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APPROPRIATENESS OF COMMONLY USED METHODS FOR ASSESSING THE IMPACTS OF CIRCULAR ECONOMY PRACTICES

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ABSTRACT

Circular economy (CE) is a trending concept in construction projects, which opposes the existing linear economy model of resource consumption. Transforming the construction industry towards a circular one requires shifting from traditional to more circular practices, while considering not only technical feasibility but also the impact that these practices have on the economy, society, and environment. There are various methods available for assessing and monitoring the economic, social and environmental (ESE) impacts of diverse CE practices in the construction context, like life cycle assessment. However, these methods are generic, thus not perfectly appropriate for assessing all categories of ESE impacts in an integrated manner. Furthermore, studies that discuss the appropriateness of these methods in CE impact assessment are deficient. Thus, this study aims to investigate the appropriateness of commonly used ESE impact assessment methods for assessing the impacts of CE practices in the construction context. An integrative review methodology was conducted to achieve the research aim. Commonly used impact assessment methods were studied in detail, considering their pros and cons. Cost-benefit analysis and life-cycle sustainability assessment using multi-criteria decision-making were proposed as the most appropriate methods for assessing the impacts of CE practices collectively. The findings of this research would assist professionals in deciding the appropriateness of the impact assessment methods based on the impact types considered for assessment.

Keywords: *Circular economy; Cost-benefit analysis; Impact assessment; Life cycle sustainability assessment; Multicriteria decision making.*

1. INTRODUCTION

The construction industry accounts for half of the global resource extraction and produces around 40 % of solid waste, along with up to 40 % of global carbon emissions (Abiodun et al., 2026). This is predominantly attributed to the linear economy model followed in the construction industry, known as 'take, make, dispose', which intensifies resource depletion and waste accumulation (Mani et al., 2025). Due to these negative impacts, the

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global construction industry is facing growing pressure to move away from traditional linear models to more sustainable models (Rashidian et al., 2025).

The circular economy (CE) has emerged as a promising approach to tackle these challenges across many industries, including construction (Senaratne et al., 2024). Since the concept of CE is still a developing concept, there exists a lack of consensus on the CE definition, with numerous different definitions in the literature (Mani et al., 2025). The most pioneering definition among those is the definition by the Ellen MacArthur Foundation (EMF), which states the CE as an industrial system that is restorative or regenerative by intention and design (EMF, 2015). Senaratne et al. (2025) have come up with another definition recently, and consequently, the CE concept is defined as "an idea about an economic system that uses a systemic approach to restore or regenerate nature by intention and design, while contributing to sustainable development". According to Mani et al. (2025), CE in the construction context focuses on practices related to the disassembly, reuse, or recycling of embedded materials, components, and systems.

Successful implementation of CE in the construction industry results in many impacts on the economy, society and environment (Gamage et al., 2025). In particular, Wuni (2022) highlighted that a circular construction industry could result in reducing waste, increasing cost efficiency, minimising energy demand, increasing employment opportunities and creating new business opportunities. According to Goh et al. (2023), considerable reductions in capital and operational cost can be observed due to CE practices and Ghafourian et al. (2022) state that buildings that have adopted circular practices can benefit from lower maintenance costs. As highlighted in social impacts-related literature, adopting CE practices in construction projects can create significant positive impacts on safe and healthy living conditions (Vanhuyse et al., 2021). Environmentally, a study reported in EMF (2015) concludes that CE may decrease carbon emissions up to 83% by 2050.

