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PRELIMINARY DEVELOPMENT OF A COMPOSITE INDICATOR OF CIRCULARITY IN THE CONSTRUCTION AND DEMOLITION WASTE (CDW) SECTOR

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ABSTRACT

The circular economy is central to promoting sustainability in the construction sector, especially in the management of Construction and Demolition Waste (CDW). This article explores the importance of circularity indicators as key tools to assess and improve practices in this sector, with a particular focus on the proposed Integrated Circularity Index for CDW (ICICDW), which would provide a comprehensive view in the framework of the Circular Economy. In the EU, indicators like energy use, waste management, and recycled content help assess the environmental impact of construction. However, growing waste and emissions, along with a lack of standardised methods, highlight the need for a more holistic approach. This article reviews thirteen EU-proposed indicators for the construction sector, evaluating their relevance to CDW and emphasizing the need for new composite indicators that also consider material use and economic factors. The Integrated Circularity Index for CDW (ICICDW) is introduced as a tool that combines specific indicators from the CDW sector with economic aspects. This integration allows for a comprehensive assessment of circular economy performance within the CDW sector. This approach seeks to address crucial challenges, thereby driving the transition towards a more sustainable model. The implementation of circular economy indicators brings significant benefits, including improved waste management, reduced environmental impact, optimised resources and costs, promotion of the circular economy and compliance with current regulations. In this context, this paper highlights the fundamental importance of developing indicators that integrate various dimensions in order to move effectively towards sustainability and more environmentally friendly construction.

1. INTRODUCTION

The European Union faces significant challenges related to waste generation and greenhouse gas emissions, producing over 2.2 billion tons of waste annually and exceeding 2.5 billion tons of CO_2 emissions. In response to climate change, the European Parliament adopted the EU Climate Law, which sets the target of reducing net greenhouse gas emissions by at least 55% by 2030 (European Commission, 2024a; European Commission 2023; European Parliamentary Research Service, 2021). This effort aligns with the goal of achieving climate neutrality by 2050, a central aim of the European Green Deal. This deal, in turn, drives the new Circular Economy Action Plan, launched by the European Commission on March 25, 2020, which identifies the construction sector as a priority area (European Commission 2019; European Commission 2020). This prioritization is not arbitrary, as the construction sector is a major consumer of resources in Europe, using approximately half of all extracted materials, nearly half of the energy consumed, and a third of all water used, in addition to generating a third of the total waste, Figure 1 (Avintia 2021; European Commission, 2024b).

In this context, also in March 2022, the European Commission presented a package of measures designed to accelerate the transition to a circular economy, as detailed in the Circular Economy Action Plan, with the aim of transforming the current “take, make and dispose” model into a fully circular, environmentally sustainable and toxin-free economy by 2050 (European Commission 2020).

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FIGURE 1: Consumption in the construction sector.

The circular economy has established itself as a fundamental approach to promoting sustainability, especially in sectors with a high environmental impact such as construction. This model seeks to reduce dependence on virgin resources and minimise waste production through reuse and recycling. In recent years, significant progress has been made at the political, methodological and scientific levels in the analysis and implementation of circular practices. However, there is still a lack of a comprehensive and agreed methodology to enable effective monitoring of processes related to the circular economy. The construction industry is rapidly shifting its focus towards sustainability and more environmentally friendly practices. Institutions have developed tools for the circular economy and adopted a monitoring framework to assess progress towards it. However, there is currently no universally recognised indicator of 'circularity' and the number of reliable indicators to describe the most important trends is limited. Further research is therefore needed to develop a set of relevant indicators to define an appropriate monitoring framework (Avintia 2021; Sacyr 2021).

As a result of this need, the European Commission developed a monitoring framework based on ten key indicators, broken down into sub-indicators and organised into four categories: (1) production and consumption, (2) waste management, (3) secondary raw materials, and (4) competitiveness and innovation. These indicators were subsequently revised in 2023 to include metrics related to material footprint and resource productivity, with the aim of monitoring material efficiency and assessing whether EU consumption remains within planetary boundaries (European Commission 2023). This new framework strengthened the EU's circular economy and climate neutrality ambitions, aligning them with the objectives of the European Green Deal.

