Anuradha, I.G.N., Ambagala, K.K., Nanayakkara, S. and Perera, S., 2023. Adaptation of blockchain and smart contracts to the construction industry of developing countries. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ramachandra, T. and Ranadewa, K.A.T.O. (eds). *Proceedings of the 11th World Construction Symposium*, 21-22 July 2023, Sri Lanka. [Online]. pp. 73-85. DOI: https://doi.org/10.31705/WCS.2023.7. Available from: https://ciobwcs.com/papers/

ADAPTATION OF BLOCKCHAIN AND SMART CONTRACTS TO THE CONSTRUCTION INDUSTRY OF DEVELOPING COUNTRIES

I.G.N. Anuradha[1], Krishni Kavindya Ambagala[2], Samudaya Nanayakkara[3] and Srinath Perera[4]

ABSTRACT

The construction industry is often criticised due to its inherited challenges. Lack of trust and transparency, inadequate collaboration and complex structure have plagued the construction sector. Blockchain is a technology that has the potential to address these issues by automating procedures and enhancing traceability and transparency with its salient features. Whereas adaptation of blockchain within the construction industry is still at its inception. The situation is bleak in developing countries and there are numerous barriers and limitations that impact the implementation process. Therefore, this paper aimed to distinguish the barriers that affect the adaptation of blockchain and smart contracts for the construction industry of developing countries. The study used a mixed research approach. The barriers were ranked based on the data collected through a questionnaire survey and strategies to overcome them were identified through expert interviews. Findings derived from the analysis indicate that having a limited number of construction related software applications (powered by blockchain), the reluctance of the companies to bear additional costs to adapt blockchain and sluggish adaptation to new technologies as the significant barriers. As per the identified strategies, conducting an industry-wide digitalisation analysis, developing an industry-wide digitalisation strategy and recruiting skillful staff can be pointed out as the weighty strategies. The outcomes of this research were gained through the data collected from Sri Lanka, which is a limitation of this study. Eventually, a framework was developed as a guideline to implement blockchain and smart contracts for the construction industry of developing countries.

Keywords: *Barriers; Blockchain; Construction Industry; Smart Contracts; Strategies.*

1. INTRODUCTION

The construction industry is an indispensable part of the economy and it is contributing approximately 13% to the global gross domestic product (Blanco et al., 2020). Whereas, the construction industry is considered as the second-lowest sector in terms of Information and Communication Technology (ICT) usage (Agarwal et al., 2016). The construction industry faces productivity related issues due to various challenges such as

[1] PhD candidate, Western Sydney University, Australia, 22068394@student.western.sydney.edu.au
[2] Master's candidate, The University of Adelaide, Australia, kavi.ambagala@gmail.com
[3] Senior lecturer, University of Moratuwa, Sri Lanka, samudayan@gmail.com
[4] Professor, Western Sydney University, Australia, srinath.perera@westernsydney.edu.au

poor payment practices, inadequate collaboration, weak information accessibility and sharing, etc. (Li et al., 2019). Inadequate technology adaptation is one of the main reasons for the low productivity of the construction industry (Nanayakkara et al., 2021). Blockchain technology is recognised as one of the evolving technologies which can improve the productivity of many sectors, including the construction industry (Kim et al., 2020).

Blockchain technology is a distributed ledger technology which stores digital data within a peer to peer network and it is the underpinning technology of the cryptocurrencies such as Bitcoin (Penzes et al., 2018). The key concepts of blockchain technology are consensus mechanism, peer-to-peer network, decentralisation and cryptography (Zheng et al., 2018). It is a secured data storing mechanism that shares and synchronizes data across different geographical locations without a centralised administration (Hewavitharana et al., 2019). The main advantages of blockchain technology are trust without third parties, greater transparency, higher security, traceability, immutability, autonomous and faster processing (Hamma-adama et al., 2020). Although blockchain technology was initially adapted to create cryptocurrencies, new applications for different sectors were found later (Dujak & Sajter, 2019).

The construction firms in developing countries are in the early stage of adapting ICT and still rely on hand-operated communication methods such as phones, emails, and faxes (Moshood et al., 2020). Even though the implementation of blockchain and smart contracts brings numerous advantages, some barriers need to be eliminated in adapting blockchain and smart contracts for the construction industry of developing countries (Graham, 2019). Therefore, the successful implementation of new technology like blockchain within the construction industry of a developing country is a challenging process (Paudyal & Prakriti, 2016).

Although there are some researches have been conducted on blockchain related to the construction industry, a limited number of research have focused on the barriers which affect the implementation of blockchain and smart contracts for the construction industry of developing countries and to come up with strategies to overcome them. Therefore, this research aimed to address this research gap by identifying the barriers which affect the implementation of blockchain and smart contracts for the construction industry of developing countries and to develop a suitable framework to overcome them.

