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ANALYZING CRITICAL SUCCESS FACTORS FOR IMPLEMENTING A CIRCULAR ECONOMY IN EAST JAVA'S CONSTRUCTION INDUSTRIES USING FUZZY SYNTHETIC EVALUATION

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Abstract

The transition to a circular economy (CE) has become a crucial global objective, with the aim of promoting sustainable development while minimizing resource depletion and environmental degradation. Nevertheless, there are a lot of challenges that need to be overcome before CE principles are feasible to apply in the construction industry, particularly in areas like East Java, Indonesia. Thus, in order to integrate CE concepts into East Java's construction industry, this paper investigates the critical success factors (CSFs). This study's research approach consists of a thorough literature review, a questionnaire survey for data collection, and a thorough analysis of the data using mean score ranking and fuzzy synthetic evaluation (FSE). The analyses revealed 40 significant success factors for CE adoption in the architecture, engineering, and construction (AEC) sector of East Java's construction industries. Furthermore, this study discovered six CSF categories that have a substantial impact on the success of CE adoption through FSE analysis. However, the three most significant categories are policy, technology, and commitment and competency. The results of this study provide crucial recommendations to the East Java government and stakeholders in the AEC sector.

Keywords:

Circular economy;
Critical success factors
Waste management;
Construction industries;
Fuzzy synthetic evaluation.

1 Introduction

The Indonesian Central Statistical Agency reported a total population of 275.77 million in 2022, making it the fourth-most populous country in the world. The population of Indonesia has been steadily increasing. The population growth is accompanied by the production of 194 tons of solid waste per day over an area of 1,910,931 km² [1]. Construction has grown in tandem with population growth, leading to increased environmental issues like resource depletion, increased carbon emissions, higher raw material consumption, and the accumulation of construction waste [2]. These problems emphasize the immediate necessity of implementing sustainable practices in the construction industry.

Currently, the construction sector primarily adheres to a Linear Economy model, wherein resources are extracted, processed, used, and finally disposed of [3]. This approach results in substantial waste and depletion of resources [4, 5]. The most important environmental impacts of construction materials are the embodied energy and the emissions generated throughout their life cycle [6]. In contrast, the Circular Economy (CE) approach provides a sustainable alternative by promoting the recycling, reuse, and recovery of materials [7], in which resources and energy are optimized and preserved throughout the economic cycle [8]. CE aims to prolong the lifespan of resources and minimize waste by employing efficient design and utilization of resources [9, 10]. Additionally, it is imperative to take into consideration both the utilization of high-quality construction techniques and the use of sustainable materials [11].

The concept of CE emerged from the principles of reducing waste, reusing materials, and recycling resources to sustain their usefulness in the economy [12]. Adopting CE principles in the construction industry requires a significant overhaul of production and consumption practices. This includes prioritizing activities such as product remanufacturing, reusing materials, exploring durable materials, and optimizing the utilization of assets. Additionally, consumer behavior modifications are essential for amplifying the favorable influence of CE [13, 14].

The construction cycle encompasses various steps, including planning, design, extraction of raw materials, production, construction activities, building maintenance and operation, and the eventual destruction process at the end of its lifespan [15]. It is essential to incorporate principles of CE throughout the entire construction process in order to achieve sustainable outcomes. However, the recycling rates of construction waste differ significantly between developed and developing countries. Developing countries frequently lack comprehension and implementation of CE principles, resulting in excessive consumption of non-renewable resources and environmental degradation. In contrast, developed nations such as China, Brazil, India, and Russia prioritize CE to mitigate ecological damage [16].

Identifying the specific barriers and drivers of CE and developing strategies that accelerate its implementation are essential for each country [17]. Nevertheless, prior studies have frequently disregarded these aspects, lacking well-defined methodological frameworks [18]. The adoption of CE is made more intricate by differing priorities between developed and developing nations [2]. In addition to the challenges, the role of stakeholders in CE implementation remains inadequately understood. Besides, the effectiveness of CE projects relies heavily on the unwavering dedication of crucial players, including clients, designers, contractors, manufacturers, and government bodies [19].

The transition from linear to circular paradigms can decrease reliance on raw materials, prolong the lifespan of products, and foster innovation, thus promoting more sustainable resource management and environmental balance [7, 20]. CE principles in the construction industry offer numerous benefits, including significant waste reduction, enhanced energy efficiency, and improved economic sustainability through the reuse and recycling of materials [8, 9]. For instance, by reusing building materials and components, the construction industry can substantially lower the consumption of virgin resources and reduce environmental impact [10]. Furthermore, CE can drive innovation by encouraging the development of new technologies and processes that enhance material efficiency and sustainability [12, 13]. However, to effectively realize these benefits, it is crucial to identify and understand the Critical Success Factors (CSFs) that facilitate the successful adoption of CE principles. Identifying these CSFs enables stakeholders to strategically focus their efforts on areas that will maximize the benefits of CE.

Understanding Critical Success Factors (CSFs) is essential for attaining zero waste and promoting circularity in the construction industry [21]. While earlier studies have identified various barriers and drivers, the practical implementation of these findings is still restricted [21]. This is especially true for the relatively new concept of CE in the global construction context, which lacks clear standards for incorporating CE principles to achieve zero waste [22]. Based on a previous study by Soto-Paz et al. [23], research related to the CE is still limited in developing countries. This supports the notion that there is a limited amount of literature specifically discussing the Critical Success Factors (CSFs) for managing and implementing CE in the construction industry, particularly in the East Java region of Indonesia. The adoption of CE in the construction sector of Indonesia is still in its early stages, compounded by the fact that Indonesia is classified as a developing country.

Nevertheless, there is ample evidence of CSFs for implementing CE. Oluleye et al. [3] identified many impediments, such as organizational, information technology, infrastructural, and logistical barriers, and emphasized the importance of developing contextual policies and allocating resources to achieve global circularity and minimize building waste. Similarly, Mahpour [24] identified behavioral, technical, and legal barriers to CE adoption, as well as Charef et al. [25] identified organizational, economic, technical, social, political, and environmental barriers. Furthermore, Munaro & Tavares [19] highlighted the significance of political and technological barriers, emphasizing the crucial role of regulatory laws, taxation measures, waste management systems, and integrated information systems. Additionally, Guerra & Leite [17] cited budgetary limitations, project timetables, insufficient knowledge and regulations, and existing business models as significant barriers to the implementation of CE techniques in the construction industry.

Furthermore, Wuni & Shen [22] identified critical success factors for circular modular construction projects (MCPs), which encompass timely completion of the design phase, customer comprehension and dedication, proficient leadership, sufficient expertise and experience within the project team, and active communication and exchange of information. In addition, Salmenperä et al. [26] highlighted the significance of waste management in facilitating the preservation of material value through recycling.

They underlined the economic advantages, sharing of waste data, cooperation, regulatory alignment, and collaboration among stakeholders as crucial factors. Moreover, Ma et al. [27] discovered eight CSFs for closed-loop waste management in China's construction industry. These factors include enhancing the quality of secondary materials, providing incentives for the use of secondary materials, implementing standards, utilizing advanced procurement and processing technologies, managing waste on-site, and promoting the use of durable materials. Additionally, Oluleye et al. [21] proposed four principal success factors (PSFs) for CE implementation. These factors include the use of digital data-based technologies, capacity building and audits before demolition, adherence to systemic circular rules and commitments, and the development of circular metrics and secondary markets.

