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RESP

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Araştırma Makalesi ● Research Article

Innovative Strategic Framework for Enhancing Sustainability in the Sri Lankan Construction Sector Through Circular Economy

Sri Lanka İnşaat Sektöründe Döngüsel Ekonomi Yoluyla Sürdürülebilirliği Artırmaya Yönelik Yenilikçi Stratejik Çerçeve

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A N A H T A R K E L İ M E L E R

Döngüsel ekonomi
İnşaat sektörü
Stratejiler
Sürdürülebilir kalkınma

ÖZ

Bu araştırma, sürdürülebilirliği iyileştirmek ve küresel çevre hedefleriyle uyumlu hale getirmek için döngüsel ekonomi kavramının Sri Lanka'nın inşaat sektörüne nasıl entegre edilebileceğini araştırmaktır. CE uyumunun önündeki engelleri belirlemek için, sistematik bir literatür incelemesiyle başlayıp kapsamlı bir anket ve korelasyon analizini kapsayan karma yöntemli bir yaklaşım kullanılmıştır. Vurgulanan temel zorluklar arasında anlayış eksikliği, değişime direnç ve yetersiz düzenleyici çerçeveler yer almaktadır. Betimleyici istatistikler, katılımcıların bu engelleri tutarlı bir şekilde algıladıklarını göstermiştir; ancak korelasyon analizi, bilgi boşlukları, bütçe sınırlamaları ve düzenleyici sorunlar gibi engeller arasında önemli bağlantılar ortaya koymuştur. Bulgular, her ikisi de Sri Lanka'nın inşaat sektörünün küresel çevre sorunları karşısında uzun vadeli dayanıklılığı için kritik öneme sahip olan yenilikçiliği ve sürdürülebilir uygulamaları teşvik etmek için stratejik bir çerçeve sunmaktadır.

K E Y W O R D S

Circular economy
Construction industry
Strategies
Sustainable development

A B S T R A C T

This research aims at how circular economy concepts could be integrated into Sri Lanka's construction sector to improve sustainability and line with global environmental goals. To identify barriers to CE adoption, a mixed-method approach was used, beginning with a systematic literature review and progressing to a complete survey and correlation analysis. Key challenges highlighted include a lack of understanding, resistance to change, and insufficient regulatory frameworks. Descriptive statistics demonstrated that respondents consistently perceived these obstacles; but correlation analysis revealed substantial links between barriers such as knowledge gaps, budgetary limits, and regulatory problems. The findings provide a strategic framework for promoting innovation and sustainable practices, both of which are critical to Sri Lanka's construction industry's long-term resilience in the face of global environmental issues.

1. Introduction

The global construction industry is a key driver of economic development, infrastructure development, and urbanization, contributing significantly to the global economy (Ahmad et al., 2019; Alaloul et al., 2021). However, this industry's incredible growth comes at a tremendous cost, since it is a major contributor to greenhouse gas (GHG) emissions and the generation of construction and demolition waste (CDW) (Marinković et al., 2023; Buchard & Christensen, 2023; Al-Omari et al., 2023). The construction sector, responsible for 39% of worldwide carbon dioxide (CO_2) emissions and 40% of CDW accumulation, is a significant contributor to

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environmental degradation and resource depletion (Gallego-Schmid et al., 2020; Labaran et al., 2021). Despite its significance for financial growth, the construction industry's traditional linear economic (LE) model is becoming more and more unsustainable, fostering a cycle of resource extraction, manufacturing, consumption, and disposal that stresses ecological systems and compromises long-term resilience (Petrovic et al., 2022, Zvirgzdins et al., 2019).

Existing initiatives to promote sustainability in the construction sector have been insufficient to mitigate its environmental implications (Cruz et al., 2019; Murtagh et al., 2020; Hernández et al., 2023). Although progress has been made toward greener practices, such as the use of energy-efficient technology and greener building materials, these measures have not been broadly applied or standardized (Dadzie et al., 2018; Lin & Yang, 2023). The sector's sustainability performance remains weak, with many projects still using resource-intensive and inefficient methods (Gallo et al., 2021; Ortega et al., 2023). This gap highlights the need for a creative strategy to more effectively address environmental concerns and promote sustainable growth in the business.

The construction industry in Sri Lanka reflects global trends, with similar patterns of unsustainable practices and environmental implications (Weerakoon et al., 2023). According to Wijerathna and Abeynayake (2021), due to rapid urbanization and infrastructural development-boosting construction activity throughout the island country, Sri Lanka is experiencing increased resource depletion, waste accumulation, and adverse environmental effects. The growth of traditional construction practices, along with poor regulatory oversight and waste management infrastructure, has increased the industry's environmental impact, jeopardizing the country's ecological equilibrium and sustainable development goals (SDGs) (Karunasena et al., 2023).

