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ASSESSING THE IMPACT OF AI INTEGRATION ON ADVANCING CIRCULAR PRACTICES IN CONSTRUCTION

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Abstract. This study provides a thorough examination of the potential and problems associated with integrating artificial intelligence (AI) into the circular economy (CE) framework within Sri Lanka's construction industry. The study uses approach that combines primary data obtained through a questionnaire survey involving several stakeholders with secondary data analysis from academic sources. The data were interpreted using descriptive and statistical analysis, such as Kendall's Tau correlation and Pearson's correlation. There is an optimistic view about AI's potential advantages, including resource and energy conservation, even if the technology is still in its early integration phases. Nevertheless, there are still significant barriers to adoption, such as a lack of knowledge and reluctance to change. The study offers a conceptual framework for combining AI with CE principles, including IoT, computer vision, and machine learning technologies to enhance the Reduce, Reuse, and Recycle (3R) CE principles. This framework supports cooperative efforts, skill development, and policy development to support sustainable building practices in Sri Lanka.

Keywords: artificial intelligence, built environment, circular economy, sustainability, Sri Lanka.

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1. Introduction

According to Wijewansha et al. (2021), Oti-Sarpong et al. (2022), Spudys et al. (2023), and Amran et al. (2022), the construction industry is a complex and dynamic field that involves both the creation and construction of new structures and engineering initiatives and the maintenance and improvement of already-existing facilities. The actions of the industry have a greater impact on achieving national socio-economic growth objectives, such as employment and infrastructure development (Fei et al., 2021; Nundy et al., 2021; Omri & Belaïd, 2021; Sultana et al., 2022). In addition, the construction sector boosts other businesses and generates a lot of employment opportunities. In fact, greater construction work seems to correlate with economic success and advancement, which makes it a reliable indicator of a country's financial state (Zhang et al., 2021; Fang et al., 2022; Wang et al., 2022; Weerakoon et al., 2023).

Like every other industry, the construction sector in any part of the world has challenges and complexities that must be overcome to be considered sustainable. Furthermore, many barriers are involved in the transition to a more environmentally conscious construction industry. The building sector has come under criticism for adopting innovations and technical developments poorly (Wang et al., 2021; Giorgi et al., 2022; Sadeghi et al., 2022; Wildenauer et al., 2022). The environmental impact of the sector increases with population growth, urbanization, and construction project size. Furthermore, it has been well-recognized for the past thirty years or so that the construction sector uses a significant number of resources–roughly 30% currently, compared to over 40% in the 1990s (Benachio et al., 2020; de Andrade Salgado & de Andrade Silva, 2022; Hickel et al., 2022; Younis & Dodoo, 2022). It produces more than three billion tons of waste from construction and demolition (C&D) annually (Jain, 2021; Umar et al., 2021; Alsheyab, 2022). It is identified that the construction sector in most of the developed and developing nations employs the linear economic (LE) method of "take, make, and dispose" when examining the underlying causes of environmental degradation and material shortages. However, the conventional LE model has continuously failed to solve the problems associated with global sustainability (Velenturf & Purnell, 2021; Sun et al., 2022; Corvellec et al., 2022). Therefore, researchers and industry practitioners are interested in exploring a different approach to address this situation. As a result, the circular economy (CE) has gained a lot of attention as a viable way to reduce waste and save resources. However, most of the developing countries including Sri Lanka are currently adopting this concept on a small scale.

The CE model emerged from the LE model and emphasizes material and resource reduction, recycling, and reuse (Weerakoon et al., 2023). Global environmental goals, like lowering CO_2 emissions and preserving resources by promoting sustainability and avoiding waste, are in line with this strategy. Artificial intelligence (AI) could serve as a helpful tool in integrating a CE within the construction industry, as it requires innovative approaches rather than traditional ones. Though there has been a lot of discussion about how AI is being utilized in other industries and frameworks, it is unclear how AI is being used practically in the CE. To close this knowledge gap, this research proposes to investigate and comprehend how AI might help with the deployment and digitalization of CE. Additionally, this research looks at how AI could facilitate the transition to CE and determines how it can be positioned in Sri Lankan CE practices. The following is a summary of this research objectives:

- to evaluate the knowledge and awareness of construction industry practitioners about AI and CE;
- to investigate the possible roles of AI technology in accomplishing circular economy objectives in the built environment;
- to determine the obstacles and limitations to using AI in circular economy approaches in Sri Lankan construction;
- to analyze the relation between AI and CE for implementation and propose strategies.

