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Blockchain in construction industry: challenges and opportunities.

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Blockchain in Construction Industry: Challenges and Opportunities

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ABSTRACT

Construction Industry is currently evolving around the world. On the other hand, despite the technological advancement across most sectors, construction industry remains amongst laggards in digitalization. Currently, engineering business is facing technological disruption ahead of the fourth industrial revolution; one of which is the blockchain technology! Blockchain is new to construction industry, its challenges and opportunities are yet to be fully realized. This study explores the challenges and potential opportunities of blockchain in the construction industry through extensive review of literature within the blockchain domain vis-à-vis construction business domain. The study presents challenges under three categories (technical, regulation and social), and the potential opportunities in to improving efficiency and reducing conflict through transparency and trust. That will ultimately create value for money in the procurement of construction works. Recommendations are made based on the study finding to advance the research on blockchain applications in to the construction industry.

Keywords: blockchain, challenges, construction, industry, opportunities

INTRODUCTION

Construction Industry is one of the oldest industries that provides human with comfort to living; and employs a significant number of skilled and unskilled persons around the world (Abdul-Rashid & Hassan, 2005). In fact, for building activities, they are as old as humans' existence. Construction industry has been conventionally operating for centuries; progressing from pit-houses construction, grass shelters, to more permanent structure (Niroumand, Zain, Jamil, & Niroumand, 2013). The traditional construction commenced in Ancient Egypt and Mesopotamia when humans abandoned nomadic life, and permanent societies started to grow (Shaw, 2003). The second Industrial Revolution brings a significant turning point in the construction industry when America began mass production of steel (Mokyr, 1998). Fast forward to the 20th century, technological development turns around most industries including the construction sector. In the 1960s, the development of Design Aided by Computer (DAC), Computer Aided Design (CAD) to 3D, 4D, …nD intelligent modelling nowadays (Dill & Kasik, 2012; Weisberg, 2008).

Despite the current technological advancement, and the continuous developments in most industries, construction industry still operates traditionally with low automation. Construction industry is classified among industries with high resistance to technology adoption. MGI industry digitalisation index of 2015 revealed "Construction ≠ Digital" as a result of been second to the least (Agriculture and hunting) digitalised industry. Construction industry has a long history of disputes, mostly between clients and contractors. Dispute on construction quality, completion period, cost variations and risk sharing are the dominant challenges faced by the industry (Adabre & Chan, 2019); These challenges are attributed to lack of trust and transparency in the way construction works is being procured.

In the recent time, there are number of developments to improve the construction industry's

processes; like Lean Construction, and Building Information Modelling (BIM). While, these developments are striving to improve the construction processes, there is still a serious concern regarding supply chain management of procuring the construction works. The concerns are about lack of trust and transparency in the whole supply chain.

Blockchain is a financial technology innovation; it is a global ledger that records transactions (i.e. cryptocurrency), store documents and documentations (Carlozo, 2017). There are increasing awareness of blockchain by big company managements due to wide publicity on investment, interest and its predicted impact (Schatsky & Pawczuk, 2016). On the same note, senior executives of big companies in the USA feared competitive disadvantage if they failed to adopt blockchain technology in the nearest future. Blockchain technology makes transactions considerably more transparent than those provided by centralized systems. Transactions are performed without relying on explicit trust (of a third party), but on the disseminated trust built on the accord of network (i.e., other blockchain users) (Francisco & Swanson, 2018).

This study attempts to explore the recent findings in the area of blockchain technology and its potentials vis-à-vis its applicability to current challenges in the construction industry. The study intends to be achieved through stratified review of literature in both generic and context (construction industry) domains of blockchain technology.

LITERATURE REVIEW

Blockchain Technology

Blockchain technology (BCT) came into existence in 2009 sequel to the development of Bitcoin by Satoshi Nakamoto; BT is a platform and system underlying Bitcoin. BCT is one of the most glorified innovations in recent times; however, it is amongst the most poorly understood technologies (Hileman & Rauchs, 2017; Risius & Spohrer, 2017). There has been substantial effort to bringing non-technical audience to a clear understanding of BT through industry reports as well as academic and non-academic publications. Despite high awareness (knowing its existence), the true understanding of BCT is still low. BCT or interchangeably used "blockchain" is a fully distributed system for capture and storage of consistent, immutable, linear event log of transactions between interacted actors cryptographically (Risius & Spohrer, 2017).

