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Barriers to the Adoption of Blockchain Technology for Sustainable Material Handling in the Malaysian Construction Industry

Siti Amirah binti Ahmad[1], Yong Siang Lee[2], and Nurhaizan binti Mohd Zainudin[3]
[1]PhD Student, Faculty of Civil Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Email: sitiamirah1691@gmail.com
[2]Senior Lecturer, Faculty of Civil Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Email: leeys@umpsa.edu.my (corresponding author).
[3]Senior Lecturer, Faculty of Industrial Management, Universiti Malaysia Pahang Al-Sultan Abdullah, Email: nurhaizan@umpsa.edu.my

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Abstract: Traditionally, material handling is commonly integrated with human labour, which has specific work limits and capabilities, resulting in slower, less efficient and less sustainable material handling. The construction industry in Malaysia faces increasing pressure to promote sustainable material handling. Blockchain technology has great potential for improving transparency, traceability and efficiency in material handling. However, the adoption of blockchain technology for sustainable material handling remains limited. Therefore, this study aims to explore the potential barriers to the adoption of blockchain technology for sustainable material handling. For data collection, interviews were carried out with selected twenty-one (21) respondents from diverse backgrounds who were experienced in the construction industry. Face to face, online meeting, and phone call interview methods were conducted. Then, all the data was analysed using thematic analysis. The findings revealed seven (7) main themes related to barriers, i) safety, ii) financial, iii) technical, iv) educational, v) environmental, vi) political and vii) social. This research identified challenges related to technological infrastructures, regulatory frameworks, cost implications, and industry readiness. Insights from industry stakeholders provide a comprehensive understanding of these barriers and suggest strategies to overcome them. The findings emphasise the need for industry-wide collaboration, supportive government policies, and enhanced awareness to drive blockchain adoption. This study contributes to the literature by offering practical recommendations for integrating blockchain technology into sustainable practices, ultimately promoting more efficient and eco-friendly material handling processes in construction.

Keywords: Blockchain, barriers, sustainable material handling, construction industry.

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1. Introduction

Material handling entails the process of managing, protecting, storing, controlling and transporting materials during the process of production, storage, distribution, consumption, and disposal (Kurniawati, 2017). Suitable material handling equipment contributes to the optimal flow of sustainable material handling by reducing the time taken by the operation cycle and the cost of handling, as well as minimising the risks associated with the workplace (Hama Kareem et al., 2022). Due to the increasing scale of the construction industry, it has become mandatory to embrace sustainability at every step by reducing material waste, improving the handling of materials, and rationally using the materials available. It is now important to have a properly planned and orderly material flow if productivity and project schedules are to be achieved. The various modes of material handling have generally become ineffective as they prolong working rates and are overly dependent on human strength (Ibrahim et al., 2021).

The solutions to these challenges, which would improve the organisation of work, lie in the adoption of advanced environmentally friendly practices. Before the great progress of technology, materials were handled manually and traditionally but many limitations were evident. Originally, the majority of commodities were lifted manually, so the quantities of materials were restricted. However, forklifts provided an opportunity by offering a more frequent way of lifting

larger quantities of materials in every work process (Harsh and Dhami, 2023). Nevertheless, a significant number of construction organisations continued to employ traditional forms of working, such as the use of entering worksheets that record information about materials. One of the major drawbacks of traditional paper-based systems is lost documents since no specific person is detailed to manage them properly. This frequently makes it challenging to find documents during critical business activities like procurement, making it time-consuming and cumbersome for companies to retrieve important documents. Nevertheless, the implementation of the Internet of Things (IoT), cloud computing, and barcode technology in the management process could help prevent these problems. Incorporating the Internet of Things (IoT) and barcode systems would assist in tracking material movements, consequently minimising the likelihood of human interference (Bose et al., 2022).

In the National Construction Policy (2030), several important points have been emphasised, includingdigitising the construction industry by at least 50% by 2030 in order to improve project efficiency and quality, in addition to reducing the dependence on unskilled labour. Industrial Revolution 4.0 (IR4.0) will provide various technologies that can be applied to facilitate and smooth operations. Blockchain is one of the technologies under this umbrella (IR4.0) and its effectiveness has been widely proven. For instance, it can increase transparency, overcome disputes and miscommunication among stakeholders, and reduce the dependence on middlemen in various sectors such as healthcare, manufacturing, supply chain and agriculture. However, explorations of blockchain in the construction industry are still lacking (Ebekozien et al., 2023).

However, despite its advantages, the adoption of blockchain technology in the Malaysian construction industry remains at 0% as depicted in Fig. 1 below highlighting the need for greater awareness, infrastructure, and support to fully realise its benefits.

