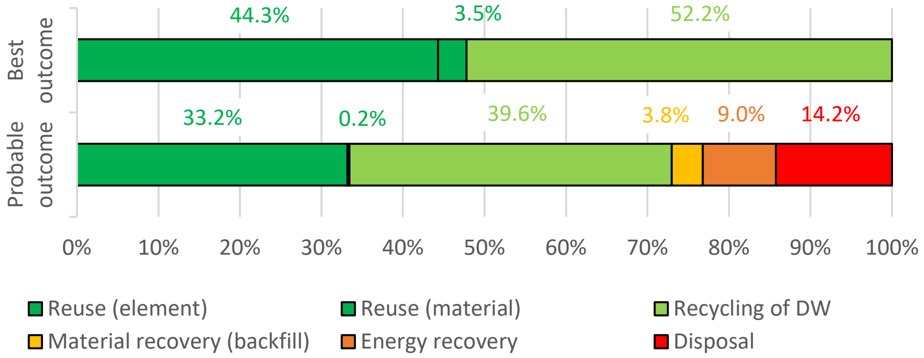


Figure 4. Split of demolition waste



4.3. Comparison of the results with the previous study

In the previous study [11], the reuse/recycling potential was assessed (without distinguishing between reuse and recycling) with the grades assigned to each material, whereby grade 1 stands for 75% reuse/ recycling 25% disposal, grade 2 for 50% reuse recycling and 50% disposal, grade 3 for 25% reuse/ recycling and 75% disposal, grade 4 for 0% reuse/recycling and 100% disposal and grade 5 for 0% reuse/recycling and 125% disposal (the additional 25% for added effort of disassembly or disposal). The results of this study predicted that for the lifetime of the building 34% will be reused/recycled and that 66% will end up in landfill. Accordingly, the results vary significantly. However, the grading system does not consider each possible outcome as the Level(s) method does, and only uses the percentages, derived from the assigned grades and multiplies them with the associated masses. Accordingly, as result, only the recyclable masses and waste that ends up in landfill is calculated.

5. Discussion

Indicator 2.1 was easy to use because a BIM model already existed. However, mapping the densities of each material is a challenging task if this information has not already been acquired. Since the case study was already used for similar circularity assessments in our previous study, a list of elements with the material layer compositions and required information, such as the densities, was available. If the building design is in a mature phase and the specific products which will be used in the construction are defined, the material densities can be derived from, e.g., environmental product declarations (EPDs). If the building is still in the design stage, the densities must be acquired from material databases such as the Austrian baubook [14] and German ökobaudat [15].

To apply Indicator 2.2, waste codes as well as possible and best end-of-life outcomes were needed, which were defined based on the method of the previous study. The probable outcome for construction waste demonstrates that almost 50% of the materials can be reused and 30% recycled, and that for 20% of the materials an energy recovery (through incineration) is possible. The estimation of the demolition waste shows, that in the most probable scenario about 30% of the materials can be reused and 40% recycled, 4% of the materials can directly be recovered through backfill (reusing or replacing the soil that is removed during the excavation), 9% of the materials can be energy recovered (through incineration) and 15% will likely end up in landfill. The best outcomes for both construction and demolition waste show that each material and element can be either reused or recycled. However, the expertise of waste managers and demolition auditors would be required to verify the results, as is also proposed by the Level(s) framework.

The indicators lacked consideration of some parameters which might have an influence on the circularity of building materials. For example, the connection type of the material layers is not taken into account in the indicators, which can have a large effect on the reuse and recyclability of materials since glued materials are difficult to disassemble and can lead to unclean fractions. Additionally, the templates offered no distinction between different insulation types. Accordingly, all insulation materials were categorized as hazardous waste. However, in this study the fibreboard insulation was categorized as material wood, and it was assumed that fibreboard insulation can be energy recovered in an incineration plant. The comparison with the previous study indicates that a significant difference in the assessment of the reuse and recycling potential exists. In the previous applied method, the connection type of materials is considered and the reuse potential downgraded, if two materials were glued. This can be one reason, why the results of the two studies vary significantly. However, due to the mismatch of the applied methods (IBO and Level(s)), the results cannot be compared directly.

The application of the indicators was challenging due to the complexity of the documents explaining the framework as well as the required expertise to fill out the templates. The documents consist of very valuable information about all aspects of buildings sustainability. However, they are complex and hard to read, especially when they want to be used to apply specific indicators and not get a general understanding of Level(s). The provided templates were used with the support of the EU Academy [6] platform, which provides a practicable guideline. As proposed by the Level(s) framework, the involvement of stakeholder expertise is needed, since very specific knowledge about waste treatment and end-of-life scenarios is required to get realistic results.

