KSCE Journal of Civil Engineering (2020) 24(9):2561-2571
DOI 10.1007/s12205-020-0188-x

pISSN 1226-7988, eISSN 1976-3808
www.springer.com/12205

Construction Management

A Study on the Application of Blockchain Technology in the Construction Industry

Kyeongbaek Kim[a], **Gayeoun Lee**[b], **and Sangbum Kim**[a]

[a]*Member, Dept. of Civil & Environmental Engineering, Dongguk University, Seoul 04620, Korea*
[b]*Dept. of Civil & Environmental Engineering, Dongguk University, Seoul 04620, Korea*

ARTICLE HISTORY

Received 5 February 2020
Accepted 12 May 2020
Published Online 29 July 2020

KEYWORDS

Blockchain
Application
Technology convergence
Construction industry
Construction contract
Cost management

ABSTRACT

Blockchain technology has been recognized as one of the emerging technologies that can significantly innovate many industries. Major advantages of using blockchain technology includes reducing transaction costs, preventing data forgery and alteration, and further flexibility. The construction industry is generally considered as an industry that has great potentials for blockchain technology utilization mainly due to the high volume of transactions among various entities. Despite the perceived positive impact, there have been few cases of blockchain applications within the construction industry. This study is conducted with an aim of finding ways to apply blockchain technology to the construction industry. In order to identify potential application areas, construction lifecycle and project management knowledge areas are used in developing a survey questionnaire. Data collected from the survey is analyzed by employing importance performance analysis (IPA) method considering both applicability of the technology and anticipated impact from utilizing the technology. In relation to the construction project lifecycle, 'Project Cost/Change Management', 'Contract Bidding and Formation', and 'Procurement Evaluation' are emerged as top three candidates for blockchain application with high applicability and impact. Regarding the knowledge area, 'Procurement Management' and 'Cost Management' are identified as the main blockchain application areas with high applicability and impact. All the identified specific construction tasks with high applicability and impact are related to 'Procurement', 'Contract', and 'Cost'. Therefore, it is reasonable to start focusing blockchain convergence efforts these areas and then expand them as the technology matures.

1. Introduction

The Fourth Industrial Revolution (4IR), characterized by fusion of emerging technologies, has rapidly been changing industrial environment. The construction industry is not an exception and various convergence activities have taken place by integrating emerging technologies such as drones, building information modeling (BIM), augmented reality (AR), virtual reality (VR), internet of things (IoT), blockchain technology, and so on. Among these new technology integrations, this study focuses on blockchain applications in the construction industry.

Blockchain technology is a distributed, ledger system that promotes decentralization, transparency, and data integrity (Seo, 2017). Each block contains a set of transaction records with a unique hash value and blocks are linked in a sequential order. The identity of each block is defined by its own hash value and that of the previous block, which makes much harder to be corrupted compared to a centralized database system. Major advantages of using blockchain technology includes reducing transaction costs, preventing data forgery and alteration and further flexibility.

Blockchain technology has been recognized as one of the emerging technologies that can significantly innovate many industries, and Bitcoin is the first popular application that adapted this technology. According to a research done by Ministry of Science and ICT (MSIT and Korea Institute of S&T Evaluation and Planning, 2018), the size of the global blockchain market is expected to grow by more than ten times over the next five years,

CORRESPONDENCE Sangbum Kim kay95@dgu.edu Dept. of Civil & Environmental Engineering, Dongguk University, Seoul 04620, Korea

and the world is aggressively developing related technologies to apply them to various industrial sectors such as finance, logistics and health care. Examples of blockchain applications include unlisted stock trading and loss claims in the financial sector (Guk, 2019), personal medical information management and genetic information sharing in the medical sector, electronic certificate distribution and online voting in the public sector, and personal customs and diamond distribution in the logistics and distribution sectors (MSIT and Korea Institute of S&T Evaluation and Planning, 2018).

The construction industry is generally considered as an industry that has great potentials for blockchain utilization mainly due to the high volume of transactions among various entities with the industry. During the complex lifecycle of construction including planning, design, construction and maintenance, various types of contracts and transactions are formed inevitably. By effectively taking advantage of blockchain technology, transaction costs can be significantly reduced while the security are greatly enhanced. The successful convergence of blockchain technology with the construction industry could lead innovative changes by increasing the efficiency of contracts and transactions and creating new business models.