2. LITERATURE REVIEW

2.1 BLOCKCHAIN TECHNOLOGY

Blockchain can be defined as a decentralised distributed ledger technology that records, stores and shares a real-time updated copy of all transactions with the members of the network (Nawari & Ravindran, 2019). Blockchain technology is a combination of the concepts, including peer-to-peer protocols, hashing algorithms, cryptographic primitives such as public-key cryptography and distributed consensus algorithms (Deng et al., 2021).

A blockchain network is made up of hundreds to thousands of peers known as nodes (Javaid et al., 2021). These nodes share data throughout the networking peer-to-peer protocols (Perera et al., 2020). All these nodes are connected with each other, and each node maintains a complete set of records named a blockchain ledger (Hewavitharana et

al., 2019). The blocks of data that make up the blockchain ledger are connected to one another by their hash values. A block consists of one or more transactions. When a new block is created, it includes the previous one's hash value and is appended to the blockchain ledger. If a single bit of data was changed in any block, the next block identifies a mismatch between the previous and new values (Alharby & Van Moorsel, 2017).

2.2 SMART CONTRACTS

Smart contracts are the computer protocols that digitally facilitate, execute, and enforce the contracts made between two or more parties on the blockchain (Wang et al., 2019). Blockchain enables smart contracts were first introduced in 1990 by Nick Szabo (Zheng et al., 2018). It is an automatically executing contract or agreement which is directly recorded in the system and exists across the entire blockchain network (Nanayakkara et al., 2021). One of the key features of smart contracts is the peer-to-peer connection between the participants of the network without the intervention of a third party (Alharby & Van Moorsel, 2017). Therefore, smart contracts can replace the traditional forms of contracts by enhancing efficiency, and transactional safety and reducing the risk of breaching contracts (Allam, 2018). Furthermore, this concept guarantees a trustful payment chain between the parties, and also it minimises cost overruns due to the reduction of disputes (Ahmadisheykhsarmast & Sonmez, 2018).

2.3 SIGNIFICANCE OF BLOCKCHAIN AND SMART CONTRACTS FOR THE CONSTRUCTION INDUSTRY

Enormous benefits can be gained by adapting blockchain technology to the different segments of construction industry such as asset management, construction supply chain, contract management, payment handling, etc. (Nanayakkara et al., 2019). Therefore, the potential of blockchain applications for the construction industry is quite high (San et al., 2019). Furthermore, blockchain technology has the capability to transform the construction industry by creating a new platform for employees to transact and collaborate with each other (Nguyen et al., 2019). Immutability, transparency, auditability, decentralisation and security are some of the main benefits of blockchain which can be used to enhance the performance of the construction industry (Singh, 2020). In addition, blockchain and smart contracts together provide a number of advantages to the construction projects, such as minimising the transaction cost, improving the trust among the parties, enhancing the efficiency, etc. (Ahmadisheykhsarmast & Sonmez, 2018).

2.4 BARRIERS IN ADOPTING BLOCKCHAIN AND SMART CONTRACTS FOR THE CONSTRUCTION INDUSTRY

Being a novel concept, there are some barriers in adapting blockchain technology for the construction industry (Graham, 2019). The main barriers are pointed out Table 1.

Table 1: Barriers in adapting blockchain technology for the construction industry

Category	Barriers	References
Organisational	The reluctance of the companies to bear expenses relate to new technologies	(Wang et al., 2019)
	Relevant leadership is not received from the management for the new technology adaptation such as blockchain	(Zamani & Giaglis, 2018)
Industrial	Slow adaptation to new technologies	(Hamma-adama et al., 2020)
	Prevailing practices in the industry (e.g., conventional requirements and norms)	(Graham, 2019)
	The status of the information technology within the construction industry	(Koutsogiannis & Berntsen, 2017)
	Lack of awareness regarding blockchain technology	(Weerakoon & Chandanie, 2021)
Human	Having few blockchain consultants/experts that suit the industry requirements	(Angelis & Da Silva, 2019)
	Low technological competency level of industry and IT related employees	(Weerakoon & Chandanie, 2021)
	The natural reluctance of the industry practitioners to change	(Weerakoon & Chandanie, 2021)
	Having low trust towards new technologies like blockchain	(Graham, 2019)
Technical	Having less number of construction related software applications (powered by blockchain)	(Kshetri, 2017)
	Privacy and security concerns regarding novel ICT	(Li et al., 2019)
	Lack of connectivity and bandwidth	(Kamble et al., 2020)
Legal and political	Lack of legal protocols to prevent misconduct	(Li et al., 2019)
	Lack of government policies	(San et al., 2019)

3. METHODOLOGY

A mixed research approach which includes both qualitative and quantitative methods, was adopted to fulfil the research aim of this study. The research process of this study mainly consists of four key steps;

A. Comprehensive literature review

A comprehensive literature review was conducted to identify the barriers which affect the implementation of blockchain and smart contracts for the construction industry.