In this way, circularity indicators are crucial tools for evaluating progress towards the adoption of sustainable and circular practices in both organisations and production systems. In this context, a longevity indicator has been developed that quantifies the contribution to material retention based on the total time a resource remains in use, considering its initial useful life, extended useful life through remanufacturing, and additional useful life achieved through recycling (Franklin-Johnson et al. 2016). However, while these indicators provide valuable information on material retention and progress towards the circular economy, it is essential to recognise that sustainability encompasses a broader perspective (Ghisellini et al 2018, Franklin-Johnson et al. 2016). It is therefore essential to complement these circularity indicators with others that assess aspects such as energy consumption, integrated waste management and resource efficiency, thus enabling a more comprehensive assessment of environmental and economic performance. Additionally, the lack of comprehensive data on the impacts of circular practices highlights the need to develop a more complete and effective set of indicators (Franklin-Johnson et al. 2016; Kirchher et al 2018).

With regard to Construction and Demolition Waste (CDW), the European Union has established the importance of moving towards high circularity in the construction sector, recognizing that this is the biggest driver of resource consumption and waste generation in Europe. While the EU Waste Framework Directive introduced a waste hierarchy and set a 70% recovery target for CDW by 2020, the inclusion of practices such as backfilling within recovery rates raises questions about the true contribution to a circular economy, as this practice does not preserve the value of materials. Although, as indicated, the EU revised the circular economy monitoring framework in 2023 by adding new indicators to monitor material efficiency and consumption footprint, a more comprehensive assessment of the effectiveness of the circular economy in the construction and demolition sector is still needed due to the lack of specific and adequate metrics (Zhang et al 2022). It is therefore crucial to develop more robust and specific indicators that allow effective monitoring of progress towards the targets set out in the EU Circular Economy Action Plan and go beyond traditional recovery metrics (European Commission 2020).

The CDW is composed of a variety of materials, including concrete, bricks, gypsum, wood, glass and metals, many of which have a high potential for recycling and reuse. The European Union has identified CDW as a priority waste stream, and despite the potential for recycling, the increasing amount of material stockpiles in cities driven by the consumption of raw materials for construction underlines the need to consider further recycling of construction and demolition waste as an option for resource conservation. Conventional practices, based on continuous resource extraction and waste generation, are being challenged in favour of a European recycling society with a high level of resource efficiency (Lederer et al 2020; European Commission 2024a).

In this context, the transition towards a Circular Economy (CE) model in the construction and demolition waste (CDW) sector is presented as a key solution whose environmental challenges could be mitigated through the adoption of circular economy practices as Menegaki et al. point out that, globally, increasing efforts are being made to recycle and reuse CDW as a means to avoid the environmental impacts associated with landfilling (Murray et al. 2017; Royal Decree 105/2008; Papargyropoulou et al 2011; Menegaki and Damigos 2018).

Ma et al. 2023 focuses on identifying the critical success factors (CSFs) for achieving a closed-loop circular economy in CDW management in China, seeking to move beyond the traditional 3R approach and stimulate a transition to a more sustainable model.

Ghisellini et al. 2018 analysed the environmental and economic costs and benefits of the circular economy (CE) in the construction and demolition (CD) sector. Their literature review found that circular strategies (reuse and recycling) decrease waste generation. The reviewed studies showed that reusing and recycling construction and demolition waste (CDW) generally provides environmental and economic benefits, reducing environmental impacts by decreasing raw material extraction and waste volume.