Despite the perceived positive impacts, there have been few cases of blockchain technology applications within the construction industry. For the domestic construction industry, integration of the technology remains at a basic and theoretical level. Although there have been some premature studies of utilizing blockchain technology in the areas of BIM and smart contract, no practical case is identified in the domestic market. Real estate transaction management is emerged as one of the first blockchain application in Korean construction industry while the scope of application is gradually expanding. In the global construction market, more active approaches are identified in the area of smart contracts, project management, procurement management and BIM.

This research aims to derive the applicable areas of blockchain technology in the construction industry. To accomplish this goal, a comprehensive analysis of blockchain technology is conducted by using extensive literature review and benchmarking other industries' blockchain applications. Based on the analysis results, it is envisioned to propose the directions of blockchain application development in the construction industry.

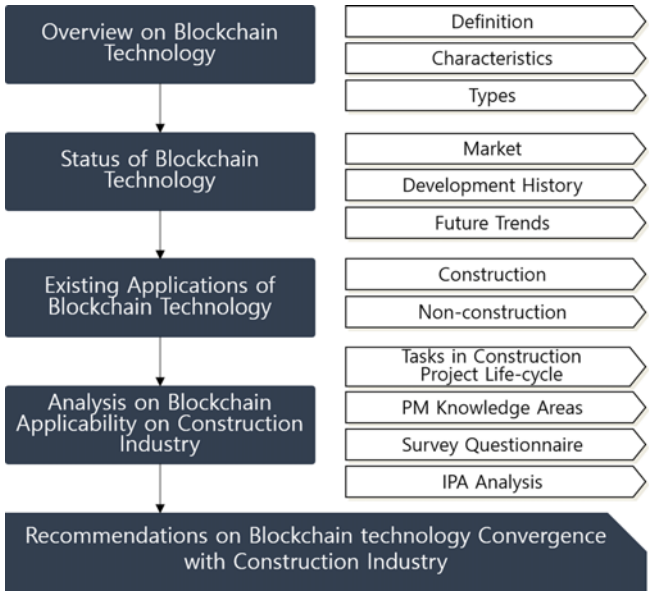

Fig. 1. Research Methods and Procedures

This study is conducted with the aim of finding ways to effectively apply blockchain technology to the construction industry. First, overview on blockchain technology is done by looking at definition and technical aspects. Detailed characteristics as well as existing types of the technology are summarized in this phase. Second, current status of the technology is investigated by focusing on the past and future market analysis, technology development history, and future trends. Summary on existing

Table 1. A Study on the Pre-Relevant Research

Researchers	Title	Summary
Lee et al. (2018)	Construction of a Sensor Network Framework Based on Blockchain Technology with Enhanced Safety and Privacy Security for Construction Workers	- Implement sensor network frameworks with blockchain technology to enhance safety and on-site data collected
Choi et al. (2018)	Development of International Trade System Using Blockchain Technology and Validation of Utilization in Construction Industry	- Develop prototypes of international trade systems using blockchain technology focusing on feasibility analysis
Kim et al. (2019)	A Basic Study of Construction Procurement Management Using Block Chain & Big Data Technology	- Introductory study on the use of big data and blockchain to increase procurement management efficiency
Kang (2018c)	Blockchain-Based BIM, Smart Contract and Trend	- Reviews on current status of BIM and smart contracts applications in the construction industry
Ziga and Robert (2017)	Potential of Blockchain Technology for Construction Management	- Informative study on using blockchain technology to increase effectiveness of Project Management Information System (PMIS)
Wang et al. (2017)	The Outlook of Blockchain Technology for Construction Engineering Management	- Investigations on current status of blockchain applications in the construction industry
Iris (2017)	The Architecture, Engineering and Construction Industry and Blockchain Technology	- A study on the application of blockchain technology to the construction industry and its policy direction

applications of blockchain technology is followed by the technology status analysis. In this process, the current applications are categorized by industry types, construction industry and non-construction industries. Next, applicability of blockchain technology on the construction industry is analyzed in details. In order to identify potential application areas, construction lifecycle and project management knowledge areas are used in developing a survey questionnaire. Data collected from the survey is analyzed by employing IPA method considering both applicability of the technology and anticipated impact from utilizing the technology. Research methods and procedures are summarized in Fig. 1.

Only limited literature is available in the area of blockchain technology convergence in the construction industry mainly because the construction is not a leading industry of employing the technology compared to others such as finance and logistics. This section gives a brief literature overview on the usage of blockchain technology in the construction industry. About a ten pilot studies dealing with blockchain technology related to the construction industry are reviewed while most prior research remain at an introductory level. Existing studies include the development of network framework using blockchain technology, prototype of procurement system and application of smart construction contract related to construction site safety management, procurement management and construction contract. Again, most of the studies focus on rather the theoretical aspects than practical development and applications. A summary of existing literature related the construction applications is provided in Table 1.