Hileman & Rauchs (2017) disclosed that, a blockchain comprises of five components in general; cryptography, Peer-to-peer (P2P) network, consensus mechanism, ledger, and validity rules. This set of components provides unique qualities of blockchain. For instance, cryptographic techniques are deployed to ensure secrecy and integrity of data in the incidence of a challenger (Gaire et al., 2019); that involve the use of variety of techniques of cryptography (i.e. symmetric key or public key cryptography, cryptographic one-way hash functions etc.). P2P network provides network for peer discovery and sharing of data in a peer-to-peer manner. Consensus mechanism is the system that regulates the ordering of transactions assuming not every party is honest (adversarial environment). Ledger is a list of transactions bundled in cryptographic linked 'blocks.' And, the validity rules are common rule set for the network in considering valid transactions and how ledger gets updated.

Although blockchains potentially reduce trust needed before transaction, but that do not completely eliminate the need for trust at all. In the same vain, trust is positioned on the validators and/or operators; for a well configured system, participants are independently verifying the state of the system and validating transactions (Hileman & Rauchs, 2017).

In the present days, there are several blockchain myths, but the common ones are:

1. The blockchains are 'trust less'
2. Blockchains are immutable or 'temper-proof'
3. Blockchains are 100% secure
4. Blockchains are 'truth machines'

However, there are corresponding realities to these myths who are mostly misunderstood by the populace; and these include:

1. Blockchains always require some degree of trust
2. Transactions on blockchain network can be reversed by network participants under specific circumstances
3. Blockchains are not automatically more secure than other systems
4. 'Garbage in, garbage out' applies to every blockchain that uses non-native digital assets and/or external data inputs (Hileman & Rauchs, 2017).

Gideon Greenspan of CoinSciences (Multichain) CEO simplified the definition of blockchain as "*a new type of database that enables multiple parties to share the database and to be able to modify that in a safe and secure way even if they don't trust each other*." More to that, blockchain is designed to achieve consistent and reliable agreement over a record of events (e.g., "who owns what") between independent participants who may have different motivations and objectives.

There are typically two blockchain types, the open and the closed one. Summary of these types are presented in Table 1 below (Hileman & Rauchs, 2017; Zheng, Xie, Dai, Chen, & Wang, 2017).

Table 1: Main types of blockchains segmented by permission model

			Read	Write	Commit	Example
Blockchain types	Open	*Public Permission-less*	Open to anyone	Anyone	Anyone*	Bitcoin, Ethereum
		Public permissioned	Open to anyone	Authorised participants	All or subset of authorised participants	Sovrin
	Closed	*Consortium*	Restricted to an authorised set of participants	Authorised participants	All or subset of authorised participants	Multiple banks operating a shared ledger
		Private permissioned ('enterprise')	Fully private or restricted to a limited set of authorised nodes	Network operator only	Network operator only	Internal bank ledger shared between parent company and subsidiaries

** Requires significant investment either in mining hardware (proof-of-work model) or cryptocurrency itself (proof-of-stake model).*

Blockchain is a promising breakthrough technology and is highly applicable to vast businesses. However, Wang, Chen, & Xu (2016) concluded that it is still hard to find experimental evidence to show the comparison between the old or traditional approaches and blockchain approaches. On the same sequence regarding its adoption, businesses should realize that the blockchain system is still evolving. BCT maturity level is not yet optimum and, extensive feasibility study is important for a successful implementation. There are some observed shortcomings in the utilisation of Bitcoins by number of established organisations in the USA. A fear of using public blockchain (i.e. Bitcoin) was reported to have the main discomfort of financial institutions as it is being run by anonymous miners and powered by an unregulated, volatile currency (Hileman & Rauchs, 2017). Thus, legal and reputational issues are the critical challenges stopping many organisations embracing the blockchain, though auditable transaction records were recognised as the key innovation in this new system.

