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A principal component analysis of barriers to the implementation of blockchain technology in the South African built environment

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Abstract

Purpose – Blockchain technology is one of the emerging innovative technologies making waves globally, and it has been adjudged to have the capability to transform businesses. With the different capabilities of the technology, such as immutability of information and decentralisation of authority attributes, the built environment is slow in its adoption. This study aims to explore the barriers to the implementation of blockchain technology in the construction using a principal component analysis (PCA) approach.

Design/methodology/approach – This research took a post-positivist philosophical stance, which informed a quantitative research approach through a questionnaire survey. From the South African built environment and information technology sector, 79 respondents were drawn through a snowballing sampling technique. The built environment professionals include architect, construction project manager, construction manager, quantity surveyor and engineer. Retrieved data were screened and analysed by adopting the descriptive analysis and PCA while Cronbach alpha evaluated the reliability. Also, Kruskal–Wallis H non-parametric test was used to determine the differences in the opinion of the respondent groups.

Findings – The analysis revealed that all the identified barriers ranked above the average mean with lack of clarity, scalability risks and lack of skills or knowledge ranking top three. PCA clustered the identified barriers into three components: organisational barriers, social barriers and technological barriers.

Research limitations/implications – This study was carried out in the Gauteng province of South Africa, leaving out other provinces due to accessibility, cost and time constraints.

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Practical implications – Built environment organisations need to be kept abreast of the capabilities of blockchain technology as the major barrier observed was the lack of clarity of blockchain technology. Also, the technological barriers identified from this study need to be addressed by information technology experts to give consumers the desired value for money in implementing blockchain technology for the built environment.

Originality/value – The blockchain technology capabilities are incomparable to any other invention thus far. Therefore, it is very important that the numerous stakeholders in the built environment be made aware of the blockchain technology capabilities while formulating a solution to the identified barriers. This will aid its implementation in the built environment and help the industry measure up with its counterparts.

Keywords Blockchain, Built environment, Construction, Innovative technology

Paper type Research paper

1. Introduction

Organisations in the built environment are experimenting and developing innovative tools and technologies as the support for the fourth industrial revolution market is progressing (Smith and O'rourke, 2019). One of the main problems standing as a barrier to modernisation in the industry is the failure to adopt technological developments that could have helped up the industry's achievements as obtained in the automobile, manufacturing and mechanical engineering sectors (Barima, 2017; Merschbrock, 2012). In its 2018 Digital World Report, the Institution of Civil Engineers (2018) reported that industries globally are gravitating into a world of networking, technology and data abundance. This move gives a potential increase in profitability, quality and competitiveness of the industry, thereby allowing development. Productive and efficient improvements are necessary for the competitiveness of the built environment. The UK Government in 2013 recognised the importance of this and published a "construction 2025 joint government-industry strategy", which set the target of reducing greenhouse gas emissions by 50%, delivering projects faster by 50%, exports improvement by 50% and cost reduction by 33%. Blockchain technology (blockchain technology) is one of the emerging innovative technologies making wave globally. It has been adjudged to have the capabilities to transform global markets in which the built environment is not an exception (Smith and O'rourke, 2019). Bitcoin (the world's first cryptocurrency), a unit of payment that uses blockchain technology platform, was developed in 2008 (Rasoloharijaona *et al.*, 2003). According to research, blockchain technology is termed a more significant technology than the breakthrough of the internet with its potential to reduce costs, improve efficiency and increase profitability (Smith and O'rourke, 2019). The blockchain serves as an encrypted ledger allowing transactions to be carried out in a shared way. Blockchain-based applications are growing in a wide range of sectors, including financial markets (Zheng *et al.*, 2017). Since the introduction of blockchain, smart contracts became one of the key common innovations due to their strong customisability to transactions. Owing to their development, smart contracts also face several problems for the parties who deal with them: consumers, developers and companies that are based on smart contracts (Zykov, 2018). A smart contract is an enforceable algorithm that operates on the top of the blockchain to negotiate, implement and enforce an arrangement among untrusted parties without the intervention of a trustworthy third party (Hasan *et al.*, 2019).

According to Busby (2018), organisations across industries are making attempts to figure out the influence of blockchain technology on businesses. Blockchain technology was tagged business buzzword of the year by *The Guardian* and some other outlets in 2017, and it prompted organisations to start assessing the different application, so blockchain technology without having a full understanding of its working principle (Popper, 2018). Accenture (2017) carried out a study that estimated that blockchain technology can save investment banks up to half of the world's annual gross domestic product. This was misunderstood by the general public as they equate Blockchain with Bitcoin. However, Leibson (2018) stated that "Bitcoin is not Blockchain and Blockchain is not Bitcoin". Smith and O'rourke (2019) buttressed this further by stating that "Blockchain is to Bitcoin what the internet is to email; a vast electronic system on which various application can be built and the currency is just one". Blockchain technology has its advantages built on its redefinition of the trust, openness and inherent immutability. These characteristics give safe and fast solutions to transactional issues both in private and public business dealings (Underwood, 2016). To clarify further, O'Boyle (2017) explained blockchain technology to be an "internet of value" because of its decentralising and irrevocability nature such that it would continue to have an impact on businesses for about 20 years (Khaqqi *et al.*, 2018). According to Akinradewo *et al.* (2021) and Tapscott and Tapscott (2017), using blockchain to streamline contractual procedures and the numerous paperwork supporting complex building projects will save time, free up limited funds and hasten project completion in the construction industry. There has been a recent confluence between blockchain with industry 4.0 technology (i.e. big data, artificial intelligence, the Internet of things and robots). This collaborative effort can result in a shared economy, transparent operations and environmentally friendly supply chain (SC) management in the built environment (Sadeghi *et al.*, 2021). With the different capabilities of blockchain technology highlighted, the slow adoption of this technology in the built environment begs for questions. To seek answers to these questions, this study explores the barriers to the implementation of blockchain technology in the construction using a principal component analysis (PCA) approach. This is with the view to categorise the barriers into clusters to assist in finding solutions to the identified barriers. A similar study has been conducted by Biswas and Gupta (2019), which took a broad approach with a general overview of different industries. This could be applied to the built environment; however, due to the peculiarity and distinct nature of the built environment, there is a need to evaluate these barriers in the built environment industry context.