Also, Ghisellini et al. 2018 and Kirchherr et al. 2018, addressed the evaluation of CE by pointing out the need for better metrics and flow accounting to assess the effectiveness of CE and identified the lack of data, as a technological barrier. This lack of data makes it difficult to fully assess the effectiveness of EC in the C&D sector. Therefore, the difficulty of evaluating EC in this sector due to the lack of specific metrics is supported by both studies. Meanwhile Menegaki and Damigos 2018 conducted a review on construction and demolition waste (CDW) management. Their study focuses on the factors, barriers and motivations that influence the generation and management of CDW. The authors calculated CDW indicators for selected countries and developed an explanatory model to identify key factors. In addition, they created a conceptual map with 36 components that represents the existing knowledge about the CDW system and its interrelationships. The main objective of their work is to provide an overview of the challenges in CDW management, including the policy framework. Lederer et al. (2020) conducted a material flow analysis in Vienna, showing that reuse and recycling of construction minerals could reduce material imports by 32%. This example highlights the potential of CE to decrease dependence on virgin resources and improve the resilience of building systems (Leader et al 2020b). However, significant barriers remain. Murray et al. 2017 and Sauvé et al. 2016 identified a lack of clarity regarding the fundamental principles and objectives of the circular economy, which hinders its assessment and widespread adoption in the sector.

Despite advances in CDW recovery and recycling, the integration of the circular economy on a large scale remains limited due to the absence of specific indicators that accurately measure progress towards circularity. Thus Mayer et al. 2019, improvements in statistical data collection, knowledge on material stockpiles and the development of criteria for ecological cycle closure are needed to advance the assessment of CE. Parchomenko et al. 2019 also emphasize the fragmentation of CE measurement approaches and the need for more comprehensive metrics.

It is therefore clear that in order to effectively implement the circular economy in the field of construction and demolition waste (CDW), multiple interrelated social, governmental, economic, behavioural, technological and environmental dimensions that influence the adoption of circular strategies need to be addressed in an integrated manner. In this context, the development of specific metrics and indicators to assess and optimize the use of CDW, improve quality control during dismantling, encourage efficient material handling and facilitate a more sustainable management that maximizes ecological and economic benefits, thus driving the transition towards a circular economy in the construction sector, is of particular relevance. The implementation of the circular economy in the management of CDW requires a combination of technical, political and economic strategies, supported by specific indicators that reflect progress towards sustainability. These efforts will not only minimize environmental impacts, but also maximize the value of materials and foster a more resilient and sustainable model in the construction sector.

This work aims to contribute to the preliminary development of a composite circularity indicator focused on waste from the construction and demolition sector, which is considered crucial for the global economy.

2. CIRCULARITY INDICATORS

2.1 Indicators of the construction sector in the EU

Public and private entities have published reports on what the indicators for the circular economy measurement framework should be. Despite these efforts, there is still no stable and recognized framework of indicators unique to the construction sector. The European Commission in 2014 proposed a set of areas to assess the environmental performance of the construction sector (European Commission 2014):

1. Total energy consumption: energy from material manufacturing processes added to construction processes and building operation and use;
2. Use of materials and their environmental impact;
3. Durability of construction products;
4. Demolition planning;
5. Construction and demolition waste management;
6. Recycled content of building materials;
7. Possibility of recycling and reuse of building materials and products;
8. Total water consumption;
9. Intensity of use of buildings: flexibility, resilience, possibility of change of typology and use, degree of space occupation, etc;
10. Interior comfort.

Subsequently the European Commission published the Level(s) report establishing a common EU framework of core sustainability indicators for residential and office buildings proposing indicators for measuring sustainability in the building sector (European Commission 2014).

Based on this work, the Green Council Building Spain (GCBe) published the report: Indicators for measuring circularity in the construction sector at the beginning of 2020 (summary in figure 2). This work, initiated jointly with the Working Group GT-6 National Environmental Congress, Conama Foundation divides the indicators into two groups (Green Building Council Spain 2023; Conama 2018):

1. Short-term indicators, those that are currently capable of being accounted for by valid and credible sources, as they are based on existing indicators that are similar or for which data are already collected, and could therefore be implemented with some ease;
2. Long-term indicators. Indicators that are recognised as strategic, but for which today we do not have the necessary reliable sources for their measurement, nor do we have solid references.