Blockchain Potentials and challenges

Blockchain is a technological breakthrough that is promising and has potential to be applied to vast businesses (Wang et al., 2016). However, it was difficult finding empirical evidence to assess blockchain approaches and compared with the traditional approaches. The challenge faced in recent times to adopt blockchain approach is predominantly policy related (Kiviat, 2015; Wang et al., 2016; Zheng et al., 2017). On the same matter, Zheng et al. (2017) explained three challenges against wide blockchain usage. Scalability, Privacy Leakage, and Selfish Mining were reported as the challenges. Some studies like Kiviat (2015) pre-empt many challenges in bitcoin storage on internet, such as the fraudulent investment schemes, wild price volatility, and multimillion-dollar hacks (McMillan, 2013). However, that do not invalidate other successes and potentials of the BCT as highlighted by many studies like Hamida, Brousmiche, Levard, & Thea (2017); Lindman, Tuunainen, & Rossi (2017); Underwood (2016); and Zheng, Xie, Dai, Chen, & Wang (2018).

BT has been developed to be able to allow anyone to check for the proof of possession of balance, and ability to reject transaction (Toyoda, Mathiopoulos, Sasase, & Ohtsuki, 2017). There has been keen interest by academia and the industry in all fields to exploring how blockchain technology is utilise to address long-lasting problems on integrity of data, transparency, and stakeholders' trust (Nanayakkara, Perera, Bandara, Weerasuriya, & Ayoub, 2019). More to that, BCT and its potentials are matured to be deployed in solving some of the construction industry's challenges especially in the area of supply chain management (Hijazi, Perera, Alashwal, & Calheiros, 2019). Thus, it is determined that, some of the potentials of using blockchain technology are; reduction of trust needed by stakeholders to transact, having a secured value transfer system, reconciliation of business processes, and increase level of transparency and ease of audit as described by Hileman & Rauchs (2017). Table 2 presents 38 publications expatiating on BCT potential to providing platform for transparency and trust; they made important points regarding the two (trust and transparency) main potentials in context of this study.

Table 2: Summary of publications elucidating the trust and transparency potentials of BCT

Subjects in context	**Publications**
Trust, and Transparency	Abeyratne & Monfared, 2016; Baliga, 2017; Belle, 2017; Cong & He, 2019; Conoscenti, Vetro, & De Martin, 2016; Crosby, Pattanayak, Verma, & Kalyanaraman, 2016; de Piraquive, Flor Nancy Díaz, Martínez, Pérez, & Crespo, ; Drescher, 2017; Erri Pradeep, Yiu, & Amor, 2019; Francisco & Swanson, 2018; Gatteschi, Lamberti, Demartini, Pranteda, & Santamaría, 2018; Hamida et al., 2017; Hargaden, Papakostas, Newell, Khavia, & Scanlon, 2019; Hewavitharana, Nanayakkara, & Perera, 2019; Kiviat, 2015; Korpela, Hallikas, & Dahlberg, 2017; Kosba, Miller, Shi, Wen, & Papamanthou, 2016; Lemieux, 2016; Li, Greenwood, & Kassem, 2018; Li, Greenwood, & Kassem, 2019a; Li, Greenwood, & Kassem, 2019b; Lindman et al., 2017; Mathews, Robles, & Bowe, 2017; Morabito, 2017; Nanayakkara et al., ; Nawari & Ravindran, 2019; Nofer, Gomber, Hinz, & Schiereck, 2017; Peck, 2017; SHOJAEI, 2019; Shojaei, Wang, & Fenner, 2019; Shrier, Wu, & Pentland, 2016; Subramanian, 2018; Turk & Klinc, 2017; Underwood, 2016; Weber et al., 2016; Wüst & Gervais, 2018; Zheng et al., 2018; Zyskind & Nathan, 2015.

On the other hand, there are some problems regarding smart contracts. Some of these problems are; Flexibility, Liability, and Enforcement as cited by Morabito (2017).