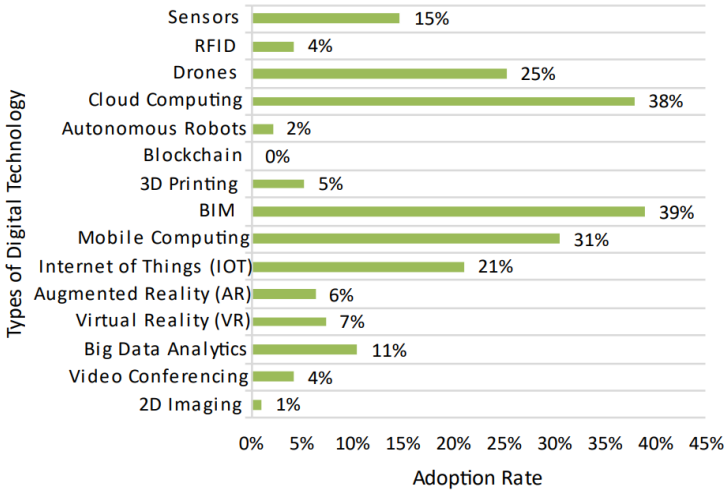

Fig. 1. The adoption of different technologies in the Malaysian construction industry (Lee and Goh, 2023)

However, blockchain in the construction industry is still underexplored, even though it offers valuable advantages that allow issues related to ambiguity in transactions to be overcome because several obstacles remain, such as a lack of information sharing, trust management issues, and companies still using old technology (Khan et al., 2023). Knowing the obstacles that must be addressed before blockchain can be successfully used in practice would allow these obstacles to be overcome first and givethe construction industry confidence about using blockchain, especially for material handling through its integration with blockchain.

However, the adoption of blockchain technology for sustainable material handling remains limited due to various barriers. Significant technological, organisational, and regulatory barriers hinder the adoption of blockchain technology for sustainable material handling in the Malaysian construction industry. This study sought to address the following question: "What are the barriers to the adoption of blockchain technology for sustainable material handling in the Malaysian construction industry?" Therefore, this study aimed to explore the potential barriers to the adoption of blockchain technology for sustainable material handling.

2. Literature Review

2.1. Overview Of Material Handling

Material handling involves the process of managing materials, information, and people in an organisation. Its purpose is to ensure that all the parts involved in the organisation can operate smoothly and achieve the organisation's objectives (Sharma and Cupek, 2023). In the construction industry, where approximately 50-60% of expenses are attributed to materials, it is crucial to manage resources efficiently and systematically to maintain work productivity and ensure effective financial management throughout a project (Mohammed and Mary, 2023).

2.2. Issues Related to Material Handling

Many current project failures stem from inadequate management, yet many construction companies still underestimate the importance of on-site material handling, prioritising project deadlines instead. Poor management, particularly in planning

and handling materials, can negatively impact a project's progress and overall organisation. Therefore, careful planning is essential from the beginning of the project through to its successful completion (Ramachandran et al., 2021). Ineffective material handling costs the construction industry between $300 million and $1 billion every year. Technologies like Radio Frequency Identification (RFID), Building Information Modelling (BIM), and the Internet of Things (IoT) can help address this issue. Radio Frequency Identification (RFID) reduces the need for extensive human resources and ensures timely access to the necessary information (Jain et al., 2024). Rework occurs when completed work does not meet the required standards and needs to be redone, whether by replacing, deleting, or repairing it. This significantly impacts project progress by causing delays (Muwafaq et al., 2020). Mahamid (2022) explored the link between rework and material waste in Saudi Arabia's construction industry. Through questionnaires and case studies, frequent rework and material waste were found to be mainly due to changes in the scope of work, workers not following the provided specifications, and inadequate on-site monitoring and supervision.

2.3. Integration of Technology in Material Handling

Many technologies are used for material handling. Among these is construction material handling using Building Information Modelling (BIM), which includes the phases of delivery, warehouse, building, modelling, procurement, and tracking. It can address issues related to uncontrolled material handling by calculating the quantities of materials needed, thus helping to avoid excess and waste on site (Hosny et al., 2023). The writer found that tracking individual shuttering components in the Indian construction industry is challenging due to widespread and variable deficiencies. To address these issues, an Aluminium Shuttering Inventory Management System (ASIMS) was developed, which used barcodes, Arduino-based IoT devices, and cloud computing to improve the tracking of aluminium formwork. This technology aimed to make aluminium formwork management more organised and efficient compared to traditional methods (Bose et al., 2022). Industries handling large volumes of materials should invest in smart handling systems to ensure orderly and efficient management. The author developed a Mobile Smart Material Handling System (MSMS), which integrates a scissor lift and TurtleBot 3. This system is controlled via a controller and has scissor-lift functions to easily adjust the heights of goods. Based on previous studies, many improvements have been made in material handling, but there is still a lack of research on the transparency of the relationship between the stakeholders involved and the efficiency with which information is tracked and retrieved. Knowledge is still at a low level and it is difficult to reach a consensus between the parties involved in the construction industry.

2.4. Background of Blockchain Technology

Blockchain was introduced by Satoshi Nakamoto in 2008 (Berneis et al., 2021). Its emergence was a result of Bitcoin. Bitcoin is a cryptocurrency that is converted to digital, and no transaction requires a third party. Seeing the potential of blockchain in Bitcoin has opened the eyes and attracted the attention of developers especially to develop blockchain applications more widely in broad sectors such as the manufacturing, supply chain, healthcare, prefabricated, and construction industries (Sayal et al., 2023).

