Ishan, M., Gamage, I. and Lingasabesan, V., 2023. Highly effective circular economic practices for the life cycle of a construction project. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ramachandra, T. and Ranadewa, K.A.T.O. (eds). *Proceedings of the 11th World Construction Symposium*, 21-22 July 2023, Sri Lanka. [Online]. pp. 532-544. DOI: https://doi.org/10.31705/WCS.2023.44. Available from: https://ciobwcs.com/papers/

# HIGHLY EFFECTIVE CIRCULAR ECONOMIC PRACTICES FOR THE LIFE CYCLE OF A CONSTRUCTION PROJECT

**Mohamed Ishan[1], Iresha Gamage[2] and Vithusha Lingasabesan[3]**

## *ABSTRACT*

*The circular economy (CE) concept has emerged as an important aspect of sustainable development in the construction industry. Inadequate knowledge and understanding on properly integrating CE practices into the construction life cycle is a significant obstacle. Thus, this research aimed to investigate the most effective CE practices at each stage of a construction project's life cycle. A literature review was conducted to comprehend the theoretical framework of the CE concept and its application in the construction industry. Adhering to a quantitative approach, a google questionnaire was distributed among experts in the field to identify the most effective CE practices for the Sri Lankan construction industry. The study's population included 70 industry experts, and a mandatory 50% response rate was achieved. In the group of construction industry experts, subgroup of experts with knowledge of sustainable construction practices was chosen using the cluster sampling method to achieve reliability of the data. According to the study's findings, the most effective CE practices for the various stages of a construction project's life cycle included minimising waste generation, promoting the use of sustainable materials, implementing prefabrication techniques, and developing a circular supply chain. The findings of the study offer insights into CE practices that can be implemented in the Sri Lankan construction industry to improve sustainability and reduce environmental impacts throughout the life cycle of a construction project. The study adds to the body of knowledge on CE practices in the construction industry and serves as a foundation for future research on the subject.*

***Keywords:*** *Circular Economy (CE) Practices; Construction Industry; Construction Life Cycle; Sustainability.*

## 1. INTRODUCTION

The construction industry is diverse and essential to all national economies, accounting for 7% to 10% of Gross Domestic Product (GDP) in many countries (Greenhalgh et al., 2021). Construction waste generation in 40 nations exceeded 3.0 billion tons per year in 2012, and this trend has been steadily expanding since then (Akhtar & Sarmah, 2018). When environmentally friendly concepts are considered, Circular Economy (CE) concept plays an important role. This concept is intended to ensure that materials and

[1] Undergraduate, Department of Building Economics, University of Moratuwa, Sri Lanka, ishanshaheer077@gamil.com
[2] Lecturer, Department of Building Economics, University of Moratuwa, Sri Lanka, ireshag@uom.lk
[3] Temporary Lecturer, Department of Building Economics, University of Moratuwa, Sri Lanka, hivithusha@gmail.com

products are used continuously, and hence, reducing waste and pollution (Ghosh & Ghosh, 2021).

CE can be defined as an economic system that aims to eliminate waste and pollution by designing products and processes in such a way that resources are used efficiently and continuously cycled within the system (Ellen Macarthur Foundation, 2023). Cooperation among construction life cycle stakeholders, CE criteria for all project stages, a guide for the planning and implementation of demolition work, and voluntary targets for the recycling of construction and demolition wastes are important steering approaches for CE in the construction sector. (Husgafvel & Sakaguchi, 2021).

One of today's most considered social issues is establishing a CE in the built environment (Andriulaitytė & Valentukeviciene, 2020). There are several challenges and risks raised during the implementation of CE in a built environment. In organisations and management, a lack of information can result in suboptimal resource consumption, inefficient waste management, and ineffective process optimisation (Geng & Doberstein, 2008). Because of the industry's negative environmental impacts, there is a growing need in the Sri Lankan construction industry to promote sustainable practices in construction projects (Samaraweera & Gunawardhana, 2020). Thus, this study focused to improve the understanding of how CE ideas can be applied to the construction industry to promote sustainability and reduce environmental consequences along with a lifecycle perspective.