2. Characteristics of blockchain technology

Blockchain works with a group of nodes connected via a network. Once a transaction is initiated, it is communicated through the network for the network nodes to validate and check the transaction by carrying out predefined tests concerning the transaction layout and activity (Karafiloski and Mishev, 2017). Blockchain technology offers various features that categorise it as a revolutionising technology across various sectors of the economy. These features include autonomy, decentralisation, peer-to-peer relationship, timestamping and immutability (San *et al.*, 2019). Blockchain technology possesses the characteristics of being autonomous such that once the blockchain application is programmed and launched, transactions are completed without having to involve the programmer (Swan, 2015). Automation entails the implementation of algorithms and guidelines that can systematically activate the performance of smart contracts through self-containment, self-enforcement, self-execution and self-verification (Aste *et al.*, 2017). Therefore, the digital aspect of blockchain technology is programmed such that the transactions are bound to computational coded rules to automatically trigger transactions between nodes without needing the intervention of humans (Heap, 2017).

The key feature of blockchain technology is decentralisation, which separates it from the conventional centralised standard database system or platform that we are using. Decentralisation ensures that no broker or central body, such as a money transfer agent or a prosecutor, is required to validate the terms of the contract (Koutsogiannis and Berntsen, 2017). Every participant or chosen participant on a blockchain has access, without the assistance of an intermediary (Heap, 2017), to check its transaction partners' records and access the full database and its complete background directly. Basically, by eliminating the need for the position of trust protection intermediary, blockchain eliminates the criteria for centralised authority (Alcazar, 2017). In other words, there is no one database or organisation or group on which it relies solely on managing data or information (Heap, 2017; Koutsogiannis and Berntsen, 2017). Another core aspect of blockchain is its notion of peer-to-peer networks that facilitate the activity of data or monetary transactions from one wallet to another wallet without the intermediary of a trustworthy third party or central authority. It was pointed out that "Both the private and public sectors have great expectations for blockchain technology because it provides the bedrock for developing peer-to-peer platforms for exchanging information, assets, and digitized goods without intermediaries" (Swan, 2015). The recording of transactions or information within the blockchain network is timestamped. This allows for chronological and historical fulfilment, especially in the smart contract of blockchain technology 2.0, which is currently evolving broadly across numerous industries. Blockchain can be used to timestamp as a proof of existence of a digital or digitalised commodity at a given moment (Swan, 2015). Since blockchain technology is a decentralised network, the same information or transaction record is exchanged and owned by any user or node in the blockchain organisation. This varies somewhat from conventional networks or centralised parties, owned entirely by central servers or trustworthy third-party officials. When the central position is compromised and hijacked, critical documents and monetary transaction records are destroyed. However, blockchain retains an eternal database of the ledger system transactions, rendering it impossible to be falsified after the event (Apte and Petrovsky, 2016) because the evidence is not stored in one location, yet encrypted and separated across everyone in the network (Ramage, 2018).

Blockchain technology's immutability, traceability and transparency result in improved accountability, auditability and decreased bureaucracy. This can change the built environment methods to promote technology improvements and align it with other automotive, mechanical engineering and logistics industries. As a result, the sector will be able to manage resources better and save costs, project durations and payment conflicts (Nanayakkara *et al.*, 2021; Perera *et al.*, 2020; Li *et al.*, 2019). Despite the numerous advantages of implementing blockchain technology in the business process of the built environment, blockchains are not as scalable as conventional centralised systems. Transactions are delayed on blockchain technology due to network congestion. This issue is connected to blockchain network scalability concerns. Simply said, the more users or nodes that join the network, the greater the odds of it slowing down. However, the way blockchain technology works is changing at an accelerating rate. Scalability alternatives are also being incorporated with the proper growth of technology. The idea is to conduct transactions off-chain and just store and access data on the blockchain. Aside from that, new approaches to scalability exist, such as permissioned networks or using a different architectural blockchain solution, such as Corda (Singh *et al.*, 2020; Ismail and Materwala, 2019). The miners must solve issues every time the ledger is updated with a new transaction, which requires a lot of energy. Not all blockchain systems, however, function in the same way. Other consensus methods have successfully handled the problem. Permissioned or private networks, for example, do not have these issues since the number of nodes in the network is limited. They also use efficient consensus procedures to obtain consensus because there is no requirement for global consensus (Woo *et al.*, 2020, 2021).

