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HOW CAN BLOCKCHAIN (BC) AND SMART CONTRACT (SC) TECHNOLOGIES FACILITATE THE CIRCULAR ECONOMY (CE) IN CONSTRUCTION

GOODLUCK OGHOGHO OKOTIE

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Abstract

This research aims at examining how blockchain and smart contract technologies can enhance the circular economy in construction. In this quantitative research, data was collected from 134 construction industry professionals from different countries with majority from the UK and Australia by an online questionnaire. The research targeted respondents who possessed certain levels of experience in the field of engineering, construction, project management, and consultation and, therefore, used purposive sampling. An analysis of the survey data indicated that there was a level of support for the application of blockchain (BC) and smart contract (SC) technologies in enhancing circular economy practises. Industry professionals provided higher consensus regarding the benefits of these technologies for promoting circular economy in construction, with mean scores in all the

[redacted]

statements above 4.6 on a 5-point scale. The pre to posttest findings were statistically significant t (58.00) p < .000 indicating that the participants' views

Keywords; Blockchain technology, smart contracts, circular economy, construction industry, sustainable construction.

shifted from being neutral about the technologies' advantages. From these findings, the research suggests awareness creation and training, implementation partnership models, policy and incentives support, and more research on the application of BC and SC technologies in the construction sector circular economy.

INTRODUCTION

Blockchain (BC) and Smart Contracts (SC) combined with Circular Economy (CE) principles can be considered as the new direction in construction industry when shifting from linear to circular economy. Using the BC technology, construction materials can be tracked transparently all through their lifecycle, and Smart Contracts for circularity are self-executing programmes.

Material passports, tracking the characteristics and history of building materials, supply chain CE through material traceability and quality, the trade of waste materials through closed-loop systems, and smart maintenance systems for construction assets are some of the core areas that BC and SC technologies enable CE in construction. Also, these technologies can facilitate tokenization of circular assets which results in innovative business models for the management of materials in circular economy. These technologies can be well applied in the construction sector, which contributes to about 40% of the overall waste according to World Green Building Council (2019). Some of the issues include technical infrastructure requirements, standardisation requirements, and industry adoption barriers (Omrany *et al*., 2023; Shojaei *et al*., 2021).

Blockchain technology and smart contracts have emerged over the last decade to prove the potential for technology in recording transactions in decentralised, peer-to-peer networks through database distribution. Through solving a single entity problem, it utilises distributed computing paradigm to blockchain network nodes to perform a secure and reliable distributed ledger within all past transactions (Laghari *et al*., 2023). Through the smart contract, blockchain technology carries out the terms of an agreement between two or more parties in a decentralised setting through adequate satisfaction of necessary circumstances (Taherdoost, 2023). According to Singh and Singh (2016), blockchain is described as the cryptocurrency technology of a shared digital ledger, which continuously updates and records all transactions. Taherdoost (2023) elaborates on smart contracts as codes that encapsulate and replicate the terms of real-world contracts in the digital domain. Blockchain and smart contract technologies can facilitate processes of circular economy through sharing, leasing, reusing, repairing, and refurbishing existing materials and products.

Thesis Statement

Blockchain (BC) and Smart Contract (SC) technologies have emerged as promising solutions in supporting the Circular Economy (CE) in the construction sector. Recent research has suggested the use of blockchain-based frameworks to improve the area of waste management in construction and support CE. For example, Lin *et al*. (2024) present a literature on a new blockchain-enabled information management system that attempts to enhance the control and traceability of construction and demolition waste (CDW). This system makes it possible to reintroduce recycled CDW into the production process, which would promote the creation of circular economy in construction.

Also, integrating blockchain with digital building twins has been considered for performance-based smart contracts. Hunhevicz *et al*. (2022) show how integrating digital building models with blockchain can improve performance reviews and payments and make construction projects more transparent and accountable.

These developments indicate that BC and SC technologies can play a major role in CE in construction by optimising waste, increasing openness and automating procedures. However, more studies and field applications can be done to fully harness the benefits of these gases and address current challenges.

Statement of Research Problem

It is clear that smart contracts are correlated with security and privacy challenges. Besides this, they are also faced with legal and usability issues. Thus, it is necessary to generate and accumulate more and more data on the topic of blockchain technology, for smart contracts to be performed with great comprehension, for sufficient circular economy. However, there is a need for the involved parties to understand smart contract development so that they can develop the right code which is responsive to the dynamic legal and market environment across various countries. This research will examine the possibilities associated with different digital technologies for creating efficient and sustainable smart contracts. By so doing, organisations will be in a position to adopt the best circular economic practises through smart contracts and blockchain technologies targeting the identified problems. This research will be focused on addressing these problems so as to achieve a controlled and profitable smart contract between organisations.