Challenges in the Construction Industry

Construction industry as one of the oldest sectors in the human life has been changing over time. However, the amount of challenges facing the industry are many compared to other industries that are not as old as it is. Most challenges of the industry are attributed to its resistance to changes and fragmented state of the industry (Walasek & Barszcz, 2017; Zhao, Hwang, & Lee, 2016). The resultant effects of these challenges include: inefficiencies (Mathews et al., 2017), and disputes due to contractual issues and lack of trust between the industry's stakeholders (Mason, 2017). Building Information Modelling has come to integrate the industry's design and construction processes (Azhar, 2011; Zhao et al., 2016); but, the current challenges are trust and transparency especially at the process of awarding contract.

METHOD OF STUDY

This study aims to explore Blockchain Technology (BCT), review the potentials in BCT and identify challenges and prospects of these in relation to the construction supply chain. Google scholar was used as search engine for the publications used; 321 materials (journals, conference papers, and reports) were initially selected from within 2015 – 2019 publications on BCT with respect to the study interest. Keywords like "blockchain," "block chain," and "blockchain technology" were used for the search. Scoping review was conducted on blockchain research, and systematic approach was adopted in selecting the evolving study stream (Paré, Trudel, Jaana, & Kitsiou, 2015). The papers scaled through the selections were basically on study subject, including BCT potentials, BCT in construction context and challenges. Figure 1 presents search and scoping structure of the publications used in the study.

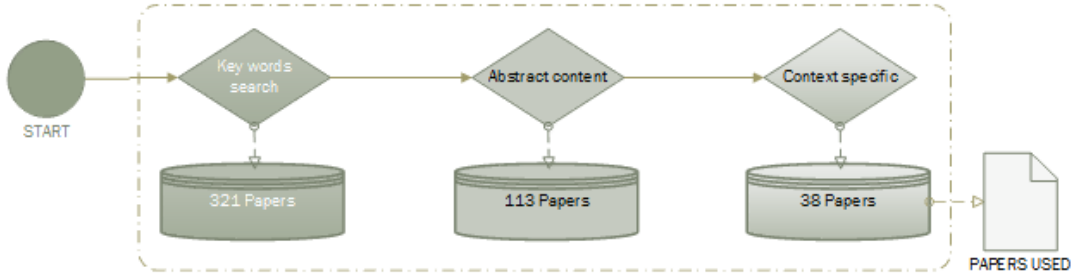

Figure 1: Search and selection process of the publications used

Existing BCT definitions and explanations were identified and explored from numerous previous studies. BCT potentials in the current disruptive era were also identified and qualitatively analysed. Then, construction industry's challenges and the BCTs' potentials were analysed through content analysis as to inform the end potential benefits of its usage in construction industry 4.0. The chart developed by Peck (2017) was used as a guide to determined the need and type of BCT needed in the elaborated challenges of the industry as illustrated in Figure 2.

DISCUSSION

The transparency and ability to bringing trust where there is no trust are the main potentials of BCT

highlighted by significant number of studies and even case studies. Out of the thirty-eight used papers elucidating the BCT potentials, the following (Belle, 2017; Hargaden et al., 2019; Hewavitharana et al., 2019; Hijazi et al., 2019; Li et al., 2018; Li et al., 2019; Li et al., 2019; Mathews et al., 2017; Nanayakkara et al., 2019; Nawari & Ravindran, 2019; and Turk & Klinc, 2017) studies concentrated directly to the potentiality of the BCT in the Architecture Engineering and Construction industry.

