Structures and Architecture. REstructure REmaterialize REthink REuse - Rinke & Frier Hvejsel (Eds)

BIM-based application of level(s) for circular economy: Recyclability case study

A. Fereydooni Eftekhari, F. Re Cecconi, O. Iuorio & B. Daniotti
Politecnico di Milano, Milano, Italy

ABSTRACT: The Architecture, Engineering, Construction, and Operation (AECO) industry significantly contributes to global material consumption and waste generation. Transitioning towards Circular Economy (CE) to reduce, recycle, and reuse building materials is a necessity. However, this procedure is also facing the challenge of data fragmentation due to complexity of the building process which necessitates a standardized and common procedure. Level(s) is acting as framework to develop as a common language in Europe. This study focuses on addressing data fragmentation challenge in CE, by integrating digital technologies with Level(s) to facilitate the creation of Bills of Quantities (BoQ) and Bills of Materials (BoM). Applying Building Information Modelling (BIM) and Industry Foundation Classes (IFC) on an Italian residential building, a methodology is proposed for Construction and Demolition Waste (C&DW) management and building recyclability calculation. The results offer practical and scalable solutions for improving waste management, reducing environmental impacts, and improving Level(s) application in construction.

Keywords: Building Information Modelling (BIM), Level(s) framework, Circular Economy (CE), Industry Foundation Classes (IFC), Building Engineering

1 INTRODUCTION

The increasing global consumption of natural resources and the excessive generation of waste have raised serious concerns about environmental sustainability. The Architecture, Engineering, Construction, and Operations (AECO) industry plays an important role in this scenario, accounting for a significant portion of material consumption and waste production (Environment, 2022). Traditional practices in this sector are based on a linear economy model, which involves material take, make, and dispose, leading to resource depletion and waste-related environmental impacts (Keena & Friedman, 2024). Addressing these issues requires a paradigm shift towards more sustainable practices, particularly the adoption of Circular Economy (CE) principles that emphasize reducing, recycling, and reusing materials throughout a building's life cycle (Charef & Emmitt, 2021).

To successfully implement these circular practices, the AECO industry must manage and integrate fragmented data on building material composition, connection types, availability, and quality. This complexity necessitates the use of advanced tools and methodologies to improve data collection and material circulation throughout the construction supply chain (Kovacic et al., 2020).

Despite existing initiatives such as the Circular Economy Action Plan (CEAP) and the EU Green Deal, the European Commission introduced the Level(s) framework to address the need for a comprehensive framework that promotes sustainability in the construction sector. Unlike other well-known Green Building Rating Systems (GBRSs) such as BREEAM (Building Research Establishment Environmental Assessment Methodology), LEED (Leadership in

DOI: 10.1201/9781003658641-4

Energy and Environmental Design), and DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen - in English: the "German Sustainable Building Council"), which serve primarily as certification tools, Level(s) is a voluntary framework designed to unify sustainability assessment across Europe. It provides a structured approach to measure and improve the sustainability performance of buildings through six macro-objectives, which focus on resource efficiency, circularity, health and well-being (European Commission, 2021).

Level(s) distinguishes itself from BREEAM and LEED by incorporating the concepts of the CE and emphasizing life cycle performance. In contrast to others, it highlights resource efficiency, the management of Construction and Demolition Waste (C&DW), and adaptability for future use, all of which facilitate recycling. Level(s) provides a clear route to CE objectives by tracking materials through Bills of Quantities (BoQ) and Bills of Materials (BoM), which are in line with European regulations (Ferrari et al., 2022).

While the Level(s) framework provides a strong approach to assessing building sustainability, its successful implementation necessitates the use of digital technologies. Emerging technologies such as Building Information Modelling (BIM) and Industry Foundation Classes (IFC) are critical in overcoming data fragmentation challenges, particularly when tracking material use and reuse throughout the building's life cycle. BIM provides a detailed digital representation of building components that can be used to track material flow, evaluate recyclability, and improve construction processes for greater circularity (Fereydooni Eftekhari et al., 2024).

This study builds upon the Level(s) framework by integrating it with BIM and IFC to form a standardized procedure for material management, specifically focusing on the creation of BoQ and BoM. A key innovation of the study is the development of a facilitator tool for Level(s) indicators calculation, designed to assist with C&DW management by assessing the circularity of building materials based on waste hierarchy principles. The integration of BIM and IFC aims to make the Level(s) framework more accessible and practical for real-world applications in the construction industry.