Table 1 summarises all the proposed key indicators and the aspects that each one assesses, and where defined, the units of measurement, analysing the advantages and disadvantages of each one.

From analysis of the indicators in Table 1, it can be deduced that the availability and reliability of the data needed for their calculation is important, as they are essential for the effective application of these indicators. Efforts are needed to improve data collection and harmonise calculation criteria at the national level.

In the specific case of construction and demolition waste, based on previous studies analysing the construction sector, a series of key indicators have been identified that enable the degree of circularity in the management of construction and demolition waste (CDW) to be accurately assessed. These indicators not only quantify material flows but also provide operational and strategic information for the design of public policies and the continuous improvement of sustainable construction projects. Analysing their usefulness and relevance on a scale of 1 (minimum) to 5 (maximum), we find that (Green Building Council Spain 2023; Conama 2018):

a. The indicator of CDW management per built-up area (Kg/m²year) is considered one of the most complete and relevant. Its high usefulness (5) is due to the fact that it makes it possible to normalise the waste generated according to the construction activity, facilitating comparisons between projects, regions or periods. By differentiating between hazardous and non-hazardous waste and classifying their final destination, this indicator provides a global and detailed vision that is indispensable for establishing baselines and measuring the impact of reduction and recovery strategies Its relevance (5) is equally high, as it is aligned with European and national objectives to minimise waste generation and maximise waste recovery.
b. The percentage of CDW at each destination is another key indicator. With a usefulness valued at 4, it allows the efficiency of waste treatment to be assessed by quantifying the fractions destined for material recovery, energy, landfill or landfill. Its relevance (5) lies in its direct alignment with the principles of the circular economy, which promote the reintroduction of materials into the value chain and the minimisation of final disposal.
c. Recycled content in building materials, measured in kg/m² or as a percentage of the total, has a high utility (4), as it evidences the demand for secondary raw materials and can influence green public procurement criteria and environmental certifications. Its relevance (5) is unquestionable, as the use of recycled materials reduces pressure on natural resources and fosters circular markets.
d. The CDW Recovery Rate, defined as the proportion of waste prepared for reuse, recycling or recovery, has both a usefulness and relevance of 4 and 5 respectively. This indicator, adopted by Eurostat (cei_wm04038) and institutions such as IHOBE 2018, provides an aggregate measure of the efficiency of waste management systems and allows the assessment of compliance with legislative targets (Conama 2018; IHOBE 2028; Ghisellini et al 2016; OECD, European Union, & EC-JRC, 2008).
e. The CDW generation per built area indicator is proposed as a direct metric of prevention. Its usefulness (4) lies in its ability to monitor material efficiency from design, while its relevance (5) lies in its connection with the waste hierarchy, which prioritises reduction at source (Conama 2018, Ghisellini et al 2016).
f. On the other hand, the Absolute amount of CDW generated in buildings is of moderate usefulness (3), as it provides gross volume without contextualising it with the activity. Even so, its relevance (4) is significant for understanding the full magnitude of the problem and guiding macro strategies (Green Building Council Spain 2023).
g. The percentage of recovered waste, aligned with Eurostat frameworks, is useful (4) to understand the aggregate performance of the management system and very relevant (5) for its contribution to circular economy and landfill reduction objectives (Green Building Council Spain 2023).