Accordingly, aim of this research is to identify most significant CE practices for each stage of the lifecycle of a construction project. The study provides insights for stakeholders in the construction industry on how to promote sustainable practices in their operations by identifying the most impactful CE practices for each stage of a construction project's lifecycle and examining the challenges and risks associated with their implementation.

# 2. LITERATURE REVIEW

## 2.1 IMPORTANCE OF CIRCULAR ECONOMY TO THE CONSTRUCTION INDUSTRY

Natural resource shortages, including those of crucial materials, are caused by construction-related activities and the built environment under a linear economy. (Ghisellini et al., 2018). The use of practises at all stages of a building's life cycle to keep materials in a closed loop for as long as possible to reduce the use of new natural resources in a construction project (Benachio et al., 2020). The CE offers a sustainable approach to the construction industry by emphasising material reduction, reuse, and recycling. Designing solutions to implement component reuse can help to reduce environmental and economic impacts (Buyle et al., 2019). The CE seeks to reduce resource input while also avoiding or reducing waste (Liu et al., 2021). This method reduces waste generation, conserves natural resources, and lowers greenhouse gas emissions.

Since waste management and waste reduction are not considered in the planning and design stages of a project, waste generated by construction and demolition (C&D) occurs throughout the life cycle of buildings (Esa et al., 2016). The negative consequences of the dominant economic development model jeopardise economic stability and the health of natural ecosystems critical to human survival (Adi & Wibowo, 2020). Implementing a CE model in the construction sector can successfully address the negative environmental impacts caused by resource consumption, waste generation, and pollution throughout a building's existence (Samaraweera & Gunawardhana, 2020).

Circular approaches to construction can result in more efficient construction practices, lowering labour and transportation costs. Furthermore, by implementing circular business models, companies can generate new revenue streams while improving their bottom line. CE can address environmental challenges while also fostering economic resilience and long-term sustainability by shifting to circular approaches. Companies that follow circular principles can reduce waste, save money, and improve social and environmental outcomes. Reusing materials, recycling post-consumer materials, and focused on leaving the environment (and society) in a better shape than before, for as by enhancing biodiversity, is known as renewing the cycle of material use (Çetin et al., 2021). As the construction industry expands, it is critical that it embraces the CE to ensure a sustainable and prosperous future for all.

## 2.2 CIRCULAR ECONOMIC PRACTICES IN DIFFERENT STAGES OF A CONSTRUCTION PROJECT'S LIFE CYCLE

CE strategies have grown in importance in the construction industry as a means of addressing environmental concerns and promoting sustainability. The building life cycle contains five stages: project design, manufacture, construction, operations, and end of life (Benachio et al., 2020). The design stage of a project is crucial for incorporating CE principles. Çimen, (2021) suggests that early-stage activities of the inception of a construction project such as investments, technical or financial viability, and planning activities, are made during the feasibility, and planning stage. Waste in construction can be reduced by defining waste reduction goals, using environmentally labelled items, selecting resources carefully, standardising procedures, and employing modular construction approaches (Adi & Wibowo, 2020). As a result, incorporating CE techniques into the design stage is critical to constructing a sustainable future.

Adopting CE methods at the material manufacturing stage can aid in the reduction of, waste, resource consumption, and environmental effects. Manufacturers can use recycled materials, repurposed waste products, and novel sustainable manufacturing techniques to create environmentally friendly and cost-effective building materials. Utilising recycled mass during the manufacturing process has been discovered to be a key element in boosting material sustainability (Giama & Papadopoulos, 2020). To recover material value at the end of the building's useful life, suppliers are encouraged to keep ownership of their materials whenever possible (Leising et al., 2018). Manufacturers can encourage a more sustainable and responsible construction industry that helps both the environment and the economy by embracing CE principles.