Assessment plays a crucial role in determining whether the expected values are being achieved and what needs to be done to achieve them. The same phenomenon is applied for CE implementation as well (de Oliveira et al., 2021). A successful CE assessment should comprise both circular flow assessment and impact assessment. Circular flow assessment considers how efficient a particular CE practice is in achieving circularity, while impact assessment considers benefits or burdens created by the practice on economic, social and environmental aspects (de Oliveira et al., 2021). This study focuses predominantly on impact assessment and the methods available for impact assessment. Construction projects employ methods like life-cycle assessment (LCA), life-cycle costing (LCC) and social life cycle assessment (S-LCA) to assess the impacts of CE implementation (Mani et al., 2025). Even though there are diverse assessment methods available, there is a lack of a universally identified method to assess the impacts of implementing CE in the construction sector (Butković et al., 2023). None of the aforementioned assessment methods was specifically developed for CE impact assessment; thus, they frequently include general impact assessment criteria rather than CE-specific criteria (Ruiz et al., 2022). Furthermore, most of the existing methods are not capable of assessing all the impact types together, as they typically focus on one dimension, mostly environmental or economic (Corona et al., 2024; Ghisellini et al., 2018). In addition, existing literature highlights that decision-making based on CE impact assessment within the construction industry remains limited due to the fragmented nature of the assessment methods (Ruiz et al., 2022). Thus, it is required to critically evaluate existing methods and see how those are capable of assessing ESE impacts of CE practices to generate an integrated result. In spite of different studies which have tried to define the exact use of each available assessment method, there is no study that compares all in one study and links them with the impacts specifically associated with CE implementation. Therefore, fulfilling the aforesaid research gap, this study aims to investigate the appropriateness of commonly used ESE impact assessment methods for assessing the impacts of CE practices in the construction context. As the final output, potential methods that can capture the ESE impacts of CE practices collectively would be proposed, which could support sound decision-making in construction projects.

The paper begins by reviewing the existing literature on environmental, social, and economic (ESE) impacts of CE practices. This is followed by a research methodology section that explains the approach adopted in the study. The findings section provides a detailed description of each identified impact assessment method. The discussion section then examines the appropriateness of these methods for CE impact assessment, highlighting their strengths and limitations and proposes potential methods that can capture the ESE impacts of CE practices collectively. Finally, the paper concludes with key insights and outlines directions for future research.

2. IMPACTS OF CE PRACTICES

A list of possible ESE impacts of adopting CE practices was identified, and these were categorised into several impact categories under the main economic, social and environmental pillars by referring to the available literature and the domain knowledge of the authors. The list of impacts and the impact categories are shown in Table 1.

A total of 18 impacts affecting the economy were identified under six (6) categories. Goh et al. (2023) revealed that CE practices may impact differently on different stakeholder groups economically, depending on the circumstances. Applying CE practices in the building lifecycle will impact the capital cost of a construction project, due to the change in the cost of materials and cost of labour and machinery (Ghisellini et al., 2018). Authors have frequently highlighted the cost savings that would be resulted due to the sustainable energy consumption during the operations (Goh et al., 2023). Conversely, there is a possibility of increased operational costs due to high-skilled manpower requirements in the operation stage to deal with circular aspects applied in the building (Ghafourian et al., 2022). Business opportunities would be available for stakeholders since companies will try numerous circular models in the industry. For instance, reusing creates business opportunities for companies which are interested in buying and selling used materials (Korhonen et al., 2018).

A total of 14 social impacts were identified from the literature and classified into six (6) categories considering their similarities as shown in Table 1. Some social impacts can either be beneficial or detrimental depending on the situation. As an example, Rizos et al. (2017) mentioned that CE practices would create a large number of job opportunities. Conversely, Luthin et al. (2023) argued that due to the necessity of special skills required for some CE practices, there would be a risk for a high turnover of low-skilled workers in industry, which would adversely affect employment percentages. As highlighted in the literature, adopting CE practices in construction projects would create significant positive impacts on safe and healthy living conditions (Vanhuyse et al., 2021).