Research Aim

The aim of this study is to identify how can blockchain and smart contract can technologies facilitate the circular economy in construction.

Research Objectives

1. To assess how the various digital technologies such as blockchain and smart contract technologies promote the development of a circular economy in construction.
2. To understand the current state-of-the-art for blockchain and smart contracts for the circular economy in construction.

Literature Review

The construction industry has some of the major challenges with regards to CE mainly in re-use, waste and sustainability. Blockchain (BC) and Smart Contracts (SC) have appeared as promising tools to increase CE uptake through improving transparency, traceability, and automation in construction supply chains (Lin *et al*., 2024). Blockchain allows for the tracking of the material throughout the supply chain from when it was purchased up to the point that it was disposed of, minimises waste, and discourages falsification of data (Kiu *et al*., 2022). The application of blockchain technology coupled with material passports will help the construction stakeholders authenticate the origin, quality, and recyclability of the materials to enhance sustainable procurement and minimization of waste (Turk & Klinc, 2017).

CE is also advanced by smart contracts which automate transactions and CE principles. Hunhevicz *et al*. (2022) discuss the function of SCs in performance-based construction contracts under which payments occur automatically due to data from building twins. Automating such contracts guarantees that obligations concerning the reapplication of materials and sustainable objectives are met with little controversy. Moreover, through pre-defined conditions of the SCs established on the blockchain, the recycling process is automatically enhanced as well as encouraging sustainable behaviour among the contractors (Lin *et al*., 2024).

However, there are still some issues arising from the implementation of BC and SC technologies in construction. Costs related to the integration of smart technologies are another factor; the implementation of smart systems is often expensive, and, therefore, making them the norm in industries is difficult (Akbarieh et al., 2022). In addition, regulatory and legal risks which are associated with blockchain transactions are a concern and there is need for more effective regulation regarding blockchain transactions (Turk & Klinc, 2017). Therefore, the next steps for research should be aimed at the creation of unified guidelines, increasing the company of blockchain technology, as well as increasing the integration of the construction value chain to optimise the use of blockchain to support CE.

Therefore, BC and SC technologies can be considered as effective solutions for implementing CE in construction through enhancing the system's transparency and using automation tools and incentives. Yet, the exploration of implementation barriers is essential for their effective implementation in the industry.

Research Method

Introduction

The research methodology chapter thoroughly explains the procedures utilised to gather and analyse the data for the study. The section's opening paragraphs discuss the study's design and data collection techniques. Here, the research strategy and approach used in this research are also highlighted. The time horizon and data analysis are also provided in this chapter. The chapter concludes with a discussion of some of the most critical ethical issues, data constraints, and the researcher's methods for determining the validity of research findings.

Research Philosophy

Research philosophy is a key determinant of identifying the origin of research knowledge and the character of a phenomenon. It encompasses two key branches: epistemology and ontology.

Epistemology centres on the theory of knowing, which outlines how knowledge is acquired and assured. The epistemological view adopted in this research was positivism since it focused on scientific evidence and knowledge to establish the use of blockchain and smart contracts in adopting circular economy in construction industry. Positivism is an objective view of the social world, by which the researcher can investigate the relationship between concepts and come to conclusion by the results of the quantitative analysis (Ryan, 2018). This approach helped the study to discover an accurate fact concerning the impact of both BC and SC technologies on CE practises, which provided measurable and accurate information.

Whereas, Ontology focuses on the study of existence and the nature of reality. As expected, given the overall research orientation of this study, objectivism was accepted as the ontological position. Objectivism holds that reality is out there and not influenced by an individual's perception of the situation (Saliya, 2023). This approach reduces prejudice and assumptions, which leads to an impartial assessment of the connexion between BC, SC technologies and CE in the construction industry (Ragab & Arisha, 2018).

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 will 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.

Research Choice

The validity and credibility of the study can be improved by selecting research approaches, methods of data collection, and analysis methods with great care. This research adopted a quantitative approach to examine the link between blockchain (BC), smart contracts (SC), and the circular economy (CE) in the construction industry. The survey was conducted using an online questionnaire to elicit the respondents' opinion, experience and knowledge regarding the application of BC and SC technologies in enhancing the CE principles. The participants were selected through purposive sampling from engineers, architects, project managers, and contractors through emails and linked accounts.