2. Materials and methods

To enhance comprehension of how AI may aid in the growth of CE in Sri Lanka's construction sector, the research will focus on significant industry players, obstacles to execution, and opportunities. Primary and secondary data were gathered using a mixed-method approach. Using databases like Scopus and Web of Science (WoS), secondary data from research articles was gathered, focusing on the role AI plays in sustainable construction and the barriers to AI and CE adoption. Primary data were collected using a questionnaire survey that focused on their familiarity with AI and CE, the benefits of integrating AI and CE, and the barriers that exist in the implementation process. The survey was distributed to 150 industry professionals from September 2023 to November 2023, yielding a 72% response rate (108 responses). The questionnaire survey consisted of 4 sections. The first section gathers data about participants' occupational information. The second section relies on the comprehension of AI and CE among participants. The third segment gathers respondents' perspectives on integrating AI and CE in the built environment. The fourth section collected data on possible challenges and barriers that may hinder the integration of AI and CE. The relationship between AI adoption and levels of CE practices was investigated through statistical analysis using the SPSS.V25 (Statistical Package for the Social Sciences) software, which included Pearson and Kendall's Tau correlation analyses. The methodology is broken down into five stages, as shown in Figure 1.

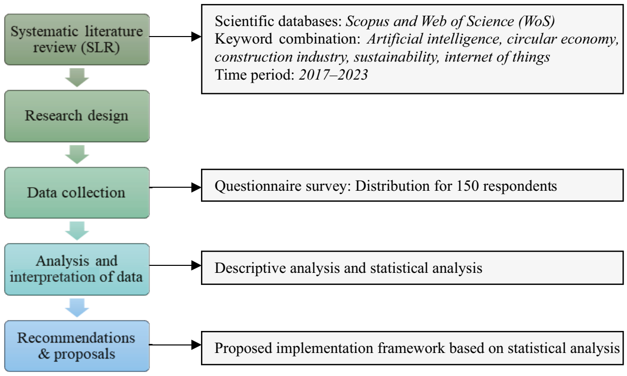

Figure 1. Flow chart of the research strategy employed

3. Results

3.1. Descriptive analysis

Engineers, project managers, architects, government officials, and quantity surveyors were among the many occupational profiles identified by the questionnaire (see Figure 2). Three-quarters of the respondents, or engineers, believe that engineers are essential in promoting innovation, embracing AI technology, and implementing circular economy concepts at different phases of initiatives. For projects to be sustainable and efficient, project managers are crucial, according to 24.1% of respondents. Regulatory frameworks are influenced by government personnel (13.9%), whilst architects (14.8%) are involved in the early conceptualization and design of projects. A key component of project cost control is quantity surveyors (11.1%). In the construction industry, collaboration and long-term success depend on tactics that are customized to the needs of each group.

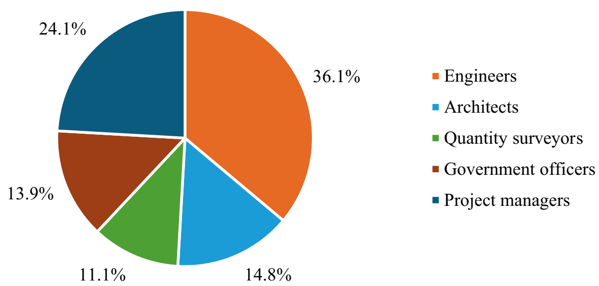

Figure 2. Occupational profile of the respondents

The results of the survey showed that respondents' familiarity with AI and CE concepts varied with some claiming a moderate grasp and others confessing to illiteracy (see Figure 3). It's interesting to note that none of the respondents claimed to be experts in either field, underscoring the necessity of educational programs for the construction sector. This emphasizes how crucial it is to implement capacity-building initiatives to improve knowledge and creativity around AI and CE concepts.