According to Victor and Waidyasekara (2023), despite growing concern about environmental degradation and resource scarcity, the circular economy (CE) concept has emerged as a compelling solution to the building industry's inherent unsustainable nature. The CE, founded on the concepts of regenerative design, resource efficiency, and waste minimization, represents a paradigm shift away from the old linear 'take-make-dispose' model and towards a closed-loop system that encourages the continual flow and utilization of resources and substances (Ogunmakinde et al., 2021; Nelles et al., 2019). Furthermore, CE promotes sustainable construction methods such as material reuse, recycling, and recovery of resources, resulting in increased resilience, energy savings, and conservation of the environment (Guerra-Rodríguez et al., 2020; Papamichael et al., 2023). Furthermore, the transition from the 3Rs to the 10Rs is a rising strategy for promoting environmental sustainability through resource conservation, and a decrease in waste. Theoretical models such as Industrial Ecology, Biomimicry, Cradle-to-Cradle, and Performance Economy give comprehensive approaches to circularity (Kuznetsova, 2022).

Despite growing recognition of the CE as a potential path to sustainability, there is a severe absence of research and practical application solutions tailored to the Sri Lankan context. Existing research focuses mostly on global perspectives and case studies from established economies, typically overlooking the unique challenges and opportunities found in emerging markets like Sri Lanka. Therefore, this research paper aims to develop a comprehensive implementation strategy for Sri Lanka's construction sector. The primary goal is to identify and assess the important elements influencing the adoption of CE practices in the local construction sector, as well as to provide concrete measures for facilitating this transformation. The hypothesis driving this study is that applying a CE framework in Sri Lanka's construction sector will greatly improve its sustainability performance. The research question addressed in this study is: "How can CE principles be effectively integrated into Sri Lanka's construction sector to promote sustainable development?"

By conducting this research, this article aims to offer insightful findings and useful suggestions that will aid practitioners, industry stakeholders, and legislators in promoting sustainable change in the construction sector.

2. Materials and Methods

The methodology section is essential for showcasing the accuracy and thoroughness of the research as well as assessing the study's contribution to the field. The validity and generalizability of the study's conclusions are guaranteed by a strict and transparent process. A mixed-method approach was used in this study, which included both quantitative and qualitative elements.

The first stage of the methodology is to perform the qualitative component using the Scopus database to carry out a systematic literature review (SLR). According to Baas et al. (2020), Scopus is a highly renowned and extensive abstract and citation database that offers scholarly academics superior quality information on books, conference proceedings, and journal articles. A thorough integration of search results and an evaluation of the quantity, nature, and quality of evidence relevant to a particular research question are all supplied by SLR (Siddaway et al., 2019).

Using the combination *"TITLE-ABS-KEY ((circular AND economy OR closed-loop AND economy OR circular AND practices) AND (construction AND industry OR construction AND sector OR built AND environment) AND (reuse OR recycle OR reduce)),"* the search was focused on the intersection of CE concepts with the construction industry. To guarantee pertinence to the latest developments in the CE framework, the initial search yielded 61 publications covering the period from 2019 to 2024. Subsequently, the scope was restricted to peer-reviewed journal articles exclusively, substantiating this necessity due to their scientific validity and reliability. The sample was reduced by this filtering process to 33 articles for further examination. A series of sifts were used to further refine the results, starting with the rejection of articles whose titles did not match the goals and objectives of the study. The pool was narrowed down to 21 pertinent items by this first filter. After evaluating abstracts, articles that were not directly related to the topic were eliminated, leaving a final selection of 17 articles for further analysis (see Fig. 1). The whole texts of the chosen articles were thoroughly reviewed as part of the qualitative analysis phase, which led to 13 articles for review for the identification of potential integration solutions as well as obstacles to the use of CE concepts in the construction sector. The subsequent phases of the investigation were built upon these findings where the findings obtained by the qualitative assessment were set into assessment by the Sri Lankan construction industry practitioners through the quantitative approach.

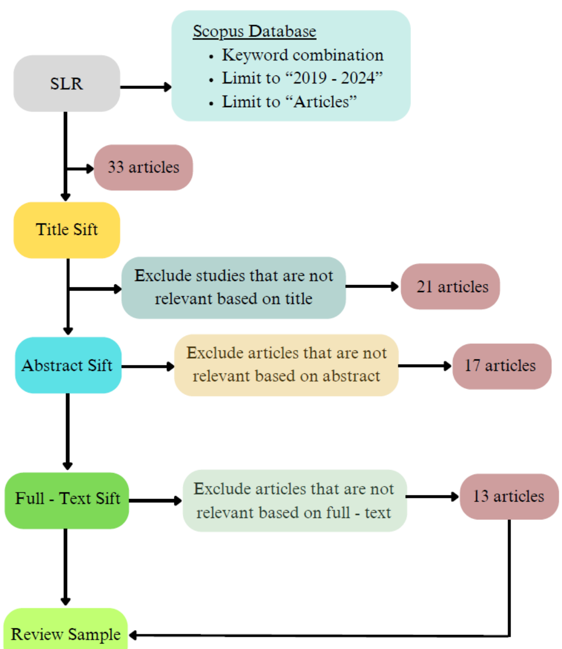

Figure 1. Overview of research methodology employed.