Besides, Akinade et al. [28] identified five key factor groups for Design for Disassembly (DfD): regulatory and policy requirements, demolition design procedures and competences, material recovery design, material reuse design, and building flexibility design. Additionally, Botchway et al. [29] identified four essential abilities that reduce construction waste during project construction. This includes awareness, managerial abilities, personnel capability, and communication. Furthermore, Garusinghe et al. [30] proposed a framework of nine CE principles (9-R) to address nine key issues in Modular Construction (MC), thereby promoting sustainability. Moreover, Barakat et al. [31] suggested that change initiatives to enhance reverse logistics (RL) efficiency and promote CE in developing countries should prioritize effective regulation and oversight in construction and demolition waste management. This finding highlights the crucial role of governments in creating an enabling environment for circular economy implementation in the construction sector.

An extensive analysis of recent research conducted from 2017 to 2023 investigates crucial elements for the successful implementation of CE in the construction industry. This review establishes a solid basis for identifying pertinent issues in the field of CE. However, previous research does not place a particular emphasis on prioritizing these characteristics specifically in the context of developing nations such as Indonesia. Based on previous studies [21, 27], there has been no research focusing on evaluating the CSFs of the circular economy from the perspective of architecture, engineering, and construction (AEC) firms, especially in developing regions like East Java, Indonesia. Hence, the objective of this study is to utilize existing knowledge in order to assess and define customized characteristics that contribute to CE, specifically those that are relevant to the East Java region. By objectively and quantitatively examining the CSFs for CE adoption from the viewpoint of Architecture, Engineering, and Construction (AEC) firms in East Java, Indonesia, this study fills an existing gap in the literature. The Fuzzy Synthetic Evaluation (FSE) method will be used to assess the significance of CSF categories, utilizing its capacity to manage subjectivity and ambiguity in evaluations conducted by experts and stakeholders. The results are anticipated to serve as valuable guidance for policymakers and stakeholders. A detailed summary of the necessary actions and the personnel responsible for carrying them out is presented in Table 5, providing a comprehensive framework for effectively achieving successful circularity in the construction industry of East Java, Indonesia.

2 Methods

2.1 Research design and approach

This study employed a quantitative research design to develop CSFs for implementing a CE approach within the East Java construction industry. The research methodology involved three key stages, including a comprehensive literature review, data collection through a questionnaire survey, and rigorous data analysis. A flowchart depicting the research process is presented in Fig. 1, with a detailed explanation of each component following. A total of 40 CSFs for CE adoption in East Java's construction industry were identified and categorized into six groups. This identification and classification were derived from an extensive review of relevant literature to ensure a comprehensive understanding of the critical factors involved. According to Munaro & Tavares [19], the drivers of CE can be categorized into five main groups: economic, informational, institutional, policy, and technological, which encompass various aspects influencing the successful implementation of CE. Additionally, based on the literature by Wuni & Shen [22], CSFs in achieving CE in the construction sector can also be categorized into commitment and competence aspects, which are essential for effectively implementing CE practices. Drawing from these sources, the CSFs were categorized into six groups, which are utilized in the FSE method. Moreover, consultations were held with two academics possessing relevant knowledge of CE to refine and itemize the pertinent CSFs for the East Java context. This step was essential because

CSFs can be highly sensitive to contextual variations [22]. Table 1 presents an overview of the CSFs for the adoption of CE, serving as the foundation of the evaluation in this study.

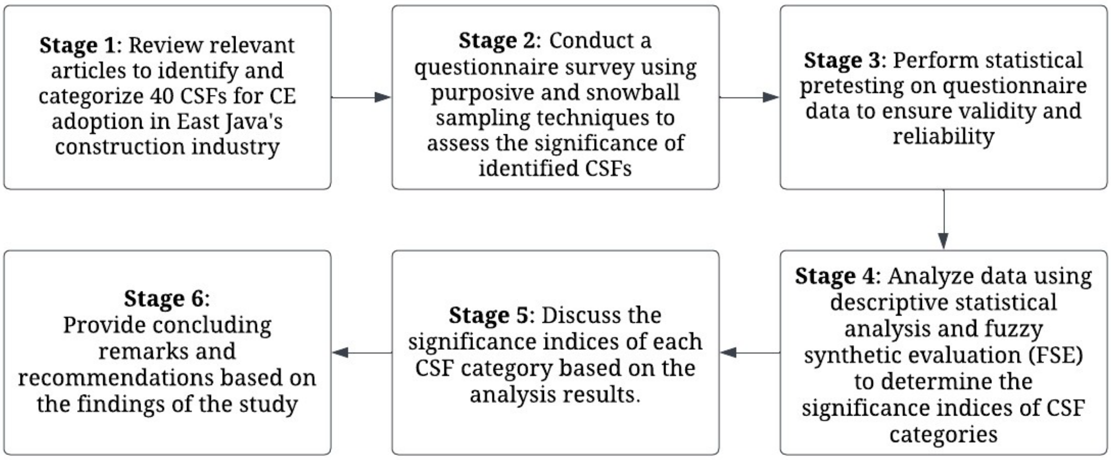

Fig. 1: Research framework for the study

Table 1: List of critical success factors for CE adoption

Category	ID	Critical Success Factors (CSF)	References
Economy	CSF01	Incentives for the construction industry that encourage adoption and awareness of the CE	[21]
	CSF02	Incentives and warranty schemes for secondary material utilization	[19, 21, 27]
	CSF03	Establishment of information platforms and marketplaces for construction and demolition waste (C&DW)	[19, 21, 27, 31]
	CSF04	Exploring the cost of various low-waste construction techniques and their potential scalability.	[19]
Informational	CSF05	Workshops among experts on the principles of the CE and its implementation	[19, 21]
	CSF06	Integrate the CE principles into the university curriculum and undertake further CE-based research.	[19, 21, 26]
	CSF07	Enhanced education and training of design-related professionals for building deconstruction.	[28]
	CSF08	Development of relevant guidelines for the implementation of the CE	[19, 21]
Institutional	CSF09	Designing for the deconstruction process to enhance end-of-life value	[21, 22]
	CSF10	Design compliance with codes and standards for deconstruction	[28]
	CSF11	Promotion of construction pre-demolition audits	[19, 21]
	CSF12	Encourages classification and sorting of waste during construction and demolition processes (C&D)	[19, 21, 27]
	CSF13	Establishing connections between demolition contractors and suppliers	[19]
	CSF14	Application of modern construction methods	[29]
	CSF15	Development of long-term circular value chains among stakeholders	[19]
	CSF16	Implementation of the C&DW management plan at the construction site	[29, 31]
Policy	CSF17	Developing a clear national plan on the objectives and vision of the CE in the construction industry	[19, 21]
	CSF18	Effective budget allocation by the government to realize the circularity of building and demolition waste	[21]
	CSF19	Sanctions for illegal disposal of construction and demolition waste (C&DW)	[21]
	CSF20	Sanctions for non-compliance and incentives for compliance with CE regulations	[19]