6. Conclusion

The Level(s) framework was developed to report and improve the environmental impacts of buildings. It offers templates that are helpful in calculating construction and demolition waste. For this paper, we used the Excel templates provided to understand the method behind the indicators and retrieve the information required to apply them.

The framework proposes to involve architects, planning and building authorities, structural engineers, building owners, auditors, waste managers, product managers and contractors. The case study confirmed that stakeholder expertise is indeed needed to gather the information necessary for the assessments. However, not all stakeholders need to be consulted for each indicator. For example, Indicator 2.1 could be calculated with only the input of the architects or structural engineers on quantitative information and product manufacturers on specific product information, while Indicator 2.2 is more complex and can also profit from the involvement of experts in waste management to define for example the nature of waste (inert, non-hazardous and hazardous) and possible end-of-life scenarios (reuse, energy recovery, etc.).

This paper aims to inform stakeholders about what Indicators 2.1 and 2.2 of the Level(s) framework entail, how they are applied, and how the outcomes could be used in their projects. Furthermore, the results of this paper should support the actors along the value chain to be aware of which information is required to assess and improve the circularity of buildings. Building on this research, Indicator 2.3 "Design for adaptability and renovation" and Indicator 2.4 "Design for deconstruction" will be applied to incorporate additional parameters for assessing circularity.

References

[1] Eurostat, "Total waste generation," *eurostat*, 2020. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics#Total_waste_generation

[2] WEF, "Shaping the Future of and Technology A Breakthrough in Mindset Construction," no. May. 2016. doi: 10.1061/9780784402474.

[3] United Nations Environment Programme, "2022 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector," 2022.

[4] M. R. Esa, A. Halog, and L. Rigamonti, "Developing strategies for managing construction and demolition wastes in Malaysia based on the concept of circular economy," *J. Mater. Cycles Waste Manag.*, vol. 19, no. 3, pp. 1144–1154, Jul. 2017, doi: 10.1007/s10163-016-0516-x.

[5] N. Dodd, M. Cordella, M. Traverso, and S. Donatello, “Level(s) – A common EU framework of core sustainability indicators for office and residential buildings,” Parts 1 and 2: Introduction to Level(s) and how it works, 2017.
[6] EU Academy, “EU Academy: Level(s) - Sustainable performance in buildings,” *EU Academy*. https://academy.europa.eu/courses/level-s-sustainable-performance-in-buildings (accessed Nov. 20, 2022).
[7] CAT, “The Level(s) calculation and assessment tool,” 2022. https://environment.ec.europa.eu/topics/circular-economy/levels/elearning-and-tools_en
[8] S. Donatello, N. Dodd, and M. Cordella, “Level(s) indicator 2.1: Bill of Quantities, materials and lifespans,” Publication version 1.1, 2021.
[9] S. Donatello, N. Dodd, and M. Cordella, “Level(s) indicator 2.2: Construction and Demolition waste and materials,” 2021.
[10] C. De Wolf, M. Cordella, N. Dodd, B. Byers, and S. Donatello, “Whole life cycle environmental impact assessment of buildings: Developing software tool and database support for the EU framework Level(s),” *Resour. Conserv. Recycl.*, vol. 188, p. 106642, Jan. 2023, doi: 10.1016/j.resconrec.2022.106642.
[11] M. Honic, I. Kovacic, and H. Rechberger, “Improving the recycling potential of buildings through Material Passports (MP): An Austrian case study,” *J. Clean. Prod.*, vol. 217, pp. 787–797, Apr. 2019, doi: 10.1016/j.jclepro.2019.01.212.
[12] IBO, “Institute for Building and Ecology,” 2022. https://www.ibo.at/ (accessed Oct. 20, 2022).
[13] dataholz, “Katalog bauphysikalisch und ökologisch geprüfter und/oder zugelassener Holz- und Holzwerkstoffe, Baustoffe, Bauteile und Bauteilfügungen für den Holzbau freigegeben von akkreditierten Prüfanstalten.,” 2022. https://www.dataholz.eu/ (accessed Oct. 20, 2022).
[14] baubook, “Web-Portal für Bauprodukte, Bauteile und Tools, das ökologisches und gesundes Bauen vereinfacht.” https://www.baubook.info/de (accessed Oct. 20, 2022).
[15] OEKOBAUDAT, “Datenbasis für die Ökobilanzierung von Bauwerken,” 2022. https://www.oekobaudat.de/ (accessed Oct. 20, 2022).