CE methods can have a substantial impact on a project's construction stage. Materials can be easily disassembled and reused at the end of a building's lifecycle by using modular and prefabricated construction techniques. This not only minimises wastage but also improves construction efficiency. Utilising new ownership models where materials are only temporarily held in the building that serves as a material bank, a life cycle strategy that maximises the functional lifetime of the building and integrates the end-of-life phase into the design (Benachio et al., 2020). Considering the significance of using waste materials in the construction industry, it is especially vital to reuse parts that are still structurally sound (reusing) or to employ raw materials as components in the creation of new structural elements (Lucena et al., 2014).

Closed-loop technologies, such as on-site waste management and water recycling, can help to minimise waste and resource consumption even further (Zulkifli & Khor, 2021). The construction sector may reduce its environmental impact while also enhancing cost-effectiveness and long-term sustainability by embracing CE strategies (Norouzi et al., 2021). CE approaches can also be used to reduce waste and resource consumption during the operating stage of a construction project. This entails implementing sustainable construction management methods such as lowering energy and water use, increasing indoor air quality, and promoting environmentally friendly mobility options (Ghufran et al., 2022).

CE principles can be utilised to extend the useful life of a structure and reduce the need for resource-intensive maintenance and repair activities by improving its efficiency. The maintenance of a closed material loop, one of CE's core concepts, has caused the end of the building stage to now interphase with manufacturing and use in the larger lifetime. (Sanchez & Haas, 2018). The desire for a CE and the highest suitable material reuse necessitates the improvement of methods for evaluating a construction project's performance throughout its entire life (Akanbia et al., 2018). CE strategies can aid in the reuse and recycling of materials and equipment during the operating stage, hence minimising waste, and the demand for new materials. Overall, introducing CE techniques into the operation stage can assist improve the construction project's environmental and economic sustainability across its full existence.

The End-of-Life stage of a construction project is critical for CE processes since it specifies how materials and products will be disposed of or repurposed. Construction waste might end up in landfills if CE concepts are not followed, contributing to environmental deterioration and natural resource depletion. Analysis of a building's disassembly performance at the end of its life can now give useful information during the early design stage because of improvements in design software. (Akanbi et al., 2019). Due to the End-of-Life (EoL) buildings' bulk/value ratio, repair and remanufacturing of their products would be done locally, stored locally, and then incorporated into new constructions locally as well to reduce costs (Hopkinson et al., 2019). Materials and products can be developed with end-of-life concerns such as ease of disassembly, reuse, and recycling by using CE processes. This can result in the recovery of valuable materials, waste reduction, and the development of new goods, lowering the need for virgin resources and reducing the environmental effect of the construction sector.

The construction sector may contribute to a more sustainable future and promote the well-being of people and the environment by implementing CE principles at all phases of a construction project's life cycle. Table 1 contains a compilation of CE practices identified according to the stages of a construction project’s life cycle through the literature review.

*Table 1: Circular economic practices for each stage of the construction project's life cycle*