To evaluate the practical application of this methodology, the study applies the proposed Level(s)-BIM-IFC integration to a case study from the Italian building sector. By comparing the calculated recyclability of the case study building with the average values obtained from existing data, the research identifies both potential levers and barriers to Level(s) implementation. The expected outcomes of the study include the generation of IFC files that provide a digital translation of Level(s) guidelines into measurable and trackable waste management practices. The results of this research have significant implications for improving waste management strategies, reducing environmental impacts, and facilitating the broader adoption of CE principles in the AECO industry.

2 METHODOLOGY

This paper evaluates the circularity of buildings, specifically their recyclability, using the Level(s) framework with a transition from materials to building scale. The study uses the bespoke programming by Python for creation of BoM and BoQ, and classification and codification of waste based on European Waste Catalogue (EWC) in an automated way from BIM and IFC as inputs for the Level(s). This procedure is applied on a case study of a residential building and the results are compared with the recyclability index of buildings based on the average recyclability rate of their materials as proposed by Building Recyclability Rate (BRR) (Fereydooni Eftekhari et al., 2024). The BRR is calculated by the weighted average recyclability of each material.

Among all six macro-objectives of Level(s), the study provides contribution in terms of Macro-objective 2: Resource Efficient and Circular Material Life Cycles, specifically the "Indicator 2.1: Bill of Quantities, Materials and Lifespans", and "Indicator 2.2: Construction and Demolition Waste and Materials". Moreover, since the Level(s) framework can be applied at different stages of the buildings design and operation, starting from Level 1 (Conceptual Design) to Level 3 (As-Built and In-Use Performance), the scope of this study is the Level 2 (Detailed Design and Construction) which involves the quantitative assessment of the designed performance and monitoring of construction.

The first input data for the calculation tool of Level(s) indicators are BoM and BoQ. These data are obtained from the BIM model of the building exported in IFC and are analyzed by a bespoke programming in Python. The output of this tool is used as the input for the calculation tool of Level(s).

Moreover, since the abovementioned indicators consider the BoQ and BoM both for the construction and lifetime of the buildings, it is required to make assumptions about building lifetime and Estimated Service Life (ESL) of the products in the building. For this reason, the building is assumed to have a lifetime of 50 years and the ESL is calculated based on the Factor Method developed by ISO 15686-8:2008 (International Organization for Standardization, 2008), considering the normal maintenance of the products as summarized in the Table 1. Based on these values, a Normalization factor will be considered which is the ratio of the building lifecycle over the ESL of the product. It is important to notice that in the cases that the normalization factor is lower than one, the tool needs to consider it equal to one and this is the amount of material which is needed for both construction and lifetime of the building. In order to evaluate the overall Building Recyclability Rate (BRR) in this case study, it is required to consider an average recyclability rate for each building material, as also reported in Table 1.

Another type of data which is important to consider during the calculation of the indicators is interpretative data which are decision-based and require assumptions and strategies. These data include the nature and waste codification based on the type of materials and their composition, and the outlet of their waste in terms of the best and probable outlet for waste and over ordering which are assumed by the authors. The contribution of the bespoke programmed tool of the authors in this kind of data is the automated assignment of the waste codification to each material.

Table 1. Estimated Service Life and average recyclability rate for building products

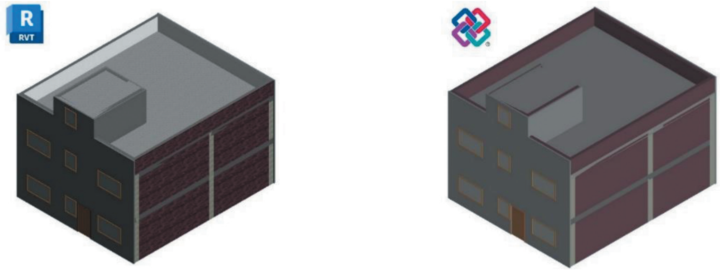
Products	ESL (years)	Average recyclability rate (%) *
Concrete	53	75
Wood	35	33
Oak flooring	33	50
Plastic ceiling	30	10
Asphalt shingle	33	70
EPDM membrane	25	96
Common brick	35	36
Gypsum wall-board	38	4
Glass	30	71
Rigid insulation	38	46

* Calculated based on average of recyclability rates from literature (Fereydooni Eftekhari et al., 2024)

The model for the case study is a hypothetical model of a typical two-story residential building. This model, as shown in Figure 1 is a building with an overall floor area of 217 m^2 with concrete structure, insulated external brick walls, and gypsum wallboard for internal partitions at Level of Detail (LOD) of 200, consisting of structural and architectural elements and excluding any service system.