Blockchain technology is based on the concept of decentralisation, which is a network that does not need to rely on a central authority or intermediaries. Blockchain 1.0 was used for digital currency transactions between 2009 and 2013. Then, in 2015, the use of smart contracts introduced Blockchain 2.0, whichprovided better authentication and reduced transaction process disruptions, while the Ethereum platform introduced Blockchain 3.0 in 2018 by using the Dapps concept. Blockchain 4.0, introduced in 2020, is the latest level of this technology (Tanwar, 2022). The focus is to make blockchain easier to use in business and industry. This phase focuses on solving the problems of previous versions and making blockchain more practical to use (Mhamdi et al., 2022). Blockchain has unique features such as decentralisation, immutability, transparency, and smart contracts, giving the entire industry the confidence to use it, especially to overcome issues like of irregularities, disputes, and negligence in sustainable material handling

2.4.1. Types of blockchain technology

There are three types of blockchain technology, private, public, and consortium. Each has its own way of operating. The capacity of nodes to join the network, add transactions to the blockchain, read transactions, and verify transactions determines the category of blockchain that is to be used.

2.4.2. Public blockchain

Every piece of information and data shared on public blockchains can be seen by all participating computers (nodes) . In addition, everyone involved in a public blockchain network can verify every piece of information, write into the blockchain to add new information, and read all shared data (Assaqty et al., 2020). Data and information on public blockchains are collectively verified by participating computers (nodes), making them highly resistant to alteration or manipulation (Yang et al., 2020).

2.4.3. Private blockchain

Private blockchains have their own restrictions, that is, only computers (nodes) that pass the restrictions can join anetwork (Assaqty et al., 2020). A private blockchain generates an extremely high transaction processing rate since only a small number of computers, or nodes, participate in it. In a network with fewer computers (nodes), consensus is reached more quickly, and numerous transactions can be completed in a single second. A private blockchain is more vulnerable to hacking and manipulation by bad actors due to its small number of computers, or nodes (Yang et al., 2020). Private blockchain examples are Hyperledger and Corda (Sivula et al., 2018).

2.4.4. Consortium blockchain

Consortium blockchains are a combination of public and private blockchains (Zhang et al., 2024). Only half of the shared information is visible to other users, whereas some users are permitted to view the complete transaction information. At the initial stage, all the computers (nodes) can access the network and see all the information displayed, but in the network, some groups of validators will be selected by the central authority or by using the consensus algorithm system. This selected validator group cannot be accessed by all the computers (nodes) involved in the public network. The ledger and information are displayed publicly and can be seen by all the computers (nodes) involved in the network, but only the selected validator can change to the information or add new information or transactions (Ramadoss, 2022). Table 1 below presents a comparison of Private, Public, and Consortium Blockchains.

Table 1. Comparison of Private, Public, and Consortium Blockchain (Hussain et al., 2019)

Characteristics	Public Blockchain	Private Blockchain	Consortium Blockchain
Permission Read	Public Class	Could be public or restricted	May be public or restricted
Determination of consensus	All miners	Only one organization	Designated set of nodes
Efficiency	Low	High	High
Immutability	Impossible to tamper	Could be tampered	Could be tampered
Centralized	No	Yes	Partial
Consensus	Permissionless	Permissioned	Permissioned

2.5 Application of Blockchain Technology for Sustainable Material Handling

Blockchain is used less in the construction industry compared to other sectors such as the healthcare, manufacturing, supply chain, education, and food industries. Reference sources for use as guides are also lacking but the construction industry can use other sectors as references. There are several situations in which this could apply such as investigating the use of blockchain in the construction industry for supply chain management. The focus is stated in terms of cost, transaction speed, and transaction security (Zilin et al., 2023). The prefabrication supply chain in the construction industry is highly fragmented, so it is very difficult to reach a consensus between stakeholders. Therefore, the study demonstrated that using blockchain technology can enhance transparency among stakeholders and eliminate miscommunication between them (Bakhtiarizadeh et al., 2022). The construction industry is also often associated with the issue of mistrust between stakeholders. The effect of the information received varies, and it is not transparent to all parties because it is controlled by a body that performs those functions centrally. Blockchain operating in a decentralised manner could reduce the risk of information being manipulated without the consent of all stakeholders arbitrarily (WANG et al., 2017). Preservation of heritage buildings is not a straightforward topic because each building has its own aesthetic value and not everyone is skilled in handling it. The integration of Chatbox, Building Information Modelling (BIM), and blockchain can ensure that information about heritage buildings is easy to access and stored data cannot be changed easily (Marzouk et al., 2024). The implementation of blockchain for sustainable material handling can increase transparency between stakeholders and facilitate transactions between them. This is because, traditionally, every transaction such as the transmission of information involves a lot of human intervention to obtain confirmation and approval, which slows the process. However, with blockchain, everything operates automatically and complies with the agreement that has been reached, as stated in the smart contract.

2.6. Knowledge Gap and Study Positioning

Based on the literature review, the application of blockchain has been utilised extensively in many major industries including manufacturing, agriculture, and healthcare. Apart from blockchain's primary application in resolving disputes in the procurement process (Yadav and Prakash Singh, 2022), smart contracts can speed up contract resolution between stakeholders and guarantee that payments are not subject to irregularities between parties (Rathnayake et al., 2022). Furthermore, the IoT system's private blockchain enables the secure and convenient reception of product and material tracking data by various parties, including manufacturers, suppliers, and contractors (Assaqty et al., 2020).