Table 1: Impacts of CE practices

Impact category	Impact
	Economic Impacts
Capital cost	Changes in the cost of labour and machinery (+/-) Reduction of the cost of materials (+)
Operational cost	Changes in operational (running) costs (+/-) Changes in maintenance costs (+/-) Reduction of expenses related to environmental legislation and taxes (+) Changes in waste management costs (+/-) High rent premiums (-) Reduction of emission control cost (+)
End-of-Life cost	High cost of dismantling (-) High cost of recycling operations (-)
Market opportunities	Creating new business opportunities (+) Improving brand reputation (+) Higher competitive advantage and improved market share (+)
Revenue generation	Changes in revenue and profit from sales (+/-) Impacting the expected return on investment and payback period (+/-)
Economic growth	Changes in GDP growth (+/-) Changes in net exports (+/-) Reduction of imports (+)
	Social Impacts
Employment	Growth in high-skilled employment (+) Changes in low and medium-skilled employment (+/-) Changes in healthy and safe working conditions (+/-)
Living standards	Improving the level of safe and healthy living conditions (+) Changes in affordability (+/-)
Behavioural aspects	Changes in public relations and social networks (+/-) Increase in community engagement in the industrial sector (+) Changes in the behaviour of the people (+/-)
Education and Technology	Improvement in education and awareness (+) Developments in innovation and technology (+)
Legal	Compliance with rights, regulations, and standards (+)
Stakeholder Responsibility & Satisfaction	Improving consumer responsibility (+) Improving client satisfaction (+) Improving suppliers' responsibility (+)
	Environmental Impacts
Environmental pollution	Impact on Greenhouse Gas (GHG) emissions (+/-) Impact on eutrophication (marine and freshwater) (+/) Reduction of acidification (+) Impact on human toxicity and ecotoxicity (+/-) Reduction of waste generation (+)
Consumption of resources	Reduction of virgin resource consumption (minerals and metals) (+) Reduction of energy consumption (+) Changes in water use (+/-) Reduction of fossil fuel consumption (+)
Regeneration	Regeneration of nature (+) Increased biodiversity (+)

Affordability is another social criterion that reflects people's living standards and is affected either negatively or positively. Nevertheless, second-hand products enhance the affordability, but bio-based and degradable materials are not favoured towards it (Kayaçetin et al., 2023).

Eleven (11) environmental impacts were identified, and those were classified into three (3) impact categories. As stated in Rizos et al. (2017), a study conducted in the UK found that the carbon footprint of remanufactured products is at least 25% lower than that of new products, demonstrating the potential for significant reductions in large-scale greenhouse gas emissions. Waste generation in the construction industry can be minimised as a result of extended product lives through reuse, remanufacturing and refurbishment (Korhonen et al., 2018) resulting in a reduction in landfills, which provides more land for development and construction (John et al., 2023). Furthermore, CE will enhance biodiversity and contribute to the regeneration of nature. Using bio-based materials will help regenerate the soil and reduce chemical runoff in the soil once disposed of (John et al., 2023).

While some of the identified impacts are general and can be assessed using general impact assessment methodologies like LCA, some CE-specific impact categories, like market opportunities, economic growth, stakeholder responsibilities and regeneration, might require hybrid or new methodologies. This study intends to highlight that concern while comparing different impact assessment methodologies in the upcoming sections.

3. RESEARCH METHODOLOGY

Reviewing the existing literature is an essential exercise for any field to grow and develop. Literature reviews can either serve as the background for an empirical study or as an independent, standalone piece that provides a valuable contribution in its own right (Chigbu et al., 2023). Among the available types of reviews, an integrative review is a unique approach for synthesising existing knowledge to create a new piece of knowledge (Cronin & George, 2020). As mentioned by Snyder (2019), integrative reviews are suitable for both mature topics and emerging topics, and conceptual thinking skills from the researcher are required for the data analysis. This study aims to examine the suitability of commonly used impact assessment methods for CE impact assessment. As a novel contribution, it identifies and recommends the most appropriate methods for conducting CE impact assessments, thereby justifying the adoption of an integrative methodological approach for this study.

As the first step, relevant literature was identified through a systematic search of literature in both Scopus and Web of Science databases using the following keyword string.

(“Circular Economy” OR “Zero Waste Economy” OR “Cradle to Cradle”) AND “Construction Industry” OR “Built Environment” OR “Buildings”) AND “Impacts” AND (“Social” OR “Economic” OR “Environmental”) AND (“Assess*” OR “Evaluate” OR “Value” OR “Measure”) AND (“Indicators” OR “Tools” OR “Measures” OR “Frameworks” OR “Parameters”)

Initially, 327 articles were identified after removing duplicates and non-English articles. Only journal papers, conference papers, review papers, books and book chapters were considered to maintain the quality of literature. After the screening process, 105 studies were selected as relevant for the study. Impact assessment methods commonly used in the literature were identified from the articles. Since this systematic search was intended to identify commonly used impact assessment methodologies to assess their appropriateness for CE impact assessment, a detailed content analysis of the selected articles was not conducted. Instead, a comparative analysis was conducted to examine the characteristics of impact assessment methods and how those capture economic, social and environmental dimensions of circular economy practices. Ultimately, the most appropriate methods for CE impact assessment were proposed, considering the findings of the comparative analysis.