The purpose of the quantitative approach of the study was to gather actual data from professionals working in Sri Lanka's construction industry to evaluate their understanding, opinions, and perceptions of the CE's principles, as well as to pinpoint obstacles and assess strategies for implementation. A questionnaire survey was created and sent throughout two months (April to June 2024) among industry practitioners. The non-probability sampling approach was adopted, allowing data to be collected from a varied spectrum of experts with the least experience to veterans in the sector. After the data was collected, the responses were combined and subjected to rigorous data analysis procedures. The correlation study was carried out to investigate the relationships between several barriers to the construction industry's adoption of a CE. For a thorough grasp of these associations, the study was conducted utilizing Pearson, Kendall's tau, and Spearman correlation approaches. Using both parametric (Pearson) and non-parametric (Kendall's tau, Spearman) correlation approaches enables a robust analysis that takes into account various data features. Pearson is best for regularly distributed data, and analyzing linear relationships, but Kendall's tau and Spearman are better suited for data that does not match normality criteria, capturing both linear and nonlinear correlations. This dual technique allows for a thorough knowledge of variable connections regardless of data distribution.

Pearson correlation is a prominent statistical method for examining the linear relationship between two independent variables. The correlation coefficient, denoted by the letter "r," is a numerical value that is obtained from it that expresses the strength and direction of the linear relationship between the variables (Schober et al., 2018; Pernet et al., 2013). The following formula (Eq.1) is used to calculate the Pearson correlation coefficient (r_p):

$$r_p = \frac{\sum_{i=1}^{n}(X_i - X_0)\,(Y_i - Y_0)}{\sqrt{\sum_{i=1}^{n}(X_i - X_0)^2\,(Y_i - Y_0)^2}}$$

where n is the number of data points;

X_i and Y_i are the variable X and variable Y unique data points;

X_0 and Y_0 are the X and Y variables' means, correspondingly.

The Kendall Tau-b correlation, often known as Kendall's Tau-b, is a nonparametric statistical method for determining the degree and direction of a relationship between two variables (Hamed, 2011). The Kendall's tau correlation coefficient (r_k) is calculated using the following equation (Eq. 2):

$$r_k = \frac{A_x - B_y}{\sqrt{\left(A_x + B_y + C_{z_i}\right)\left(A_x + B_y + C_{z_o}\right)}}$$

Where A_x is the number of concordant pairs, which are observations in the same order;

B_y is the number of discordant pairs, which are observations with different order:

C_{zi} is the number of tied values in the variable i;

C_{zo} is the number of tied values in variable o.

A Spearman correlation coefficient is a measure of a monotonic relationship between variables that is utilized for nonnormally distributed continuous data, ordinal data, or data with significant outliers (Puth et al., 2015). The Spearman correlation coefficient (r_s) is calculated using the following equation (Eq.3):

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2 - 1)}$$

where, d_i is the difference between the ranks of corresponding variables;

n is the number of observations.

Both Kendall's tau and Spearman correlation analysis were done to further validate the results obtained from the Pearson correlation analysis. Table 1 below indicates the variables and their designated codes used in the analysis.

Table 1. Variables and their codes used for correlation analysis.

Variable name	Variable code
Lack of awareness	B1
Regulatory challenges	B2
Technological incapabilities	B3
Financial constraints	B4
Cultural resistance	B5

3. Results and Discussion

3.1. Preliminary Results

The descriptive statistics (Table 2) reflect the data collected on the barriers to adopting a CE in the construction industry. This summary covers the mean, standard deviation, variance, and skewness for each barrier, providing information about their distribution and variability. The questionnaire survey resulted in useful quantitative data for the research. The survey was able to capture 113 viewpoints from diverse industry professionals.

Table 2. Descriptive statistics of the data set.

Descriptive Statistics									
	N	Minimum	Maximum	Mean		Std. Deviation	Variance	Skewness	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error
B1	42	10	12	10.43	.091	.590	.348	1.037	.365
B2	42	10	12	10.48	.092	.594	.353	.828	.365
B3	42	10	12	10.95	.113	.731	.534	.074	.365
B4	42	10	13	10.81	.119	.773	.597	.682	.365
B5	42	10	13	10.71	.119	.774	.599	.885	.365
Valid N (listwise)	42								

The descriptive data show that all five obstacles have mean scores close to 10 and comparatively small standard deviations, indicating that respondents see them similarly. The positive skewness of most barriers (B1, B2, B4, and B5) indicates a preference for higher values within the range, meaning that respondents frequently ranked these barriers toward the upper end of the scale. Barrier B3, with its almost symmetrical distribution, represents a more equally distributed view. These observations contribute to a better understanding of the primary tendencies and variability in views of hurdles to establishing a CE, which may be used to inspire focused initiatives to overcome the most frequently identified challenges.

The survey reveals a diverse range of roles and responsibilities in the construction industry. Figure 2 depicts the occupational profile of the responders. Engineers, architects, quantity surveyors, project managers, technical officers, and government personnel all play a crucial role in developing and implementing sustainable practices and CE concepts. Assessing how each of these key stakeholders contribute towards implementing CE and their responsibilities in the transition is crucial. Engineers, responsible for civil, mechanical, electrical, and environmental engineering, are crucial in maximizing resource efficiency and reducing waste. Quantity surveyors, responsible for cost estimation, procurement, and financial management, are also crucial in promoting CE concepts. Project managers, responsible for project operations, are crucial in promoting resource optimization and waste minimization. Technical officers and construction managers, responsible for managing building processes, are also crucial in adopting CE concepts. Government personnel play a crucial role in shaping the regulatory environment and encouraging sustainable growth. Therefore, the survey underscores the multifaceted nature of the construction industry and the need for collaboration among various stakeholders to drive innovation and sustainable practices.

