December 31, 2024 Vol. 6 No. 4 E-ISSN 3027-0170 P- ISSN 3027-2548

International Journal of

ENVIRONMENTAL DESIGN & CONSTRUCTION MANAGEMENT (IJEDCM)

www.harvardpublications.com

EXPLORING OPPORTUNITIES OF DIGITAL TECHNOLOGIES FOR ENHANCING EFFICIENCY IN THE CIRCULAR ECONOMY WITHIN THE CONSTRUCTION INDUSTRY

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DOI: https://doi.org/10.70382/hijedcm.v06i4.005

Abstract
The construction industry is the largest consumer of raw materials and the largest generator of waste all over the world making it vulnerable to sustainability challenges. This research aims at establishing how blockchain (BC) and smart contract (SC) could improve circular economy strategies in construction industries. The research method used in the study is quantitative and data

Keywords: Blockchain Technology, Smart Contracts, Circular Economy, Construction Industry, Digital Transformation.

INTRODUCTION

The construction industry is the largest user of raw materials and producer of waste worldwide, using about 40% of all resources and contributing to 35% of the total global waste (Ellen MacArthur Foundation, 2020). Therefore, the implementation of circular economy principles has become one of the most effective approaches in sustainable construction practises, as environmental problems grow and resources get depleted. The circular economy idea can be defined as the idea of doing more with less, of minimising waste, and of keeping products and materials in use for as long as possible; therefore, it seems much more appealing than the linear "take-

was collected through an online survey of 134 construction industry professionals from different countries with the most from the United Kingdom and Australia. The results of the study show that there is great potential for the enhancement of resource efficiency and efficiency of waste management within the construction sector through the adoption of BC and SC technologies but these are constrained by the following challenges. These are high infrastructure costs, lack of digital skills, and issues to do with security. The study recognises financial stability, organisational management, and government support as enablers in the adoption of the technology. Thus, the study enriches the existing body of knowledge by presenting a holistic view of the role of digital technologies in enabling circular economy in construction. The paper provides the concrete suggestions to the representatives of the tourism industry, stressing the need for the staged implementation strategies, sufficient technical support, and cooperation with other industries. This study provides evidence that despite the barriers, the benefits of adopting BC and SC technologies in construction circular economy practises are compelling enough to warrant implementation, given the right enabling environment.

make-dispose" model (Adams *et al*., 2017).

The use of ICT innovative solutions has proved to be a strong driver that supports the application of circular economy strategies in construction. Building Information Modeling (BIM), Internet of Things (IoT), blockchain, smart contract and artificial intelligence are advancing technologies are transforming the construction projects' planning, performance and management during their life cycle (Benachio *et al*., 2020). These technologies help in better management of material track, waste management and optimization of material use, thereby assisting the principles of circular economy of minimising waste and maximising resource utilisation.

The analysis of the digital technologies in construction confirms their positive impact in several aspects of circularity. For example, BIM is capable of calculating the precise material requirements and waste estimation during the design process, whereas IoT sensors can evaluate building performance and material decay in real-time (Charef & Lu, 2021). In addition, blockchain technology improves supply chain information and material chain, guaranteeing the effectiveness of recycled materials and promoting their recycling (Yang *et al*., 2020).

However, as the following sections reveal, the construction industry still has a long way to go in terms of adopting digital technologies for circular economy execution. These are; high fixed costs, low levels of modularity, limited digital competencies in the workforce, and resistance to change from conventional construction practises (Leising *et al*., 2018). It is important to address these barriers and leverage the opportunities in order to build strategies that will increase the speed of digitization of the construction industry towards circular economy.

Statement of Research Problem

The construction industry has been rated as one of the most unsustainable industries in the world due to its linear economic model of production that has resulted to environmental degradation, resources depletion and generation of wastes (Munaro *et al*., 2020). Despite the potential of the circular economy to address these challenges, the application of circular economy in construction is still not well developed due to technological and operational constraints. As the use of technological solutions is gradually increasing, their ability to support circular economy in construction practises has not been significantly unlocked or investigated comprehensively (Çetin *et al*., 2021).