Many studies have used blockchain to enhance project management, guarantee transparent payments, and prevent fraud, but there is still a lack of research on sustainable material handling techniques like accurately tracking the origins of materials', accurately monitoring the quantity of materials entering and leaving a site, and maintaining data and document storage folders that are difficult for outside parties to alter. These techniques are still less common in the construction industry.

Thus, this study was conducted to address the research gap by exploring the barriers to the adoption of blockchain technology for sustainable material handling in the Malaysian construction industry.

3. Methodology

This section outlines the process used to obtain detailed information from those involved in projects related to the construction industry in Malaysia. Several protocols needed to be followed, such as for the type of sample selected, obtaining permission from participants, the source of data obtained through interviews or questionnaires, the equipment used and how to analyse each set of information obtained. Qualitative data was collected in order to understand data obtained about the experiences shared by industry layers with experience in the construction sector in Malaysia (Caron and Markusen, 2016). Fig. 2 below shows the research methodology flowchart of this study.

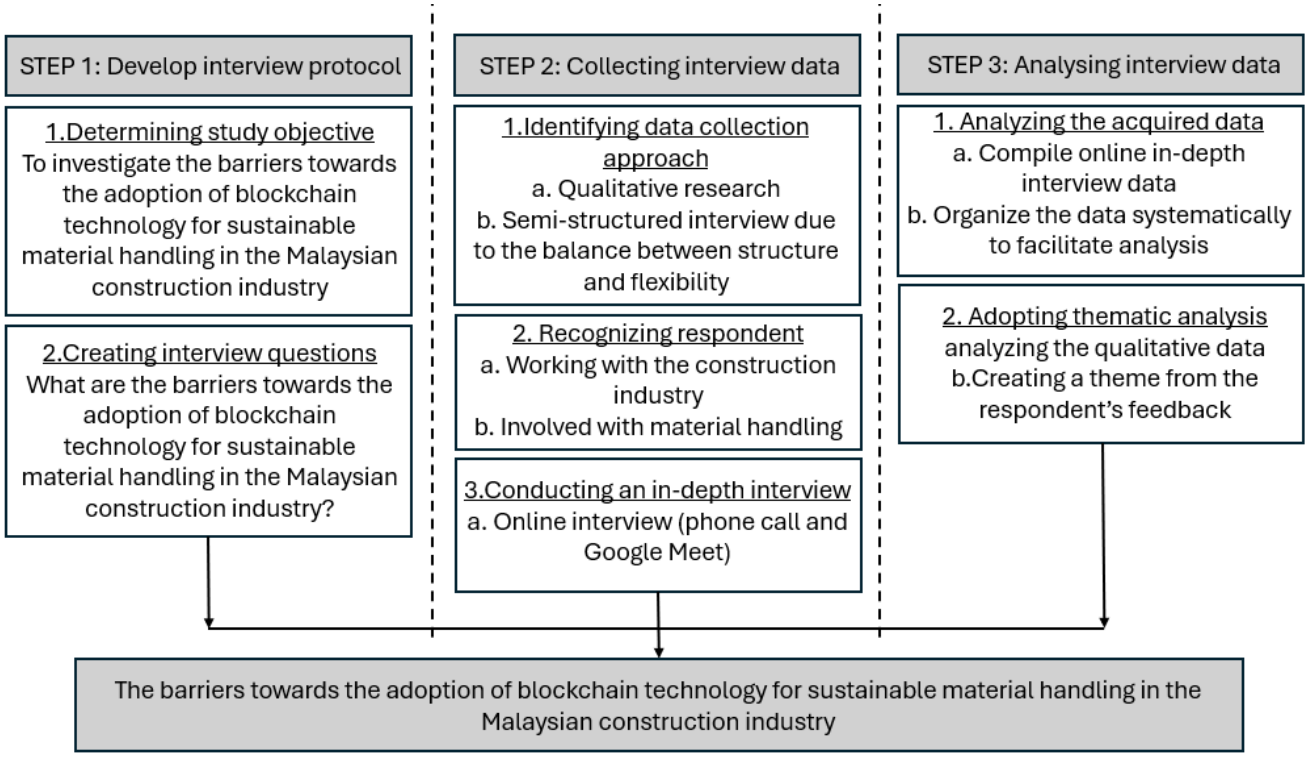

Fig. 2. Research Methodology Flowchart

3.1. Data Collection: Semi-Structured Interviews

Data was collected through interviews conducted via phone calls or Google Meet. Due to respondent non-locality, the time constraints on personal meetings, and the fact that most respondents were professionals and too busy with their actual jobs to attend face-to-face meetings, the interviews conducted over the phone or via Google Meet. This method is more flexible in that it enables more flexibility during the process. Therefore, it was necessary to shift the mode of contact to an online one to ensure that the data collection process ran effectively. A crucial aspect is the ability of respondents to offer comprehensive and in-depth views and opinions.. Semi structured interviews with respondents are used to ensure that the information received is more detailed and that respondents are not prevented from sharing their opinions. Meanwhile, structured interviews are limited because the questions are fixed and the probability of not answering them accurately is high. To maintain the quality of the interview data, purposive sampling was utilised to select participants with experience in and knowledge of the construction industry (Hosseini Dehshiri and Amiri, 2024). The following selection criteria were applied i) the respondents must have at least five years of work experience in the construction industry, and ii) the respondents must have knowledge of and skills in material handling. The 21 respondents chosen represented a variety of backgrounds, with a site engineer, a safety and health officer, a site supervisor, a procurement executive, a project manager, and an Inspector of Work (IoW), participating in this study. Diverse and extensive sharing can be facilitated by respondents with varying backgrounds (Mustaffa et al., 2023). The demographic data (21) of the interviewees is displayed in Table 2.