Category	ID	Critical Success Factors (CSF)	References
	CSF21	Regulations for compulsory deconstruction planning at the planning permission stage	[28]
	CSF22	Government support in the secondary material market	[26]
	CSF23	Circularity requirements on public procurement	[19, 26]
	CSF24	Tax exemption for goods produced from secondary materials	[19]
	CSF25	Financing for innovation, CE research, and technology subsidies	[19]
Technology	CSF26	Standardization of secondary materials	[19, 27]
	CSF27	Development of advanced resource and processing technologies for construction and demolition waste management (C&DW)	[19, 27]
	CSF28	Create datasets for BIM and explore the potential of BIM in conducting analysis for resource management	[19]
	CSF29	Using BIM to simulate processes and sequences of building demolition	[19, 28]
	CSF30	Development of guidelines and tools for assessing circularity on buildings	[19]
	CSF31	Availability of data and support tools to optimize the supply chain, along with regional waste data	[26]
	CSF32	Increased durability and material quality for longer service life	[27, 30]
	CSF33	C&DW data collection methods and systems	[21, 31]
	CSF34	Improves the quality and value of secondary materials	[27]
	CSF35	Metric development and CE indicators	[21]
Commitment and Competency	CSF36	Effective leadership and support from specialist contractors	[22]
	CSF37	Adequate knowledge and experience of the project team	[22]
	CSF38	Effective coordination and integration of stakeholders	[22, 31]
	CSF39	Initial and active involvement of key parties in the project	[22]
	CSF40	Initial understanding and client commitment	[22]

A questionnaire survey was conducted to evaluate the significance of the identified CSFs for CE adoption in East Java's construction industry. Section I of the survey gathered background information about the respondents, while Section II asked them to rate the significance of each CSF on a 5-point Likert scale (1-not significant, ...5-very significant). The 5-point Likert scale was chosen because it provides a manageable number of options, reduces the margin of error, and effectively captures the respondents' perspectives with adequate interpretation.

This study employed a combination of purposive and snowball sampling techniques to select participants. Initially, purposive sampling identified eligible respondents based on specific criteria: companies operating within the AEC sector in East Java, Indonesia; large-scale companies; involvement in building construction projects; and respondents with the authority to make strategic decisions related to construction projects. Once this initial pool of eligible respondents was established, snowball sampling expanded the participant base by asking existing participants to recommend additional individuals meeting the selection criteria. This approach was particularly valuable for reaching potential respondents who might not have been readily identifiable through purposive sampling alone. Data collection utilized paper-based questionnaires, digital copies, and an online link to reach diverse respondents and accommodate their preferred communication channels.

The distribution of the research questionnaire was conducted across 12 large-scale companies in East Java that met the specified criteria mentioned earlier. Out of these, 8 companies agreed to participate in the study. Resulting, a total of 36 valid responses were received, providing a sufficient sample size for statistical analysis. Fig. 2 summarizes the respondent profiles, highlighting the characteristics of the participants. Despite the limited sample size, it exceeds the minimum threshold of 30 responses necessary for the Central Limit Theory to draw a credible conclusion.

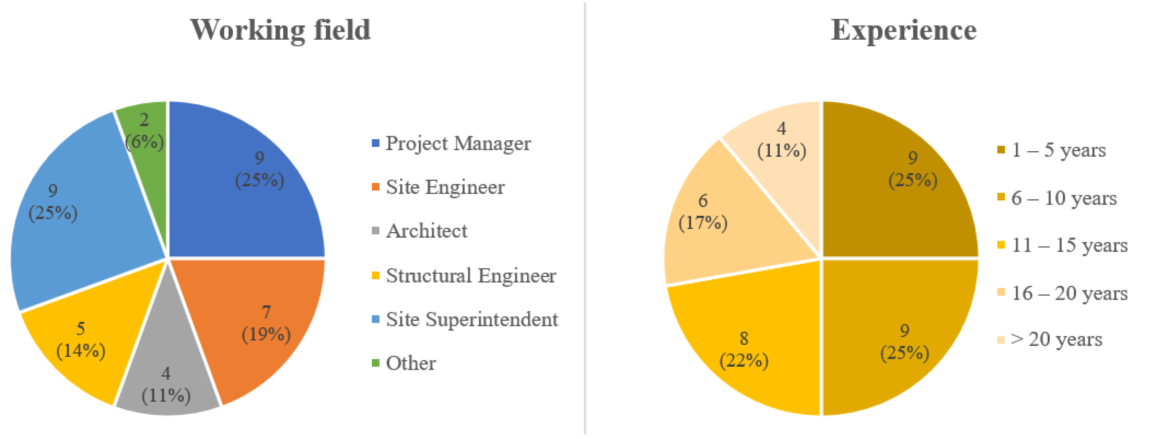

Fig. 2: Relevant information of the respondents

The selection of East Java province for this study is strategically determined by its significant role in Indonesia's construction sector. According to the 2023 data from the Central Statistics Agency [32], East Java ranks second after West Java in terms of the number of large-scale construction firms. This reflects the province's substantial construction activities and its position as a key player in the sector. Additionally, East Java is one of the rapidly developing regions in Indonesia, with considerable growth in both urbanization and infrastructure projects. By focusing on this province, this study provides insights that are relevant to a region experiencing dynamic changes and challenges in adopting Circular Economy (CE) practices. Geographically, East Java is located in the eastern part of the island of Java, bordered by the Java Sea to the north, Bali Strait to the east, the Indian Ocean to the south, and Central Java province to the west.

2.2 Statistical pretesting of questionnaire survey data

The questionnaire survey data underwent meticulous coding and organization using SPSS v.25. Validity was ensured through Pearson's correlation, with all items meeting the criteria. Subsequently, Cronbach's Alpha yielded a score of 0.942 for the 40 identified CSFs, indicating high internal consistency. Adhering to a 95% confidence interval ($\alpha = 0.05$) maintained statistical rigor. An alpha value above 0.7 indicates that the data in the study possesses a very high level of reliability [27]. Through these procedures, the questionnaire's reliability was validated, laying a strong foundation for subsequent data analysis.

2.3 Descriptive statistical analysis

Descriptive statistical methods, encompassing mean, standard deviation, and normalized mean, were applied to assess and prioritize CSFs essential for CE adoption in East Java. Mean scores (μi), standard deviation (σi), and normalized mean scores (Nμi) were computed using equations 1–3, respectively. The outcomes of the mean analysis served as the foundation for assigning indices to the CSF categories through the application of the FSE approach [21, 22].

$$\text{Mean score } (\mu i) = \frac{\sum Xi}{N} \quad (1)$$

$$\text{Standard deviation } (\sigma i) = \sqrt{\frac{\sum (Xi \times \mu i)^2}{N}} \quad (2)$$

$$\text{Normalized mean score } (N\mu i) = \frac{\mu i - Min.\mu i}{Max.\mu i - Min.\mu i} \quad (3)$$

where:
x_i – the i-th data value,
N – total amount of data,

2.4 Fuzzy synthetic evaluation (FSE) method

This study adopted the FSE approach to achieve an objective quantification of the significance of CSF categories for CE adoption. The use of Fuzzy Synthetic Evaluation (FSE) in this study was deemed appropriate due to its advantages in addressing the uncertainty and subjectivity commonly encountered in multi-criteria evaluation processes. FSE utilizes fuzzy logic to convert subjective human judgments into a quantitative form, taking into account the inherent uncertainty and vagueness present in the evaluation process. This approach helps to mitigate subjectivity and provides a more objective evaluation. The FSE method employs mathematical computations to transform linguistic criteria or variables into measurable forms during the decision-making process. The limitations of binary Boolean logic (i.e., True/False or Yes/No) in the evaluation of events are overcome by the use of fuzzy logic in FSE [33]. The ability of FSE to handle such imprecision and uncertainty makes it an appropriate choice for evaluating complex situations, such as the adoption of Circular Economy (CE) principles in the construction industry. In this study, FSE is used to evaluate the significance of CSF categories in achieving CE in the construction industry. The FSE analysis was conducted through a four-step process [22].