A significant research limitation lies in the lack of insight into how digital technologies may be adopted to underpin circular economy practises in construction activities. Although previous research has focused on the effectiveness of technologies singly, or some attributes of circularity, there is a lack of research that explores the full implementation of digital solutions throughout the construction value system (Papadonikolaki *et al*., 2017). Furthermore, there is limited awareness of how these applications complement each other and their combined interaction in delivering circular economy goals in construction projects.

In addition, the construction industry requires specific guidelines as to how digital tools should be integrated to support circular economy improvements; however, it currently has no coherent process (Guerra *et al*., 2019). This study seeks to fill these gaps by providing a conceptual framework to understand how digital technologies can support circular economy in construction.

Objectives

i. To determine opportunities resulting from digital technologies (blockchain and smart contract) toward the enhancement of efficiency in the circular economy in the construction industry.

ii. To examine the challenges of using BC and SC technologies for circular economy in the construction industry

Methods

Research Philosophy

Research philosophy defines the origin of knowledge and the characteristics of the phenomenon under investigation. It is useful in informing the overall research and determining the method that should be used. This research adopted positivism as its epistemology given that it sought to use scientific methods and data to examine the connexion between BC and SC and the way they enhance the construction of a circular economy. Positivism has an opportunity to describe reality objectively as it focuses on a quantitative approach to analysing the state of the social world (Bisel & Adame, 2017). In parallel to this epistemology, an objectivist ontology was used, claiming that reality is objective and people do not influence it (Saliya, 2023). This approach helped the research to reduce biases and prejudices hence increasing the chances of having a correct perception of the phenomenon (Ragab & Arisha, 2018). Together, these philosophies contributed to the study having a robust and impartial identification of how digital technologies increase efficiencies in construction.

Research Approach

There are three key types of research approaches; deductive, inductive, and abductive. The deductive research approach begins with a broad theory and makes use of it to handle certain predictions (Young *et al.*, 2020). Researchers gather data to try out these predictions and find out whether the theory is true. This approach is suitable when existing theories come up with a strong foundation for producing research questions and conducting data collection. Researchers start with observations and collecting data and make use of these findings to put in place large concepts. They are applied when the research topic requires deep-rooted theories (Young *et al.*, 2020).

The abductive research approach is a combination of deductive and inductive approaches. It entails giving rise to reasonable explanations to clarify observed phenomena. Existing knowledge and creative thinking are used by researchers to come up with possible explanations for the data which are afterward tested and purified (Earl Rinehart, 2021). The abductive research is adequate for this research topic because it gives room for the investigation of new ideas and the initiation of innovative perceptions. This study aim at understanding and exhibit the possible ways in which BC and SCs can facilitate the circular economy in the establishment, which needs a flexible and innovative mindset.

This research adopted a deductive research approach because it will consider the new ideas, practical suggestions, and theories, facilitating the investigation of opportunities of digital technologies for enhancing efficiency in circular economy within construction industry. Questionnaire was developed based on the literature read and tested that the theory in the literature in regards to benefits, opportunities resulting from digital technologies (blockchain and smart contract) toward the enhancement of efficiency in the circular economy in the construction industry and challenges of using BC and SC technologies for circular economy in the construction industry.

Research Strategy

According to Abutabenjeh and Jaradat (2018), a research strategy is a set of activities that an investigator needs to embark on while conducting the research. In this research, survey strategy was used. The data for the study was collected with the help of the survey research strategy from the respondents. Survey research strategy entails collection of information from a sample of respondents. It was used to collect and dissect information from the respondents. Data is also collected through qualitative interviews which enables the researcher to understand the investigated question. The quantitative survey is mainly used in business studies and allows the researcher to reach many respondents (Myers, 2019). As for the above statement, to address how can BC and SC technologies support the circular economy in construction, quantitative surveys were obtained by an online survey method. The choice of the quantitative research strategy proved to be beneficial in this study, as it allowed the researcher understand the opportunities of BC and SCs technologies.

Research Choice

The probability of obtaining meaningful and valid results can be enhanced by choosing the right research methodology, data collection techniques, and data analysis techniques (McCusker & Gunaydin, 2015). The current study also used a quantitative approach to gather real-world data by analysing the digital technologies (BC and SC) the circular economy in construction. The data for this investigation was collected through an online questionnaire. The online questionnaire asked respondents about their perceptions, and their prior knowledge of how BC and SCs could be utilised to enhance circular economy principles within the building sector. This representative sample was collected through email and LinkedIn with engineers, architects, project managers, and contractors in the construction industry. The researcher then quantified the collected data in order to analyse it.