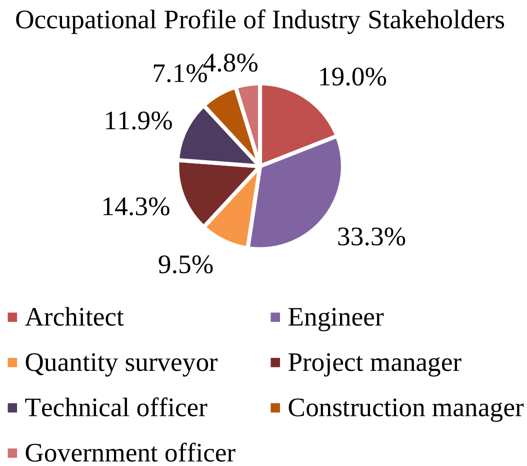

Figure 2. Occupational profile of respondents (developed by the authors)

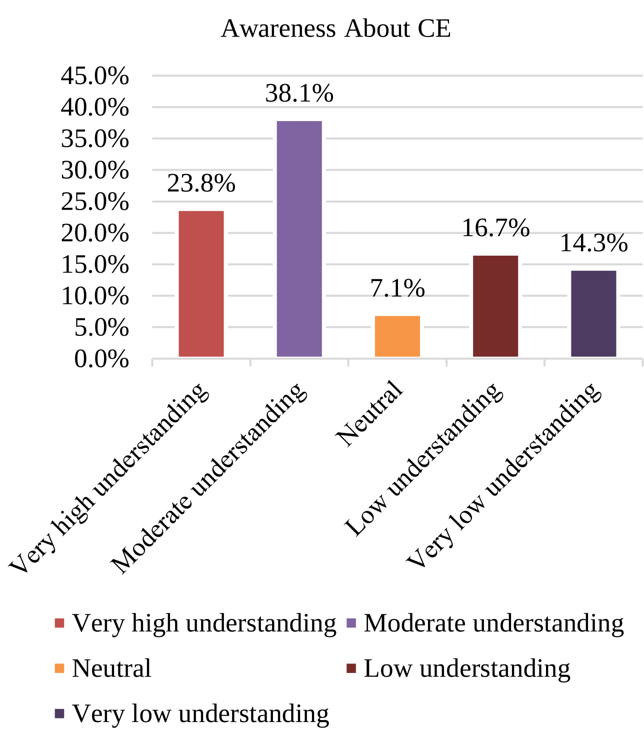

Figure 3. Awareness of CE among industry stakeholders (developed by the authors)

The study examined respondents' awareness of the CE concept in the construction industry. Figure 3 illustrates a wide variety of awareness levels. 38.1% had moderate understanding, while 23.8% had strong awareness. This is a positive indication of laying the transition towards circular practices as industry practitioners are aware of CE principles. However, 16.7% demonstrated little comprehension and 14.3% had very little knowledge, showing a need for improved awareness and education. This group might benefit from focused outreach and capacity-building initiatives that encourage information sharing and enable professionals to integrate CE concepts. Furthermore, the survey shows a strong consensus on the importance of sustainable building practices in Sri Lanka's construction sector. 95.2% of respondents consider these practices essential, highlighting the industry's shift towards responsible practices. This shift can lead to reduced carbon emissions, improved resource efficiency, and increased market competitiveness.

The study's findings offer a mixed picture of Sri Lanka's current application of CE concepts in construction practices.

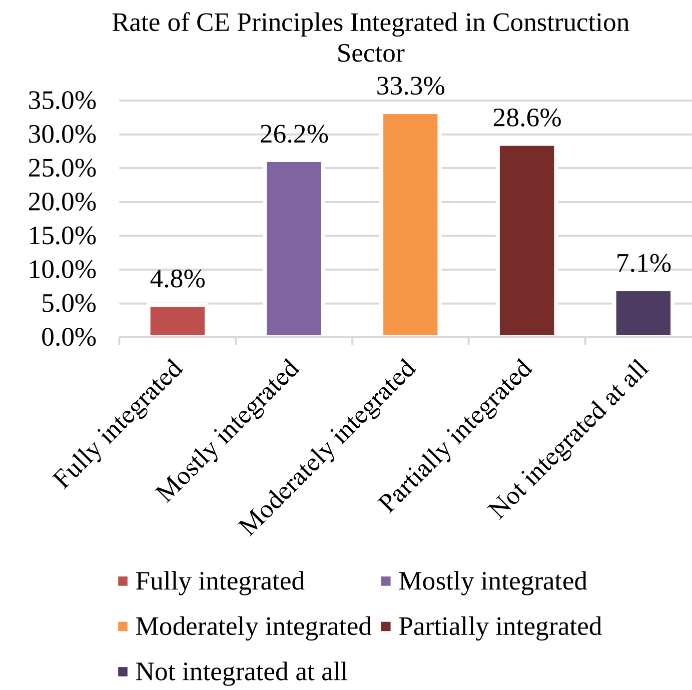

Figure 4. Usage of CE principles in Sri Lankan construction sector.