2.1 Blockchain technology in built environment

The launch of Industry 4.0 technologies has been both fashionable and appealing due to its potential benefits and its role in the real world (Frank *et al.*, 2019). However, businesses and SCs require further analysis to appreciate these exponential and growing developments better, particularly where Business 4.0 technology presents unique operational advantages and tangible business opportunities (Frank *et al.*, 2019). One of the most common technologies that can effectively be used for all Industry 4.0 SC management applications is the blockchain (Osterwalder and Pigneur, 2010). Firms should consider how their business model can be affected by rapidly growing blockchain implementations (Pournader *et al.*, 2020). Also, creating a digital identity enables individuals to exchange the related knowledge approved by the awarding institution. Identities of individuals and companies in the construction industry can be safely registered in the blockchain and used to create credibility over time for work or contracts. This identity and credibility scheme would make it easier for individuals who do not already recognise or have trust in each other to do business (Hughes and Hughes, 2017). Most of the emphasis on blockchain today focuses on the ability to change the financial services sector fundamentally. However, the reach of blockchain technology goes beyond the financial market (Hughes *et al.*, 2019). Thus, blockchain is projected to challenge existing business structures and generate opportunities for new value creation. Blockchain technology has the potential to address several of the industry's concerns regarding building information modelling (BIM) adoption, including confidentiality, provenance tracking, disintermediation, non-repudiation, multiparty aggregation, traceability, inter-organisational record-keeping, change tracing and data ownership (Turk and Klinc, 2017). There are numerous applications of blockchain technology in the construction industry in general, which include recording digital property, timestamping transactions, multi-signature of transactions, smart contracts (computer programmes that monitor and execute themselves) and smart oracles (real-world repositories of information used in conjunction with smart contracts) (Li *et al.*, 2019; Turk and Klinc, 2017).

Blockchain-based BIM implementation is an administrative task that has experienced significant changes over the years. In this system, modelled information on the BIM platform is managed using blockchain technology, ensuring the information is secured while all the professionals involved have access to them (Sinenko *et al.*, 2020). The electronic document management (EDM) platform was developed only before blockchain technology was established. It has been modified from time to time over the past years. EDM in the construction industry plays a major role in simplifying the added complexity of construction and procurement projects (Ogunde *et al.*, 2017). Blockchain technology is expected to deliver a more robust and cheaper technological alternative to the existing EDM system. Blockchain can provide a secure information storage infrastructure across the life cycle design processes of a construction project. With the introduction of blockchain technology, each record may be stored in a digital database, allowing for a complete signature of its formation, deletion and update. Record of relevant design records, including sketches, site instructions, certificates, variation orders and construction work, program can be done in a decentralised setting where certain records require confirmation of participants in the blockchain platform (Hung *et al.*, 2009).

2.2 Barriers to blockchain technology implementation

The introduction of blockchain technology into businesses involves high costs as emerging technology procurement, and deployment costs are always high (Heilig *et al.*, 2017). Also, the preparation of workers to deal with these shifts is often costly but necessary (Rohleder, 2017). Therefore, to incorporate blockchain technology into a business, significant investments have to be made at the outset, after which profits can be made by reducing workload and time saves, but only after the technology has been used efficiently for a prolonged time span (Dobrovnik *et al.*, 2018; Hinckeldeyn, 2019). Casey and Wong (2017) pointed attention to the organisational, logistics and political challenges of blockchain technology. The authors pointed out the absence of regulatory frameworks, the lack of legal protections, the lack of standardisation and the lack of a roadmap for market growth. There is also a new allocation of roles that comes with the adoption of blockchain technology. Companies have to take on different and unfamiliar positions, especially in the deployment process, which can negatively impact businesses (Seebacher and Schüritz, 2020). The predefined block size of the sent information, the speed of transmission via the network, the underlying proof-of-work protocol and the verification of miner information on every node are important factors in blockchain use (Gervais *et al.*, 2016). The size of each block is currently restricted to 1 MB (Abramova and Böhme, 2016; Beer and Weber, 2015), since the inventors of blockchain feared that bigger blocks would bring centralisation in network operations, jeopardising the entire core of blockchains (Nakamoto, 2008). On the other hand, the increased block size will allow for a bigger number of transactions right away, as well as a scalable blockchain application in sectors and services other than cryptocurrencies (Biswas and Gupta, 2019).

Blockchain users are constantly concerned about whether payment merchants would use the new instrument effectively in the future (Böhme *et al.*, 2015). Otherwise, the whole exercise of establishing blockchains as a transformative platform for many businesses may be rendered fruitless. If existing users are unsure about the success of blockchains, the current buzz around their adoption becomes suspect (Biswas and Gupta, 2019). Furthermore, blockchain users confront a distinct shallow market issue due to the relatively limited availability of blockchain-based instruments in the real market (Urquhart, 2016). As a result, if a person wants to trade or withdraw a substantial number of such instruments, he or she would most likely disrupt the general market. Because of the present market's volatility, consumers may be tempted to hoard their assets. This behaviour obstructs the successful flow of the blockchain through peer-to-peer networks and delays a smooth trading process in the open market (Zohar, 2015). While running blocks via the network or processing transactions, blockchains might present unique issues (Beer and Weber, 2015). Furthermore, it is very hard to reverse a user's decision to communicate information over blockchain to another user (Beer and Weber, 2015). When two or more miners simultaneously publish blockchains containing transactions with the same previous block, this situation is known as a fork16 in the blockchain (Sapirshtein *et al.*, 2017). Other miners in the network eventually accept the longest chain and continue mining with it (Biswas and Gupta, 2019).