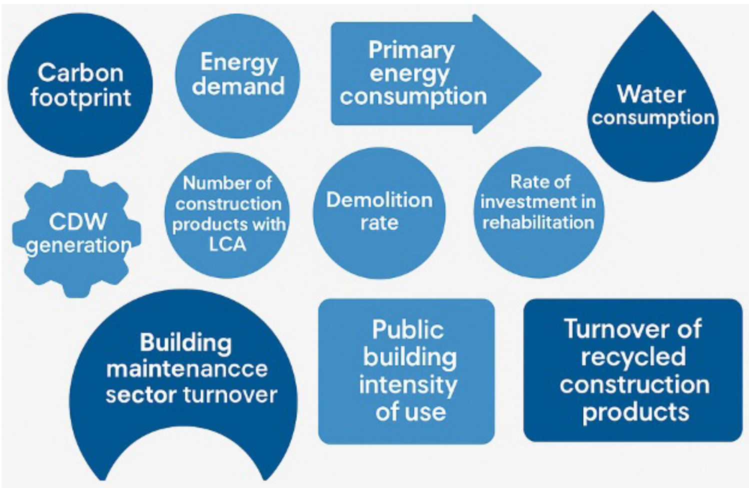

FIGURE 2: Summary of indicators.

TABLE 1: Summary of the proposed key indicators.

Indicator	Target	Advantages	Disadvantages	Units
Carbon footprint	Track GHG emissions and promote low-impact strategies	Shows impact evolution; encourages efficiency and renewables	May omit transport and end-of-life stages	$kgCO_2/m^2 \cdot year$
Energy demand	Evaluate building envelope efficiency and long-term performance	Highlights efficiency and supports 2050 savings goals	Risk of theoretical values being disconnected from reality	$kWh/m^2 \cdot year$
Primary energy	Better represent energy flows in Circular Economy	Reflects system/source efficiency; closer to real use	Risk of disconnect with real consumption	$kWh/m^2 \cdot year$
Water use	Promote reduction and efficient management	Supports sustainable water use and resource synergy	No major drawback noted	$m^3/occupant \cdot year$
Material use	Promote efficient material use and prioritise refurbishment	Encourages efficiency, durability, and environmental awareness	Data reliability and standardisation issues	$(kg, T)/m^2 \cdot year$
CDW generation	Monitor and reduce construction and demolition waste	Encourages reuse, recycling, and controls illegal dumping	Hard to track rehabilitation without permits	$(kg, T)/m^2$
Products with LCA	Encourage use of EPD/LCA for sustainability assessment	Facilitates sustainability at product/building levels	Limited by market maturity	N° of EPDs/LCAs
Refurbishment ratio	Track refurbishment vs. new construction	Supports life extension and performance improvement	Lacks unified refurbishment data	m^2/m^2 (%)
Demolition rate	Discourage unnecessary demolitions	Emphasises preference for refurbishment	Indirect; requires interpretation	m^2/m^2 (%)
Rehab investment	Track economic trends and quality of rehab	Shows value generation and depth of interventions	Data may mix different rehab types	$€/m^2$
Maintenance sector	Define and size the building maintenance market	Clarifies sector scope and aids CNAE classificatio	No major drawback noted	€ or workers
Public building use	Avoid underuse of public buildings	Promotes efficient space use	No major drawback noted	Not specified

h. Finally, the Level of on-site segregation, measured by the percentage of mixed waste LER 17 09 04, is one of the most practical and operational indicators. Its usefulness is maximal (5), as it allows the quality of on-site management to be assessed, and its relevance (5), as good segregation is a precondition for efficient and high-quality recovery (Green Building Council Spain 2023).

Figure 3 shows a comparative assessment of the key indicators for the construction and demolition waste sector.