Figure 4 illustrates the participants' varying degrees of optimism regarding numerous applications of AI. Although there was cautious optimism over AI's application in material lifecycle assessments, many thought it may increase resource efficiency and decrease waste. Respondents had varying opinions on AI's capacity to improve supply chain efficiency, forecast maintenance, and make wise decisions about green design.

Important barriers to implementing AI and CE in construction are highlighted by survey data (see Figure 5). "Lack of Awareness and Knowledge," "Resistance to Change," and "Higher Implementation Cost" are some of the major problems. To integrate AI with CE, technological compatibility, skill development, and regulatory challenges must be addressed, with data privacy and security concerns being more crucial than data quality and availability.

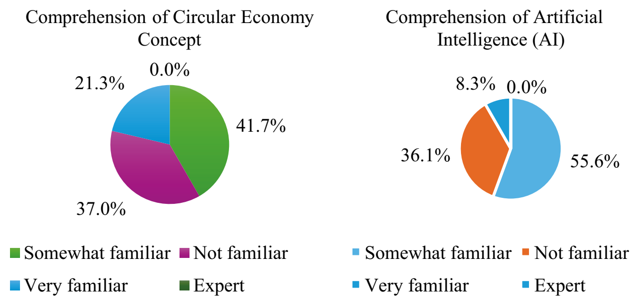

Figure 3. Awareness of CE and AI among industry practitioners

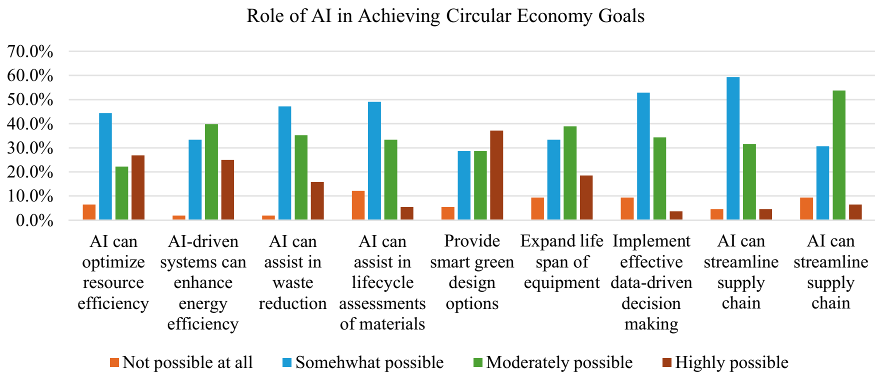

Figure 4. Sustainability goals that could be met by integrating AI and CE

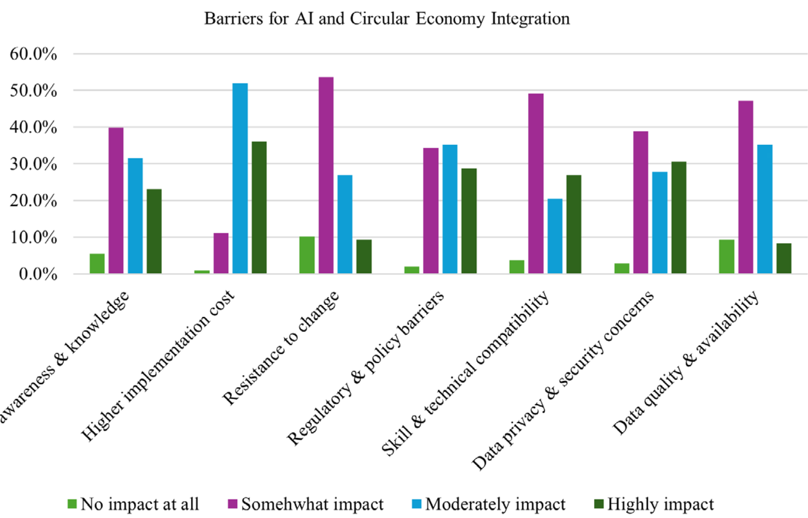

Figure 5. Barriers for implementing AI and CE in construction industry

In summary, the findings from the survey indicate a generally positive outlook for AI's revolutionary influence on the construction industry during the next ten years. However, deliberate measures are required in the construction firm to accomplish the revolutionary outcomes.

3.2. Analysis of the relationship between AI and CE adoption

Researchers employed Pearson correlation and Kendall's Tau correlation analysis to examine the association between the degree of AI deployment and the integration of CE practices. Expressed as a linear relationship between two continuous variables, Pearson correlation analysis quantifies the link between variables (Schober et al., 2018). The value of Kendall's Tau, a correlation measure between survival endpoints in randomized controlled trials, is dependent upon the treatment arms (Emura et al., 2021). The findings of Kendall's Tau correlation analysis provide greater clarity on the relationships between the use of AI and CE principles. The stability of the relationships is confirmed by the fact that, in particular, the positive correlations found in Kendall's Tau analysis frequently match those stated in the Pearson correlation. For the simplicity of analysis and representations, variables used for the analysis were assigned codes and it is shown in Table 1.