Quantitative data was analysed using statistical techniques such as regression analysis to ensure that the study established meaningful relationships and associations thus the validity and reliability of the study (Castleberry & Nolen, 2018; Uffelmann et al., 2021). Quantitative research was selected because it enables data collection from a large population in a short time and is relatively cheap (Oyuga et al., 2019; Asgari et al., 2021).

Research Methods

Sampling Techniques

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.

Questionnaire

Quantitative data were gathered from various construction industry respondents via an online questionnaire. Nayak and Narayan (2019), state that an online survey is a systematic online questionnaire filled out by your intended audience. There questionnaire was designed using Google Forms. The researcher effectively reached many relevant parties by emailing them a survey. The link was sent to several construction companies via email and LinkedIn. The informed consent was integrated in the questionnaire. The questionnaire aimed to collect data about the construction industry's potential use of BC and SC technologies to promote the circular economy. Many relevant parties were reached by emailing them a survey. This helped collect extensive quantitative data from a wide range of respondents uniformly and systematically to the questionnaire.

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. Quantitative method, therefore, was the best research methodology due to the broad areas of study in the related research topic. The approach is the best for analysing a complex research topic that requires a wide analysis and dynamic mechanisms. The quantitative also provides a richer insight into the research topic than what a qualitative approach could offer. As noted by Leavy (2022), quantitative research enables a combination of different knowledge that helps the research findings due to the study of complex figures depending on the research topic.

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.

RESULTS

Introduction

This section presents the results of the study. These results came from the responses of the respondents who filled out the online survey sent to them. The respondents were stakeholders from different construction companies in different countries. The first section presents the demographics of the respondents which includes their age, education, location, job role, and work experience. The second part is the descriptive statistics analysis of the results from survey. The next part presents the inferential statistics for the results from this survey. This is where the significance of the data is demonstrated.

Demographic Characteristics of the 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

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	11-15 years	15	11.2
	16+ years	7	5.2
		134	**100.0**

Source: Author's Survey (2024)

From Table 1, 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%.

Benefits of BC and SC Technologies for Circular Economy in the Construction Industry

Hypothesis 1: The application of Blockchain (BC) and Smart Contract (SC) technologies has a significant impact on facilitating the circular economy in the construction industry.

Null Hypothesis (H0): BC and SC technologies do not offer significant benefits for the circular economy in the construction industry.

Alternative Hypothesis (H1): BC and SC technologies offer significant benefits for the circular economy in the construction industry.

Table 2: One -sample statistics from Q1 to Q5

	N	Mean	Std. Deviation	Std. Error Mean
Q1	134	4.60	.672	.058
Q2	134	4.66	.637	.055

Q3	134	4.64	.554	.048
Q4	134	4.63	.644	.056
Q5	134	4.65	.604	.052

Source: Author's Analysis (2024)

The hypothesis is evaluated using the one-sample t-test findings against a mean of 3, where 3 is considered to be neutral on a scale of 1 to 5 (See Table 1). This does not represent agreement or opposition. The average response from the respondents was 1.604 for the first question (Q1). This number deviates by .672 from neutral (standard deviation in Table 2), indicating a minor tendency towards agreement. With a p-value of .000, this variation was determined to be statistically significant. Further clarification is provided by the 95% confidence interval, which shows that we can be certain that the true mean for the larger population would fall between 2.604 and 2.72.

Table 3: One-sample t-test Q1 to Q5

	Test Value = 3					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Q1	27.644	133	.000	1.604	1.49	1.72
Q2	30.264	133	.000	1.664	1.56	1.77
Q3	34.311	133	.000	1.642	1.55	1.74
Q4	29.398	133	.000	1.634	1.52	1.74
Q5	31.610	133	.000	1.649	1.55	1.75

The average score for the second question (Q2) was 4.66, according to the results. This indicates that the respondents tended to agree with the statement only a little bit more than they did not. This view is supported by the significant p-value of.000 and a 95% confidence interval spanning from 1.49 to 1.72. The average response for question 3 was 4.55. This demonstrates a slight movement in opinion in favour of neutrality. The true mean, which lies between 1.55 and 1.74, is predicted to fall within the range given by the related 95% confidence interval. Instead of taking a neutral position in response to the fourth question (Q4), respondents tended to lean somewhat in the direction of agreement. This is clear from the 4.63 average score. The results are given much more significance because the 95% confidence interval's limits for this query fall between 1.52 and 1.74.