Together, these indicators form a robust and coherent framework for monitoring circularity in the construction sector, allowing an assessment of the environmental and operational performance of current practices, and identifying opportunities for improvement for a real transition towards the circular economy. But for an effective implementation of the circular economy in the construction and demolition waste (CDW) sector, it is essential to propose indicators that integrate environmental and economic aspects in a balanced way. While the circular economy seeks to increase resource efficiency and promote closed-loop production patterns, with a particular focus on industrial and municipal waste, measuring progress towards these goals requires going beyond traditional resource efficiency metrics (Parpomenko et al 2029, Ghisellini 2026). Approaches purely focused on reducing resource consumption may not capture the main objective of the circular economy, which is to maintain the value of products and materials for as long as possible. The integration of environmental dimensions, such as environmental burden reduction and prevention of impacts, with economic dimensions, such as value creation through material retention, is crucial to guide decision-making and assess performance in the CDW sector within a circular economy framework (Franklin-Johnson 2010, Ghisellini 2016). The current lack of specific indicators that combine material environmental and economic aspects and the need for further research in this area highlight the importance of developing tools that enable comprehensive monitoring and facilitate the transition to a circular model in the construction sector (Parpomenko et al., 2029; Ghisellini, 2026).

3. PRELIMINARY DEVELOPMENT OF A CIRCULARITY INDICATOR IN THE CONSTRUCTION AND DEMOLITION WASTE SECTOR. DEVELOPMENT METHODOLOGY

The evaluation of the circular economy in the construction and demolition waste (CDW) sector has traditionally focused on material and environmental indicators. However, as seen in the previous section, in order to promote an effective and realistic transition towards circular models, it is also necessary to incorporate economic variables that reflect the viability and financial impact of the strategies applied. In this context, the preliminary development of a

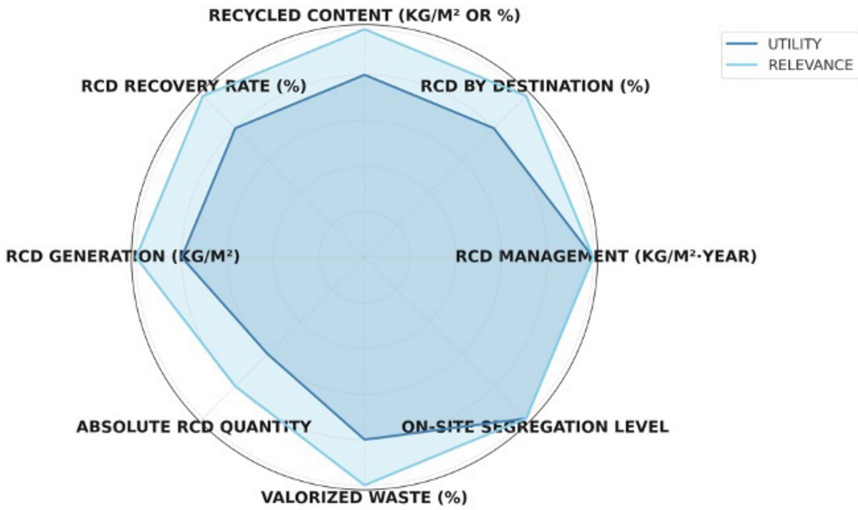

FIGURE 3: Benchmarking circular economy indicators applied to the construction and demolition sector.

new composite indicator integrating environmental and economic aspects is proposed, allowing for a more comprehensive assessment of the circular performance of the sector. The transition towards the circular economy in the CDW sector faces several barriers (European Commission 2020; Parpomenko et al 2029):

1. Technical barriers: There is significant variability in the quality of recycled materials, as well as a lack of advanced technologies for efficient processing;
2. Economic barriers: The high costs associated with recycling, coupled with the lack of financial incentives, make it difficult for recycled materials to compete with virgin materials;
3. Regulatory barriers: Insufficient, inadequate or complex regulations limit the adoption of circular practices, increasing bureaucracy for companies;
4. Social and behavioural barriers: Resistance to change and lack of knowledge about circular economy practices hinder its implementation in the sector;
5. Logistical barriers: Limited infrastructure to manage CDW and difficulties in the supply chain increase costs and make it difficult to incorporate recycled materials into processes.

Overcoming these barriers requires a combination of financial incentives, technological advances, targeted regulations and increased sustainability education.