| Stages of a construction project's life cycle | Circular economic practices | References |
|---|---|---|
| Design stage | Design and use of modular buildings | [1] |
| | Design for adaptability of existing buildings | [2],[14],[16],[17], |
| | Design for disassembly of building structures | [2],[3],[16],[18], [19], [14], [20] |
| | Design for adaptability and flexibility | [4] |
| | Design out the waste/set target for allowable wastage | [4] |
| | Increase the lifespan | [4] |
| | Specify recycled/eco-label materials procurement | [4] |
| | Use secondary materials | [4] |
| | Take-back schemes/reverse logistics construction | [4] |
| | Use of life-cycle analysis to find the benefits of reusing different types of materials | [18],[27] |
| Material manufacture | Change of use of materials, by giving it ownership to the manufacturers to reuse | [3], [21] |
| | Development of material passports | [3],[22],[23],[24] |
| | Reuse of secondary materials in the production of building materials | [5] |
| | Developing a schedule of recyclable resources | [4] |
| | Follow environmental accreditation standards and sustainable construction guidelines | [6] |
| | Take-back schemes | [4] |
| Construction stage | Reuse of building materials in a new construction | [7],[16],[19],[14] |
| | Waste reduction | [8], [25] |
| | Off-site construction | [8],[16], [26] |
| | Use of recycle materials | [4] |
| | Use of material stock data to help reuse of materials | [9] |
| | Double checking of material quantities before ordering | [6] |
| | Procuring material from green certified suppliers | [6] |
| Operation stage | Use of a tool to evaluate the state of materials during the lifespan and end of life of a building | [10] |
| | Use of water management practices | [11] |
| | Minimise recuperative maintenance | [8] |
| | Proper scheduling to keep track of material usage | [6] |
| | Life-cycle information management | [12] |
| | Environmental impact assessment of CDW | [12] |
| | The material spaces must be constantly updated | [13] |
| | Ensure easy repair and upgrade | [8] |
| End of Life | Analyse the potential for reuse or recycling of existing materials | [14] |
| | Management of demolition waste | [15], [2] |
| | CDW management performance evaluation | [12] |
| | Closed-loop recycling | [8] |

Sources: [1] Kyrö et al. (2019); [2] Maerckx et al. (2019); [3] Leising et al. (2018); [4] Adi & Wibowo (2020); [5] Nußholz et al. (2019); [6] Wijewansha et al. (2021); [7] Smol et al. (2015); [8] Adams et al. (2017); [9] Oezdemir et al. (2017); [10] Akanbi et al. (2019); [11] Pimentel-Rodrigues & Siva-Afonso (2019); [12] Yu et al. (2022); [13] Drangevåg (2022); [14] Sanchez & Haas (2018); [15] Ghisellini et al. (2018); [16] Mangialardo & Micelli (2018); [17] Geldermans (2016); [18] Eberhardt et al. (2018); [19] Rasmussen et al. (2019); [20] Manelius et al. (2019); [21] Swift et al. (2017); [22] Sauter, et al. (2018); [23] Honic et al. (2019); [24] Munaro et al. (2019); [25] Esa et al. (2016); [26] Minunno et al. (2018); [27] Hossain & Ng (2018)

### 2.3 CHALLENGES IN IMPLEMENTING CE IN THE SRI LANKAN CONSTRUCTION INDUSTRY

CE transition is a multifaceted task that involves factors from the environment, the economy, technology, society, government, and behaviour (Pomponi & Moncaster, 2017). High levels of waste generation, energy consumption, and greenhouse gas emissions are some of the global challenges associated with the construction industry. The lack of understanding of CE principles was identified as a barrier to its implementation, emphasising the importance of raising awareness among both professionals and clients in the Sri Lankan construction sector (Wijewansha et al., 2021). Implementing CE methods in the built environment is difficult since it necessitates waste prevention through maintenance, reuse, and remanufacture. One of the largest societal difficulties of the modern era is creating CE in the built environment, as the basic pillar of CE is to prevent waste by making the best use possible of internal processes like "maintenance," "reuse," and "remanufacture." (Andriulaitytė & Valentukeviciene, 2020).

The traditional linear construction model, which is strongly embedded in the industry, presents a considerable barrier to the move to circularity. To address these issues, it is critical to educate and increase awareness among stakeholders, implement suitable policies and regulations, invest in technical breakthroughs, and encourage stakeholder collaboration and partnerships. The absence of defined standards for monitoring CE success, as well as supporting legislation and regulations, can stymie the adoption of circular practices. Risks associated with the application of CE solutions in manufacturing contexts include a mismatch between changing demand, supply, and used component values, which makes it difficult to predict costs and return on investment (Jabbour et al., 2018). One of the most significant challenges confronting the Sri Lankan construction industry is a lack of awareness about potential CE practices that can be implemented at each stage of a construction project. This emphasises the importance of research to identify the most impactful CE practices for each stage of the project lifecycle and to provide guidance to industry stakeholders on how to promote sustainable practices in their operations.