2. Overview on Blockchain Technology

2.1 Definition of Blockchain Technology

Blockchain technology is defined as a technology of liking blocks of information like a chain which can substantially improve the integrity and reliability of data. "Blockchain Technology Development Strategy" (Korea Institute of Science and Technology Information, 2018) identifies blockchain technology as one of the emerging technologies that ensures data reliability and security while increasing efficiencies. Blockchain technology enables network participants to collaborate with each other in recording, verifying, storing, and extracting information without having centralized data intermediaries.

The basic components of the block are transactions, a hash value, and a nounce value. Transactions can be interpreted as information or data that the network participants want to store and manage. Typically, a block stores about 1,000 transaction data and the average size is approximately 1 Megabyte. Hash value is a unique identifier of the block generated by a hash function characterizing the contents of the block and is usually 64 characters long. Nounce values are basically random values which make the first digits of corresponding hash values equals 'zero'. The number of zero digits closely relates to the difficulty of the block forming, which also defines the security level of blocks.

The operational process of blockchain technology starts with construction of a block which contains data and information that the network manages. The first block, called as 'Genesis block', is formed by storing the preset number of transaction data. Once the data is stored, it must be encrypted with a hash value which is generated by using a nounce value. The second block, like the first block, is generated when the preset number of transaction data is stored. It also has its own encrypted hash value as well as the hash value of the previous block, 'Genesis block', to provide the connection to the first block. Due to this process, the hash value encrypted on the first block has chain effects on the following blocks as illustrated in Fig. 2. This chain process makes it extremely hard to manipulate data in Nth block, because all the hash values of the previous blocks need to be changed to make this manipulation legitimate.

2.2 Characteristics of Blockchain Technology

The main characteristic of blockchain technology is decentralized and distributed platform. Blockchain technology is a distributed digital platform that lets all the network participants jointly store and verify transaction information whereas only one controller manages the integrity of data in a centralized database (Kang,