A key first step is the development of simplified and measurable indicators to assess progress towards the circular economy. Based on the indicators analysed and following the recommendations on how to design, develop and disseminate a composite indicator from the OECD Handbook on constructing composite indicators: methodology and user guide, a composite indicator is proposed, the Integrated Circularity Index for RCD (ICICDW), which simplifies and combines these key dimensions into a single framework of analysis by adding the economic dimension (OECD, European Union, & EC-JRC, 2008).

The creation of an Integrated Circularity Index for CDW (ICICDW) addresses the above-mentioned barriers and allows for a comprehensive assessment of the circular performance of CDW management. The proposed index combines three key dimensions: (1) the recycling rate of CDW, (2) the environmental impact avoided through the substitution of virgin materials by recycled materials, and (3) the relative economic benefit derived from the efficient reuse of recycled materials in new construction. Thus, the proposed indicator will combine material circularity with the economic benefits generated by waste recovery, incentivising sustainable practices that are also economically viable.

3.1 Development methodology

This methodology is based on a sequence of steps adapted from the "Handbook on Constructing Composite Indicators" for the creation of a composite indicator to assess circularity, applied to the construction and demolition waste (CDW) sector (OECD, European Union, & EC-JRC, 2008).

3.1.1 Stage 1: Developing a Theoretical Framework

This step is fundamental. The ICICDW aims to provide a comprehensive and multidimensional view of circular performance in CDW management, combining material circularity (MC), avoided environmental impact (AEI) and relative economic benefit (REB).

The theoretical framework recognises that an effective transition to the circular economy in the CDW sector requires consideration not only of material and environmental aspects, but also of financial viability and impact.

The selected ICICDW components are:

- Material Circularity (MC): Measures the proportion of CDW that is reintegrated into the production cycle through reuse, recycling and recovery, in relation to the total amount of CDW generated;
- Avoided Environmental Impact (AEI): Evaluates the environmental benefit of replacing virgin materials with recycled materials by comparing the avoided impact with a theoretical baseline impact;

- Relative Economic Benefit (REB): Quantifies the economic value recovered from CDW in relation to the total cost of its management.

This framework seeks to encourage sustainable practices that are also economically viable.

Defining the ICICDW as:

$$ICICDW = w_1 * MC + w_2 * AEI + w_3 * REB \quad (1)$$

with $w_1 + w_2 + w_3 = 1$

3.1.2 Stage 2: Selection of Variables

At this stage, the individual indicators that make up each dimension of the ICICDW are defined.

In this step, the data necessary to calculate each component of the index are collected:

Material Circularity (MC)

$$MC = \frac{CDW_{reused} + CDW_{recycled} + CDW_{valorized}}{CDW_{generated}} \quad (2)$$

The data should be obtained from authorised manager's certificates, site reports, waste management platforms.

Avoided Environmental Impact (AEI)

Calculated from an estimate of the savings in CO_2 emissions, water, energy or raw material use by replacing virgin materials with recycled materials

$$AEI = \frac{Impact_{avoied}}{Impact_{theoretical}} \quad (3)$$

The AEI can be calculated using LCA databases (Ecoinvent, Simapro, One Click LCA) or references.

Relative Economic Benefit (REB)

$$REB = \frac{Recovered\ economic\ value}{Total\ management\ cost\ CDW} \quad (4)$$

Includes revenues from sale of materials, savings from reuse, treatment and transport costs.

It can be calculated on the basis of invoices, sales contracts, cost bases, construction budgets.

3.1.3 Step 3: Imputation of Missing Data (Simplified)

As this is a preliminary development, priority will be given to collecting complete data for the selected study units. If there are missing data, a simple imputation, such as using the mean of the indicator for similar cases, could be considered, always documenting this decision. A more complex imputation strategy (such as multiple imputation) could be implemented at later stages if the amount of missing data is significant and may generate important biases.

3.1.4 Step 4: Multivariate analysis

In a preliminary development with a small number of dimensions clearly defined by a theoretical framework, this step can be omitted to simplify the initial methodology. A more in-depth analysis of the relationships between the individual indicators could be carried out at later stages with a larger dataset.