According to Figure 4, respondents reported that CE principles are mostly integrated (26.2%) or slightly integrated (28.6%). This suggests that there is a growing knowledge and use of CE concepts in the construction industry, although there is still room for growth and refinement. With around 33.3% of respondents evaluating integration as moderate, there is evidence of continued efforts to incorporate CE principles into construction methods, showing a steady trend towards more sustainable and resource-efficient approaches to building and development. However, a small minority of respondents (7.1%) reported that CE principles are not implemented at all, underlining the need for targeted interventions and capacity-building initiatives to promote CE principles.

Since there is still room for development in understanding CE principles before the effective incorporation of the idea, the survey indicates that the Sri Lankan construction sector needs measures to promote CE practices. Awareness and education activities are the most commonly acknowledged, with 83.3% of respondents recognizing their significance.

Policy and legal regulation are also important, with 66.7% indicating the necessity for government involvement. Research and development funding is likewise encouraged, with 78.6% seeing its innovation potential. Stakeholder involvement and collaborative platforms are essential, as is embedding the CE into national engineering curricula and providing financial incentives. Figure 5 indicates proposed strategies by respondents to overcome the barriers and for successful integration.

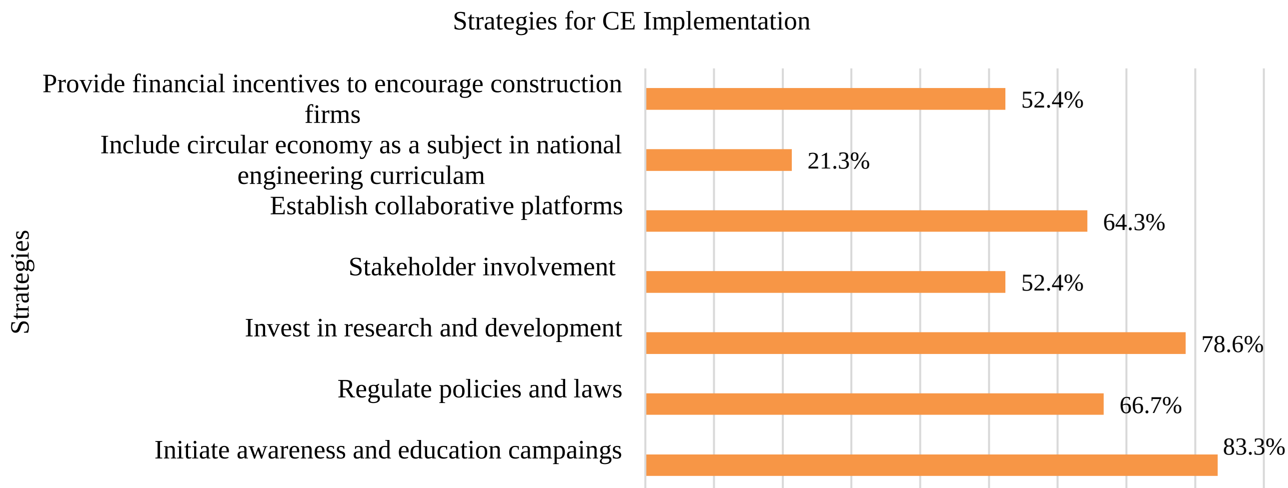

Figure 5. Proposed strategies for CE implementation.

As a result, preliminary results suggest that coordinated work is required to encourage the adoption of CE concepts in Sri Lanka's construction sector. However, it is necessary to completely identify the link between the barriers and their nature to overcome them through effective measures and achieve SDGs.

3.2. Assessing the Relationship Among Barriers to Implementing CE.

The correlation analysis of the barriers to adopting CE in the construction industry gives a thorough understanding of their interrelationships. Pearson, Kendall's tau, and Spearman correlation approaches all yield significant results, providing important details into how to overcome these hurdles.

The Pearson correlation analysis in Table 3 shows some significant correlations among the obstacles that exist. For instance, barriers B1 and B2 have a moderate positive correlation ($r = 0.377$, $p = 0.014$), indicating that when barrier B1 increases, so does barrier B2. Similarly, B1 and B5 have a modest positive correlation ($r = 0.328$, $p = 0.034$), showing that these barriers follow a similar pattern. The noteworthy positive correlation ($r = 0.568$, $p < 0.001$) between B2 and B5 indicates a significant connection between these obstacles. In addition, a moderate positive correlation ($r = 0.372$, $p = 0.015$) between B3 and B4, as well as between B4 and B5 ($r = 0.355$, $p = 0.021$), indicates interconnectivity. Pearson correlations suggest that specific barriers tend to co-occur, implying underlying similar causes or reasons.

Table 3. Results of the Pearson correlation analysis among barriers for implementing CE.