3.2. Data Analysis: Thematic Analysis

Thematic analysis is a qualitative approach that requires the translation of every piece of information obtained based on an appropriate pattern or theme (Chen et al., 2021). The process of translating information requires reading the script or listening to the audio recordings repeatedly to identify matching and related themes (Rice and Ezzy, 1999). The purpose of this process is to summarise long scripts and audio into material that is simpler and easier for readers from different backgrounds to understand. Thematic analysis helps a researcher understand the scope of the study in more detail and the study being conducted more clearly (Mohd Ali et al., 2024). Fig. 3 below illustrates the thematic analysis steps followed in this study.

4. Results and Discussion

Fig. 4 below presents data gathered from interviews with twenty-one (21) respondents who are actively engaged in the Malaysian construction industry. The respondents shared their insights, information, and opinions regarding the barriers to adoption of blockchain technology for sustainable material handling in this sector. These responses were analyzed and categorized into relevant themes, which are grouped into seven (7) main themes of barrier, which consisted of i) safety, ii) financial, iii) technical, iv) educational, v) environmental, vi) political and vii) social.

4.1. Educational

The advent of technology has changed the traditional work system but drastic changes will disrupt the productivity of the existing work system. Blockchain is a new technology so awareness about it is still at a minimum level. It has been proven by (Singh et al., 2023) stating the lack of blockchain that is understanding about it and the lack of technical experts make it difficult to get stakeholder acceptance. Few theoretical and practical reference sources on blockchain limit the construction

industry to integrate it into the existing work system because it is feared that work productivity will stop if something undesirable happens such as troubleshooting. Rejection of employees to change because they are comfortable with the conventional work system. This statement is proven by (Cheng and Chong, 2022) stating that employees who have become accustomed to conventional work routines make it difficult for them to accept the use of blockchain in their daily routine because they have to spend a long time to learn and think the process is useless and a waste of time.

The complex and complicated blockchain system makes it difficult for stakeholders to adapt to it. In addition, not all employees are able to accept this technological change easily, especially for older employees, which will limit their acceptance when the blockchain interface and features are not user friendly. This statement has been proven by (Zheng et al., 2019) stating that the complexity of the blockchain system makes it difficult for developers to gain confidence from stakeholders to adopt blockchain easily. So, based on the obstacles above, it clearly shows that the education system in Malaysia needs to make some changes by including a syllabus on the use of technology as is being talked about in Industrial Revolution 4.0 (IR4.0) which is in line with the National Construction Policy 2030 which wants to modernize the construction industry system in Malaysia comparable to developed countries by 2030. Changes in the education system will lead to better future.

4.2. Financial

Blockchain technology helps to simplify the process and work but finance is the main factor that will be considered by the construction industry in Malaysia. Industry opinion regarding adaptation to blockchain requires companies to spend profit income to buy new hardware and software in order to be able to use blockchain smoothly and effectively. Investment in new software and hardware causes organizations to reject the adoption of blockchain in the organization and maintain conventional work methods even though the effectiveness is not as efficient as using blockchain technology (Fu et al., 2020). The construction sector has rejected blockchain, according to a study by (Ebekozien et al., 2023), because it demands them to use corporate revenues to upgrade hardware and software with sophisticated specifications that inevitably require significant capital. Here, it is evident that money is a major concern for some businesses, as they utilise their earnings to pay for costly, highly specialised software and gear.

Table 2. Demographic Information of Respondents

No of respondent	Stakeholder	Current position	Years of industrial experience
R1	Main contractor	Site engineer	9
R2	Subcontractor	Site supervisor	6
R3	Main contractor	Safety & health officer	7
R4	Consultant	Inspector of work	32
R5	Developer	Assistant project manager	14
R6	Subcontractor	Project manager	8
R7	Consultant	Site engineer	7
R8	Consultant	Inspector of work	31
R9	Main contractor	Procurement executive	10
R10	Main contractor	Project manager	26
R11	Subcontractor	Instrumentation engineer	12
R12	Subcontractor	Project manager	15
R13	Main contractor	Site safety supervisor	5
R14	Main contractor	Site engineer	5
R15	Government	Civil engineer	9
R16	Subcontractor	Site engineer	6
R17	Developer	Site supervisor	6
R18	Main contractor	Safety & health officer	10
R19	Main contractor	Manager, Co-developer cum quantity surveyor	5
R20	Main contractor	Procurement executive	7
R21	Government	Site engineer	9

4.3. Technical

The presence of blockchain is the main solution to the issue of trust because it is equipped with features such as decentralised, immutability and smart contract but no technology is without technical problems. The purpose of using blockchain is to remove dependence on middlemen and verbal agreements that often lead to disputes (Mahmudnia et al., 2022). Smart contracts are able to overcome disputes between stakeholders by making agreements digitally. The issue of weak blockchain control is that when information or data is entered into it, it cannot be changed, causing organizations to reject the adoption of blockchain because it will make it difficult for organizations to update data continuously or to make corrections to data if there are changes and improvements. This problem has been supported by (Politou et al., 2021) stating that the immutable nature of the blockchain has interfered with the adoption of the blockchain.