2.4.1 Setting up the fuzzy synthetic evaluation index system

This study employed a two-tiered index system for quantifying the CSFs. The first level consists of six overarching CSF categories: (1) economy, (2) informational, (3) institutional, (4) policy, (5) technology, and (6) commitment and competence. Each category encompasses a set of underlying CSFs that represent the second level. For example, {CSF05, CSF06, CSF07, and CSF08} constitute the underlying CSFs within the information category. The index systems were utilized as input variables in the FSE process. The significance of the CSFs was evaluated using a rating scale defined as V = {1, 2, 3, 4, 5}, representing the range of grade alternatives, ranging from V_1 (not significant) to V_5 (very significant).

2.4.2 Calculating the weightings of the CSFs and their categories

In this phase, the weightings of the underlying CSFs and their respective categories were determined by normalizing their mean values. This computation was performed using equation 4, as follows:

$$Wi = \frac{\mu i}{\sum_{i=1}^{5} \mu i}, 0 < wi < 1, \sum_{i=1}^{5} wi = 1 \tag{4}$$

In this context, Wi represents the weights assigned to the underlying CSFs or categories of CSFs, while μi denotes the mean values of the CSFs or mean values of the CSF categories.

2.4.3 Computing the membership function (MF) of the CSFs and categories of CSFs

This stage involves calculating the membership functions (MFs) for the identified CSFs. Initially, the MFs for the second level are computed, followed by the first-level MFs. The second-level MFs are derived from the respondents' evaluations of the relevant CSFs obtained through the questionnaire survey. For instance, the membership function of MFCSF07 (enhanced education and training of design-related professionals for building deconstruction) could be illustrated using equation 5 as:

$$MF_{CSF07} = \frac{X_{1v_{in}}}{V_1} + \frac{X_{2v_{in}}}{V_2} + \frac{X_{3v_{in}}}{V_3} + \frac{X_{4v_{in}}}{V_4} + \frac{X_{5v_{in}}}{V_5} \tag{5}$$

where, Xjv_{in} (j = 1, 2, 3, 4, 5) represents the percentage of a score the respondents assigned to a CSF v_{in}; and Xjv_{in} /Vj explains the relation between Xjv_{in} and its associated grade alternative based on the rating scale.

However, the MF of CSF categories (Di) was computed which is the product of the fuzzy matrix of the MFs (Ri) of its underlying CSFs and the weighting function of the underlying CSFs under each category. Both Ri and Di are determined using equations 6 and 7, respectively.

$$\text{Ri} = \begin{bmatrix} MF_{v_{i1}} \\ MF_{v_{i2}} \\ MF_{v_{i3}} \\ \cdots \\ MF_{v_{in}} \end{bmatrix} = \begin{bmatrix} X_{1V_{i1}} & X_{2V_{i1}} & X_{3V_{i1}} & X_{4V_{i1}} & X_{5V_{i1}} \\ X_{1V_{i2}} & X_{2V_{i2}} & X_{3V_{i2}} & X_{4V_{i2}} & X_{5V_{i2}} \\ X_{1V_{i3}} & X_{2V_{i3}} & X_{3V_{i3}} & X_{4V_{i3}} & X_{5V_{i3}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ X_{1V_{in}} & X_{2V_{in}} & X_{3V_{in}} & X_{4V_{in}} & X_{5V_{in}} \end{bmatrix} \quad (6)$$

$$\text{Di} = Wi \cdot \text{Ri} = (w1, w2, w3, \ldots, wn) \cdot \begin{bmatrix} X_{1V_{i1}} & X_{2V_{i1}} & X_{3V_{i1}} & X_{4V_{i1}} & X_{5V_{i1}} \\ X_{1V_{i2}} & X_{2V_{i2}} & X_{3V_{i2}} & X_{4V_{i2}} & X_{5V_{i2}} \\ X_{1V_{i3}} & X_{2V_{i3}} & X_{3V_{i3}} & X_{4V_{i3}} & X_{5V_{i3}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ X_{1V_{in}} & X_{2V_{in}} & X_{3V_{in}} & X_{4V_{in}} & X_{5V_{in}} \end{bmatrix}$$

$$= (d_{i1}, d_{i2}, d_{i3}, d_{i4}, \ldots, d_{in}) \quad (7)$$

where "●" is a fuzzy composite operation and di_n denotes the degree of membership of the grade alternative for a CSF.

2.4.4 Quantifying the significance indices of the CSF categories

The significance index for each category of CSFs is determined by multiplying the fuzzy evaluation matrix (Di) by the grade alternatives of the rating scale (Vi). This calculation is performed using equation 8.

Significance index = $\sum_{i=1}^{n} (D_i \times V_i) = (d_{i1}, d_{i2}, d_{i3}, d_{i4}, \ldots, d_{in}) \times (V_1, V_2, V_3, V_4, V_5)$ (8)

3 Results and discussion

3.1 Significant critical success factors for CE in the East Java region

An analysis using mean values and standard deviations (detailed in Table 2) ranked the success factors for CE adoption in construction. Notably, factors with equal means were prioritized based on lower standard deviation [3]. Interestingly, all 40 identified success factors had mean values ranging from 4.19 to 3.58, suggesting their overall significance for CE adoption in the East Java region.

Table 2: Statistical scores and ranking of the CSFs for adopting CE in East Java

ID	Critical Success Factors	μi	σi	Nμi	Rank
CSF01	Incentives for the construction industry that encourage adoption and awareness of the CE	3.58	0.77	0.00	40
CSF02	Incentives and warranty schemes for secondary material utilization	3.69	0.86	0.18	38
CSF03	Establishment of information platforms and marketplaces for construction and demolition waste (C&DW)	3.81	0.79	0.36	26
CSF04	Exploring the cost of various low-waste construction techniques and their potential scalability.	3.72	0.78	0.23	35
CSF05	Workshops among experts on the principles of the CE and its implementation	3.78	0.59	0.32	30
CSF06	Integrate the CE principles into the university curriculum and undertake further CE-based research.	3.81	0.75	0.36	25
CSF07	Enhanced education and training of design-related professionals for building deconstruction.	4.03	0.70	0.73	7
CSF08	Development of relevant guidelines for the implementation of the CE	3.81	0.82	0.36	28
CSF09	Designing for the deconstruction process to enhance end-of-life value	3.89	0.78	0.50	18
CSF10	Design compliance with codes and standards for deconstruction	3.86	0.80	0.45	21
CSF11	Promotion of construction pre-demolition audits	3.83	0.74	0.41	23
CSF12	Encourages classification and sorting of waste during construction and demolition processes (C&D)	3.94	0.53	0.59	12
CSF13	Establishing connections between demolition contractors and suppliers	3.58	0.60	0.00	39
CSF14	Application of modern construction methods	3.83	0.65	0.41	22
CSF15	Development of long-term circular value chains among stakeholders	3.89	0.67	0.50	16
CSF16	Implementation of the C&DW management plan at the construction site	3.92	0.73	0.55	13
CSF17	Developing a clear national plan on the objectives and vision of the CE in the construction industry	4.08	0.77	0.82	5