B. Questionnaire survey

A questionnaire survey was carried out to determine the level of impact of both barriers and the blockchain applicable areas identified through literature and to know the current ICT status in Sri Lankan construction industry. Sri Lankan construction industry professionals with good ICT knowledge, including blockchain, were selected as a purposive sample to collect the data through a questionnaire survey. Since blockchain technology is still new to Sri Lanka, there are only a few blockchain experts in the Sri Lankan construction industry. Therefore, the construction digitalisation experts who have knowledge on blockchain technology were selected. The selected sample for the study included project managers, engineers, quantity surveyors, architects and facility

managers. The questionnaire was distributed among 60 professionals within the Sri Lankan construction industry, and 44 had responded. Three main sections, applicable areas of blockchain technology for the construction industry, current construction-related ICT level in Sri Lanka, level of impact of the barriers for the adaptation of blockchain and smart contracts for the construction industry of developing countries, were targeted by this questionnaire.

The respondents of the questionnaire were asked to rank the statements and barriers using a five-point Likert scale. Next, the data (which were gained from respondents) were analysed using the Relative Important Index (RII) method. The following formula was used to analyse the collected data.

RII = (∑W)/(A x N)

W = Weight given to each variable by the respondent, A = The highest weight (5)

N = Total number of people who participated as the respondents for the survey

In order to rank the barrier categories, the Weighted Mean Average (WMA) method was used. The following formula was adopted to rank the barrier categories.

$$W = \frac{\sum_i^n wiXi}{\sum_i^n wi}$$

W = Weighted average, n = Number of terms to be averaged, wi = Weights apply to x values, X = Data values to be averaged.

C. Expert interviews

Expert interviews were used to come up with strategies to overcome the identified barriers through the questionnaire survey. Since there were only a few blockchain experts in the Sri Lankan construction industry, expert interviews were limited to five (5). There the collected data through expert interviews were analysed with the use of content analysis (manually).

D. Framework development

Based on the questionnaire survey and findings of content analysis, a framework was developed to implement blockchain and smart contracts for the construction industry of developing countries.

4. FINDINGS AND DISCUSSION

4.1 THE CURRENT CONSTRUCTION RELATED ICT LEVEL

In order to adapt blockchain technology to the construction industry, identifying the current construction-related ICT level is crucial. Therefore, it was targeted within the questionnaire. The analysis revealed that infrastructure and facilities (e.g., computers, networks, etc.), awareness regarding new ICT and government policies related to new ICT (e.g., digital signature) are at a satisfactory level. Therefore, those factors have a positive impact on blockchain implementation. Nevertheless, as per the analysis results, adapting to new technologies, the interest of the construction industry, including governing bodies and policymakers, to adopt new ICT like blockchain and industry standards regarding information technologies (e.g., BIM requirement standards) need to be improved for the better adaptation of blockchain technology for the construction

industry of Sri Lanka. RII analysis results relate to the "current construction-related ICT level" is portrayed in Table 2.

Table 2: RII results of the current construction-related ICT level

Statements	RII	Rank
Infrastructure and facilities (e.g., computer, network, etc.) to implement novel technologies like blockchain	0.886	1
Awareness regarding new ICT	0.874	2
Government policies related to new ICT (e.g., digital signature)	0.820	3
Adapting to new technologies	0.660	4
The interest of the construction industry (governing bodies and policymakers) to adopt new ICT like blockchain	0.614	5
Industry standards regarding Information Technologies (e.g., BIM requirement standards)	0.585	6

4.2 BARRIERS WHICH AFFECT THE IMPLEMENTATION OF BLOCKCHAIN AND SMART CONTRACTS FOR THE CONSTRUCTION INDUSTRY

In referring to barriers, having less number of construction related software applications (powered by blockchain) was identified as the highest impactful barrier, with a RII value of 0.909. Being a novel technology, market ready software applications (powered by blockchain) are limited. The reluctance of the companies to bear expenses relate to new technologies has received the second place in the overall ranking with a 0.877 RII value. This is followed by slow adaptation to new technologies, having few blockchain consultants/experts that suit the industry requirements and low technological competency level of industry and IT related employees with RII values of 0.845, 0.832 and 0.827, accordingly.

As per the results, it was identified that the organisational barriers are the most significant barrier category with a grand mean value of 4.182. Moreover, the industrial barriers were posed as the second most significant category (grand mean value-3.813), and human, technical and legal & political barriers received the third, fourth and fifth places with grand mean values of 3.744, 3.523 and 3.159 accordingly. It is graphically shown in Table 4.