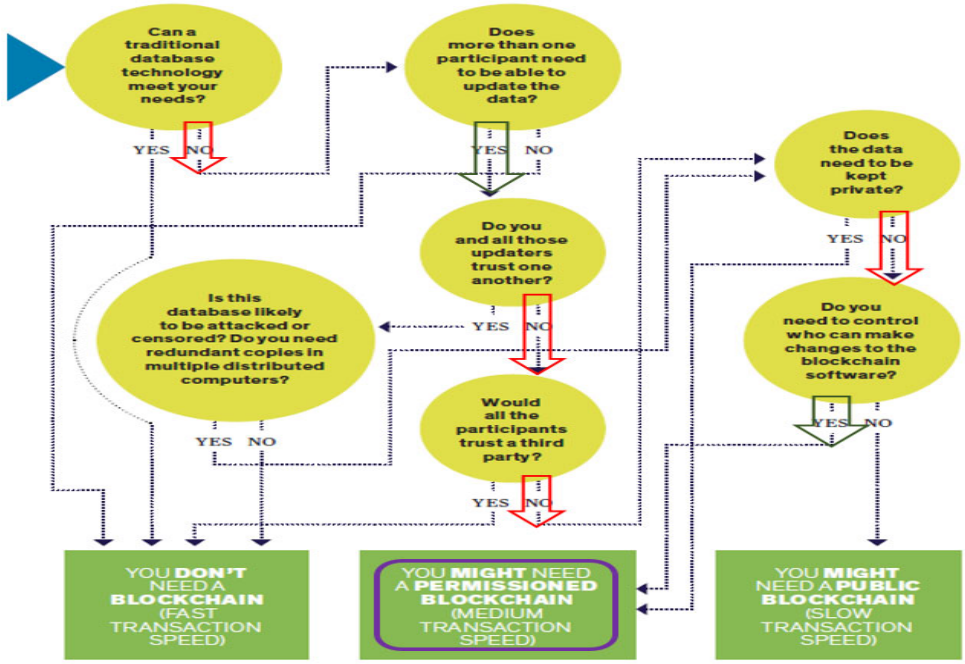

Figure 2: Need for permissioned blockchain (Adopted from (Peck, 2017))

Despite enormous anticipated impact of blockchain technology in economic and social systems; however, it may take decades to get soak into economies and social infrastructure (Iansiti & Lakhani, 2017). If right applications are deployed, blockchain is potential to "changing how records are kept and transactions are processed" (Carlozo, 2017). Moreover, that could potentially generate wealth.

CONCLUSIONS

This study attempts to explore the recent findings in the development of blockchain technology and its potentials vis-à-vis its applicability to some of the current construction industry's challenges. Going by the definition of blockchain as an open-source, decentralized, distributed database for storing transaction information (Francisco & Swanson, 2018), and the high distribution of publications elucidating the BCTs' potentials (Table 1); it is imperative to conclude that the BCT is a right and matured technology to be deployed in the procurement process of construction works. Specifically, in the area of award of contract, contract administration, and valuation of work and interim payments. However, level of preparedness in technology, policy, and awareness posed challenge to its usage in the industry; thus, preparation is necessary in the area of right application (technology), legislative provision (regulation), and awareness/knowledge (social).

References

Abdul-Rashid, K., & Hassan, S. F. (2005). Capability of a country's construction industry to combat poverty: A case study on the OIC member countries. Paper presented at the *Proceedings of the 4th MICRA Conference,* 4-5.