The Pearson correlation coefficients (r) and associated significance levels are shown in Table 2.

Table 1. Variables and their codes used in the correlation analysis

Variable	Code
AI can optimize resource efficiency	RE
AI-driven systems can enhance energy efficiency	EE
AI can assist in identifying opportunities for waste reduction	WR
AI can assist in lifecycle assessments of materials	LC
Provide smart green design options	SD
Expand the life span of the equipment by predictive maintenance	PM
Implement effective data-driven decision-making	DM
AI can streamline the supply chain	SC
AI can enable traceability of construction materials	TM

Table 2. Results of the Pearson correlation analysis

		RE	EE	WR	LC	SD	PM	DM	SC	TM
		1	2	3	4	5	6	7	8	9
RE	Pearson Correlation	1	0.370**	0.316**	–0.043	0.644**	0.314**	–0.176	0.060	0.250**
	Sig. (2-tailed)		0.000	0.001	0.657	0.000	0.001	0.069	0.537	0.009
	N	108	108	108	108	108	108	108	108	108
EE	Pearson Correlation	0.370**	1	0.128	0.187	0.464**	0.323**	0.287**	0.012	0.424**
	Sig. (2-tailed)	0.000		0.188	0.053	0.000	0.001	0.003	0.898	0.000
	N	108	108	108	108	108	108	108	108	108
WR	Pearson Correlation	0.316**	0.128	1	–0.091	0.259**	0.101	0.006	0.334**	0.160
	Sig. (2-tailed)	0.001	0.188		0.346	0.007	0.298	0.955	0.000	0.099
	N	108	108	108	108	108	108	108	108	108
LC	Pearson Correlation	–0.043	0.187	–0.091	1	0.091	0.134	0.366**	0.121	0.162
	Sig. (2-tailed)	0.657	0.053	0.346		0.348	0.166	0.000	0.213	0.093
	N	108	108	108	108	108	108	108	108	108
SD	Pearson Correlation	0.644**	0.464**	0.259**	0.091	1	0.538**	–0.029	0.078	0.419**
	Sig. (2-tailed)	0.000	0.000	0.007	0.348		0.000	0.766	0.423	0.000
	N	108	108	108	108	108	108	108	108	108
PM	Pearson Correlation	0.314**	0.323**	0.101	0.134	0.538**	1	0.116	0.000	0.416**
	Sig. (2-tailed)	0.001	0.001	0.298	0.166	0.000		0.230	1.000	0.000
	N	108	108	108	108	108	108	108	108	108
DM	Pearson Correlation	–0.176	0.287**	0.006	0.366**	–0.029	0.116	1	0.277**	0.177
	Sig. (2-tailed)	0.069	0.003	0.955	0.000	0.766	0.230		0.004	0.066
	N	108	108	108	108	108	108	108	108	108
SC	Pearson Correlation	0.060	0.012	0.334**	0.121	0.078	0.000	0.277**	1	0.376**
	Sig. (2-tailed)	0.537	0.898	0.000	0.213	0.423	1.000	0.004		0.000
	N	108	108	108	108	108	108	108	108	108
TM	Pearson Correlation	0.250**	0.424**	0.160	0.162	0.419**	0.416**	0.177	0.376**	1
	Sig. (2-tailed)	0.009	0.000	0.099	0.093	0.000	0.000	0.066	0.000	
	N	108	108	108	108	108	108	108	108	108