4. RESEARCH FINDINGS

This section describes the commonly used impact assessment methods in the construction industry for assessing ESE impacts of CE practices, which were identified through the literature. As identified, many of these methods are with a life cycle approach, thus facilitating more rational assessment (Rigamonti & Mancini, 2021). Among the selected 105 articles, 86 articles have used LCA or modified LCA methods for environmental impact assessment, confirming that environmental as the highly researched impact category. Six (6) articles have used LCC for economic impact assessment, while three (3) studies have used SLCA for social impact assessment of CE. To fulfil the requirement of an integrated approach to assess the impacts on all three aspects together, the life cycle sustainability assessment (LCSA) was discussed in several review articles (Butković et al., 2023; Caldas et al., 2022; Larsen et al., 2022); however, no practical applications have been identified. The above-identified methods are discussed below.

4.1 LIFE CYCLE COSTING (LCC)

LCC is used to assess all costs that occur over the building's lifetime, including construction, operations, maintenance, and end-of-life related costs (Butković et al., 2023). In addition, LCC-based methods are mainly used for comparing the capital expenditure and profitability of investment options (Larsen et al., 2022). Three main variants to LCC can be noticed as Conventional LCC (C-LCC), Environmental LCC (E-LCC) and Societal LCC (S-LCC) (Kulakovskaya et al., 2023). Conventional LCC only addresses the financial costs, considering the investor's perspective (Hoogmartens et al., 2014). In E-LCC, monetary values of externalities are included in addition to the direct monetary flows of the particular product or service, while S-LCC mainly supports the government in decision-making and provides the monetary value of the social impacts that the product would have (Jansen et al., 2020). Waste disposal costs, environmental-related taxes are some costs considered under E-LCC, and costs associated with public health and human wellbeing are a few examples comes under S-LCC (Hoogmartens et al., 2014). LCC methodology considers different cost categories when assessing the economic impact of a particular project, and there are many modified versions available for the construction industry. As per the second edition of the ISO 15686-5 (International Standard Organisation [ISO], 2017), the cost categories of LCC for a construction project are construction cost, maintenance cost, operation cost and end-of-life cost.

4.2 SOCIAL LIFE CYCLE ASSESSMENT (S-LCA)

S-LCA is a methodology capable of assessing the social impacts of services, projects, and products, taking into consideration both definite and probable positive and negative impacts along the life cycle (Larsen et al., 2022). In contrast to economic or environmental impact assessments, social impact assessment requires the use of both qualitative and quantitative data (Kayaçetin et al., 2023). Therefore, S-LCA can be performed as a quantitative, semi-quantitative or qualitative assessment. A stakeholder-based approach is employed by the S-LCA methodology, which involves taking into account potential impacts on different types of stakeholders. These potential social impacts are categorised under common impact categories, namely human rights, working conditions, cultural heritage, governance, and socio-economic implications (United Nations Environment Programme [UNEP], 2020).

4.3 LIFE CYCLE ASSESSMENT (LCA)

LCA is the most widely accepted and well-known tool for assessing the environmental impacts throughout the life cycle of a product (Butković et al., 2023), and it facilitates comparisons of environmental impacts among different products, processes and services (Iacovidou et al., 2017). As explained by Steen (2005), LCA was initiated to focus on energy and mass balances in material and waste streams, which was further developed as a framework to assess environmental impacts. It is based on quantitative evaluations, which show how the inputs and outputs of a product or system induce environmental impacts (Larsen et al., 2022). LCA has been applied in the construction sector for a long period; thus, included in several sustainability certification systems of buildings, for instance, BREEAM (Building Research Establishment Environmental Assessment Method), published by the Building Research Establishment (BRE - UK) and LEED (Leadership in Energy and Environmental Design), a green building rating system developed by the US Green Building Council (USGBC) (Larsen et al., 2022). ISO standard for LCA is widely used in many environmental impact assessments (Cottafava & Ritzen, 2021). According to ISO (1997), LCA assessment comprises four steps, namely, definition of goal and scope; inventory analysis; impact assessment; and interpretation of results. Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system, whereas impact assessment evaluates potential environmental impacts using the information gathered from inventory analysis (ISO, 1997).