Sampling Technique

Sampling Technique

Sampling is used to pick a representative sample from a larger population for analysis. As stipulated by Stratton (2021), to get data that are both representative and trustworthy, researchers often use sampling methods. This research made use of a purposive sampling strategy. In this method, respondents are selected from a pool of people who understand the nature of concepts being explored; in this case, they were the construction industry workers who are aware of BC, SC and circular economy. The fundamental benefit of purposive sampling is its efficiency and applicability, particularly in research that is technical (Strickland and Stoops, 2019). Due to the exploratory character of this study and the online survey approach used to collect data, purposive sampling was opted for.

The researcher used purposive sampling to efficiently reach respondents via an online questionnaire. It sped up the procedure by recruiting online-accessible respondents with relevant expertise and experience, such as specialists in the field. While convenience sampling does have certain useful benefits, researchers should not overlook its drawbacks. For instance, according to Speklé and Widener (2018), possible biases and limited generalisability of the findings are associated with the fact that the sample obtained using this method may not completely represent the larger population.

Data Analysis

The data were analysed using the SPSS software that provided the information linked to the research objectives. Quantitative data is easily translated when figures like charts, tables, and diagrams are used to analyse and simplify the data (Guetterman *et al.*, 2021). Chi-Square test, specifically the McNemar-Bowker Test were conducted that aimed at evaluating the correlation. The tables, charts and the graphs were easily translated to get the clear and valid findings from the data collected.

Ethics

There were several ethical considerations that were followed in this study. Ethical considerations are principles that guide the design and practices of the research (Pietilä *et al.*, 2020). The first ethical consideration followed in this study was the principle of informed consent. respondents were informed about the nature of the research and given an opportunity to accept or refuse to take part in it. The principle of informed consent ensures that the respondents voluntarily participate in the study. The supervisor was informed about the nature of the topic and approved it before commencing. The study ensured the dignity and wellbeing of all the respondents has been protected. Principles of confidentiality and anonymity were adhered to in this study. Anonymity and confidentiality principles ensured that the privacy of the respondents was protected when gathering and analysing data. Data were encrypted and stored securely to prevent unwanted access. The principle of integrity was adhered to in this study. This was achieved by employing the right methods to gather and analyse data. The elements of transparency and honesty ensured integrity had been achieved in this data. Data collection and analysis methods were verifiable to enhance the principle of integrity.

Methodology Limitation

The major limitation of the methodology was time. Application of BC and SC technology to facilitate circular economy is a wide area that requires a lot of time to gather and analyse data. To counter this limitation the gathering and analysing of data concentrated on the research objectives. Other concepts and themes that were not in the objectives of the research were not applied while collecting and analysing data.

Resulfts

Demographic Characteristics of Respondents

Table 1: Demographics of respondents

Demographic	Responses	Frequency	Percentage
Age	18-25 years	7	5.2
	26-34 years	45	33.6
	35-44 years	51	38.1
	45-54 years	21	15.7
	55+ years	10	7.5
		134	**100.0**
Level of education	GSCEs	1	0.7
	A-Levels	5	3.7
	HNC/HND	4	3.0

	Bachelor's degree	69	51.5
	Master's degree	48	35.8
	Ph.D.	7	5.2
		134	**100.0**
Location	UK	72	53.7
	Australia	34	25.4
	Canada	3	2.2
	Ireland	1	0.7
	Nigeria	4	3.0
	South Africa	1	0.7
	USA	18	13.4
	Other	1	0.7
		134	**100.0**
Job Role	Project manager	23	17.2
	Engineer	45	33.6
	Contractor	36	26.9
	Consultant	19	14.2
	Academic	4	3.0
	Student	6	4.5
	Other	1	0.7
		134	**100.0**
Years of experience	1-5 years	31	23.1
	6-10 years	81	60.4
	11-15 years	15	11.2
	16+ years	7	5.2
		134	**100.0**

There were total of 134 respondents. As shown in Table 1, the largest group of respondents was aged between 34-44 years (38.1%), followed by 26-24 years (33.6%). Respondents aged between 18-25 were the least forming (5.2%). Most of the respondents had a bachelor's degree (51.5%) or a master's degree (35.8%). One (0.7%) of the respondents had GSCE-level education. Fifty-three percent of the respondents were from the United Kingdom given the link to the questionnaire was sent to many construction companies in the UK. Most respondents from outside UK were from Australia followed by the United States of America.