ID	Critical Success Factors	μi	σi	Nμi	Rank
CSF18	Effective budget allocation by the government to realize the circularity of building and demolition waste	4.17	0.62	0.96	2
CSF19	Sanctions for illegal disposal of construction and demolition waste (C&DW)	3.81	0.89	0.36	29
CSF20	Sanctions for non-compliance and incentives for compliance with CE regulations	3.78	0.80	0.32	33
CSF21	Regulations for compulsory deconstruction planning at the planning permission stage	4.00	0.59	0.68	9
CSF22	Government support in the secondary material market	4.11	0.75	0.86	3
CSF23	Circularity requirements on public procurement	3.69	0.75	0.18	37
CSF24	Tax exemption for goods produced from secondary materials	3.89	0.82	0.50	19
CSF25	Financing for innovation, CE research, and technology subsidies	3.86	0.76	0.45	20
CSF26	Standardization of secondary materials	3.97	0.62	0.64	11
CSF27	Development of advanced resource and processing technologies for construction and demolition waste management (C&DW)	3.81	0.79	0.36	26
CSF28	Create datasets for BIM and explore the potential of BIM in conducting analysis for resource management	3.78	0.68	0.32	31
CSF29	Using BIM to simulate processes and sequences of building demolition	4.00	0.64	0.68	8
CSF30	Development of guidelines and tools for assessing circularity on buildings	3.69	0.62	0.18	36
CSF31	Availability of data and support tools to optimize the supply chain, along with regional waste data	4.03	0.65	0.73	6
CSF32	Increased durability and material quality for longer service life	4.08	0.69	0.82	4
CSF33	C&DW data collection methods and systems	3.89	0.67	0.50	16
CSF34	Improves the quality and value of secondary materials	4.19	0.71	1.00	1
CSF35	Metric development and CE indicators	3.75	0.69	0.27	34
CSF36	Effective leadership and support from specialist contractors	3.78	0.68	0.32	31
CSF37	Adequate knowledge and experience of the project team	3.81	0.71	0.36	24
CSF38	Effective coordination and integration of stakeholders	3.91	0.57	0.54	15
CSF39	Initial and active involvement of key parties in the project	3.97	0.57	0.64	10
CSF40	Initial understanding and client commitment	3.92	0.60	0.55	14

Furthermore, using a normalized mean score (threshold ≥ 0.5), nineteen critical success factors (CSFs) emerged as significant for CE adoption in construction. Among these, based on both mean and normalized mean scores, the top five most significant CSFs for CE adoption in East Java construction are CSF34 (improves the quality and value of secondary materials), CSF18 (effective budget allocation by the government to realize the circularity of building and demolition waste), CSF22 (government support in the secondary material market), CSF32 (Increased durability and material quality for longer service life), and CSF17 (developing a clear national plan on the objectives and vision of the CE in the construction industry).

The highest-ranked critical success factor for achieving a CE in East Java is improving the quality and value of secondary materials (CSF34), with a mean score of 4.19. Enhancing secondary material quality reduces reliance on primary raw materials, which are often scarce and environmentally harmful during extraction and processing. Effective utilization of secondary materials can alleviate pressure on natural resources and minimize environmental impacts [34]. Additionally, higher-quality secondary materials extend product lifecycles, reduce construction waste, and promote sustainable recycling. However, current C&D waste recycling often results in downcycling, where recycled materials are of lower quality than primary raw materials. To address this, policies should focus on upcycling, maintaining comparable quality and value to primary materials [27].

The second most critical factor is effective budget allocation by the government to realize the circularity of building and demolition waste (CSF18), with a mean score of 4.17. Government support through budget allocation is crucial for strengthening CE infrastructure in the construction sector. Adequate funding provides essential incentives for construction companies to adopt environmentally friendly practices and transition towards sustainable resource utilization [17]. This financial commitment is fundamental for CE implementation, particularly in developing countries [21].

Government support in the secondary material market (CSF22) ranks third, with a mean score of 4.11. Strengthening the secondary material market encourages the growth of the recycling industry and technological innovation in producing high-quality secondary materials, thereby enhancing circularity in the construction supply chain. This aligns with Salmenperä et al. [26], who identified the lack of government support as a significant barrier to CE implementation. Support includes economic incentives to stimulate the secondary material market and direct funding for research and development (R&D).

Increased durability and material quality for longer service life (CSF32), scoring 4.08 on the mean, is the fourth critical factor. Improving material durability and quality is essential for realizing CE principles in construction, extending building lifespans, and reducing the need for component replacement. Longer-lasting materials reduce construction waste and enhance resource efficiency [27]. Policies promoting the development and use of durable materials are therefore crucial.

Lastly, developing a clear national plan on the objectives and vision of the CE in the construction industry (CSF17) also means 4.08. This highlights the importance of clear government direction and objectives in driving CE implementation in the construction sector. A comprehensive national plan detailing CE goals and vision is essential for guiding the industry towards CE practices [19]. Strategic and clear policymaking is vital for CE adoption in both developed and developing countries [21].

3.2 Significant critical success factors for CE in the East Java region

According to the established stages in the FSE analysis of CSFs for CE in building construction, weightings and MFs of the CSFs were calculated, leading to significance indices for CSF groups. Table 3 summarizes CSF weightings and categories. MFs were used to calculate the significance indices for CSF categories in building construction for CE. The FSE results are presented in Table 4.

Table 3: Weightings and membership functions of the underlying CSFs and their categories