3 RESULTS AND DISCUSSION

Using a BIM- and IFC-based methodology integrated in bespoke python programming, this study employed the Level(s) framework to analyze the building's overall material circularity



(a) (b)

Figure 1. Hypothetical model of the building: a) in Revit and, b) 3D representation of the exported IFC

and recyclability, and its comparison with the previously developed recyclability indicators. The primary results of the study can be seen as follows:

3.1 *BoQ and BoM for construction and lifetime*

The first result of the study is the BoQ and BoM both for the construction and lifetime of the building. The automatically achieved list of the materials and their quantities is inserted into the calculation tool for Indicator 2.1 and used in integration with ESL of the components and materials to calculate the BoQ and BoM. The results are shown in Figure 2. As can be seen in the figure, although the amount of concrete required does not decrease, its relative share in the BoM is reduced when considering the building's lifetime. This is due to the increase in required quantities of other materials that have shorter ESLs and therefore need replacement or refurbishment during the building's lifecycle.

For instance, materials such as wood, plaster ceiling, and gypsum wallboard have ESLs that are shorter than the building's overall 50-year expected life. Thus, these materials contribute

Bill of Quantities/ Materials (for construction)

Breakdown by material type	Material total (t)	Material total (%)
Combined total	324.42355	100.0%
Concrete, brick, tile, natural stone, ceramic	269.69393	83.1%
Wood	8.1727188	2.5%
Glass	3.0661295	0.9%
Plastic	10.77455	3.3%
Bituminous mixtures	13.796265	4.3%
Metals	8.6841546	2.7%
Insulation materials	3.5897843	1.1%
Gypsum	6.64602	2.0%
Mixed	0	0.0%
Electrical and Electronic Equipment	0	0.0%

Building floor area (m^2)	217	Totals check (should =0)	0	
Breakdown by building aspect				
Shell	Core	External	Total	Units
313.1578298	11.265722	0	324.423552	tonnes
96.5%	3.5%	0.0%	100.0%	mass %
29.33412758	0.888033	0	30.2221606	000 €
97.1%	2.9%	0.0%	100.0%	€ %

Total cost €/m2	Total cost €/t
139.3	93.2

	Inert	Non-haz	Hazardous	Total
Tonnes	40.91	5.59	0.72	47.22
% split	86.6%	11.8%	1.5%	100.0%

Bill of Quantities/ Materials (for lifetime)

Breakdown by material type	Material total (t)	Material total (%)
Combined total	395.94653	100.0%
Concrete, brick, tile, natural stone, ceramic	314.56321	79.4%
Wood	12.36939	3.1%
Glass	5.1102158	1.3%
Plastic	19.25115	4.9%
Bituminous mixtures	20.903432	5.3%
Metals	8.6841546	2.2%
Insulation materials	6.3202075	1.6%
Gypsum	8.7447632	2.2%
Mixed	0	0.0%
Electrical and Electronic Equipment	0	0.0%

Building floor area (m^2)	217	Totals check (should =0)	0
Breakdown by building aspect			
Shell	Core	External	Total
378.1430805	17.803445	0	395.946526
95.5%	4.5%	0.0%	100.0%
37.80140479	1.3748714	0	39.1762762
96.5%	3.5%	0.0%	100.0%

Total cost €/m2	Total cost €/t
180.5	98.9

Figure 2. BoQ and BoM for construction and lifetime from Indicator 2.1

additional quantities to the BoM to fulfill refurbishment needs, resulting in a proportional decrease in concrete's share, even though the total amount of concrete remains constant. The BoQ and BoM breakdown for construction and lifetime helps create a more accurate material profile that anticipates material replacement needs, improving resource management and aligning with CE goals. Figure 2 presents this dynamic change in material shares.