4.4 LIFE CYCLE SUSTAINABILITY ASSESSMENT (LCSA)

To fulfil the requirement of an integrated approach to assess the impacts on all three aspects, the LCSA was initiated (UNEP, 2020). It combines LCC, S-LCA and LCA into a single framework and provides a comprehensive assessment of sustainability at different occasions (Arulnathan et al., 2022). At present, there is no ISO standard published separately for LCSA.

5. DISCUSSION

There is no ideal methodology for assessing the ESE impacts of different CE practices in construction projects (Jansen et al., 2020). Thus, the impact assessment methods discussed in Section 4 are compared here in terms of their strengths and weaknesses to propose an appropriate ESE impact assessment methodology to assess all impacts collectively, depending on the circumstances.

A few of the general strengths that LCC possess are its simplicity, familiarity among the practitioners and availability of data (Kambanou & Sakao, 2020). Furthermore, the conventional LCC has been extended to capture not only direct financial costs but also environmental (ELCC) and social costs (SLCC) of the considered product or service (Hoogmartens et al., 2014). However, since LCC mainly uses market prices, which do not capture environmental and social values, these variants are less competent in providing a full assessment of the environmental and social impacts of a product or service. In particular, economic impact categories like market opportunities and economic growth (in Table 1) are hardly captured through an LCC analysis. Furthermore, Hoogmartens et al. (2014) mentioned that ELCC does not provide a comprehensive environmental assessment like LCA. Thus, even though LCC can be used to assess ESE impacts of CE practices, it should be coupled with another assessment methodology (Kambanou & Sakao, 2020), which makes the entire process complex. Apart from that, Hoogmartens et al. (2014) figured out that LCC does not cover the full lifecycle of the project, but the economic lifecycle on some occasions, which can be considered a weakness of LCC. In addition, LCC focus on a product or specific service as its functional unit (Larsen et al., 2022); hence, it may not be suitable for assessing the ESE impacts of individual CE practices.

Several studies have identified SLCA as a way of assessing the social impacts of products or services (Tsalis et al., 2022). However, there are more weaknesses associated with S-LCA than strengths, since it is still a novel approach (Pollok et al., 2021; Venkatesh, 2019). As indicated by Luthin et al. (2023), S-LCA does not cover all the social impact categories of CE; thus, there is a need to add additional sub-categories which specifically address the social impacts of CE practices. ISO 14075:2024 is the international standard developed by ISO that formalises principles for S-LCA, which employs a more flexible approach and does not mandate a fixed list of impact categories to be assessed, as social impacts are context dependent. However, it specifically focuses on product S-LCA and is less appropriate for assessing the ESE impacts of CE practices. As stated by Petti et al. (2018), S-LCA follows the same methodology as in LCA, which makes S-LCA uncertain in assessing specifically the positive sides of social impacts. Apart from that, S-LCA includes different data sources and types, making it difficult to share, reuse or compare results (Larsen et al., 2022; Pollok et al., 2021). There is no common unit for assessment in S-LCA, as both semi-quantitative and qualitative indicators are present (Petti et al., 2018). There are fewer provisions in S-LCA to provide a quantitative, impactful assessment, especially in the construction sector (Venkatesh, 2019). In a nutshell, it can be identified that S-LCA is a weak methodology in terms of its indicators, assessment methodology and unit of assessment.