## 3. RESEARCH METHODOLOGY

A quantitative research design has always been concerned with defining an epistemological methodology for judging the veracity of propositions. It offers a structured and systematic approach to data collection and analysis and allows flexibility in how data are treated in terms of comparisons, statistical analysis, and repeatability of data collection to ensure reliability (Amaratunga et al., 2002). The rationale for using a quantitative technique for the research is that a larger sample size with a greater number of respondents can improve the accuracy and reliability of the research findings.

Questionnaire survey was the adopted technique for data collection and an online questionnaire form was prepared and circulated among the specific experts in the construction industry to determine the most impactful CE practices throughout the life cycle of a construction project. Participants were asked to assign a number weight ranging from 1 to 5 to each of the practices under consideration throughout the questionnaire survey. Cluster sampling is a technique in which researchers divide a population into smaller groups (Thomas, 2020). Therefore, cluster sampling method was used as the sampling method within the population of construction industry experts who have the academic qualification and experience in construction industry and a subgroup of experts who have knowledge on sustainable construction was selected as the cluster. Content analysis is a research technique for describing the manifest content of communication in an objective, systematic, and quantitative manner (Harvey, 2022).

The correct data analysis approach must be chosen to analyse the collected data and come to an accurate conclusion. Content analysis, statistical analysis, hypothesis analysis, and discourse analysis can all be categorised as the most often utilised data analysis techniques in research (Maryville, 2021). As the nature of quantitative data is numerical, quantitative data analysis entails working with numerical variables such as statistics, percentages, calculations, measurements, and other data (Maryville, 2021). The relative importance index (RII) method was employed in this study to identify the most significant CE practices in the built environment. The use of the relative importance index method was justified due to its fairness through the incorporation of diverse opinions from a group of individuals, and ability to effectively rank a wide range of items, thereby improving the validity and comprehensiveness of the research findings. The research would identify the elements as highly influential CE practices when they had a RII score of greater than 80% (Munshi & Chaudhuri, 2011).

## 4. DATA ANALYSIS, FINDINGS AND DISCUSSION

The responses to the questionnaire survey were analysed, and the CE practices were ranked according to their effectiveness according to the RII value. It entails interpreting and synthesising data to reach meaningful conclusions and insights.

### 4.1 RESPONDENTS' PROFILES

A total of 70 construction industry experts were invited to participate in the questionnaire, and 35 completed it, that produced a 50% response rate. The sample size ensures that the target population is adequately represented, allowing for reliable data analysis and meaningful insights into the construction industry. Figure 1 shows the breakdown of the 35 respondents by their professional expertise. Out of the 35 respondents, 19 individuals are Quantity Surveyors, which indicates that most of the respondents have expertise in cost management and estimating in the construction industry. X axis shows the expertise and Y axis demonstrate the number of experts.

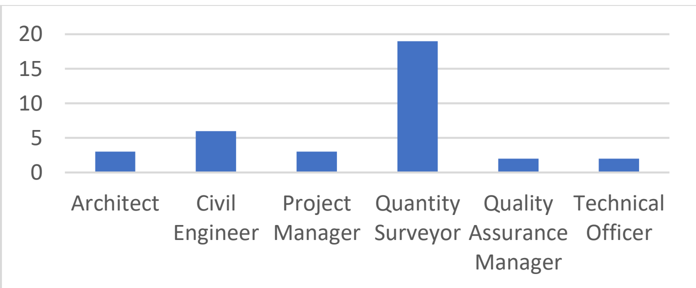


*Figure 1: Responses according to their profession*

The distribution of the 35 respondents by construction industry experience reveals that most respondents have a considerable level of experience in the field, with 20 individuals having 1-5 years of experience. Most respondents demonstrated a high level of knowledge and awareness of CE principles.