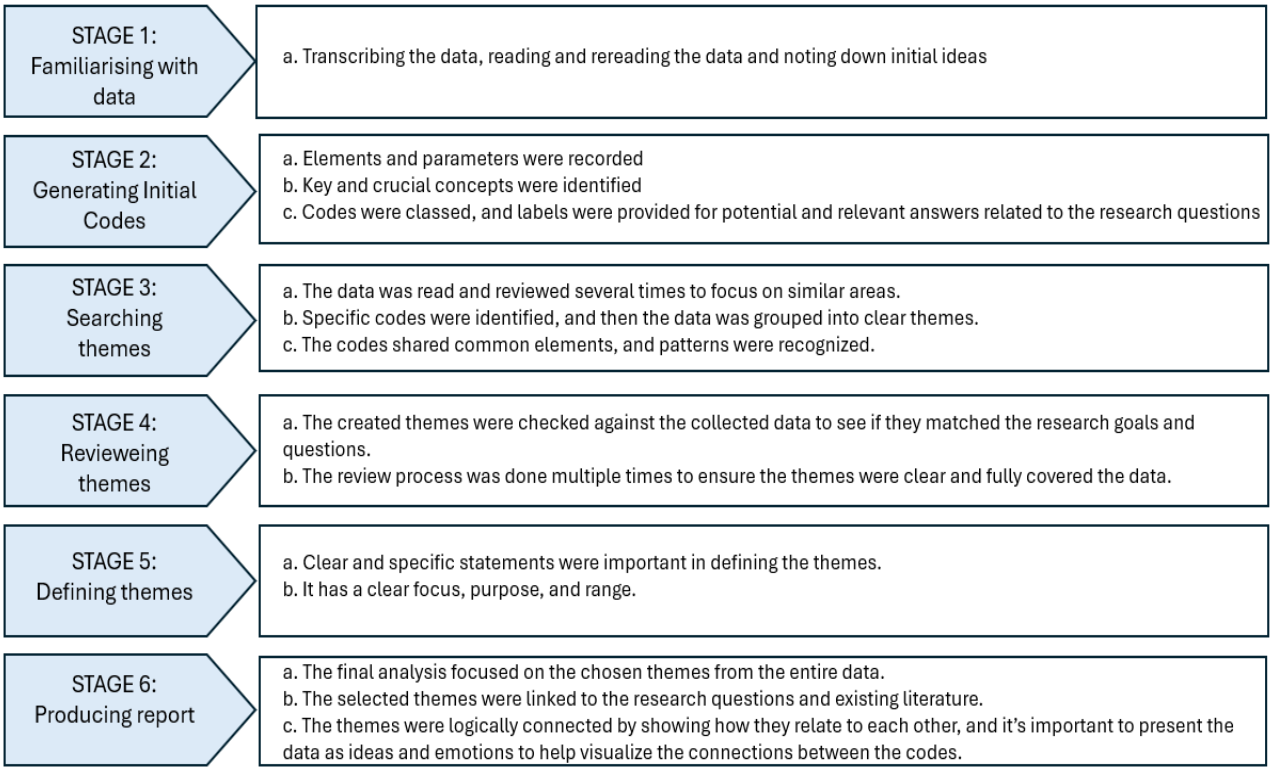

Fig. 3. Steps of thematic analysis followed in the study

The construction industry rejects public blockchain due to the issue of privacy data that is shown publicly without protection as emphasized by (Yontar, 2023) by calling on organizations to use private blockchain instead of public blockchain when involving private and confidential transactions. The blockchain storage data is very small, which is as large as 1MB, and the dumping of a lot of construction industry data causes many new blocks to be added until the blockchain chain becomes long (Tabatabaei et al., 2023). The implication when the blockchain chain becomes long will slow down the smooth process of the blockchain, i.e. transactions only happen as much as 7 transactions/second (Kohad et al., 2021) compared to visa and mastercard being able to do 2000transactions/second (Ruoti et al., 2020).

In total, issues related to weak blockchain control, publicly disclosed privacy data and limited data storage are technical problems that contribute to the disruption of blockchain adoption in the construction industry that need to be given attention and specific solutions need to be devised to overcome them.

4.4. Safety

The effectiveness of technology becomes smooth when it is integrated with smart devices such as laptops, tablets and smart phones but the frequent use of devices also leads to a decrease in work productivity and disrupts the focus of employees with the daily work done (Dubey et al., 2020). Construction sites are notorious for dumping a lot of material and there are dangerous materials if not stored properly. The use of electronic devices near explosive materials will contribute to the risk of danger to workers while on duty. So the use of devices without strict monitoring and systematic rules will have a negative effect on employees while on duty and increase the risk to the smooth operation of work.

4.5. Environmental

No technology can function without internet access, which has become essential for all users. Respondents raised concerns about internet connectivity, particularly in rural areas. While using blockchain in urban areas poses no issues, they pointed out that if a construction site is in a rural location, poor internet access could significantly hinder the use of blockchain (Alshahrani and Alshahrani, 2021).This would, in turn, slow down employee productivity and efficiency, making it a critical concern for the successful implementation of blockchain in such areas.