Table 3: RII and mean values of the barriers which affect the implementation of blockchain and smart contracts for the construction industry

Category	Barriers	RII	Mean	Rank
Organisational	The reluctance of the companies to bear expenses relate to new technologies	0.877	4.386	2
	Relevant leadership is not received from the management for the new technology adaptation such as blockchain	0.795	3.977	6
	Grand mean of organisational barriers		4.182	
Industrial	Slow adaptation to new technologies	0.845	4.227	3
	Prevailing practices in the industry (e.g., conventional requirements and norms)	0.773	3.864	7

	The status of the information technology within the construction industry	0.736	3.682	9
	Lack of awareness regarding blockchain technology	0.695	3.477	10
	Grand mean of industrial barriers		3.813	
Human	Having few blockchain consultants/experts that suit the industry requirements	0.832	4.159	4
	Low technological competency level of industry and IT related employees	0.827	4.136	5
	The natural reluctance of the industry practitioners to change	0.750	3.750	8
	Having low trust towards new technologies like blockchain	0.586	2.932	14
	Grand mean of human-related barriers		3.744	
Technical	Having less number of construction related software applications (powered by blockchain)	0.909	4.545	1
	Privacy and security concerns regarding novel ICT	0.664	3.318	11
	Lack of connectivity and bandwidth	0.541	2.705	15
	Grand mean of technical barriers			
Legal and political	Lack of legal protocols to prevent misconduct	0.645	3.227	12
	Lack of government policies	0.618	3.091	13
	Grand mean of legal & political barriers		3.159	

Organisational barriers

These barriers emphasise that the companies within the construction industry are reluctant to change their existing practice. In supporting this Li (2019) stated that the organisations within the construction industry are historically resistant to change. Since there is no proper leadership and funds from the side of the company, it is really though to adopt new technology like blockchain, and employees like to adopt it. Therefore, this reflects that the organisational barriers have a notable impact on the blockchain implementation process.

Industrial barriers

The category of industrial barriers has been crowned as the second most impactful barrier category. Among the four barriers within the industrial category, slow adaptation to new technologies plays a major role. In proving it, Hamma-adama (2020) states that the construction industry is still lagging in terms of digitalisation. Lack of awareness regarding blockchain technology is another impactful barrier that belongs to the category of industrial barriers. In supporting it, Weerakoon & Chandanie (2021) reveals that the awareness regarding blockchain technology is low in Sri Lanka. Furthermore, Wang (2017) mention that the blockchain is still a new technology for most construction professionals. Therefore, the lack of awareness and the slow adaptation to new technologies like blockchain affects the implementation of blockchain and smart contracts to the construction industry of developing countries.

Human-related barriers

The most impactful human-related barriers identified from the analysis are the having few blockchain consultants/experts that suit the industry requirements and the low technological competency level of industry and IT related employees. In confirming this,

Weerakoon and Chandanie, (2021) has identified that the technical incapacity of the professionals within the construction industry is one of the predominant barriers to adapt a new technology like blockchain. This reflects that the knowledge and technical skills of industry professionals related to blockchain need to be improved for the proper implementation of blockchain and smart contracts in the construction industry in developing countries. Further, the RII analysis revealed that the natural reluctance of the industry practitioners to change is another key human-related barrier. Therefore, less collaboration can be seen among the industry professionals especially related to ICT-related new implementations, and this barrier should be overcome. In emphasising it, (Li et al., 2019), suggests that the blockchain implementation process requires the collaboration of all the construction professionals in the industry. Therefore, all the construction professionals should be ready to change accordingly to adopt a new technology like blockchain for construction projects.

Technical barriers

Technical barriers have received fourth place out of all five categories. Nevertheless, the most impactful barrier out of all fifteen barriers belongs to this category which is having less number of construction related software applications (powered by blockchain). Wang (2019) even utters in their study that there are few blockchain-based construction-related applications are currently available. This is crucial as the implementation of blockchain and smart contracts for the construction industry is not successful without the relevant software. However, the other two barriers belong to this category, privacy and security concerns regarding novel ICT and lack of connectivity and bandwidth, are ranked 11th and 15th accordingly. The reason for receiving low ranks from respondents is privacy and security concerns regarding novel ICT, and connectivity and bandwidth are at a satisfactory level in Sri Lanka. Therefore, the impact of these two barriers is very less for the adaptation of blockchain and smart contracts for construction projects.

Legal and political barriers

The legal and political barrier category has received last (fifth) place in the ranking. Barriers which belong to this category are a lack of legal protocols to prevent misconduct and a lack of government policies. Both the barriers have received the ranks of 12th and 13th among the fifteen barriers. However, according to Li (2019), there is a lack of legal protocols and regulations related to blockchain. Nevertheless, the existing legal protocols and regulations in Sri Lanka are fair enough to start the implementation process of blockchain and smart contracts for construction projects. Therefore, the category of legal and political barriers has posed as the lowest impactful barrier category.