3.1.5 Stage 5: Data Normalisation

Since MC, AEI and REB will have different units and scales, it is necessary to normalise their values to make them comparable before aggregation. As this is a preliminary design, simple standardisation has been chosen, using the Min-Max method for all dimensions and scaling them to a range of 0 to 1.

3.1.6 Step 6: Weighting and Aggregation

In this stage, the weights (w1, w2, w3) are assigned to each of the three dimensions of the ICICDW. The sum of the weights must equal 1 (w1 + w2 + w3 = 1).

The allocation of weights can be based on different criteria: a) technical if they give more weight to the dimension considered most relevant to sustainability objectives or normative e.g., more weight to the AEI if environmental impact is prioritised. b) Expert judgement, through stakeholder consultations or surveys to reflect their priorities (Budget Allocation Process) or c) sensitivity analysis, exploring different combinations of weights to assess their impact on the ICICDW.

3.1.7 Stage 7: Robustness and Sensitivity Analysis (Initial)

A preliminary robustness and sensitivity analysis is necessary to assess the reliability of the ICICDW in the face of different methodological choices.

In this initial phase, it will be analysed how these variations affect the final value of the ICICDW and the relative ranking of the study units, if a comparison is made. Further sensitivity analysis could include methods such as Monte Carlo analysis in later stages.

3.1.8 Stage 8: Component Analysis

It is important to analyse the contribution of each dimension (MC, AEI, REB) to the final value of the ICICDW. This allows identifying which aspects are driving better or worse circular performance.

3.1.9 Step 9: Linkages to Other Variables

In a preliminary development, the analysis of the linkages of the ICICDW with other relevant variables (such as policy indicators, infrastructure investment, etc.) should be postponed until the indicator is consolidated and more data are available.

3.1.10 Stage 10: Presentation and Dissemination

The presentation of the ICICDW should be clear and precise. The overall value is proposed to be visualised through graphs of its components to facilitate interpretation.

In addition, the limitations inherent in this preliminary phase of indicator development shall be clearly communicated.

This simplified methodology allows the ICICDW to be properly formulated at a preliminary stage, focusing on the essential steps of definition, data selection, normalisation, weighting, aggregation and an initial robustness assessment. The more complex steps can be incorporated in future developments of the indicator. The summary of ICICDW development methodology stages is show in Figure 4 (OECD, European Union, & EC-JRC, 2008).

4. CONCLUSIONS

It is concluded that effective implementation of the circular economy in the management of CDW requires a combination of technical, political and economic strategies, supported by specific indicators that reflect progress towards sustainability. These efforts will not only minimise environmental impacts, but also maximise the value of materials and foster a more resilient and sustainable model in the construction sector.

The paper is presented as a contribution to the preliminary development of circularity indicators focusing on waste generated in the construction sector, an area considered crucial for the global economy.

Despite the efforts of public and private entities, there is still no stable and recognised framework of indicators exclusively for the construction sector. Therefore, it is concluded that there is a need to formulate new comprehensive indicators that not only address environmental aspects, but also material consumption and/or economic aspects.

The Integrated Circularity Index for CDW (ICICDW) is introduced as an approach to address challenges such as material contamination, environmental impact while encouraging economic transition towards a more sustainable model. The formulation of indicators that integrate different aspects is considered crucial to move towards sustainability and more sustainable construction.

Finally, for an effective implementation of the circular economy in the CDW sector, it is concluded that it is essential to propose indicators that integrate environmental and economic aspects in a balanced way. Measuring progress towards circular economy objectives requires going beyond traditional resource efficiency metrics by integrating environmental and economic dimensions to guide decision-making and assess performance in the CDW sector. The current lack of specific indicators and the need for further research in this area underlines the importance of developing tools that enable comprehensive monitoring and facilitate the transition towards a circular model in the construction sector. The preliminary development of the ICICDW is proposed as a key step in this direction.

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