Correlations

		B1	B2	B3	B4	B5
B1	Pearson Correlation	1	.377*	.162	.076	.328*
	Sig. (2-tailed)		.014	.307	.631	.034
	Sum of Squares and Cross-products	14.286	5.429	2.857	1.429	6.143
	Covariance	.348	.132	.070	.035	.150
	N	42	42	42	42	42
B2	Pearson Correlation	.377*	1	.110	.096	.568**
	Sig. (2-tailed)	.014		.489	.545	.000
	Sum of Squares and Cross-products	5.429	14.476	1.952	1.810	10.714
	Covariance	.132	.353	.048	.044	.261

	N	42	42	42	42	42
B3	Pearson Correlation	.162	.110	1	.372*	.062
	Sig. (2-tailed)	.307	.489		.015	.698
	Sum of Squares and Cross-products	2.857	1.952	21.905	8.619	1.429
	Covariance	.070	.048	.534	.210	.035
	N	42	42	42	42	42
B4	Pearson Correlation	.076	.096	.372*	1	.355*
	Sig. (2-tailed)	.631	.545	.015		.021
	Sum of Squares and Cross-products	1.429	1.810	8.619	24.476	8.714
	Covariance	.035	.044	.210	.597	.213
	N	42	42	42	42	42
B5	Pearson Correlation	.328*	.568**	.062	.355*	1
	Sig. (2-tailed)	.034	.000	.698	.021	
	Sum of Squares and Cross-products	6.143	10.714	1.429	8.714	24.571
	Covariance	.150	.261	.035	.213	.599
	N	42	42	42	42	42

**. Correlation is significant at the 0.05 level (2-tailed).*

***. Correlation is significant at the 0.01 level (2-tailed).*

Kendall's tau and Spearman correlation study (see Table 4) indicates the Pearson correlation results by stressing the non-parametric correlations among the obstacles. A positive correlation ($\tau = 0.212$, $p = 0.159$) between B1 and B2 supports the Pearson results, although it is not statistically significant. A positive correlation ($\tau = 0.220$, $p = 0.132$) between B1 and B5 confirms the pattern found in the Pearson analysis. The substantial positive correlation ($\tau = 0.529$, $p < 0.001$) between B2 and B5 indicates a meaningful link between these obstacles. Furthermore, a moderate positive correlation ($\tau = 0.305$, $p = 0.030$) between B3 and B4 confirms the Pearson correlation, whereas a positive correlation ($\tau = 0.217$, $p = 0.125$) between B4 and B5 underlines the interconnectivity found. Kendall's tau results support the patterns obtained using Pearson correlation, however, some connections are weaker.

The Spearman correlation analysis reveals the substantial correlations between the barriers, demonstrating the stability of these findings across correlation methods. A positive correlation ($\rho = 0.218$, $p = 0.165$) between B1 and B2 backs with Pearson's and Kendall's tau findings. The positive correlation ($\rho = 0.237$, $p = 0.131$) between B1 and B5 is consistent with other correlation approaches. A considerable positive correlation ($\rho = 0.555$, $p < 0.001$) between B2 and B5 shows a significant link. A moderate positive correlation ($\rho = 0.334$, $p = 0.031$) between B3 and B4 is consistent with Pearson and Kendall's tau results, while a positive correlation ($\rho = 0.238$, $p = 0.128$) between B4 and B5 confirms the interconnectivity.

Table 4. Results of the non-parametric correlation analysis among barriers for implementing CE.

Correlations							
			B1	**B2**	**B3**	**B4**	**B5**
Kendall's tau	**B1**	Correlation Coefficient	1.000	.212	.134	.050	.220
		Sig. (2-tailed)	.	.159	.354	.729	.132
		N	42	42	42	42	42
	B2	Correlation Coefficient	.212	1.000	.082	.067	.529**
		Sig. (2-tailed)	.159	.	.570	.644	.000
		N	42	42	42	42	42
	B3	Correlation Coefficient	.134	.082	1.000	.305*	.069
		Sig. (2-tailed)	.354	.570	.	.030	.625
		N	42	42	42	42	42
	B4	Correlation Coefficient	.050	.067	.305*	1.000	.217
		Sig. (2-tailed)	.729	.644	.030	.	.125
		N	42	42	42	42	42
	B5	Correlation Coefficient	.220	.529**	.069	.217	1.000

		Sig. (2-tailed)	.132	.000	.625	.125	.
		N	42	42	42	42	42
Spearman's	**B1**	Correlation Coefficient	1.000	.218	.143	.054	.237
		Sig. (2-tailed)	.	.165	.366	.734	.131
		N	42	42	42	42	42
	B2	Correlation Coefficient	.218	1.000	.087	.073	.555**
		Sig. (2-tailed)	.165	.	.583	.644	.000
		N	42	42	42	42	42
	B3	Correlation Coefficient	.143	.087	1.000	.334*	.074
		Sig. (2-tailed)	.366	.583	.	.031	.640
		N	42	42	42	42	42
	B4	Correlation Coefficient	.054	.073	.334*	1.000	.238
		Sig. (2-tailed)	.734	.644	.031	.	.128
		N	42	42	42	42	42
	B5	Correlation Coefficient	.237	.555**	.074	.238	1.000
		Sig. (2-tailed)	.131	.000	.640	.128	.
		N	42	42	42	42	42

***. Correlation is significant at the 0.01 level (2-tailed).*

**. Correlation is significant at the 0.05 level (2-tailed).*

The correlation study demonstrates the interconnectedness of barriers to establishing a CE in the construction industry. The substantial positive correlations across numerous barriers, which were detected consistently across Pearson, Kendall's tau, and Spearman techniques, indicate that these impediments are not isolated but rather interconnected. For example, the high relationship between B2 and B5 suggests that eliminating one of these obstacles may simultaneously overcome the other. This interconnection necessitates integrated methods that address numerous barriers to improve efficacy. Furthermore, the moderate correlations detected between other pairs of barriers (e.g., B1 and B2, B3 and B4) indicate shared roots or implications. A comprehensive strategy that takes into account the larger context and relationships between these barriers may be more effective than tackling them individually. Understanding these connections enables improved intervention prioritization, perhaps leading to more significant increases in CE adoption.