4.3 STRATEGIES TO OVERCOME THE BARRIERS

The experts were asked to propose suitable strategies to overcome the identified barriers in implementing blockchain in the construction industry. Altogether, seven strategies were proposed by them. All five experts emphasised that conducting an industry-wide digitalisation analysis to figure out the IT status of the construction industry is the most significant strategy that needs to be followed prior to the implementation of blockchain technology. In accordance with the experts, knowing the current IT status is really crucial to deciding the other strategies for better adaptation of blockchain and smart contracts. The development of an industry-wide digitalisation strategy was suggested as the second most prominent strategy by all interviewees, A, B, C, D, and E. As per the interviewees,

proper implementation of the first strategy is quite crucial to materialise this strategy. As the next strategy, all five experts proposed to have skilful IT staff for construction companies to implement blockchain and smart contracts for construction projects. Further, they pointed out that currently, there are very few skilful IT staff is within the construction companies of developing countries, and this has become a major reason for less adaptation to new ICT technologies like blockchain for construction projects.

Next, A, B, D and E suggested that it is necessary to influence the policy-making bodies regarding the benefits of adopting blockchain technology in construction projects. In Sri Lanka, some policy-making bodies relate to construction industry such as CIDA, UDA, etc. and influencing these policy-making institutes regarding the benefits of adopting blockchain and smart contracts will trigger them to implement new policies related to blockchain implementation to the construction projects. This may reason to attract construction professionals and companies to adopt blockchain and smart contracts for construction projects. Furthermore, A, B, C and E emphasised that the awareness of the construction firms and the construction industry professionals regarding blockchain technology is necessary to be improved. There they suggested conducting CPD programs by different professional institutes to make aware and educate the construction industry professionals on blockchain and smart contracts.

Moreover, conducting awareness sessions for the construction and consultancy firms is also a fruitful way to enhance the awareness of blockchain and smart contracts within the construction industry. Three interviewees, A, C and E proposed that it is necessary to create certain action plans and materialise them to promote blockchain and its benefits among the people within the society. Next, B, C and E suggested that including blockchain and smart contracts in the curriculums of construction-related degree programs and other higher education programs as a very good initiative. This may urge to take the attraction of the various young stakeholders who enter the construction industry and subsequently leads to the adaptation of blockchain and smart contracts to the construction industry.

4.4 FRAMEWORK TO ADAPT BLOCKCHAIN AND SMART CONTRACTS FOR THE CONSTRUCTION INDUSTRY

A comprehensive framework was developed to adopt blockchain and smart contracts for the construction industry with the use of the findings of literature and the collected and analysed data from questionnaire survey and expert interviews. Figure 2 represents the developed framework to adopt blockchain and smart contracts for the construction industry of developing countries.

The first step of the framework is to identify the barriers that affect the implementation of blockchain and smart contracts. The barriers have been classified into five categories organisational, industrial, human, technical and legal and political. The barrier categories have been listed within the framework according to their impact on the adaptation of blockchain and smart contracts for the construction industry of developing countries. Afterwards, suitable strategies to overcome the identified barriers (which were gained through expert interviews) have been listed within the next cage. There the strategies have been listed from the highest rated to the lowest based on the answers of the interviewees. The third step of this framework is to distinguish the suitable blockchain-appliable areas within the construction industry. There it has highlighted payment management, construction supply chain, sustainability management, tendering and contract

management as the key areas where blockchain and smart contracts can be mainly applicable within the construction industry of developing countries. After distinguishing the applicable areas, the last step has illustrated the outcomes which can be gained through the adaptation of blockchain and smart contracts for the construction industry. As a whole, this framework can be adopted by policy-making institutes and governments as a guideline to adapt blockchain and smart contracts. Sri Lanka is a developing country (Department of Foreign Affairs and Trade [DFAT], 2022). In considering the status of other developing countries they have similar technological background in terms of construction (Mahbub, 2012). Therefore, this framework can be adapted to those countries as well. Further, this framework was not validated, and it is a limitation of this study.