Most people who responded to the survey were engineers (33.3% of total respondents) and contractors (26.7%). Academics and students were the least being 4% and 4.4% respectively. Sixty-point-four percent of the respondents had 6-10 years of experience in construction; 23.1% of them had 1-5 years of experience. People with 16+ years of experience were the least respondents 5.2%.

Challenges of using BC and SC technologies for circular economy in the construction industry

The One-Sample T-test results for the questions about BC and SC technologies, as well as the issues and factors they raise, offer important insights into how respondents view these topics. Each question focuses on a distinct element of how these technologies are being used in the construction sector, highlighting both the advantages and disadvantages. Respondents demonstrated a statistically significant mean difference of 0.57463 for the first question (Q1.1), with a t-value of 10.183 (p .000). This demonstrates the widespread acceptance of BC and SC technology among responders. The wide range of this opinion's 95% confidence interval, from 0.4630 to 0.6862, emphasises how strong it is.

Table 2: One-Sample Test for Q7-Q11

One-Sample Test

	Test Value = 3					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Q6	26.380	133	.000	1.567	1.45	1.68
Q7	11.732	133	.000	1.149	.96	1.34
Q8	21.596	133	.000	1.478	1.34	1.61
Q9	23.907	133	.000	1.552	1.42	1.68
Q10	22.313	133	.000	1.575	1.44	1.71
Q11	18.673	133	.000	1.448	1.29	1.60

Moving on to issue on question 6 in Table 2, which is about incorporating current industrial practices, the mean difference of 1.567 and a p =.000 indicate a level of agreement. This difference, which falls within the confidence interval of 1.45 to 1.68, shows that respondents are inclined to see such integration favourably. Respondents reported a high consensus regarding the difficulties encountered during implementation (Q7), with a mean difference of 1.149 and a t-value of 11.732 (p .000). The confidence interval of 0.96 to 1.34 further supports the idea that implementation issues are a given. The mean difference of 1.5528 and a t-value of 23.907 (p .000) indicate that Q9 security and privacy problems also attracted a lot of attention. The strong agreement among respondents on these problems is highlighted by the confidence interval, which ranges from 1.42 to 1.68.

Strong agreement is shown in the area of legal and regulatory considerations (Q10) by the significant mean difference of 21575 and the high t-value of 22.313 (p .000). Confidence intervals of 1.44 to 1.71 demonstrate that respondents are aware of the importance of taking these factors into account. The difficulties in developing decentralized systems (Q11), with a mean difference of 1.448 and a t-value of 18.673 (p .000), also emerged as a significant subject. The respondents' consensus that such difficulties exist and must be addressed is supported by the confidence interval of 1.29 to 1.60.

Enablers of BC and SCs for the Circular Economy in Construction

The analysis of variance (ANOVA) results elucidates the significance of enablers for the adoption of BC and SCs in the construction industry's circular economy. The p-value, which serves as an indicator of statistical significance, is shown by the column labelled "Sig." in the context of an ANOVA (Analysis of Variance). Finding the statistical significance of variations in group means is the aim of this statistical approach. The null hypothesis is disproved when the p-value is less than.05, demonstrating that at least one group mean clearly differs from the others. There is no statistically significant difference between the groups if the p-value is bigger than this.

The analysis of variance (ANOVA) shows how Blockchain (BC) and Smart Contract (SC) technologies might allow Circular Economy (CE) creation. Q12's statistical significance (p=.004) shows that business continuity (BC) and supply chain (SC) practises have several influences. Combining BC with SC practises is tricky. Q14's.001 p-value shows the study's focus on organisational management. The company needs a stable economy and a good work environment, as shown by the p-values of.000 for Q15 and Q16. Q13's p-value of.088 indicates disagreement regarding government actions. This study reveals how hard it is for companies to embrace supply chain and business continuity practises. These studies focus effective management, money, and working environment. Recognising the numerous government involvement views on this subject is crucial. In essence, while certain factors like organizational management, financial stability, and the work environment garner collective agreement as facilitators, others like government policies present a more divided stance, underscoring the intricate nature of BC adoption in the construction sector.