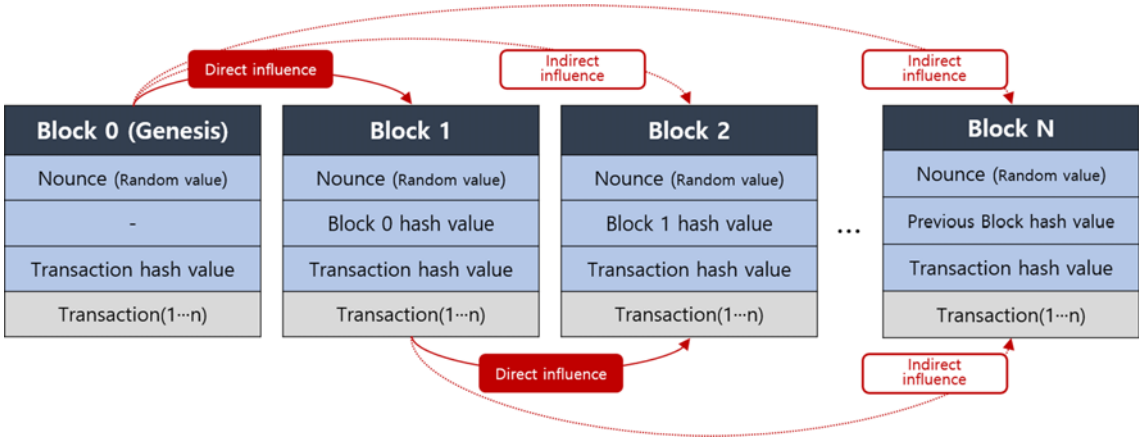

Fig. 2. Blockchain Technology Operation Process

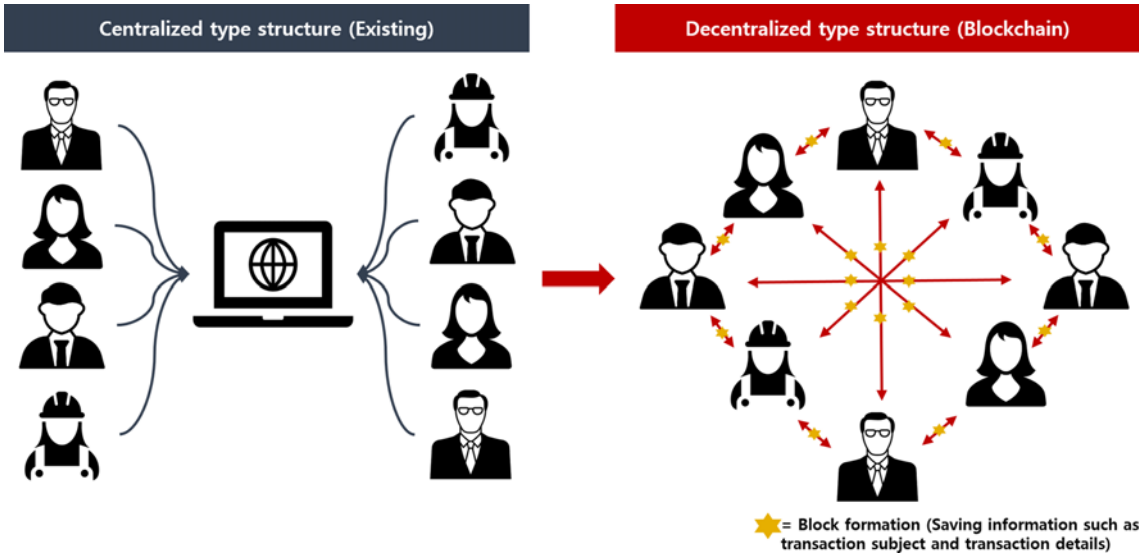

Fig. 3. Comparison between Centralized and Decentralized Structure

2018b). It is a technology that secures integrity and reliability without having an authorized central agency. Decentralized feature enables condition processing, state change management, data storage, verification and control by operating various distributed applications on the network (MSIT and Korea Institute of S&T Evaluation and Planning, 2018). Blockchain technology, due to the characteristic of this distributed platform and block formation, has excellent technical features compared to centralized platforms, as illustrated in Fig. 3.

The most outstanding advantage of blockchain technology is highly enhanced security. Because the technology consists of sharing hash values, which act as encryption keys between the blocks, it makes it almost impossible for hackers to attack specific data as described before. In addition, since many participants jointly own information, it is not feasible to change or delete some data at random unless all participants and corresponding blocks are hacked.

Second, decentralized blockchain technology can substantially reduce transaction cost. Since it is possible to make direct transactions between participants without having to go through an authorized central agency, unnecessary fees can be saved. In addition, the speed of transactions can also be improved due to the omission of the brokerage process without compromising the security.

Third, blockchain technology has excellent technological expandability. A blockchain application can be easily built, connected, and expanded by using public-open sources, thus minimizing IT deployment and maintenance cost is possible. Popular examples include cases of token development such as EOS and Binance Coin based on the Etherium platform which is publicly accessible by anyone with minimized investments.

Finally, blockchain can assure the transaction transparency due to its open characteristic. Although there may be some restrictions on the level of the open access grants in a private blockchain, all participants basically are given accesses to all transaction records which are connected by chained blocks. This also enables significant reduction on regulatory costs to ensure security and surveillance while fostering free transactions.

Table 2. Types and Characteristics of Blockchain Network

	Public blockchain	Consortium	Private blockchain
Management principals	All participants	A participant in a consortium	The central authority has full authority
Governance	High difficulty in changing rules	Medium difficulty of changing rules	Low difficulty of changing rules
Trading speed	Slow	Fast	Fast
Data access	Everyone	Only authorized users	Only authorized users
Identity	Anonymity	Identifiable	Identifiable
Proof of transaction	By PoW* and PoS**	By pre-agreed rules	By the central authority
Existing applications	Bitcoin	R3 CEV***	Link****

*Proof of work (PoW): PoW is the original consensus algorithm in a blockchain network.
**Proof of Stake (PoS): PoS is a process of maintaining consensus on a blockchain network.
***R3 CEV: R3 CEV is the world's largest blockchain consortium leading the application of blockchain technology to the financial sector.
*****Link: Powered by link chain, the blockchain platform of the Line, paid as compensation according to user contribution.

2.3 Types of Blockchain Technology

Blockchain technology applications can be divided into non-licensed and licensed blockchain types, depending on the openness of the network. Non-licensed blockchain has public blockchain, while licensed blockchain has private blockchain. Consortium blockchain can be seen as semi-public platform.

Public blockchain is a non-licensed blockchain that allows anyone to participate in a blockchain platform without permission, and all transaction participants will take on the role of blockchain's managing body. Since it is almost impossible to obtain the agreements of an unspecified number of management entities, it is very difficult to arbitrarily change the network rules once the platform is set. On the other hand, private blockchain and consortium blockchain are licensed blockchain, and only authorized participants will be able to participate in the blockchain network with the permissions. In a licensed/private platform, the rules of the network can be relatively easily changed compared to an unlicensed/public blockchain. Different types of blockchain technology differ not only in terms of control subject, but also in transaction speed, data accessibility and transaction verification methods (Kang, 2018a). Characteristics of each type are summarized in Table 2.