Category	ID	Wi	MF for level II	MF for level I
Economy				(0.00, 0.02, 0.44, 0.35, 0.19)
	CSF01	0.242	(0.00, 0.03, 0.50, 0.33, 0.14)	
	CSF02	0.250	(0.00, 0.03, 0.47, 0.28, 0.22)	
	CSF03	0.257	(0.00, 0.03, 0.33, 0.44, 0.19)	
	CSF04	0.251	(0.00, 0.00, 0.47, 0.33, 0.19)	
Informational				(0.00, 0.02, 0.28, 0.53, 0.17)
	CSF05	0.245	(0.00, 0.00, 0.31, 0.61, 0.08)	
	CSF06	0.247	(0.00, 0.03, 0.31, 0.50, 0.17)	
	CSF07	0.261	(0.00, 0.00, 0.22, 0.53, 0.25)	
	CSF08	0.247	(0.00, 0.06, 0.28, 0.47, 0.19)	
Institutional				(0.00, 0.01, 0.31, 0.52, 0.17)
	CSF09	0.126	(0.00, 0.03, 0.28, 0.47, 0.22)	
	CSF10	0.126	(0.00, 0.00, 0.39, 0.36, 0.25)	
	CSF11	0.125	(0.00, 0.03, 0.28, 0.53, 0.17)	
	CSF12	0.128	(0.00, 0.00, 0.17, 0.72, 0.11)	
	CSF13	0.117	(0.00, 0.00, 0.47, 0.47, 0.06)	
	CSF14	0.125	(0.00, 0.00, 0.31, 0.56, 0.14)	
	CSF15	0.126	(0.00, 0.00, 0.28, 0.56, 0.17)	
	CSF16	0.127	(0.00, 0.00, 0.31, 0.47, 0.22)	
Policy				(0.00, 0.02, 0.26, 0.48, 0.24)
	CSF17	0.115	(0.00, 0.00, 0.25, 0.42, 0.33)	
	CSF18	0.118	(0.00, 0.00, 0.11, 0.60, 0.29)	
	CSF19	0.108	(0.00, 0.06, 0.33, 0.36, 0.25)	
	CSF20	0.107	(0.00, 0.03, 0.36, 0.42, 0.19)	
	CSF21	0.113	(0.00, 0.00, 0.17, 0.66, 0.17)	
	CSF22	0.116	(0.00, 0.00, 0.22, 0.44, 0.33)	
	CSF23	0.104	(0.00, 0.06, 0.31, 0.53, 0.11)	
	CSF24	0.110	(0.00, 0.03, 0.31, 0.42, 0.25)	

	CSF25	0.109	(0.00, 0.03, 0.28, 0.50, 0.19)	
Technology				(0.00, 0.00, 0.28, 0.52, 0.20)
	CSF26	0.101	(0.00, 0.00, 0.20, 0.63, 0.17)	
	CSF27	0.097	(0.00, 0.00, 0.42, 0.36, 0.22)	
	CSF28	0.096	(0.00, 0.00, 0.36, 0.50, 0.14)	
	CSF29	0.102	(0.00, 0.00, 0.20, 0.60, 0.20)	
	CSF30	0.094	(0.00, 0.00, 0.39, 0.53, 0.08)	
	CSF31	0.103	(0.00, 0.00, 0.19, 0.58, 0.22)	
	CSF32	0.104	(0.00, 0.00, 0.19, 0.53, 0.28)	
	CSF33	0.099	(0.00, 0.00, 0.28, 0.56, 0.17)	
	CSF34	0.107	(0.00, 0.00, 0.17, 0.47, 0.36)	
	CSF35	0.096	(0.00, 0.00, 0.39, 0.47, 0.14)	
Commitment and Competency				(0.00, 0.01, 0.23, 0.63, 0.13)
	CSF36	0.195	(0.00, 0.03, 0.28, 0.58, 0.11)	
	CSF37	0.196	(0.00, 0.03, 0.28, 0.56, 0.14)	
	CSF38	0.202	(0.00, 0.00, 0.21, 0.68, 0.12)	
	CSF39	0.205	(0.00, 0.00, 0.17, 0.69, 0.14)	
	CSF40	0.202	(0.00, 0.00, 0.22, 0.64, 0.14)	

Table 4: FSE values on significant differences in the CSF categories to CE adoption in East Java

Categories of CSFs for CE adoption	FSE Index	Rank
Economy	3.70	6
Informasional	3.86	4
Institutional	3.85	5
Policy	3.94	1
Technology	3.93	2
Commitment and competency	3.88	3

3.2.1 Policy category

According to the FSE analysis, the policy category ranks first with a significance index value of 3.94, indicating its substantial role in CE implementation in the construction sector. This category encompasses 9 CSFs related to policies, underscoring the pivotal role of governmental support and regulations in fostering sustainable practices.

Effective budget allocation by the government to realize the circularity of building and demolition waste (CSF18), highlighted as the most significant for promoting CE in construction, as it fosters innovation, CE research, and technology subsidies (CSF25), driving a CE paradigm shift [21]. Additionally, developing a clear national plan on the objectives and vision of the CE in the construction industry (CSF17) and government support in the secondary material market (CSF22) are essential components, as discussed in the section above However, governmental focus on short-term economic gains and rapid industrial development hinders CE implementation, exacerbated by insufficient environmental regulation compliance and fragmented decision-making [19].

Regulations for compulsory deconstruction planning at the planning permission stage (CSF21) ensure early waste reduction measures in construction projects, necessitating strict government targets and contractual requirements for practitioners' compliance [28]. Additionally, tax exemption for goods produced from secondary materials (CSF24) provide significant financial incentives, addressing the lack of public subsidies for secondary materials by encouraging businesses to adopt eco-certified building practices through innovative programs and new tax policies [19].

Enforcement of strong legal sanctions for illegal disposal of construction and demolition waste (CSF19) and non-compliance with CE regulations, along with incentives for compliance (CSF20), ensures adherence to environmental standards. High fines for waste disposal and other sanctions are essential for compelling construction industries to adopt CE practices, minimizing waste, and avoiding penalties [21]. Also, circularity requirements on public procurement (CSF23) are crucial as they drive construction projects to adopt CE principles by establishing standards for goods and services procurement, thereby promoting the use of secondary materials and fostering circular business models [19, 26]. These policy-related CSFs complement each other, creating a conducive environment for CE principles implementation in the construction industry in East Java.

3.2.2 Technology category

According to FSE analysis, the technology category ranks second with a significance index of 3.93, highlighting its critical role in CE implementation in the construction sector. Encompassing 10 CSFs, this category facilitates innovative and efficient practices, enabling companies to enhance operational efficiency, reduce waste, and optimize resource use. The most significant CSF in the technology category is improving the quality and value of secondary materials (CSF34), with an average rating of 4.19. Both CSF34 and enhancing the durability and quality of materials for longer lifespans (CSF32) were discussed in the section above.

The availability of data and support tools to optimize the supply chain, along with regional waste data (CSF31), is crucial for effective and efficient material and waste management, enabling better resource planning and waste reduction. However, the lack of systematic supply chain planning and CE-related knowledge, compounded by incomplete regional waste data and inadequate indicators and follow-up, significantly hinders CE implementation in Finland [26]. Additionally, using BIM to simulate processes and sequences of building demolition (CSF29) can enhance project planning and execution, reduce errors, and optimize material use. However, the lack of comprehensive regional waste data, adequate indicators, and integrated demolition information with BIM technology poses significant challenges to CE implementation [28].

Standardization of secondary materials (CSF26) ensures quality and compatibility, yet lacking comprehensive standards in China impedes their use in construction due to unclear technical specifications and properties, discouraging designers [27]. Ideal standards encompass technical specifications and properties crucial for advancing the construction industry. Furthermore, development of advanced resource and processing technologies for C&DW management (CSF27) is vital for leveraging construction waste as a valuable resource, aiming to upgrade recycling processes through advanced processing technologies, such as AI-driven smart robotic systems, to consistently produce high-quality standardized products [27, 35].

C&DW data collection methods and systems (CSF33) are crucial for CE success, providing essential waste management insights. Developing a comprehensive data collection system, including construction waste quantity and composition tracking, is vital [31]. Developing a comprehensive data collection system, including construction waste quantity and composition tracking, is vital [31]. Create datasets for BIM and explore the potential of BIM in conducting analysis for resource management (CSF28), can significantly enhance this aspect. This approach can improve stakeholder collaboration, facilitate the visualization of demolition processes, and enable simulations of end-of-life scenarios [19].