Blockchains, unlike conventional application software and operating systems, have significant technological obstacles. Installing large software changes across all mining machines, for example, is difficult. Protocol updates are often hampered by the existence of a software defect or inconsistencies in a single user's blocks, which may cause the whole blockchain to split needlessly (Zohar, 2015). In such cases, all users on the network must revert their upgrades to maintain blockchain consistency. Intentional software protocol changes are also difficult to perform, and experienced network users must be careful of, if not outright block, such behaviour (Biswas and Gupta, 2019). Other identified barriers are presented in Table 1 with the accompanying authors.

3. Research methodology

This research took a post-positivist philosophical stance with a view to unearthing the barriers to the implementation of blockchain technology in the built environment through empirical evidence. This philosophical perspective informed the use of a quantitative research approach conducted using a questionnaire survey as indicated in Figure 1. According to Creswell (2014), the quantitative research method gathers numerical data, which can be placed in rank order, classified or evaluated using units of measurements. For this study, a close-ended questionnaire was designed to retrieve data from the target

S/N	Barriers	Authors
1	High energy consumption	Boudguiga *et al.* (2017), Farooque *et al.* (2020), Petri *et al.* (2020)
2	System complexity and cost	Beer and Weber (2015), Böhme (2015), Castellanos (2017), Cohen and Zohar, 2018
3	Scalability risks	Ateniese *et al.* (2017), Biswas and Gupta (2019), Nakamoto (2019), Huang *et al.* (2020)
4	Market-based risks	Ametrano *et al.* (2016), Sivarajah *et al.* (2017), Kshetri (2018)
5	Vague supportive data regulation	Kajinami *et al.* (2018), Bhuvana and Aithal (2020), Heister and Yuthas (2020)
6	Poor/absence of collaboration	Pouryazdan *et al.* (2016), Tao and Qi (2017), Heister and Yuthas (2020)
7	Lack of skills or knowledge	Risius and Spohrer (2017), Hawlitschek *et al.* (2018), Vidan and Lehdonvirta (2019)
8	Lack of standardisation	De Kruijff and Weigand (2017)
9	Intellectual property concerns	Weinberg (2010), Bannerman (2020)
10	Audit concerns	Katsoulacos and Ulph (2017), Menges *et al.* (2018), Putz *et al.* (2019)
11	Transactional-level uncertainties	Beer and Weber (2015), Sapirshtein *et al.* (2017), Nofer (2017)
12	Poor economic behaviour	Böhme *et al.* (2015), Sompolinsky and Zohar (2015), Luther (2016)
13	Legal and regulatory uncertainties	Grant and Hogan(2015), Sompolinsky and Zohar (2015), Abramova and Böhme (2016)
14	Lack of clarity	Koteska *et al.* (2017), De Smith (2018), Mendling *et al.* (2018)
15	Interoperability issues	Schrammel and Wilhelm (2016), Riley (2017)
16	Social acceptance	Stefanini (2020)
17	Authorisation issues	Siris (2020)
18	Security issues	Li (2018), Fernández-Caramés and Fraga-Lamas (2018)
19	Vulnerability of smart contracts	Cuccuru (2017), Parizi and Dehghantanha (2018), Singh and Kim (2019)

Table 1.
Barrier to the implementation of blockchain technology in the built environment

population using information from reviewed literature on barriers to implementing blockchain technology. The questionnaire was divided into two separate sections, and section A retrieved information about respondents' background information, while section B focused on the barriers to the implementation of blockchain technology. The premise of using the questionnaire was that it covers a wide range of respondents within a short time and has been widely used in most construction-related studies (Oke *et al.*, 2020). Participants answered the questionnaires using the five-point Likert scale given in the survey to rate their level of agreement or disagreement with the variables as identified in Table 1. To boost response rate and quality while lowering respondents' "frustration level", a five-point Likert-type scale was adopted (Joshi *et al.*, 2015). Due to the statistical approach of the research study, a target population was drawn, which includes both government and private sector professionals in Gauteng province of South Africa. The selected professionals are quantity surveyors, architects, engineers, construction managers, construction project managers and information technologist. These professional groups were selected as they are directly involved in the construction process as well as the decision process in the built environment. However, information technologists were introduced because blockchain technology is an innovation that most professionals in the built environment are not familiar with yet, and

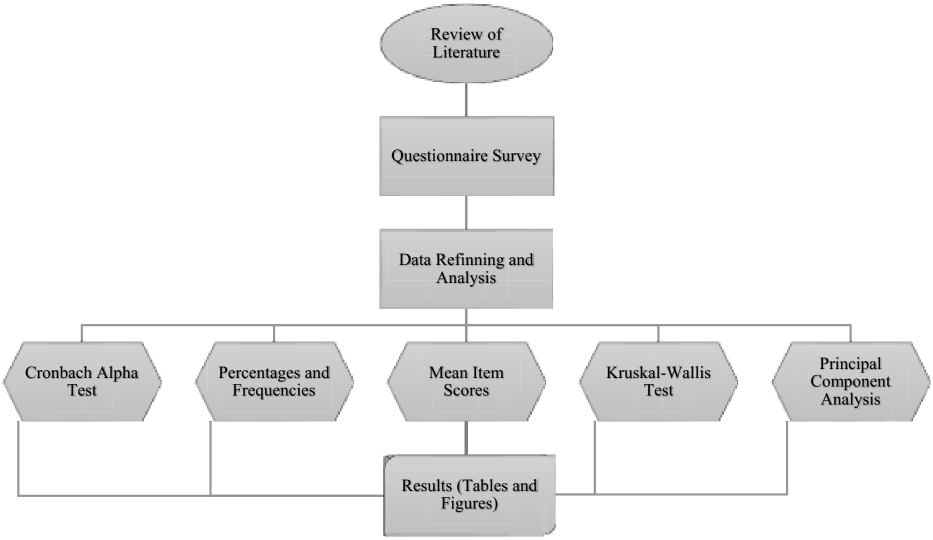

Figure 1. Research method adopted

there is a need to verify the authenticity of their opinion on the research objective. Thus, a pilot study was conducted using six professionals with one each from the identified professional groups for the study. The pilot study responses indicated that the designed survey instrument is standardised and sufficient for the study objective, which therefore validates the data collection instrument adopted for the study.