4.6. Political

Conventionally, the construction industry is controlled centrally by special bodies such as the National Institute for Occupational Safety and Health (NIOSH), Construction Industry Development Board (CIDB), Board of Engineers Malaysia (BEM) and local authorities. The use of blockchain that will eliminate its dependence on a central authority is quite difficult to accept this change. In addition, the limited support from the authorities will delay the process of spreading the blockchain successfully delivered easily to the construction industry (Erol et al., 2022). It is clear that the lack of involvement and support of the authorities will delay the adaptation process of the construction industry with blockchain technology.

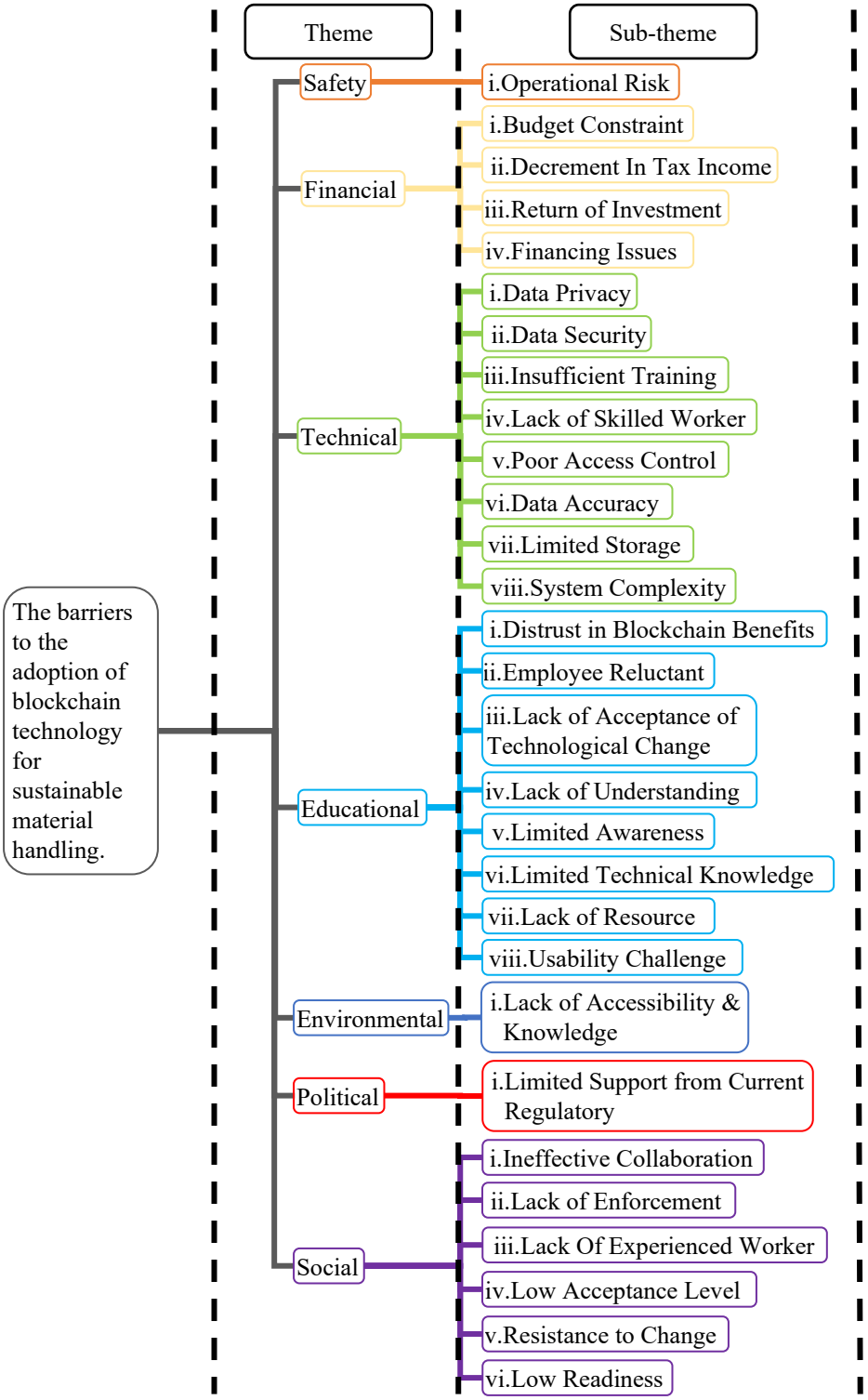

Fig. 4. The phases of identifying the themes and sub-themes for the adoption of blockchain technology for sustainable material handling in Malaysian construction industry

4.7. Social

Ineffective collaboration between stakeholders will slow down the blockchain adoption process in the construction industry. The organization's level of readiness for blockchain is still at a minimum level because there are many things that need to be taken into account such as agreement between stakeholders, changes in new work patterns, hidden costs to launch operations

and the skilled workforce required if there are unwanted technical problems. Furthermore, the construction industry believes that there is no urgent need and factor that requires companies to use blockchain in the organization because for them by practicing conventional work methods they can still complete daily work demands even if it is not as smooth and efficient as using blockchain in daily work operations. So social obstacles such as ineffective collaboration, low readiness level among stakeholders and enforcement have contributed to the construction industry lagging behind in technological advancements such as blockchain compared to other industries such as manufacturing, healthcare and agriculture.