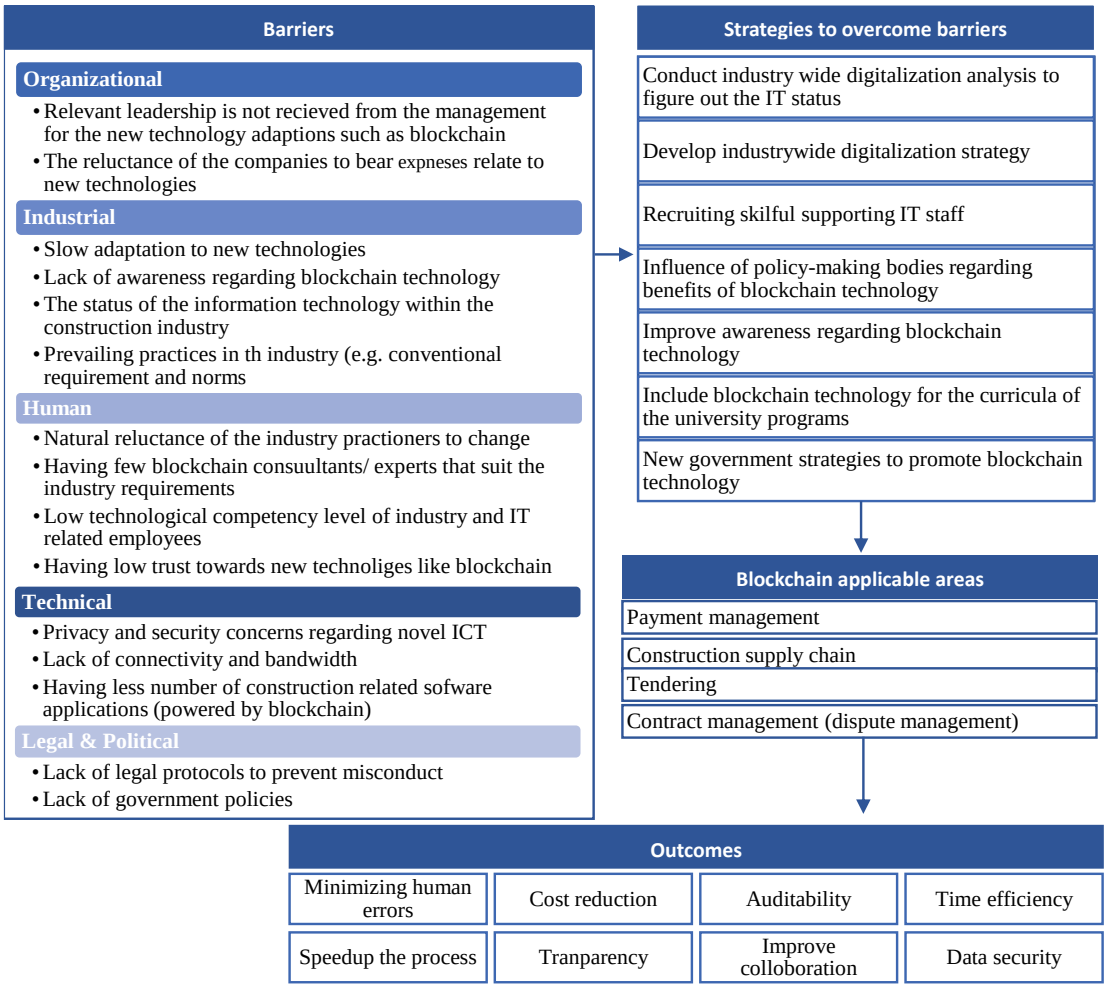

Figure 1: Framework to adapt blockchain and smart contracts for the construction industry of developing countries

5. CONCLUSIONS

Comparing to developed countries, developing countries face numerous barriers in implementing a new technology such as blockchain for the construction industry. Therefore, this research aimed to address this research gap by identifying the barriers which affect the implementation of blockchain and smart contracts for the construction

industry of developing countries and to come up with a suitable framework to overcome the identified barriers. Fifteen barriers were identified through a comprehensive literature review and in referring to the findings of the analysis, having a smaller number of construction related software applications (powered by blockchain) was highlighted as the most impactful barrier to blockchain adaptation. Moreover, the reluctance of the companies to bear additional costs to adapt new ICT such as blockchain, slow adaptation to new technologies, having few blockchain consultants/experts that suit the industry requirements, technical incompetency of industry professionals and IT professionals in construction companies were posed as the 2nd, 3rd, 4th and 5th most significant barriers accordingly. Therefore, more focus has to be given to these barriers in adapting blockchain and smart contracts for the construction industry of developing countries. Moreover, seven strategies were identified in order to overcome the distinguished barriers in blockchain adaptation to the construction industry. Conducting industry-wide digitalisation analysis (to figure out the IT status) was suggested as the most important strategy by the experts, and developing an industry-wide digitalisation strategy, recruiting skilful supporting IT staff, and influencing policy-making bodies regarding the benefits of blockchain technology were also highlighted as the next main strategies to overcome the barriers in adapting blockchain and smart contracts. Based on the findings of the analysis, a framework was developed, and it can be followed by the policy-making bodies and the governments of developing countries as a guideline to adapt blockchain and smart contracts for the construction industry. Further, implementing these strategies appropriately will lead to more productive construction industry for the future generation of developing countries. Eventually, future research should focus more towards developing blockchain related software applications for the construction industry and to come up with certain mechanisms to feed data to the nodes of the blockchain.