Due to the nature of the study, a snowballing sampling technique was adopted to ensure only constructions professionals who know blockchain technology are used for the study. Snowball sampling techniques is a system of data collection in which research respondents help in recruiting other respondents for the study, which has been used in studies with few identified respondents (Mould-Millman *et al.*, 2017). To achieve this, three construction professionals were identified from a blockchain technology sensitisation workshop, and they further identified their colleagues who have met the requirements and qualified to be a respondent for the study. A total of 79 questionnaires were distributed online as directed by the ethics clearance approval obtained for the study due to the COVID-19 pandemic, and all of them were retrieved. All the retrieved questionnaires were vetted and ascertained to be suitable for analysis.

Given that blockchain technology is a new research area in the built environment, the 79 responses retrieved for the study were considered adequate for this research study with the study area being a developing country (Etz and Arroyo, 2015). Based on their responses, statistical conclusions were drawn with the use of tables and charts. The retrieved responses were analysed using Microsoft Excel and the Statistical Package for Social Science software. Percentiles and frequencies, mean item scores (MIS) and PCA were determined from the retrieved data. Percentiles and frequencies were adopted to analyse the respondents' demographic information, while MIS ranked the variables according to the respondents' responses. PCA is a statistical analysis tool useful for reducing large data into clusters by exploring the fundamental theoretical structure of the variables (Marzoughi *et al.*, 2018). It helps point out the relationship structure between the respondents and each variable (Pallant, 2011; Yong and Pearce, 2013). The principal component decomposition (T) of a variable X is expressed mathematically as shown in equations (1) and (2):

$$T = \mathbf{X}W \tag{1}$$

where W is a p-by-p matrix of weights whose columns are the eigenvectors of $\mathbf{X}^T\mathbf{X}$.

$$W_{(1)} = \arg\max\{\frac{w^T X^T X^w}{w^T w}\} \tag{2}$$

Further to the descriptive analysis carried out, there is a need to examine the differences in the opinion of the different groups of respondents to understand how they perceive the barriers to the implementation of blockchain technology in the built environment. To achieve this, the Kruskal–Wallis H test was used, which is suitable for determining the difference in respondents' opinion that belongs to more than two groups (Yong and Pearce, 2013). The reliability of the research instrument was carried out using Cronbach's alpha, and the result revealed an alpha value of 0.966, which confirms that the data retrieved using the questionnaire survey can be relied upon.

4. Research findings

4.1 Demographic information of respondents

From the analysis of the respondents' background information as shown in Table 2, the majority of the respondents have bachelor's degree as their highest educational qualification (36.7%), followed by honours' degree (30.4%), while 15.2% possess technical certificate. From Table 2, quantity surveyors formed the largest respondent group with 31.6% of the total population, followed by construction managers with 25.3%, while engineers are 17.7%. Also, from Table 2, most of the respondents have about seven–nine years of experience

Variables	Frequency	(%)
What is your highest educational qualification?		
Technical certificate	12	15.2
Diploma certificate	11	13.9
Bachelor's degree	29	36.7
Honours degree	24	30.4
Master's degree	2	2.5
Doctorate degree	1	1.3
Total	*79*	*100.0*
What is your profession?		
Architect	5	6.3
Construction Manager	20	25.3
Quantity Surveyor	25	31.6
Construction Project Manager	5	6.3
Engineer	14	17.7
Information Technologist	10	12.7
Total	*79*	*100.0*
How many years of experience do you have?		
1–3 years	3	3.8
4–6 years	10	12.7
7–9 years	65	82.3
10 years and more	1	1.3
Total	*79*	*100.0*

Table 2. Background information of respondents

(82.3%), followed by four–six years of experience (12.7%), while only 3.8% have one–three years of experience. From the foregoing, it is evident that the respondents possess a handful of years of experience in their area of expertise with some educational qualifications. The respondents recorded a high level of academic qualification on average, which might have influenced their knowledge of blockchain technology. It can also be deduced from the findings that quantity surveyors in the study area are equipped with knowledge of blockchain technology than other categories of respondents. This could be attributed to the sensitisation workshops on blockchain technology held by the professional body in the study area. This shows that they are capable of providing the needed information to achieve the objective of this study.

4.2 Barriers to blockchain technology implementation in built environment

Having subjected the retrieved data to descriptive analysis, the result as presented in Table 3 reveals the respondents' ranking of the barriers to the implementation of blockchain technology in the built environment. In Table 3, the MIS of each barrier was indicated to show respondents'' level of agreements to each barrier. At the same time, the Kruskal–Wallis test was adopted to check the differences in the opinions of the various groups of respondents. In the Kruskal–Wallis H test, asymp. Sig. values below 0.05 indicate that there is a significant difference in the opinion of the respondents. Notably, all the identified barriers have an MIS above the average of 3.00 of a five-point Likert scale used for this study. This indicates that respondents agree that these barriers affect the implementation of blockchain technology in the built environment. Also, only vulnerability of smart contracts and transactional-level uncertainties have asymp. sig. values lower than 0.05, indicating that the group of respondents ranked these barriers differently. This can be attributed to the nature of these barriers as they can be fully understood by information technologists and blockchain technology professionals only.