4.8. Global Implications and Adaptability of Findings

The main focus of this study is to identify barriers to the use of blockchain for sustainable materials handling in the construction industry in Malaysia. Nevertheless, the results of this study can be put into practice by other countries and are not focused on Malaysia alone, such as less effective collaboration, financial issues, lack of expert staff, data privacy problems and others.

However, the level of challenges of using blockchain varies from country to country. For example, for countries that have reached a high level of technological revolution such as Japan, Canada, the United Kingdom and other developing countries may not face significant financial issues but it is difficult to reach a consensus between stakeholders.

In conclusion, policy makers, legislators, developers and stakeholders can formulate appropriate plans or measures to overcome the barriers to the use of blockchain at the global and local levels according to the suitability, demand and conditions of their respective countries. The results of this study show that it is not only suitable to be practiced by the construction industry in Malaysia, but globally can also use it to achieve the sustainability goals of the construction industry in their respective countries.

4.9. Limitations

As this blockchain is still in its infancy and is not being operated by experienced parties, very little information has been gathered, and many enquiries concerning it do not provide answers to the problems raised. The process of critically understanding this blockchain will be slowed down by the absence of reference materials like theory and practical.

4.10. Study Implications

The goal of this study is to determine the barriers to the adoption of blockchain technology towards sustainable material handling in Malaysian construction industry. The outcome of finding which are the barriers can be used as a reference when construction parties want to utilise blockchain technology for sustainable material handling. Policymakers, regulatory agencies will be beneficial in improving existing regulations and laws that must be adhered to in order to get past the aforementioned challenges and guarantee a smooth blockchain implementation. While the users can also utilise the design and customisation of blockchain technology to practice sustainable material handling in more efficient way.

5. Conclusion and Recommendation

In a nutshell, this study has successfully achieved the aim of study where all the significant barriers to the adoption of blockchain technology towards sustainable material handling in Malaysian construction industry have been explored. Currently, material handling is commonly integrated with human labor that have specific work limits and capabilities that resulted in slower, less efficient and less sustainable material handling. Blockchain technology has great potential for improving transparency, traceability and efficiency in term of material handling. Based on the findings from in-depth interview data, there are seven (7) main themes of barrier, which consisted of i) safety, ii) financial, iii) technical, iv) educational, v) environmental, vi) political and vii) social. All these barriers are essential to lay a foundation for blockchain-enabled material handling method that able to promote sustainability that aligned with Construction 4.0 and also Sustainable Development Goal (SDG) 9 Industry, Innovation and Infrastructure. Overall, this study makes an important theoretical contribution by identifying the barriers to blockchain adoption in sustainable material handling within the Malaysian construction industry. It offers valuable insights for researchers and practitioners by discussing these challenges and proposing potential solutions to overcome them in the future. In future, the researchers can further explore other variables such as strategies and opportunities for adoption of blockchain technology towards sustainable material handling in construction industry. Also, other potential technology besides blockchain technology can be studied as well to promote sustainable material handling.

Authors Contributions

In this study, Siti Amirah binti Ahmad has made significant contributions to all aspects, including conceptualization and design, methodology, data collection, data analysis, and manuscript preparation. However, Ts. Dr. Lee Yong Siang has primarily focused on reviewing the paper to ensure its scientific rigor. Additionally, Dr. Nurhaizan binti Mohd Zainudin provided support during the data collection phase.

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Institutional Review Board Statement

Not applicable.

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Siti Amirah binti Ahmad is a PhD student from Faculty of Civil Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA). Her research interest mainly focus on adoption of blockchain technology for sustainable material handling in construction industry.

Ts. Dr. Lee Yong Siang is a distinguished civil engineering professional, academic, and trainer with expertise in project management, research, and consultancy. He is a certified QLASSIC assessor, Circular Economy specialist, and has experience in both building and infrastructure projects. As a Senior Lecturer at Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA), he manages academic programs, research, and industry collaborations in civil engineering. Dr. Lee has extensive experience in construction and excels in applying LEAN and SIX SIGMA principles to meet budget and operational goals. Proficient in digital construction tools, risk assessment, and data analysis, he is certified as a Professional Technologist (MBOT), AutoCAD Certified Associate, and registered as a graduate engineer (BEM).

Dr. Nurhaizan Mohd Zainudin is a Senior Lecturer and Head of the Project Management Program at the Faculty of Industrial Management, Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA). She brings extensive professional experience as a Quantity Surveyor and has previously worked in the oil and gas industry. Nurhaizan holds a Master's degree in Project Management from Queensland University of Technology, Australia, and a Doctorate from Iowa State University, USA. Nurhaizan has been deeply engaged in research activities, with expertise spanning workers' safety, risk management, project management, construction management, and contract administration. Her current research projects include exploring decision-making processes using advanced tools such as Space Syntax for building design assessment. Additionally, her team is actively investigating issues related to CIPAA (Construction Industry Payment and Adjudication Act) and dispute resolution mechanisms.