Table 3: ANOVA for Q12-16

				Sum of Squares	df	Mean Square	F	Sig.(p values)
Q12	Between Groups	(Combined)		10.436	3	3.479	4.619	.004
		Linear Term	Weighted	8.995	1	8.995	11.945	.001
			Deviation	1.440	2	.720	.956	.387
	Within Groups			97.893	130	.753		
	Total			108.328	133			
Q13	Between Groups	(Combined)		4.670	3	1.557	2.229	.088
		Linear Term	Weighted	.891	1	.891	1.276	.261
			Deviation	3.779	2	1.889	2.706	.071
	Within Groups			90.763	130	.698		
	Total			95.433	133			
Q14	Between Groups	(Combined)		5.275	3	1.758	5.543	.001
		Linear Term	Weighted	2.995	1	2.995	9.443	.003
			Deviation	2.279	2	1.140	3.593	.030
	Within Groups			41.240	130	.317		
	Total			46.515	133			
Q15	Between Groups	(Combined)		8.653	3	2.884	7.743	.000
		Linear Term	Weighted	6.411	1	6.411	17.210	.000
			Deviation	2.242	2	1.121	3.009	.053
	Within Groups			48.429	130	.373		
	Total			57.082	133			
Q16	Between Groups	(Combined)		7.556	3	2.519	10.484	.000
		Linear Term	Weighted	6.247	1	6.247	26.004	.000
			Deviation	1.309	2	.654	2.725	.069
	Within Groups			31.228	130	.240		
	Total			38.784	133			

Discussion

Digital technologies requires robust infrastructure and technical expertise to implement technologies (Alhanaee & Alhanaee, 2021). There is the risk of security and privacy challenges linked with utilising BC and SC technologies for initiatives of circular economy in the construction industry. Despite the positive impact of the technology, if the legal systems have not been followed well, it cannot be of help and it is likely to bring more challenges to the company than the benefits.

To determine opportunities resulting from digital technologies toward the enhancement of efficiency in the circular economy in the construction industry, the benefits and enablers of BC and SC for CE were identified. Enablers like government policy, financial stability and organisation management help in identifying areas that construction companies should look at before implementing the technologies. The financial resources are needed to ensure the company is able to purchase tools and equipment that will ensure the implementation of the technologies is successful (Hossain *et al*., 2020). The enablers, benefits and challenges help this study to identify recommendations to the construction sector on how they can adopt circular economy practices.

Conclusion

The application of blockchain (BC) and smart contracts (SC) in construction industry's circular economy: Opportunities and threats. From the research, it has been established that these digital technologies can improve efficiency and sustainability in construction practises especially in waste management. Nevertheless, the following challenges have to be resolved in order to implement the approach successfully: infrastructure, expertise, and security.

The study also emphasise the role of the enablers like financial readiness, organisational readiness and government policies in enhancing the use of these technologies. One of the most important categories of resources is financial for purchasing required tools and equipment for implementation. The research also focuses on the importance of effective legal regulation of the technologies and prevention of security and privacy threats.

Despite the construction industry's positive attitude toward implementing BC and SC technologies to enhance circular economy principles, the shift entails several factors. Implementation is therefore a function of managing technical issues, acquiring and developing infrastructure, building workforce competencies, and providing right regulation. These will be important considerations as the industry progresses to define how digital technologies can be best implemented to support sustainable construction and circular economy principles.

Recommendations

Based on the findings, the study offers the following recommendation;

i. It was found that due to lack of technical skills this aspect was a big hindrance to implementation, therefore the development of technical infrastructure and training of the workforce in matters concerning digital skills.

ii. Mapping out legal and regulatory frameworks to allow for security and privacy issues to be addressed, covering data protection and responsibilities of all stakeholders.

iii. Preliminary expenditures, recurring costs, staff development, and software upgrade should be factored into financial planning and resource procurement before the implementation of the programme.

iv. Implement these systems incrementally beginning with pilot projects rather than going to full-scale implementation right away to deal with resistance to change and to make modifications.

v. Build a professional community for knowledge exchange and collaboration to mitigate implementation issues more effectively through cooperation with other industries.

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