A further analysis using PCA was conducted on the identified barriers to help determine correlation patterns within them. According to Pallant (2011), to determine the factorability

S/No.	Barriers	Mean	Kruskal–Wallis H	Asymp. Sig.	Rank
1	Lack of clarity	3.53	5.137	0.399	1
2	Scalability risks	3.48	4.103	0.535	2
3	Lack of skills or knowledge	3.47	10.737	0.057	3
4	Social acceptance	3.43	10.520	0.062	4
5	Lack of standardisation	3.41	9.306	0.097	5
6	Poor economic behaviour	3.34	5.958	0.310	6
7	Interoperability issues	3.33	9.670	0.085	7
8	High energy consumption	3.32	6.694	0.244	8
9	Poor/absent collaboration	3.32	7.255	0.202	8
10	Vulnerability of smart contracts	3.29	14.288	0.014	10
11	Legal and regulatory uncertainties	3.29	6.070	0.299	10
12	Audit concerns	3.27	4.019	0.547	12
13	Authorisation issues	3.23	5.335	0.376	13
14	Security issues	3.22	9.317	0.097	14
15	Market-based risks	3.20	5.231	0.388	15
16	System complexity and cost	3.11	4.982	0.418	16
17	Vague supportive data regulation	3.09	5.224	0.389	17
18	Transactional-level uncertainties	3.09	11.440	0.043	17
19	Intellectual property concerns	3.06	9.251	0.099	19

Table 3. Barriers to the implementation of blockchain technology in the built environment

of the variables, the correlation matrix should show some correlations of $r = 0.3$ or greater, and this data set was found suitable as the coefficient values are above 0.3. Kaiser–Meyer–Olkin Measure of Sampling Adequacy indicates how the distribution of values is adequate for PCA, and it was found to be 0.925 for this study, which is greater than 0.6 (the acceptable threshold), while Bartlett's test of sphericity has a value of 0.000, revealing that there is statistical significance in the variables. Figure 2 shows the steep slope of the components which broke below 1.0 after the third component to show only three components met the requirement using the Kaiser's criterion eigenvalues. These three components explained a cumulative percentage of 73.436 of the variables.

For the PCA rotation, direct Oblimin rotation was used since there was a correlation among the 19 identified barriers. The results of the percentage of variance, communalities extraction and pattern matrix are presented in Table 4, showing the three-component classifications of the variables based on their interrelationships.

5. Discussions

From the analysis presented in Table 4, there are three clusters generated from the identified barriers. These clusters are therefore named based on the characteristics common to them as shown in the following subsections.

5.1 Cluster one – organisational barriers

A total of six barriers loaded onto this cluster and they are "intellectual property concerns" (89.1%), "lack of skills or knowledge" (79.9%), "lack of clarity" (69.7%), "audit concerns" (62.9%), "poor/absence of collaboration" (57.7%) and "market-based risks" (57.1%). These factors relate to the barriers from organisations in the built environment, and they explain a cumulative variance of 62.438% of the total variance. The findings agree with the studies of

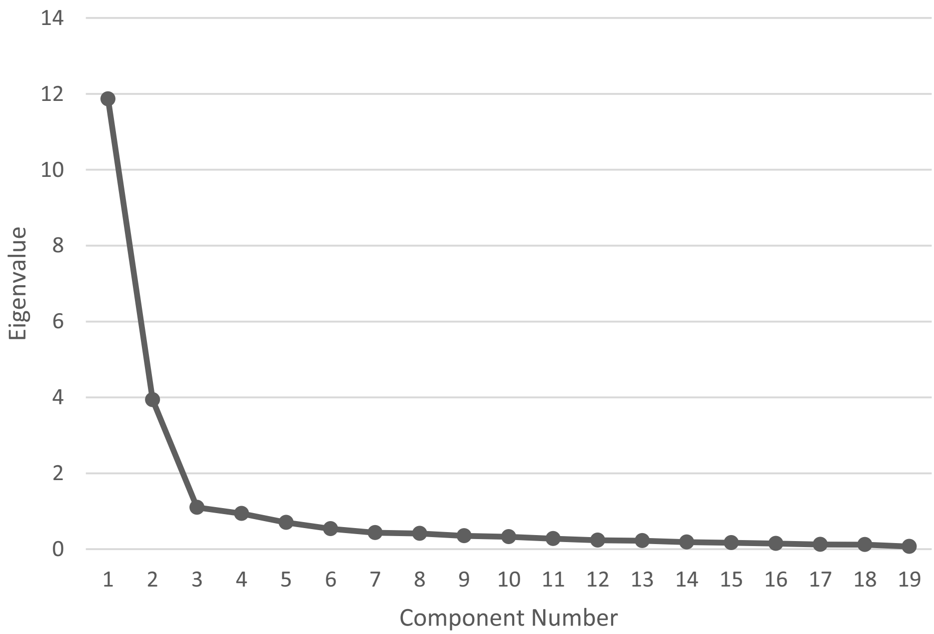

Figure 2.
Scree plot for the PCA rotated barriers

Barriers	Communalities extraction	% of variance	Component 1	Component 2	Component 3
Intellectual property concerns	0.541	62.438	0.891		
Lack of skills or knowledge	0.609		0.799		
Lack of clarity	0.680		0.697		
Audit concerns	0.684		0.629		
Poor/absent collaboration	0.629		0.577		
Market-based risks	0.669		0.571		
Social acceptance	0.807	5.756		0.888	
High energy consumption	0.757			0.855	
Legal and regulatory uncertainties	0.685			0.781	
System complexity and cost	0.613			0.780	
Transactional-level uncertainties	0.673			0.777	
Vague supportive data regulation	0.605			0.726	
Poor economic behaviour	0.750			0.639	
Scalability risks	0.679	5.242			0.992
Vulnerability of smart contracts	0.750				0.854
Interoperability issues	0.744				0.786
Security issues	0.698				0.672
Authorisation issues	0.684				0.648
Lack of standardisation	0.700				0.611