3.2 *Construction Waste (CW) and Demolition Waste (DW)*

Using Indicator 2.2 of Level(s), it is possible to estimate the amount and share of the pre-demolition inventory as DW, CW, and actual CDW. Regarding the scope of the study which considered the model of the building, the estimation about actual CDW is not considered in this paper as it requires the logging of actual waste produced from any construction, demolition or renovation activities.

To have the estimation of DW as pre-demolition inventory, the nature of the demolition activities has been assumed for each material among five main activities defined by Level(s) which are: a) prepare elements for onsite reuse, b) decontamination and selective removal of hazardous materials, c) stripping of high value materials for sale or reuse offsite, d) deconstruction of elements for sale or reuse offsite, and e) demolition. Moreover, the best and most probable outlet for each material should be defined by the auditor and waste manager, respectively.

In the case of CW, it is required to have an estimation based on rules of thumb about the rate of waste during the construction activities, and the rate of Over Ordering (OO) of materials based on rules of thumb or intended spare stock that the client wants. Since here there would be an additional source of materials for waste which is the OO, it is required to consider the best and most probable outlet also for this source of possible waste. However, the nature of this possible waste may be different from the previous sources of waste, since it might not be used in the construction activities and can be returned to the producer or manufacturer without any (or minor) modifications. The summary of estimated wastage rate (%) of CW and estimated OO material (%) is provided in the table below:

Table 2. Summary of estimated wastage rate and estimated OO rate for Indicator 2.2.

Products	Estimated wastage rate (%) CW	Estimated OO rate (%)
Concrete	7	13
Wood	10	5
Plaster ceiling	10	5
Asphalt shingle	10	3
Insulation	20	5
Common brick	10	5
Gypsum wall-board	20	5
Glass	5	0

The primary results of the Indicator 2.2 are provided in Figure 3. This figure indicates that although the concept of reuse of materials is achievable, in this case study (like the general construction projects), most materials will go to be recycled or disposed of. This difference between the amount of achievable reuse and probable reuse is even higher in terms of DW, which shows that there is a big challenge in reuse of materials and components at the end of life. In the case of CW and OO, significant challenges persist in reducing waste from OO. It shows the importance of using digital technologies such as BIM to have a better estimation of required materials to avoid OO during the construction.

3.3 *Integration of BRR and Level(s)*

Based on the proposed formula for BRR, the recyclability rate for this building is calculated and is equal to 51.7%. For this calculation, it was assumed that all the materials will be recycled at the end of life of the building which means that none of the materials are reused or

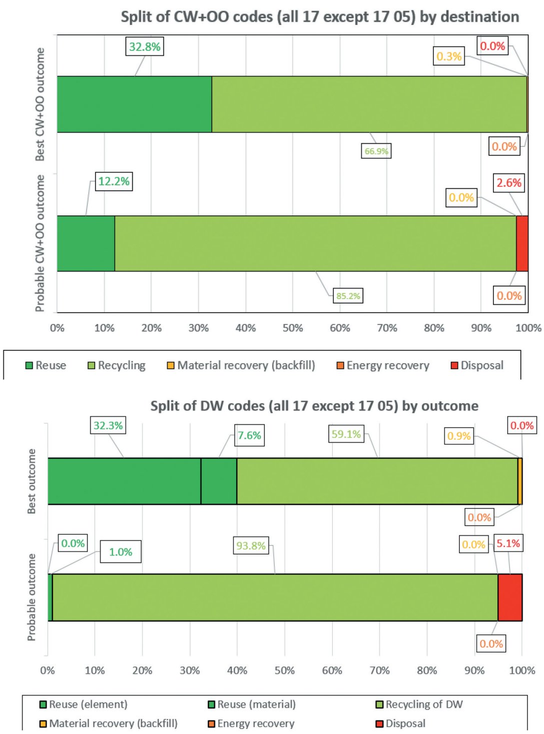


Figure 3. Split of DW and CW+OO (chapter 17 of Level(s) except 17 05 which is soil, stones, and dredging) based on the type of outcome.

disposed directly. However, if the probable and best outcome of the materials for each case of CW+OO and DW would be considered, some of the materials will be reused or disposed of. It means that not all materials can be recycled, and it will change the recyclability rate of the building, and the circular behavior of the building will be more realistic in terms of combination of recycling, reuse and other approaches.