## 4.2 HIGHLY IMPACTFUL CIRCULAR ECONOMY PRACTICES AT EACH STAGE

A comprehensive literature review was used to identify 53 CE practices for all stages of the construction project lifecycle. These practices were then distributed to field experts via a Google questionnaire, which asked respondents to rate each practice on a scale of 1 to 5, with 1 representing a very low-impactful practice and 5 representing a very high-impactful practice. The highly impactful practices were identified using the RII analysis method, with a RII value of more than 80%. This process ensured that only the most effective CE practices were chosen for each stage of the construction project lifecycle, providing valuable insights for construction industry stakeholders on how to promote sustainable practices in their operations.

The RII analysis has been presented in tables (Refer to Tables 2 to 6) for each stage in construction project life cycle, indicating the highly influential CE practices identified through the questionnaire survey.

*Table 2: RII and rank for CE practices at design stage*

| Design Stage | RII | Rank |
|---|---|---|
| Design and use of modular buildings | 93.714 | 1 |
| Design for disassembly of building structures | 90.857 | 2 |
| Use of life-cycle analysis to find the benefits of reusing materials | 84.000 | 3 |
| Use secondary materials | 71.429 | 4 |
| Design for adaptability of existing buildings | 64.000 | 5 |
| Use of a scale to analyse the level of implementation of CE practices in the company | 63.429 | 6 |
| Increase the lifespan | 61.714 | 7 |
| Design strategically to minimise waste | 57.714 | 8 |
| Focus on disassembly during building design | 57.143 | 9 |

Table 2 shows the respondents' opinion on the impact of different CE practices in the design stage of a construction project. The top three practices are the design and use of modular buildings, building structure design for disassembly, and the use of life-cycle analysis to determine the benefits of reusing different types of materials. "Design and use of modular buildings" is the most impactful CE practice in the design stage, accounting for 93.7% of RII value. Many authors and industry experts promote that the use of Design for Disassembly in building structures, as well as the use of Life-cycle analysis to identify the benefits of reusing various materials.

*Table 3: RII and rank for CE practices at Material manufacture stage*

| Material manufacture stage | RII | Rank |
|---|---|---|
| Change of use of materials, by giving it ownership to the manufacturers to reuse | 91.429 | 1 |
| Development of material passports | 86.286 | 2 |
| Reuse of secondary materials in the production of building materials | 82.286 | 3 |
| Take-back schemes | 56.571 | 4 |
| Follow environmental accreditation standards and sustainable construction guidelines | 55.429 | 5 |
| Developing a schedule of recyclable resources | 54.857 | 6 |

| Material manufacture stage | RII | Rank |
|---|---|---|
| Avoid toxic and/or hazardous materials | 54.857 | 6 |
| Supply chain environmental impact assessment | 52.571 | 8 |
| The material spaces must be constantly updated | 52 | 9 |
| Real-time supply chain tracking & monitoring | 50.286 | 10 |

The RII analysis and ranking of CE practices in the material manufacturing stage are shown in Table 3. The most significant practice is changing the use of materials, allowing manufacturers to reuse them after the first building's life. The second most influential practice is material passports, which track the life cycle of building materials. The third most influential practice is the use of secondary materials in the manufacture of building materials. Prominent authors and construction industry experts support the promotion of manufacturers taking ownership of materials for reuse to facilitate material change and the establishment of material passports.