Ultimately, the correlation analysis provides useful information on the intricate network of barriers to implementing a CE in the construction sector in Sri Lanka. These findings can help shape more comprehensive plans for overcoming these challenges and promoting sustainable practices in the sector.

3.3. Strategic Framework for Implementation of CE

Implementing a CE in Sri Lanka's construction industry necessitates a strategic framework linked with the SDGs. The correlation study of barriers to CE gives vital insights for establishing focused strategies to effectively overcome these challenges. Figure 6 illustrates the proposed strategic framework for implementing CE that aligns with SDGs for the Sri Lankan built environment.

The correlation analysis demonstrated strong correlations between various barriers, indicating they are interrelated. As a result, a strategic framework must take a comprehensive approach to address several impediments at once. For example, the substantial relationship between barriers B2 (Lack of Knowledge and Awareness) and B5 (Financial constraints) suggests that increasing knowledge and awareness may also ease financial restrictions (Rodriguez-Espindola et al., 2022; Atiku, 2020). This method supports SDG 4 (Quality Education) and SDG 9 (Industry, Innovation, and Infrastructure) by encouraging educational programs and creative finance solutions. Implementing comprehensive educational and training programs is critical for addressing the knowledge and awareness gap. These initiatives should address all stakeholders in the construction industry, including legislators, contractors, and workers. Workshops, seminars, and certification programs based on CE principles and best practices might be among the initiatives (Guerreschi et al., 2023; Bugallo-Rodriguez & Vega-Marcote, 2020; Zandee et al., 2022). Collaboration with academic institutions and international organizations can improve the quality and scope of these educational initiatives (Mendoza et al., 2019; Danvers et al., 2023). This method supports SDGs 4 (Quality Education) and 12 (Responsible Consumption and Production). Financial restrictions are a substantial impediment to CE adoption. According to Munaro et al. (2020), the implementation framework should contain measures that incentivize enterprises to adopt CE practices, including tax breaks, subsidies, and grants. Furthermore, increasing access to green finance choices might assist overcome financial constraints (Jinru et al., 2021; Zhang et al., 2020). Public-private partnerships may also be effective in mobilizing resources and sharing risks (Kolodiziev et al., 2017; Matayev & Berzhanov, 2020). This method promotes long-term economic growth and climate resilience, which contributes to SDGs 8 (Decent Work and Economic Growth) and 13 (Climate Action).