In the CE context, LCA is a well-recognised quantification tool for the environmental impacts of different products (Lei et al., 2022). However, existing LCA indicators are not enough to cover all the CE-related environmental impact categories (Saade et al., 2022), which can be considered as a weakness of LCA. In particular, regeneration-related impacts (Table 1) are not covered in traditional LCA. Most of the time, LCA is considered a negative impact assessment (Bhambhani et al., 2022). LCA is a quantitative analysis of environmental impacts, thus providing an objective and influencing results through its analysis (Miah et al., 2017). However, different LCA indicators are assessed using different units of measurement; thus, less harmonisation in the result (Butković et al., 2023) can be observed. Another weak point of LCA's result is that it does not indicate how it aligns with monetary terms (Steen, 2005). Especially for an industry like construction, it is always a concern for the project stakeholders to understand how these environmental impacts have resulted in monetary values. Therefore, merely an LCA assessment of the environmental impacts of CE practices may not convince them to adopt CE practices in their projects. To do that, sometimes LCA is coupled with LCC when assessing environmental impacts (Butković et al., 2023). Another weakness of LCA is that it applies in a product (project) context (Rigamonti & Mancini, 2021; Rønning & Brekke, 2014); thus, it may not be suitable for assessing the environmental impacts of CE practices individually.

Since LCSA is an integration of the above-discussed three methods, it could provide a holistic evaluation of the ESE impacts of CE practices (Bhambhani et al., 2022). The same strength of LCSA makes it weak in numerous ways. The aggregation of the results from the three assessments into a single frame is not clearly identified (Arulnathan et al., 2022). As mentioned by Iacovidou et al. (2017), while integrating three methods, there can be difficulties in defining system boundaries, as the three methods have different boundaries when carrying out the assessment (Larsen et al., 2022). Similarly, as identified in UNEP (2020), it is not easy to combine three methods since there can be overlaps when interpreting results. For instance, S-LCA covers the impact on human health, whereas LCA also cover it via its indicators. One of the major weaknesses of this method is heavy reliance on the nature of the assessment indicators. LCA indicators are quantitative and assess negative impacts on the environment. LCC indicators are both quantitative and qualitative, with a life cycle perspective and mostly consider the investor/client's point of view. S-LCA indicators are qualitative and consider the societal point of view (Bhambhani et al., 2022; Larsen et al., 2022). In addition, though LCSA provides an integrated assessment of all three sustainability pillars, Bhambhani et al. (2022) mention that it mainly focuses on damage assessment, not on benefit assessment.

Consequently, Table 2 summarises the main strengths and weaknesses of the commonly used impact assessment methods.

Table 2: Key strengths and weaknesses of the commonly used impact assessment methods

Methodology	Strengths	Weaknesses
LCA	A quantitative analysis method which provides objective and influential results.	Uses different units of measurement, thus less harmonisation in the result. Majorly focus on negative impacts.
LCC	A simple, frequently used method that uses readily available data.	Less competent in providing a full assessment of environmental and social impacts. Only focus on costs.
SLCA	Uses a wide range of social indicators to evaluate the social impact	Requires different data types (qualitative, quantitative) and no common unit for assessment.
LCSA	An integrated method of LCA, LCC and SLCA, which provides a full assessment of ESE impacts	The process is complex as it integrates three different methods and has no common unit for assessment.

6. PROPOSED METHODS FOR AN INTEGRATED IMPACT ASSESSMENT

All commonly used methods have considerable weaknesses and are not suitable for use individually for CE impact assessment. Thus, a new approach needs to be identified that assists in mitigating the weaknesses mentioned in the above methods. Accordingly, the proposed approach should be able to fulfil the following.

1) Assess ESE impacts using a single unit of measurement

2) Assess both positive and negative impacts
3) Assess all CE-specific impacts in addition to the general impacts
4) Generate an integrated impact value to compare different CE options in projects

To fulfil the aforesaid requirements, this study proposed two approaches: 1) Using a cost-benefit analysis; 2) using LCSA while integrating the results through multicriteria decision making (MCDM). How these methods are appropriate in fulfilling the above requirements is explained below.