Kaiser–Meyer–Olkin Measure of Sampling Adequacy = 0.925
Bartlett's test of sphericity sig = 0.000
Extraction method: principal component analysis
Rotation method: Oblimin with Kaiser Normalization
a. Rotation converged in 13 iterations

Note: BT = Blockchain technology

Table 4. PCA extraction for barriers to BT implementation in the built environment

Farooque *et al.* (2020) and Vidan and Lehdonvirta (2019), who found that having trained experts in blockchain technology for the built environment is a real challenge at the moment. This proves that there is a lack of skills and knowledge about blockchain technology in the built environment. According to Hawlitschek *et al.* (2018), many organisation executives have a limited grasp of blockchain technology and its improvements to the industry, while some executives limit blockchain technology to cryptocurrencies. To ensure the implementation of blockchain technology, it is necessary to have an exchange of knowledge between the information technology professionals and construction professionals. Also, the findings indicated that there is a lack of clarity, which according to Kajinami *et al.* (2018), the study of C-level corporate executives revealed that 23% of its respondents were worried about the lack of consistency in blockchain guidelines. The findings further revealed that market-based risk is a major barrier to blockchain technology implementation in the built environment. According to Sivarajah *et al.* (2017), the launch of transformative technology in every field brings several difficulties and uncertainties in the commercial market, especially in technological, regulatory, social and adoption-related fields. Also, Kshetri (2018) opined that organisations flourish in their commercial structure and only enter into contracts to purchase innovative products that comply with their business processes to produce value.

5.2 Cluster two – social barriers

A total of seven barriers loaded onto this cluster and they are "social acceptance" (88.8%), "high energy consumption" (85.5%), "legal and regulatory uncertainties" (78.1%), "system complexity and cost" (78.0%), "transactional-level uncertainties" (77.7%), "vague supportive data regulation" (72.6%) and "poor economic behaviour" (63.9%). These factors relate to the societal barriers at large, and they explain a cumulative variance of 5.756% of the total variance. Social acceptance is an identified barrier from the study, which aligns with the conclusion of Stefanini (2020), who opined that people should begin exploring blockchain technology regardless of when they plan to adopt it. This was based on Gartner's proposed growth framework for blockchain technology, which shows that for social acceptance to be achieved, there must be "a strong view of the market prospects challenges of blockchain technology; the possible effects of blockchain technology on the industry; a strong view of the strengths and weaknesses of blockchain technology; a reassessment of individual company and industry confidence in blockchain technology architecture; and a commitment to adopt blockchain technology" (Stefanini, 2020). The findings also revealed that high energy consumption is one of the major barriers encountered in the implementation of blockchain technology, which synchronises with the findings of Farooque *et al.* (2020) and Petri *et al.* (2020). These authors submitted that the high computational power required for significant blockchain technology consensus frameworks consume a large amount of energy. High energy utilisation implies higher carbon emissions, which have been a key challenge globally, because it leads to temperature increase, ozone depletion, environmental change, thereby affecting human well-being and the biological system. In the same vein, the high computing power required by blockchain technology leads to substantial costs (Cohen and Zohar, 2018). Also, the findings indicated that there is vague supportive data regulation. Bhuvana and Aithal (2020) posited that the General Data Protection Regulation does not adapt well to the unchanging data records on a blockchain network. Another finding from the study showed that transactional-level uncertainties are a barrier to implementing blockchain technology in the built environment. A popular issue associated with blockchain technology transactions is known as *fork*, whereby two or more miners publish a block containing the same previous transactions concurrently (Sapirshtein *et al.*, 2017). In such a situation, subsequent miners will follow the longest chain, and a transaction record can be missed in the abandoned block. Nofer *et al.* (2017) pointed out that a miner can be blacklisted together with a mined block, leading to all transactions held in the block being forfeited by the owners. Also, legal and regulatory uncertainties affect blockchain technology's implementation as most countries do not have a regulation in place for its usage. In a submission by Abramova and Böhme (2016), the government cannot charge value-added services and income tax on blockchain technology transactions, while a monetary policy cannot be imposed.

5.3 Cluster three – technological barriers

A total of six barriers also loaded onto this cluster, and they are "scalability risks" (99.2%), "vulnerability of smart contracts" (85.4%), "interoperability issues" (78.6%), "security issues" (67.2%), "authorisation issues" (64.8%) and "lack of standardisation" (61.1%). These barriers relate to the technological issues of blockchain technology, and they explain a cumulative variance of 5.242% of the total variance. Also, the finding about scalability risks is in line with the submission of Nakamoto (2019) that some recently developed blockchain systems are helpless against attacks (such as the 51% attack) because they lack participating hubs and they have little processing pool. Thus, some undesirable data needs to be recorded on the blockchain network, which is difficult to eliminate or reverse because of the immutability characteristics of blockchain technology (Ateniese *et al.*, 2017). These are part of the vulnerability of smart contracts, which consumers are afraid of. Sompolinsky and Zohar (2015) added that the issue of blockchain technology governance is still a global debate as the decentralisation of the platform does not give power to a particular entity in the network. This makes authorisation of transactions within the blockchain network the responsibility of miners who can operate from anywhere, and proper identity might not be known.