The development of CE metrics and indicators (CSF35) alongside guidelines and tools for assessing circularity in buildings (CSF30) is essential for providing a clear framework and practical instruments for stakeholders to measure and enhance circularity in construction projects. According to Oluleye et al. [21], measuring and reporting CE progress play a vital role in the transition towards CE globally. Developing holistic indicators covering various CE scales, from macro (cities and regions) to nano (materials), is necessary to standardize circularity measurement and assessment. This view is reinforced by Chang & Hsieh [36], emphasizing the need for more guidelines and tools to optimize building circularity assessments and designs.

3.2.3 Commitment and competency category

Based on FSE analysis, the commitment and competence category ranks third with a significance index of 3.88, comprising five CSFs crucial for CE implementation. These factors emphasize the necessity of dedication and adequate skills within companies to support CE principles, ensuring both clear vision and necessary capabilities. The most significant CSF in this category is the early and active involvement of key stakeholders in projects (CSF39), mean 3.97. This underscores the crucial role of active stakeholder engagement, particularly with clients and key project team members such as designers, manufacturers, contractors, project managers, and logistics companies, in leveraging relevant inputs for CE implementation in construction [22].

Furthermore, initial understanding and client commitment (CSF40) are vital, as strong client commitment can drive the entire project team to adopt CE principles. Success in achieving circularity in construction relies on initial client understanding and commitment, ensuring projects are designed considering CE principles, and securing adequate funding for circular construction material procurement [22]. Effective coordination and integration of stakeholders (CSF38) are crucial for project alignment and efficiency, enhancing sustainability. Barakat et al. [31] emphasize communication and coordination among architects, engineers, and contractors to achieve waste diversion goals, raise environmental awareness, and educate stakeholders on waste reduction and management strategies.

Adequate knowledge and experience within the project team (CSF37) ensure successful implementation of CE strategies. Wuni & Shen [22] stress the importance of project stakeholders' knowledge, particularly design and demolition managers, in circular material usage and project lifecycle understanding. Additionally, manufacturer comprehension of CE and lean production supports achieving circularity targets in construction projects. Effective leadership and support from specialist contractors (CSF36) are vital, as they possess specialized knowledge to address technical and operational challenges. Integrating CE principles into construction requires contractors' technical expertise in material choices, processes, and decision-making, enhancing success prospects [22].

3.2.4 Informational category

Based on FSE, the informational category ranks fourth with a significance index of 3.86, highlighting its critical role as a success factor in promoting awareness, understanding, and access to CE knowledge in the construction industry. Implementation success relies heavily on disseminating sustainable practices information to stakeholders, addressing challenges like limited comprehension and misinterpretation of CE concepts, as emphasized by Paiho et al. [37]. Deep understanding and heightened awareness facilitate easier adoption of CE principles, fostering construction industry transformation towards circularity. The most significant CSF in the informational category is enhancing education and training for professionals in design for deconstruction (CSF07), averaging 4.03. This underscores the pivotal role of education and training in empowering professionals to apply CE principles. Akinade et al. [28] stress the importance of improving education on design for deconstruction for architects and design engineers, advocating for comprehensive training covering building design, relevant demolition regulations, documentation, BIM-based software, and safety considerations for material handling and demolition.

In the informational category, the development of relevant guidelines for the implementation of the CE (CSF08) is crucial, providing clear direction for practitioners. These guidelines, as emphasized by Oluleye et al. [21], serve as strong management tools for recycling, reusing, and recovering materials throughout the building lifecycle. Furthermore, integrating CE principles into the university curriculum and undertaking further CE-based research (CSF06) establishes a strong knowledge foundation for future generations. This transition, vital for sustainable development, necessitates significant research and development efforts, as emphasized by Munaro & Tavares [19] and Oluleye et al. [21]. Organizing workshops among construction industry experts on CE principles and implementation (CSF05) facilitates information exchange, fostering deeper understanding and more effective CE application. Enhancing management team competencies, including architects, structural engineers, contractors, and technicians, is emphasized as crucial for achieving comprehensive circularity in construction [21].

3.2.5 Institutional category

Based on the FSE analysis, the institutional category ranks fifth with a significant index value of 3.85, comprising eight significant CSFs related to organizational strategies supporting circular practices in the construction industry. These factors include stakeholder collaboration, top management commitment, and internal policy formulation conducive to CE implementation. Integrating these strategies into daily operations enhances institutions' readiness to achieve CE goals in the construction sector. The most significant CSF in the institutional category is promoting waste classification and sorting during construction and demolition (C&D) processes (CSF12), with a mean value of 3.94. This underscores the systematic effort needed in waste classification and sorting during the early stages to enhance waste management efficiency and maximize material reuse. Effective waste management, categorized based on value, is crucial from project inception, ensuring materials are diverted from landfills and reused appropriately [21, 27].

Within the institutional category, another crucial CSF is the implementation of Construction and Demolition Waste (C&DW) management plans on construction sites (CSF16), ensuring efficient waste handling in line with CE principles. These plans outline contractors' strategies for minimizing and managing C&DW throughout project phases, enabling effective waste management strategies [29, 31]. Also, the development of long-term circular value chains among stakeholders (CSF15) is crucial for sustainable collaboration, promoting collaborative efforts and industrial synergy. Initiatives in this direction facilitate closed-loop systems, wherein waste from one company becomes a valuable resource for another [19]. Designing for the deconstruction process to enhance end-of-life value (CSF09) maximizes material reuse, which is crucial in ensuring CE implementation success, emphasizing the importance of easy disassembly in construction [21].

Ensuring design compliance with codes and standards for deconstruction (CSF10) ensures adherence to regulations. Effective design management is crucial for CE project success, yet the construction industry lacks well-defined methods to enhance demolition design efficiency despite existing standard procedures [28]. Furthermore, promotion of construction pre-demolition audits (CSF11) aids in identifying recyclable materials pre-demolition, which is crucial for effective CE implementation. These audits provide stakeholders such as clients, architects, planners, and engineers with data to optimize building reuse and predict quantities of materials for reuse, recycling, and remanufacturing [21].

Application of modern construction methods (CSF14), such as prefabrication and modularization, supports efficiency and waste reduction, with research indicating significant waste reduction of up to 84% [29]. However, limited adoption hinders these benefits, particularly in conventional methods that generate more waste, notably in concrete work, reinforcement, plastering, and ceramic installation. The widespread use of modern methods is crucial for substantial waste reduction. Also, establishing connections between demolition contractors and suppliers (CSF13) lays the groundwork for closer collaboration in managing construction resources and waste more effectively.

3.2.6 Economic category

Based on the FSE analysis, the economic category ranks last but remains significant for CE implementation in construction, with an index significance value of 3.7. Despite this, it plays a crucial role in fostering sustainable economic growth and creating financial opportunities and markets supportive of circular practices in the construction industry. The most significant CSF in the economic category is the establishment of an information platform and marketplace for C&DW (CSF03), averaging 3.81. This implies its crucial role in driving sustainable economic growth in the construction sector by enabling efficient utilization of C&DW as new resources, creating new financial opportunities, and expanding the market for circular practices. This finding aligns with Oluleye et al. [21], indicating the benefits of recycling marketplaces for construction and demolition waste in both developed and developing countries. The complexity of C&DW necessitates an information platform for sharing data on location, composition, and properties, with e-marketplaces for C&DW exchange proven successful in western countries, reducing costs and generating employment [27].