6.1 COST-BENEFIT ANALYSIS (CBA)

CBA is an assessment methodology that is used in decision-making based on the estimated economic, social and environmental costs and benefits of a project (Butković et al., 2023). It is a more advanced and comprehensive methodology used in assessing ESE impacts (both positive and negative), where the above-mentioned methods can be used as a part of the assessment (New South Wales Government [NSWG], 2023). To assess the costs and benefits of a project, CBA uses monetary value as the standard unit of measurement (Office of Impact Analysis [OIA], 2023). Even though methods like LCA and LCC are mostly used with product-related assessments, CBA focuses either on products or processes, making it more suitable for assessing the ESE impacts of individual CE practices. The most important strength of CBA is the nature of the result. CBA assesses all the impacts using monetary terms, and the result would be in one unit of measurement (OIA, 2023) where it allows for an easy comparison among different options. Main weaknesses of CBA are the complexity of converting social and environmental impacts into monetary values and the requirement of a large amount of data (Iacovidou et al., 2017). Few authors have studied the possibility of CBA to analyse different CE options in construction projects with respect to financial, economic, social and environmental dimensions. Yuan et al. (2011) and Begum et al. (2006) have carried out CBA assessments for different construction and demolition waste management options. Wijayasundara et al. (2018) discussed the suitability of using recycled concrete aggregate to replace natural aggregate using a CBA analysis. However, compared to a method like LCA, a limited application of CBA can be observed as a method to assess the ESE impacts of CE practices in construction projects.

6.2 LCSA WITH MCDM

As identified earlier, in LCSA, it is necessary to integrate the assessment results obtained by methods such as LCA, LCC, and S-LCA. One of the most common ways used to integrate the results obtained from different tools/methods is multi-criteria decision making (MCDM) (Kalbar & Das, 2020). Given the inherent complexity of circular systems, many authors have chosen to evaluate these through a multi-criteria system (Sassanelli et al., 2019), and it is well recognised as a novel tool to measure CE practices (Dos Santos Goncalves & Campos, 2022). Even though there are many individual indicators to assess the impacts of CE practices, MCDM methods are capable of simultaneously analysing multiple dimensions and provide a broad assessment for CE implementation (Dos Santos Goncalves & Campos, 2022; Terra Dos Santos et al., 2023). In this approach, different criteria (LCSA indicators) can be selected and using the MCDM method, an integrated value can be obtained to compare the total ESE value addition that each CE practice would create. As examples, Hossaini et al. (2014) have used LCSA, combined with MCDM, to develop a sustainability evaluation framework for mid-rise residential buildings, and Masseck et al. (2024) have used MCDM and the LCSA concept for assessing waste-based shading devices for public school building stock. The requirement of actual data is minimal in this approach; however, there can be issues with the subjectivity of the final output. Those can be minimised using fuzzy set theory in combination with MCDM methods.

Table 3 presents a conceptual matrix for identifying which methods can be used to assess the impact categories identified in Section 2, depending on project requirements and the availability of data. This conceptual matrix is based on the above discussion and the researcher's domain knowledge, which requires confirmation through a primary data collection.

Table 3: Conceptual matrix for CE impact assessment methods and impact categories

Impact category	LCC	LCA	SLCA	LCSA+MCDM	CBA
Capital cost	x			x	x
Operational cost	x			x	x
End-of-Life cost	x			x	x
Market opportunities				x	x
Revenue generation				x	x
Economic growth				x	x
Employment			x	x	x
Living standards			x	x	x
Behavioural aspects			x	x	x
Education and Technology			x	x	x
Legal			x	x	x
Stakeholder Responsibility & Satisfaction				x	x
Environmental pollution		x		x	x
Consumption of resources		x		x	x
Regeneration				x	x

7. CONCLUSIONS

This study aimed to investigate the appropriateness of the commonly used ESE impact assessment methods for assessing the ESE impacts of CE practices in an integrated manner. According to the study, it was evident that each method has its own strengths and weaknesses. However, the CBA method and LCSA with MCDM have been proposed as potential methods to assess ESE impacts collectively and generate an integrated impact value. Although many studies have identified and used these methods in assessing ESE impacts of CE practices, they have not commented on the appropriateness of using them in the assessment. This study fulfilled the said gap through a comparative analysis of impact assessment methods. The findings conceptually mapped the impact assessment methods and types of impacts assessed, which aid in using assessment methods appropriately. Furthermore, proposed methods can be used to compare different CE practices in terms of ESE value creation, since they can consider CE-specific impacts and provide the total impact as a comparable value. Further research can be conducted to validate the findings of this research and develop methods to assess the ESE impacts of CE practices, overcoming the weaknesses mentioned in the other methods.

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