Based on the findings of this study, a model was generated to depict the cluster of barriers to the implementation of blockchain technology in the built environment, as shown in Figure 3.

6. Conclusion and recommendation

Blockchain technology is an innovative technology that is expected to transform businesses across different industries. There are quite several identified barriers to its implementation in the other sectors that were evaluated in this study regarding the built environment. Through the use of a questionnaire survey, respondents ranked the barriers according to their severity. From the analysed data, the major barriers include lack of clarity, scalability risks, lack of skills or knowledge, social acceptance and lack of standardisation. Other identified barriers also have an MIS value above the average 3.00, which indicates that they are all bottlenecks to the implementation of blockchain technology in the built environment. A further analysis was carried out to factorise the barriers into clusters, and three clusters were generated, namely: organisational barriers, social barriers, and technological barriers.

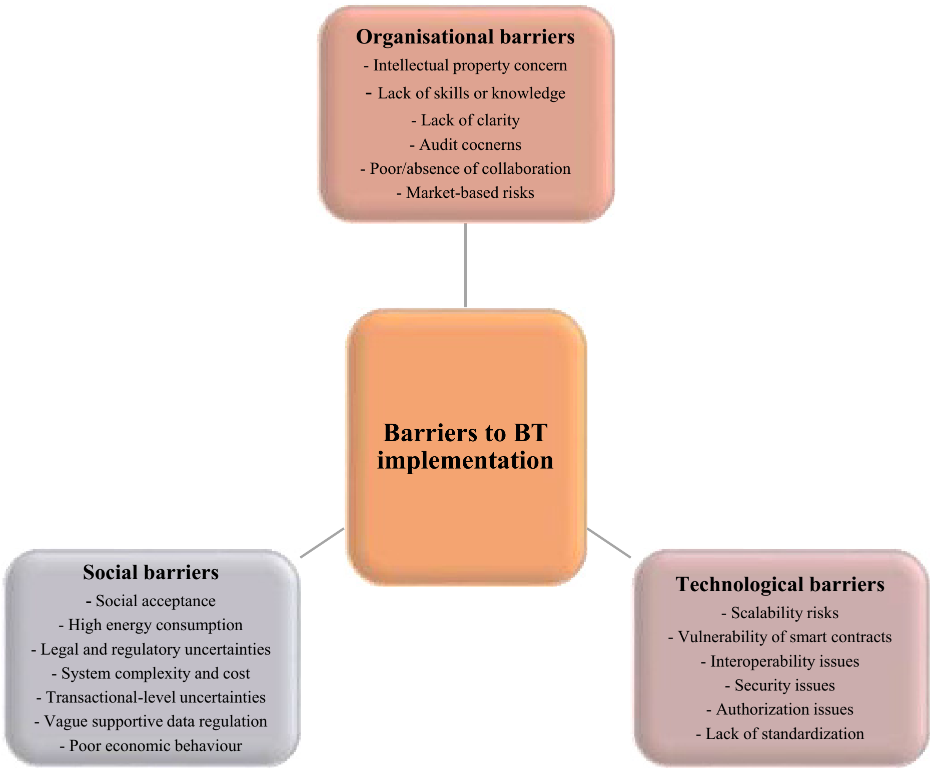

Figure 3. Barriers to the implementation of blockchain technology in the built environment

These three clusters explain how the respondents view these barriers in the implementation of blockchain technology in the built environment.

In the built environment, organisations operate differently, and their business processes differ, which makes collaboration tasking. This could be linked to the challenge of implementing blockchain technology. Also, there are various considerations at the organisational level before an innovation can be adopted, which most organisations cannot achieve in developing countries like South Africa. The cost of acquiring the needed technological infrastructure for the implementation of blockchain technology is high. This poses a significant challenge to its adoption in the built environment. Therefore, it is very important that the numerous stakeholders in the built environment be made aware of the blockchain technology capabilities while formulating a solution to the identified barriers. This will aid its implementation in the built environment and help the industry measure up with its counterparts. As a recommendation, it is proposed that built environment organisations be kept abreast of blockchain technology's capabilities as the major barrier observed was the lack of clarity of blockchain technology. Also, the technological barriers identified from this study need to be addressed by information technology experts to give consumers the desired value for money in the implementation of blockchain technology for the built environment. Organisations in the built environment need to improve their business culture to allow for the adoption of innovations, which will help promote the organisation's profit margin. With the implementation of awareness programmes by professional bodies in the built environment, social acceptance of innovative technologies such as blockchain can be achieved. This will help the industry in adopting blockchain technology for its business processes. The study was carried out in South Africa using only Gauteng province due to time and cost constraints. Also, the accessibility of professionals from other provinces of South Africa limited the reach of this study. Therefore, the findings of this study cannot be generalised for the South African built environment. Also, the study could not investigate the interrelationships of the barrier categories identified from the analysis, which is a further limitation of this study. In this regard, further studies can be conducted using other provinces of South Africa to have a general knowledge of how blockchain technology is perceived by built environment professionals and the barriers encountered in its adoption. Also, further study can be carried out to assess the benefits of blockchain technology implementation in the built environment.

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