Exploring the costs of various low-waste construction techniques and their potential scalability (CSF04) is crucial for identifying economically efficient and environmentally friendly strategies. Consequently, conducting cost-benefit analyses for stakeholders adopting CE principles justifies investments in reuse, recycling, and energy recovery while promoting sustainable building benefits to enhance market demand and competitiveness [19]. Incentives and warranty schemes for secondary material utilization (CSF02) bolster support for circular practices in the construction industry by providing economic motivation. Since costs are a primary concern for contractors with limited profit margins, secondary materials become viable when they are more cost-effective than primary materials [27]. Thus, public-private partnerships can help establish feasible incentives and guarantee schemes for using secondary materials [19].

Similarly, providing Incentives for the construction industry that encourage adoption and awareness of the CE (CSF01) offers recognition and motivation for circular practices. By awarding certifications, financial incentives, or other recognitions, businesses are more likely to engage in recycling materials, efficient waste management, and eco-friendly technologies. This not only benefits the environment but also promotes sustainable economic growth in the long term. This aligns with research by Oluleye et al. [21], emphasizing that recognizing the efforts of construction industry stakeholders in adopting CE is a crucial factor for CE implementation in both developed and developing countries.

4 Implication of the study

This study makes a significant contribution to the knowledge and application of CE in the construction industry, particularly in East Java. The first step involves identifying and categorizing Critical Success Factors (CSFs) for the adoption of CE in the construction industry based on literature reviews. This study classifies these CSFs into six defined categories, which simplifies the process of implementing and managing them. The CSFs and their categories are examined through the viewpoints of Architecture, Engineering, and Construction (AEC) professionals in East Java. In addition, the study emphasizes the necessity for context-specific approaches by demonstrating the significance of comprehending regional variations in critical factors for effective CE implementation.

Valuable insights are supplied to stakeholders such as deconstruction engineers, designers, architects, contractors, clients, and government authorities, which have managerial implications. For instance, the policy category plays a crucial role in facilitating the adoption of CE, as proven by effective budget allocation and government support in the secondary material market. Similarly, the technology category has a crucial role in improving the quality and value of secondary materials. Moreover, the commitment and competency category emphasizes the importance of including stakeholders early in initiatives. Furthermore, the informational category emphasizes the significance of improving education and training for professionals, while the institutional category focuses on promoting waste classification and sorting during construction and demolition processes. Additionally, the economic aspect is of equal significance, as it emphasizes the establishment of an information platform and marketplace specifically for construction and demolition waste (C&DW). This initiative aims to promote sustainable economic development within the construction industry.

Based on the research findings, the policy category ranks first as the most critical CSF for CE adoption in the construction industry. The other five categories (technology, commitment & competency, institutional, informational, and economy) are inextricably linked to the policy category, as policy plays a pivotal role in supporting these other aspects. Therefore, an evaluation mechanism involving regular monitoring and assessment by the government is essential to ensure the successful implementation of CE, which ultimately supports the achievement of sustainable construction. This government oversight would facilitate the effective implementation and continuous improvement of CE practices by ensuring that policies are adhered to and updated as needed. This systematic evaluation and monitoring process will ensure that all categories work synergistically towards achieving sustainable construction in East Java.

Finally, this study examines how these CSFs might be practically applied to promote CE in East Java construction industries. It offers useful insights into how these CSFs can be implemented in real-world circumstances. In summary, the results provide a thorough comprehension of the complex consequences of implementing CE principles in the construction industry, along with practical suggestions for the various stakeholders involved to promote sustainable building construction. To enhance clarity and actionable guidance, a summary of the necessary actions and the personnel responsible for carrying them out is presented in Table 5.

Table 5: Summary of Key Actions and Stakeholders for Circular Economy Practices

CSF Categories	Actions Required	Stakeholder/ Person in Charge	Information of Stakeholder
Policy	1. Effective budget allocation by the government to achieve circularity of building and demolition waste	Government	government establishments, legal authorities, regional development agencies
	2. Government support in enhancing the secondary material market		
	3. Developing a clear national plan on the objectives and vision of the CE in the construction industry		
Technology	1. Improving the quality and value of secondary materials	Manufacturers	-
	2. Increasing durability and material quality to extend service life		
Commitment and competency	1. Ensuring initial and active involvement of key parties in the project	Project Professionals	architects, engineers, project managers, subcontractors, clients, builders, employees
	2. Securing initial understanding and commitment from clients		
Informational	1. Enhancing education and training for design-related professionals in building deconstruction 2. Developing relevant guidelines for CE implementation	Public, Government	academic institutions, professional associations, industry associations, regulatory bodies
Institutional	1. Encouraging classification and sorting of waste during construction and demolition processes (C&D)	Project Professionals	project managers, site managers

CSF Categories	Actions Required	Stakeholder/ Person in Charge	Information of Stakeholder
	2. Implementing a Construction and Demolition Waste (C&DW) management plan at construction sites		
Economy	1. Establishing information platforms and marketplaces for Construction and Demolition Waste (C&DW)	Government	government establishments
	2. Exploring the costs and scalability of various low-waste construction techniques	Project Professionals	consultants and industry experts

5 Conclusion

The construction sector must urgently transition to a Circular Economy (CE) due to its significant environmental impact, which includes waste production and resource depletion. Critical success factors (CSFs) are requirements for the effective implementation of CE. These CSFs push the paradigm toward systemic circularity and zero waste, which in turn promote sustainable development. After a thorough assessment of the literature, 40 CSFs were carefully identified and divided into six groups. Following that, 36 valid replies to a targeted questionnaire survey that was conducted among stakeholders in East Java's Architecture, Engineering, and Construction (AEC) sector were obtained. These responses were then subjected to a thorough analysis using statistical software (SPSS).

The gathered data was carefully examined using descriptive statistical analysis methods and fuzzy synthetic evaluation (FSE). The FSE analysis underscored the overarching significance of all six CSF categories, each registering significance indices surpassing 3.50 on a 5-point scale, thus affirming their collective importance. However, policy, technology, and commitment and competency are the top three important categories. This study provides insights from the FSE results, which extends significant contributions to practical applications. Through the establishment of an allocation function, the results offer the East Java government and AEC stakeholders significant insight that enables them to prioritize relevant CSFs that are essential for achieving systemic circularity in the region.

Although this study provides insightful information, it is important to recognize that it has inherent constraints that may limit how broadly the results may be applied. Geographically limited to Indonesia's East Java region, the findings may not be as applicable to other areas with different settings. In order to address these limitations, future studies can enhance the analysis and improve the comprehensiveness of the results by employing other research methodologies. Furthermore, it is recommended to broaden the study's scope to encompass additional territories. Consequently, researchers and construction stakeholders can acquire a more extensive comprehension of CE activities in diverse situations, thereby enhancing their understanding of the subject of CE.

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