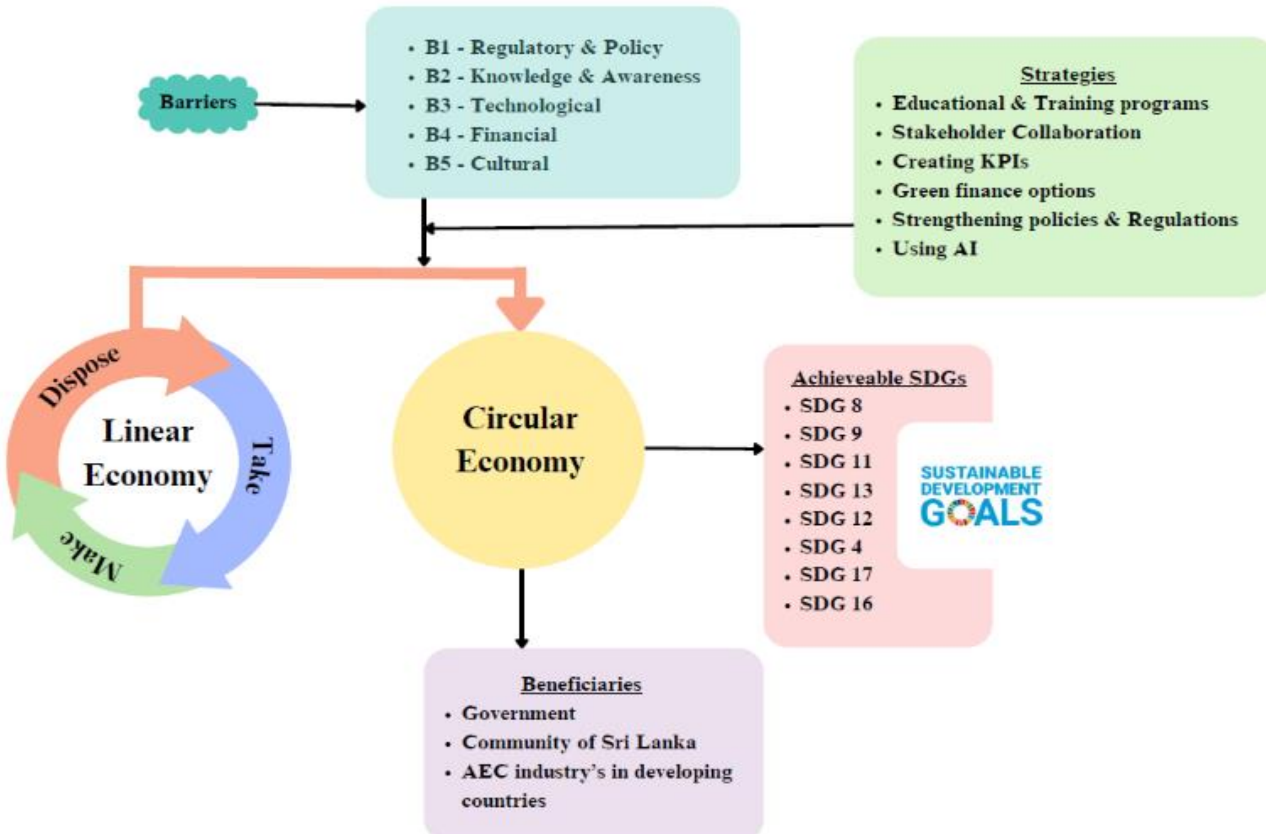

Figure 6. Framework for implementing CE and achieving SDGs in the built environment.

The correlation analysis reveals that legislative constraints (B1), technological impediments (B3), and a lack of infrastructure (B4) are all linked. Regulations must be strengthened to promote CE practices (Mhatre et al., 2021). This entails creating clear CE standards and requirements for construction, guaranteeing compliance via efficient evaluation and enforcement, and promoting innovation in sustainable technology (Ghufran et al., 2023). It is also vital to invest in infrastructure that promotes recycling, reuse, and the use of sustainable materials through technological advancements such as artificial intelligence (AI) (Weerakoon et al., 2024; Nascimento et al., 2019; Joensuu et al., 2023). This strategy is consistent with SDGs 9 (Industry, Innovation, and Infrastructure) and 11 (Sustainable Cities and Communities).

All stakeholders, including government agencies, private sector firms, civil society groups, and the general public, must actively participate and collaborate to ensure effective CE implementation (Mishra et al., 2019; Arsova et al., 2021). Multi-stakeholder forums may help with discourse, information exchange, and coordinated action. Fostering collaborative projects and activities can result in novel solutions and increased impact (Eisenreich et al., 2021). This strategy promotes SDG 17 (Partnerships for the Goals) by encouraging collaboration and collective effort for sustainability. Furthermore, a strong monitoring and evaluation system is required to track progress, identify difficulties, and assess the effectiveness of CE projects (Alamerew et al., 2020). Creating key performance indicators (KPIs) that are connected with CE objectives and SDGs can give useful data for continual development (Hristov & Chirico, 2019). Regular reporting and open sharing of findings help foster confidence along with accountability within parties. This method supports SDG 16 (Peace, Justice, and Strong Institutions) by encouraging openness and good governance.

The strategic action plan for establishing a CE in Sri Lanka's construction industry must overcome the interconnected hurdles discovered by correlation analysis. The suggested approaches not only help to accomplish a number of SDGs but also promote Sri Lanka's building sector to being more robust and sustainable.

4. Conclusions

The outcomes of this study highlight the crucial need to incorporate CE principles into Sri Lanka's building sector to improve sustainability and resilience. Despite advancements, challenges such as a lack of knowledge, opposition to change, and insufficient regulatory frameworks remain. There were significant relationships between regulatory and financial barriers and the requirement for specific initiatives such as policy assistance and financial incentives. These findings underline the importance of interventions including awareness campaigns, policy regulation, R&D funding, and stakeholder involvement in overcoming these barriers and promoting sustainable practices in the business.

Furthermore, the study draws many critical conclusions, including the construction industry's significant contribution to GHG and worldwide construction waste. It is critical to effectively manage construction and demolition waste (CDW) and use novel techniques. The shift from the 3Rs to the 10Rs is a growing approach for sustainability, resource efficiency, and waste reduction. Theoretical frameworks such as Industrial Ecology, Biomimicry, Cradle-to-Cradle, and Performance Economy provide holistic approaches to circularity. Policies at all levels play an important role in aiding this transformation, and most respondents understand the crucial relevance of sustainable building techniques for the future of Sri Lanka's construction sector.

Some significant recommendations are suggested to establish CE principles. Government and commercial organizations should conduct targeted awareness campaigns, and government agencies should work together to distribute information and promote awareness through seminars and training programs. Relevant entities should develop and implement regulatory frameworks and incentives to encourage sustainable activities. Prioritizing multi-stakeholder engagement will encourage cooperation and community involvement in achieving long-term construction objectives. Furthermore, funding for research and development in sustainable technology and construction processes is critical.

Implementing these recommendations and encouraging cross-sectoral collaboration would assist in removing bottlenecks, encouraging innovation, and accelerating Sri Lanka's transition to a more sustainable and resilient construction industry, in line with the SDGs. As a result, this study contributes significantly to society by offering a road map for incorporating CE principles into Sri Lanka's building sector, which is critical for promoting sustainability and resilience. This research prepares the road for successful policy interventions and stakeholder involvement by identifying and addressing the major impediments to sustainable practice. The recommendations for awareness campaigns, policy regulations, and R&D funding are directly aligned with the United Nations Sustainable Development Goals (SDGs), particularly those for sustainable cities and communities (SDG 11), responsible consumption and production (SDG 12), and climate action (SDG 13). Implementing these measures will speed up the construction industry's transition to sustainability, benefitting society as a whole.

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