6. REFERENCES

Agarwal, R., Chandrasekaran, S., & Sridhar, M. (2016). Imagining construction's digital future. *McKinsey & Company*, *24*(06). https://www.arataumodular.com/app/wp-content/uploads/2021/01/McKinsey-ImaginingConstructionsDigitalFuture.pdf

Ahmadisheykhsarmast, S., & Sonmez, R. (2018). Smart contracts in construction industry. *Proceedings of the 5th International Project & Construction Management Conference*, (pp. 767-774), Kyrenia, Cyprus. https://www.academia.edu/download/58138811/Smart_Contracts_in_Construction_Industry-_IPCMC_2018.pdf

Alharby, M., & Van Moorsel, A. (2017). Blockchain-based smart contracts: A systematic mapping study. *Computer Science & Information Technology (CS & IT)*. doi: 10.5121/csit.2017.71011

Allam, Z. (2018). On smart contracts and organisational performance: A review of smart contracts through the blockchain technology. *Review of Economic and Business Studies*, *11*(2), 137-156. doi: 10.1515/rebs-2018-0078

Angelis, J., & Da Silva, E. R. (2019). Blockchain adoption: A value driver perspective. *Business Horizons*, *62*(3), 307-314. doi: 10.1016/j.bushor.2018.12.001

Blanco, J., Mischke, J., Ribeirinho, M., Rockhill, D., Sjödin, E., Strube, G., Palter, R., & Andersson, T. (2020). The next normal in construction. *McKinsey & Company*. https://www.mckinsey.com/~/media/McKinsey/Industries/Capital%20Projects%20and%20Infrastructure/Our%20Insights/The%20next%20normal%20in%20construction/The-next-normal-in-construction.pdf

Deng, T., Zhang, K., & Shen, Z.-J. M. (2021). A systematic review of a digital twin city: A new pattern of urban governance toward smart cities. *Journal of Management Science and Engineering*, *6*(2), 125-134. doi: https://doi.org/10.1016/j.jmse.2021.03.003

Dujak, D., & Sajter, D. (2019). Blockchain applications in supply chain. *SMART supply network*, 21-46. doi: 10.1007/978-3-319-91668-2_2

Graham, S. (2019). Implementation of blockchain technology in the construction industry. https://digitalcommons.calpoly.edu/cmsp/190

Hamma-adama, M., Salman, H., & Kouider, T. (2020). Blockchain in construction industry: challenges and opportunities. *International engineering conference and exhibition (IECE 2020)*, 2-5 March 2020, Riyadh, Saudi Arabia, 1-9. https://rgu-repository.worktribe.com/output/828858

Hewavitharana, T., Nanayakkara, S., & Perera, S. (2019). Blockchain as a project management platform. *Proceedings 8th World Construction Symposium (2019).* Colombo, Sri Lanka. http://dl.lib.mrt.ac.lk/handle/123/15252

Javaid, M., Haleem, A., Singh, R. P., Khan, S., & Suman, R. (2021). Blockchain technology applications for Industry 4.0: A literature-based review. *Blockchain: Research and Applications*, *2*(4), 100027. doi: 10.1016/j.bcra.2021.100027

Kamble, S. S., Gunasekaran, A., & Sharma, R. (2020). Modeling the blockchain enabled traceability in agriculture supply chain. *International Journal of Information Management*, *52*, 101967. doi: 10.1016/j.ijinfomgt.2019.05.023

Kim, K., Lee, G., & Kim, S. (2020). A study on the application of blockchain technology in the construction industry. *KSCE journal of civil engineering*, *24*(9), 2561-2571. doi: 10.1007/s12205-020-0188-x

Koutsogiannis, A., & Berntsen, N. (2017). Blockchain and construction: the how, why and when. *https://www.bimplus.co.uk/blockchain-and-construction-how-why-and-when/*

Kshetri, N. (2017). Will blockchain emerge as a tool to break the poverty chain in the Global South? *Third World Quarterly*, *38*(8), 1710-1732. doi: 10.1080/01436597.2017.1298438

Li, J., Greenwood, D., & Kassem, M. (2019). Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases. *Automation in construction*, *102*, 288-307. doi: 10.1016/j.autcon.2019.02.005

Department of Foreign Affairs and Trade [DFAT] (2022*). List of developing countries as declared by the Minister for Foreign Affairs*. Minister for Foreign Affairs. https://www.dfat.gov.au/sites/default/files/list-developing-countries.pdf