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

Table 3. Strategies to overcome barriers based on statistical analysis

Strategy	Code	Relationship	Key takeaway
Interactions between green design and resource efficiency	GD	The value of "Provide smart green design options" and the idea that "AI can optimize resource efficiency" are significantly positively correlated	The application of clever green design principles should be emphasized while promoting the use of AI in procedures meant to increase resource efficiency
Traceability of the supply chain with strategic alignment	SC	There are positive connections between the belief that "AI may streamline supply chain" and the acknowledgment that "AI can enable traceability of construction materials"	To create a cohesive approach to sustainability, efforts to enhance construction material traceability should be strategically linked with the integration of AI into supply chain management
Integrated methods for creating energy-efficient designs	EF	Positive correlations between several AI adoption factors, including increased energy efficiency, less waste, and clever green design choices, suggest a more extensive relationship	A comprehensive strategy for integrating AI into circular economy initiatives should acknowledge the interdependence of several elements, promoting a cooperative execution blueprint
Collaboration among stakeholders via effective decision-making	DM	When favorable correlations are acknowledged, strategic efforts may be directed toward sectors where stakeholders may already be aware of strong connections between AI and circular economy practices	Implementing AI in circular economy projects can be more successful if measures align with current positive perceptions
Continues research and development	RD	Adaptive strategies and ongoing research are essential for staying abreast of shifting viewpoints and filling in any knowledge gaps	The ongoing study and observation will enable the creation of adaptable solutions for AI and CE integration

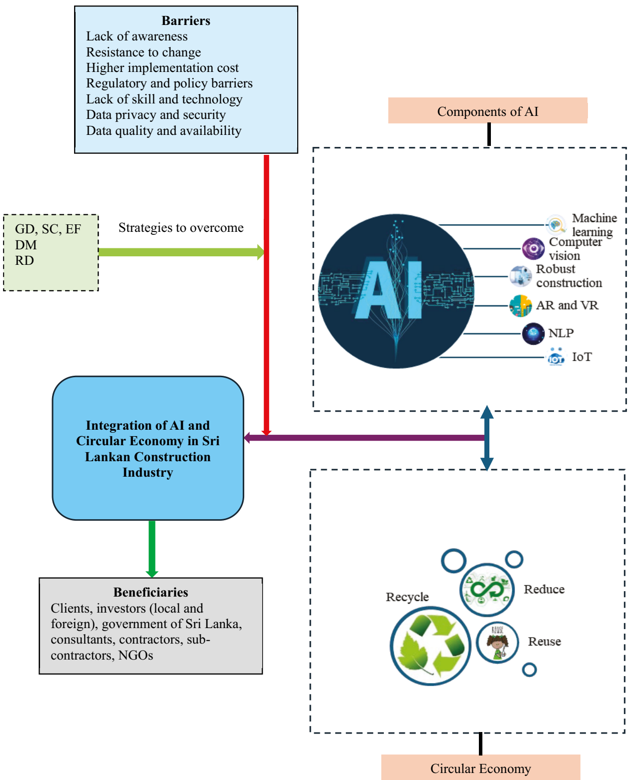

Figure 6. Proposed framework for integrating AI and CE

Table 3 illustrates the significant findings on the link between AI adoption and the application of CE methodologies in construction according to the performed correlation analyses.