Abeyratne, S. A., & Monfared, R. P. (2016). Blockchain ready manufacturing supply chain using distributed ledger.
Adabre, M. A., & Chan, A. P. C. (2019). *Critical success factors (CSFs) for sustainable affordable housing* doi:https://doi.org/10.1016/j.buildenv.2019.04.030
Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and Management in Engineering, 11*(3), 241-252.
Baliga, A. (2017). Understanding blockchain consensus models. *Persistent* ()
Belle, I. (2017). The architecture, engineering and construction industry and blockchain technology. *Digital Culture, 2017*, 279-284.
Carlozo, L. (2017). What is blockchain? *Journal of Accountancy, 224*(1), 29.
Cong, L. W., & He, Z. (2019). Blockchain disruption and smart contracts. *The Review of Financial Studies, 32*(5), 1754-1797.
Conoscenti, M., Vetro, A., & De Martin, J. C. (2016). Blockchain for the internet of things: A systematic literature review. Paper presented at the *2016 IEEE/ACS 13th International Conference of Computer Systems and Applications (AICCSA),* 1-6.
Crosby, M., Pattanayak, P., Verma, S., & Kalyanaraman, V. (2016). Blockchain technology: Beyond bitcoin. *Applied Innovation, 2*(6-10), 71.
de Piraquive, Flor Nancy Díaz, Martínez, O. S., Pérez, E. V., & Crespo, R. G.Knowledge management model for project management: Km pmtic. *Construction Projects,* , 55.
Dill, J., & Kasik, D. J. (2012). Discovering and transitioning technology. *Expanding the frontiers of visual analytics and visualization* (pp. 481-498) Springer.
Drescher, D. (2017). *Blockchain basics* Springer.
Erri Pradeep, A. S., Yiu, T. W., & Amor, R. (2019). Leveraging blockchain technology in a BIM workflow: A literature review. Paper presented at the *International Conference on Smart Infrastructure and Construction 2019 (ICSIC) Driving Data-Informed Decision-Making,* 371-380.
Francisco, K., & Swanson, D. (2018). The supply chain has no clothes: Technology adoption of blockchain for supply chain transparency. *Logistics, 2*(1), 2.
Gaire, R., Ghosh, R. K., Kim, J., Krumpholz, A., Ranjan, R., Shyamasundar, R. K., & Nepal, S. (2019). Crowdsensing and privacy in smart city applications. *Smart cities cybersecurity and privacy* (pp. 57-73) Elsevier.
Gatteschi, V., Lamberti, F., Demartini, C., Pranteda, C., & Santamaría, V. (2018). Blockchain and smart contracts for insurance: Is the technology mature enough? *Future Internet, 10*(2), 20.
Hamida, E. B., Brousmiche, K. L., Levard, H., & Thea, E. (2017). Blockchain for enterprise: Overview, opportunities and challenges. Paper presented at the
Hargaden, V., Papakostas, N., Newell, A., Khavia, A., & Scanlon, A. (2019). The role of blockchain technologies in construction engineering project management. Paper presented at the *2019 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC),* 1-6.
Hewavitharana, T., Nanayakkara, S., & Perera, S. (2019). Blockchain as a project management platform.
Hijazi, A. A., Perera, S., Alashwal, A., & Calheiros, R. N.Blockchain adoption in construction supply chain: A review of studies across multiple sectors.
Hileman, G., & Rauchs, M. (2017). Global blockchain benchmarking study. *Cambridge Centre for Alternative Finance, University of Cambridge, 122*
Iansiti, M., & Lakhani, K. R. (2017). The truth about blockchain. *Harvard Business Review, 95*(1), 118-127.
Kiviat, T. I. (2015). Beyond bitcoin: Issues in regulating blockchain tranactions. *Duke LJ, 65*, 569.

Korpela, K., Hallikas, J., & Dahlberg, T. (2017). Digital supply chain transformation toward blockchain integration. Paper presented at the *Proceedings of the 50th Hawaii International Conference on System Sciences,*

Kosba, A., Miller, A., Shi, E., Wen, Z., & Papamanthou, C. (2016). Hawk: The blockchain model of cryptography and privacy-preserving smart contracts. Paper presented at the *2016 IEEE Symposium on Security and Privacy (SP),* 839-858.

Lemieux, V. L. (2016). Trusting records: Is blockchain technology the answer? *Records Management Journal, 26*(2), 110-139.

Li, J., Greenwood, D., & Kassem, M. (2018). Blockchain in the built environment: Analysing current applications and developing an emergent framework. Paper presented at the

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

Li, J., Greenwood, D., & Kassem, M. (2019b). Blockchain in the construction sector: A socio-technical systems framework for the construction industry. *Advances in informatics and computing in civil and construction engineering* (pp. 51-57) Springer.

Lindman, J., Tuunainen, V. K., & Rossi, M. (2017). Opportunities and risks of blockchain technologies–a research agenda.

Mason, J. (2017). Intelligent contracts and the construction industry. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 9*(3), 04517012.

Mathews, M., Robles, D., & Bowe, B. (2017). BIM blockchain: A solution to the trust problem in collaboration?

McMillan, R. (2013). $1.2 m hack shows why you should never store bitcoins on the internet. *Wired.Nov, 7*

Mokyr, J. (1998). The second industrial revolution, 1870-1914. *Storia Dell'economia Mondiale,* , 219-245.

Morabito, V. (2017). The blockchain paradigm change structure. *Business innovation through blockchain* (pp. 3-20) Springer.