It also highlights the significant potential for waste reduction in construction, particularly through material reuse as recent studies have explored component reuse as a key factor in sustainable building practices. For example, (Kitayama et al., 2024) demonstrated that reusing lightweight exterior infill walls in construction can notably minimize the need for virgin material production and avoiding disposal at end-of-life.

In this study, the BRR is calculated for four cases of: a) probable outcome of CW+OO, b) best outcome of CW+OO, c) probable outcome of DW, and d) best outcome of DW as shown in table below:

Table 3. Calculate BRR for Best and Most probable outcome of CW+OO and DW.

Cases of outcome	Probable outcome of CW+OO	Best outcome of CW +OO	Probable outcome of DW	Best outcome of DW
BRR (%)	55	48	56	43

As can be seen from the table above, the BRR in both cases of CW+OO and DW is reduced when the decision about the outcome is changed from the probable to the best outcome. It indicates that although the reusing of materials in the best outcome will decrease the need for recycling materials, the remaining materials for recycling are the ones which have lower ability to be recycled. This fact highlights the importance of developing in the future a common circularity indicator for the building.

4 CONCLUSION

This study had the main objective of enhancing the applicability of Level(s) framework by integration of BIM and IFC into a bespoke programming tool. The paper used the hypothetical model of a residential building in BIM to export its data to IFC and apply the EWC, ESL of factor method proposed by ISO 15686-8:2008, and BRR to evaluate the circularity of the building.

The results of this study are beneficial for the industry, since they showed that using the digital tools in the application of Level(s) framework can improve its applicability in terms of speed and accuracy of data input as those tools can get the BoQ and BoM from IFC and assign the relevant EWC to them automatically. Also, the application of BIM has a great impact on enhancing the circularity of the building, since it plays an important role in better estimation of required materials to avoid OO of the materials. Moreover, the integration of BRR into the Level(s) framework highlighted the importance of considering other approaches of circularity such as reducing and reuse, and the importance of the necessity to develop a common, standardized, and comprehensive circularity indicator.

For future considerations, there exist still some gaps and challenges in application of Level(s) which are directly related to the concept and definition of the calculation tool. Furthermore, the application of other emerged digital technologies such as Artificial Intelligence (AI) can be a playground for future research. All these challenges necessitate further work to do a critical assessment over application of Level(s).

REFERENCES

Charef, R. & Emmitt, S. 2021. Uses of building information modelling for overcoming barriers to a circular economy. *Journal of Cleaner Production* 285, 124854.

Environment, U. N. 2022. *2022 Global Status Report for Buildings and Construction | UNEP - UN Environment Programme*. Available at: https://www.unep.org/resources/publication/2022-global-status-report-buildings-and-construction

European Commission. 2021. *Level(s), A common language for building assessment*. Publications Office of the European Union.

Fereydooni Eftekhari, A., Khodabakhshian, A., Iuorio, O., Re Cecconi, F. & Daniotti, B. 2024. A New Building Information Modelling-Based Approach to Automate Recyclability Rate Calculations for Buildings. *Buildings* 14(6): Article 6.

Fereydooni Eftekhari, A., Khodabakhshian, A., Re Cecconi, F., & Daniotti, B. (2024). Improving Circularity in Construction Through a BIM-Based Waste Management Framework. *IOP Conference Series: Earth and Environmental Science* 1363(1), 012042.

Ferrari, S., Zoghi, M., Blázquez, T. & Dall'O', G. 2022. New Level(s) framework: Assessing the affinity between the main international Green Building Rating Systems and the european scheme. *Renewable and Sustainable Energy Reviews* 155, 111924.

International Organization for Standardization. 2008. *Reference service life and service-life estimation (ISO Standard 15686-8)*. ISO. Available at: https://www.iso.org/standard/39070.html

Keena, N. & Friedman, A. 2024. *Sustainable Housing in a Circular Economy*. Oxfordshire: Taylor & Francis.

Kitayama, S., Iuorio, O., Josa, I., Borrion, A. & Black, L. 2024. Determining the carbon footprint reduction of reusing lightweight exterior infill walls: A case study of a school building in the United Kingdom. *Journal of Cleaner Production* 469, 143061.

Kovacic, I., Honic, M. & Sreckovic, M. 2020. Digital Platform for Circular Economy in AEC Industry. *Engineering Project Organization Journa*l 9(1).