4. Discussion

Pearson and Kendall's Tau correlation studies reveal a strong correlation between AI and CE concepts, guiding the development of a model (see Figure 6) that effectively combines the 3Rs for sustainable construction practices across various civil engineering specializations.

The 3R principles offer a clear framework for stakeholders to commit to waste reduction and resource conservation, and they are in line with global sustainability objectives such as the United Nations Sustainable Development Goals (SDGs). Besides, the 3R principles are ideal for broad acceptance and significant use in current systems, even if there are more evolved frameworks of 3R concepts available such as 6R and 10R.

5. Conclusions

This study offers a thorough analysis of the effects of incorporating AI into the advancement of circular processes in the construction sector in Sri Lanka. The researchers sought to clarify the possibilities and difficulties related to AI integration in the context of the CE using a methodological approach that included primary data collected via a questionnaire survey involving a variety of stakeholders and secondary data analysis from academic sources.

Results highlight a significant lack of understanding of CE concepts among the stakeholders in Sri Lanka's construction industry, highlighting the necessity of focused educational initiatives. Notwithstanding this shortcoming, there is general optimism about the potential advantages of AI, particularly in the areas of resource and energy conservation, even if the technology is still in its early stages of integration. However significant barriers to adoption still exist, including inadequate awareness and expertise as well as resistance to change.

The study provides a conceptual framework for combining AI with CE principles, embracing technologies like IoT, computer vision, and machine learning, to overcome these obstacles and realize possible benefits. In addition to promoting collaboration, this framework emphasizes the need for regulatory changes and capacity-building programs to promote sustainable construction practices in Sri Lanka.

Furthermore, this research provides significant fresh details about how AI integration might stimulate sustainable growth in the construction sector, especially in the context of the circular economy paradigm. Stakeholders may leverage AI's catalytic power to promote resource efficiency, waste reduction, and overall sustainability in construction processes by filling in knowledge gaps, overcoming adoption barriers, and cultivating cooperative collaborations.

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DIRBTINIO INTELEKTO, TAIKANT ŽIEDINĘ EKONOMIKĄ STATYBOJE, POVEIKIO VERTINIMAS

T. G. Weerakoon, J. Šliogerienė, Z. Turskis

Santrauka

Šiame tyrime nagrinėjamos dirbtinio intelekto (DI) integravimo į žiedinės ekonomikos (ŽE) sistemą Šri Lankos statybos pramonėje galimybės ir ribojantys veiksniai. Tyrime taikomas metodas, kuriame derinami duomenys, gauti atlikus kelių suinteresuotųjų šalių anketinę apklausą, ir duomenys, gauti atlikus mokslo literatūros šaltinių analizę. Duomenys buvo interpretuojami taikant aprašomąją ir statistinę analizes, Kendall's Tau koreliaciją ir Pearson'o koreliaciją.

Optimistiškai vertinant, nors DI technologija dar tik pradedama integruoti statybų sektoriuje, pastebimi jos privalumai, pvz., išteklių ir energijos taupymas. Nepaisant to, vis dar esama didelių diegimo kliūčių, tokių kaip žinių trūkumas ir nenoras keistis. Tyrime siūloma koncepcinė sistema, sistema, kurioje DI derinamas su ŽE principais, įskaitant daiktų internetą, kompiuterinę regą ir mašininio mokymosi technologijas. Tai leistų patobulinti ŽE principus: „mažinti, pakartotinai naudoti ir perdirbti" (3R). Taikant siūlomą sistemą skatinamas bendradarbiavimas, įgūdžių ugdymas ir politikos formavimas siekiant remti tvarią statybos praktiką Šri Lankoje.

Reikšminiai žodžiai: dirbtinis intelektas, užstatyta aplinka, žiedinė ekonomika, tvarumas, Šri Lanka.