Mahbub, R. (2012). Readiness of a developing nation in implementing automation and robotics technologies in construction: A case study of Malaysia. *Journal of Civil Engineering and Architecture*, *6*(7), 858. ISSN 1934-7359. https://www.academia.edu/download/69665652/555af6b3b7bf8.pdf

Moshood, T. D., Nawanir, G., Sorooshian, S., Mahmud, F., & Adeleke, A. Q. (2020). Barriers and benefits of ICT adoption in the Nigerian construction industry. A comprehensive literature review. *Applied System Innovation*, *3*(4), 46. https://www.mdpi.com/2571-5577/3/4/46

Nanayakkara, M., Anuradha, I., Liyanage, D., & Devapriya, K. (2021). Developing a Cost-Effective Web-Based Communication and Information Management System for Construction Projects. *International Research Conference (KDU IRC)*. http://ir.kdu.ac.lk/handle/345/5170

Nanayakkara, S., Perera, S., Bandara, D., Weerasuriya, T., & Ayoub, J. (2019). Blockchain technology and its potential for the construction industry. *Proceedings of the 43rd Australasian Universities Building Education Association (AUBEA) Conference: Built to Thrive: Creating Buildings and Cities that Support Individual Well-being and Community Prosperity*, (pp. 662-672). Central Queensland University.https://www.researchgate.net/profile/Arezoo-Shirazi/publication/337811399_A_cost_benefit_analysis_of_retrofitting_public_policies_on_Atlanta_residential_housing/links/5e33c713458515072d710ada/A-cost-benefit-analysis-of-retrofitting-public-policies-on-Atlanta-residential-housing.pdf#page=665

Nawari, N. O., & Ravindran, S. (2019). Blockchain and the built environment: Potentials and limitations. *Journal of Building Engineering*, *25*, 100832. doi: 10.1016/j.jobe.2019.100832

Paudyal, G., & Prakriti, K. (2016). Role of ICT in construction. *National Students Conference on Information Technology (NaSCoIT)*, Kathmandu, Nepal. https://www.researchgate.net/publication/329538632_ROLE_OF_ICT_IN_CONSTRUCTION?enrichId=rgreq-78ca57cb156545a0042db1480171ab12-XXX&enrichSource=Y292ZXJQYWdlOzMyOTUzODYzMjtBUzo3MDIyOTEyMzc2ODMyMDJAMTU0NDQ1MDY4NzU1OQ%3D%3D&el=1_x_2&_esc=publicationCoverPdf

Penzes, B., KirNup, A., Gage, C., Dravai, T., & Colmer, M. (2018). Blockchain technology in the construction industry: Digital Transformation for High Productivity. *Institution of Civil Engineers (ICE)*, https://www.ice.org.uk/ICEDevelopmentWebPortal/media/Documents/

Perera, S., Nanayakkara, S., Rodrigo, M., Senaratne, S., & Weinand, R. (2020). Blockchain technology: Is it hype or real in the construction industry? *Journal of industrial information integration*, *17*, 100125. doi: 10.1016/j.jii.2020.100125

San, K. M., Choy, C. F., & Fung, W. P. (2019). The potentials and impacts of blockchain technology in construction industry: A literature review. In IOP Conference Series: Materials Science and Engineering (Vol. 495, p. 012005). IOP Publishing. doi: 10.1088/1757-899X/495/1/012005

Singh, P. (2020). Blockchain based security solutions with IoT application in construction industry. In IOP conference series: earth and environmental science (Vol. 614, No. 1, p. 012052). IOP Publishing. doi: 10.1088/1755-1315/614/1/012052

Wang, Y., Han, J. H., & Beynon-Davies, P. (2019). Understanding blockchain technology for future supply chains: a systematic literature review and research agenda. *Supply Chain Management: An International Journal*, *24*(1), 62-84. doi: 10.1108/SCM-03-2018-0148

Weerakoon, H., & Chandanie, H. (2021). Analysis of Feasibility of Blockchain Technology for International Trade related to Sri Lankan Construction Industry. *Proceedings of the 9th World Construction Symposium*, Sandanayake, Y.G., Gunatilake, S. and Waidyasekara, K.G.A.S. (eds), 9-10 July 2021, Sri Lanka. [Online]. pp. 75-85. http://dl.lib.uom.lk/handle/123/16552

Zamani, E. D., & Giaglis, G. M. (2018). With a little help from the miners: distributed ledger technology and market disintermediation. *Industrial Management & Data Systems*, *118*(3), 637-652. doi:10.1108/IMDS-05-2017-0231

Zheng, Z., Xie, S., Dai, H.-N., Chen, X., & Wang, H. (2018). Blockchain challenges and opportunities: A survey. *International journal of web and grid services*, *14*(4), 352-375. doi: 10.1504/IJWGS.2018.095647