The respondents' mean sentiment for Q5 in table 3 is 4.65. Over the neutral score, this result indicates a modest degree of agreement. This observation is even more solid when the 95% confidence interval is between 1.55 and 1.75. Overall, the respondents' opinions tended to trend more toward agreement than neutrality for all five questions (Q1 to Q5).

Hypothesis 2;

Regarding the degree to which Blockchain and Smart Contracts may advance a certain element or purpose within the sector, the general view among the population under investigation differs from a neutral stance.

The third question (Q3) within the context of hypothesis 2 was subjected to a one-sample t-test against a test value of 3, which on a scale of 1 to 5 reflects a neutral viewpoint. This doesn't imply acceptance or denial of the assertion in question. The average score from the respondents for Q3 was 4.64, according to the data. This deviates by 0.554 points from neutral, indicating a little tendency towards agreement. The p-value of.000, which implies that this result is not by chance but rather represents an actual trend among the respondents, confirms the statistical significance of this deviation. The 95% confidence interval provides further precision by indicating that, if we were to regularly sample from the larger population, we could be confident that the true average response would lie between 1.55 and 1.74 as indicated in table 4 below.

Table 2: One-Sample Test for Q3

	Test Value = 3				
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference

					Lower	Upper
Q3	34.311	133	.000	1.642	1.55	1.74

The key takeaway from these results is that respondents generally concur with the assertion made in Q3 in table 4. There is evidence that the respondents incline more towards agreement than remaining neutral, even when the departure from neutrality insignificant. The interpretation or application of hypothesis 2 may be affected by this. If the null hypothesis assumes that there is no significant agreement or departure from neutrality, this may provide evidence to reject the null hypothesis in favour of the alternative.

Discussion

To understand various digital technologies such as BC and SC technologies promote the development of a circular economy in construction, this study identifies the benefits that are linked with BC and SC for CE. By understanding the advantages the BC and SC technologies are able to bring to CE, this study can help identify technologies that are able to help these advantages to be identified. BC and SC technologies promote the speedy completion of projects in the construction industry (McNamara and Sepasgozar, 2021). This help in understanding BC and SC technologies that promote speed. Stakeholders are able to receive information immediately after any updates have been made (Sadeghi, Mahmoudi, and Deng, 2022).

To understand the current state-of-the-art for BC and SC for the CE in construction, the study identified the challenges and benefits linked with them. This helped in understanding what they experience that benefits them and challenges them. We understand companies that have employed the technologies for the CE have been able to sustainably manage resources and speedy completion of projects and stakeholders are able to follow operations easily. It requires robust infrastructure and technical expertise to implement technologies (AlHanaee and 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

Facilitating circular economy is a major challenge that construction industry has faced over the years. Challenges of the speed completion of projects, sustainable resource management, supply chain transparency, slow decision making are experienced by CE in construction sector. These challenges emerge because efficient and effective technologies have not been employed in the industry. The aim of this study was to identify how can blockchain and smart contract can technologies facilitate the circular economy in construction. This aim was achieved by understanding the benefits, challenges and enablers of BC and SC for CE. From the results BC and SC technologies can facilitate the circular economy ways like sustainable resource management, speedy completion of the project, supply chain transparency and saving energy and other resources.

Recommendations

i. Promote Awareness and Training on BC and SC Technologies

In order to increase the BC and SC implementation in the construction industry, training courses for engineers, architects, contractors, and project managers should be designed. It means that stakeholders are aware of the opportunities that can be provided by such technologies in terms of operations and costs.

ii. Collaborative Implementation Frameworks

Establish structures that work towards fostering cooperation of stakeholders in the use of BC and SC. This also involves developing best practise guidelines for applying these technologies in increasing circularity within projects, to optimise project performance and reduce waste.

iii. Policy Support and Incentives

For instance, governments and industry regulators should provide incentives like tax credit or grant that will encourage organisations to adopt BC and SC technologies. The integration of such technologies can be encouraged by the policies in the industry.

iv. Expand Research on Industry-Specific Applications

Promote more extensive studies on BC and SC for other areas of the circular economy including waste identification, resource exchange and material flows.

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