Nanayakkara, S., Perera, S., Bandara, H. D., Weerasuriya, G. T., & Ayoub, J.Blockchain technology and its potential for the construction industry.

Nawari, N. O., & Ravindran, S. (2019). Blockchain and the built environment: Potentials and limitations. *Journal of Building Engineering,* , 100832.

Niroumand, H., Zain, M. F. M., Jamil, M., & Niroumand, S. (2013). *Earth architecture from ancient until today* doi:https://doi.org/10.1016/j.sbspro.2013.08.838

Nofer, M., Gomber, P., Hinz, O., & Schiereck, D. (2017). Blockchain. *Business & Information Systems Engineering, 59*(3), 183-187.

Paré, G., Trudel, M., Jaana, M., & Kitsiou, S. (2015). Synthesizing information systems knowledge: A typology of literature reviews. *Information & Management, 52*(2), 183-199.

Peck, M. E. (2017). Blockchain world-do you need a blockchain? this chart will tell you if the technology can solve your problem. *IEEE Spectrum, 54*(10), 38-60.

Risius, M., & Spohrer, K. (2017). A blockchain research framework. *Business & Information Systems Engineering, 59*(6), 385-409.

Schatsky, D., & Pawczuk, L. (2016). Deloitte blockchain survey 2017.

Shaw, I. (2003). *The oxford history of ancient egypt* Oxford University Press.

SHOJAEI, A. (2019). Exploring applications of blockchain technology in the construction industry.

Shojaei, A., Wang, J., & Fenner, A. (2019). Exploring the feasibility of blockchain technology as an infrastructure for improving built asset sustainability. *Built Environment Project and Asset Management,*

Shrier, D., Wu, W., & Pentland, A. (2016). Blockchain & infrastructure (identity, data security). *Massachusetts Institute of Technology-Connection Science, 1*(3), 1-19.

Subramanian, H. (2018). Decentralized blockchain-based electronic marketplaces. *Commun.ACM, 61*(1), 78-84.

Toyoda, K., Mathiopoulos, P. T., Sasase, I., & Ohtsuki, T. (2017). A novel blockchain-based product ownership management system (POMS) for anti-counterfeits in the post supply chain. *IEEE Access, 5*, 17465-17477.

Turk, Ž, & Klinc, R. (2017). Potentials of blockchain technology for construction management. *Procedia Engineering, 196*, 638-645.

Underwood, S. (2016). Blockchain beyond bitcoin. *Communications of the ACM, 59*(11), 15-17.

Walasek, D., & Barszcz, A. (2017). Analysis of the adoption rate of building information modeling [BIM] and its return on investment [ROI]. *Procedia Engineering, 172*, 1227-1234. doi://dx.doi.org/10.1016/j.proeng.2017.02.144

Wang, H., Chen, K., & Xu, D. (2016). A maturity model for blockchain adoption. *Financial Innovation, 2*(1), 12.

Weber, I., Xu, X., Riveret, R., Governatori, G., Ponomarev, A., & Mendling, J. (2016). Untrusted business process monitoring and execution using blockchain. Paper presented at the *International Conference on Business Process Management,* 329-347.

Weisberg, D. E. (2008). The engineering design revolution: The people, companies and computer systems that changed forever the practice of engineering. *Cyon Research Corporation,* , 1-26.

Wüst, K., & Gervais, A. (2018). Do you need a blockchain? Paper presented at the *2018 Crypto Valley Conference on Blockchain Technology (CVCBT),* 45-54.

Zhao, X., Hwang, B., & Lee, H. N. (2016). Identifying critical leadership styles of project managers for green building projects. *International Journal of Construction Management, 16*(2), 150-160.

Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017). An overview of blockchain technology: Architecture, consensus, and future trends. Paper presented at the *2017 IEEE International Congress on Big Data (BigData Congress),* 557-564.

Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2018). Blockchain challenges and opportunities: A survey. *International Journal of Web and Grid Services, 14*(4), 352-375.

Zyskind, G., & Nathan, O. (2015). Decentralizing privacy: Using blockchain to protect personal data. Paper presented at the *2015 IEEE Security and Privacy Workshops,* 180-184.