*Table 4: RII and rank for CE practices at construction stage*

| Construction stage | RII | Rank |
|---|---|---|
| Off-site construction | 86.286 | 1 |
| Reuse of building materials in a new construction | 85.714 | 2 |
| Waste reduction | 85.143 | 3 |
| Use reversible mechanical fastening methods instead of chemical ones | 53.143 | 4 |
| Procuring material from green certified suppliers | 52.571 | 5 |
| Use of material stock data to help reuse of materials of a new building | 52.000 | 6 |
| On-site material, labour & equipment control | 52.000 | 6 |
| Double checking of material quantities before ordering | 50.857 | 8 |

Three CE practices were found to be highly impactful in construction stage, with a RII value greater than 80%, according to the RII analysis. The most impactful practice was identified as off-site construction, followed by the reuse of building materials in new construction and waste reduction. These practices have the potential to significantly reduce waste and the construction industry's overall environmental impact, making them promising avenues for future exploration and implementation. Various construction industry authors and experts support the advancement of off-site construction, the use of recycled building materials in new construction projects, and the implementation of waste reduction measures.

*Table 5: RII and rank for CE practices at operation stage*

| Operation stage | RII | Rank |
|---|---|---|
| Use of water management practices | 87.429 | 1 |
| Use of a tool to evaluate the state of materials during the lifespan and end of life of a building | 80.000 | 2 |
| Life-cycle information management | 78.857 | 3 |
| Environmental impact assessment of CDW | 62.286 | 4 |
| Minimise recuperative maintenance | 57.714 | 5 |
| The material spaces must be constantly updated | 56.000 | 6 |
| Ensure easy repair and upgrade | 54.857 | 7 |

According to the RII analysis, two CE practices were discovered to be highly impactful in the construction industry's operation stage. With a RII value of 87.429%, the use of water management practices was identified as the most impactful practice, followed using a tool to evaluate the state of materials during the lifespan and end-of-life of a building with a RII value of 80.00%. These practices have the potential to significantly reduce water consumption and waste while also improving construction project's sustainability, making them promising areas for further investigation and implementation.

*Table 6: RII and rank for CE practices at end of life*

| End of life | RII | Rank |
|---|---|---|
| Management of demolition waste | 89.143 | 1 |
| Analyse the potential for reuse or recycling of existing materials | 84.571 | 2 |
| CDW management performance evaluation | 56.571 | 3 |
| Closed-loop recycling | 54.286 | 4 |

According to the RII analysis, the construction industry's end-of-life stage has two highly impactful CE practices. The management of demolition waste was found to be the most impactful practice, with a RII value of 89.14%, followed by the analysis of the potential for reuse or recycling of existing materials, with a RII value of 84.57%. This emphasises the potential importance of these practices in the long-term management of construction waste and resources.

Based on the questionnaire responses, the Relative Importance Index (RII) analysis revealed 13 CE practices with more than 80% RII value. A significant finding among these practices is that most of them were suggested by more than one author, indicating expert consensus on their effectiveness. This convergence of recommendations from multiple authors strengthens the credibility and dependability of these practices in promoting sustainable and resource-efficient approaches in the construction industry.

## 5. CONCLUSIONS

The study successfully uncovered extremely effective CE concepts for each stage of a building project's lifecycle using a quantitative approach and a google questionnaire. In design stage the most effective CE practices found to be as design and use of modular buildings and the design for disassembly of building structures. The most effective CE practices discovered during the material manufacturing stage is the development of material passports. In construction stage the most effective CE practices found to be as off-site construction and the reuse of building materials in new construction. The most effective CE practices discovered during the operation stage were waste reduction and the use of water management practices. In end-of-life stage the most effective CE practices found to be as the management of demolition waste. Implementing these practices has the potential to significantly reduce waste, increase efficiency, and improve sustainability in the construction industry. This study provides valuable insights into the application of CE principles in the sector by investigating CE concepts relevant to the Sri Lankan construction industry and identifying highly impactful CE activities. The findings can be used as a guide for industry experts and policymakers interested in implementing CE strategies that will result in more efficient and sustainable construction processes. This research benefits construction stakeholders significantly by identifying the most effective CE practices for each stage of construction. However, further research and effort are required to fully realise the potential of CE principles in the construction industry and ensure a sustainable future for both the industry and the environment. One significant limitation of this research is its exclusive focus on the Sri Lankan construction industry.

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