3. Status of Blockchain Technology

3.1 Overview on Blockchain Market

The size of the blockchain technology market is rapidly growing as technological advances and convergences with various industries occur including finance, logistics and health care. According to Korea Institute of Science and Technology Information (2018), the size of the global blockchain technology market has significantly grown from about $130 million in 2015 to about $550 million in 2018 which is almost doubling in every two years. This trend of growth is expected to be continued and blockchain market in 2022 will exceed $3.74 billion globally. Korean blockchain technology market has also grown rapidly from 12.4 billion won in 2015 to 52.4 billion won in 2018, which is 4.2 times larger than that of 2015. Korean blockchain market is estimated to be about 356.2 billion won by 2022 as shown in Fig. 4.

3.2 Evolvement of Blockchain Technology

Since blockchain technology is introduced, the technology standard has gradually evolved the last ten years. Typically, the generation of blockchain technology can be divided into four stages as shown in Table 3. The characteristics of each generation are as follows.

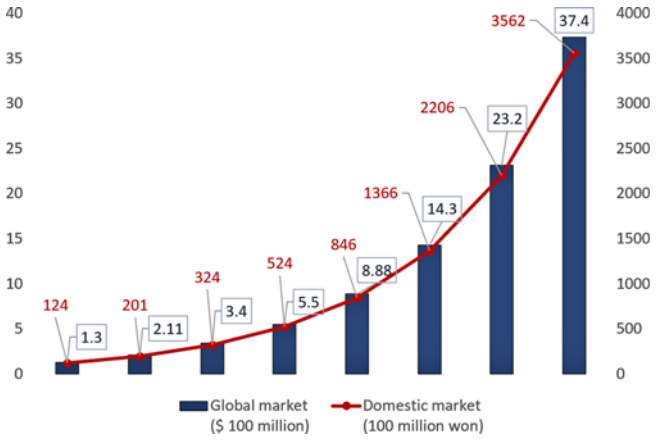

Fig. 4. Trends in Market Size for Blockchain Technology

The first-generation blockchain 1.0, named as technology introduction period, was used as a simple payment method and is characterized as an open blockchain. The most popular applications of blockchain 1.0 include the popular Bitcoin. In second-generation blockchain 2.0, technology development phase, usage of blockchain technology was expanded as a means of trading and contract. In this phase, private platform had emerged to allow the formation of closed bookings around specific participants and its applications include smart contracts and automated stock transactions. The third-generation blockchain 3.0, which corresponds to the technology diffusion period, can be defined as multiple industry convergence period. Blockchain technology are actively used not only in financial transactions, but also in diversified types of transactions such as Supply-Chain management (SCM) and energy transactions. The fourth-generation blockchain 4.0, starting in 2022, is expected to provide more public-accessible services, including general administrative services in the public service sector, such as budget management and voting and some of them are already in the commercial stage (Kim, 2018).

3.3 Element-Based Blockchain vs. Platform-Based Blockchain

Starting with the development of cryptocurrency technology, initial blockchain applications mainly targeted to improve element-based transactions such as asset registration, Bitcoin,

Table 3. Blockchain Generation Features

Generation	Blockchain 1.0	Blockchain 2.0	Blockchain 3.0	Blockchain 4.0
Stage	Generation 1	Generation 2	Generation 3	Generation 4
Period	2009 – 2013	2013 – 2016	2017 – 2022	2022 – 2030
Characteristics	Open blockchain	Private blockchain and smart contracts	Technology expansion through convergence with other industries	National infrastructure
Applications	Bitcoin	Stock trading, Etherium	SCM, energy, logistics, etc	Budget management, voting, etc Government public service

Table 4. Typical Structure of Blockchain Platform

Application technology	Structural layer	Component
Blockchain platform skill	Technology layer	Blockchain layer
		Core application
	Service layer	Side chain
		User application

and litecoin (Yoo and Kim, 2018). Targeting specific trading market such as stocks, cars, and buildings are the examples of element-based blockchain technologies. Focus of blockchain technology has gradually shifted from element-based to platform-based-technology which can be applied to various industries. Etherium is a good example of platform blockchain technology which promotes convergence with other industries. Platform-based blockchain refers to providing scalable and compatible technology structures that allows integration with multiple technologies. The basic structure of the blockchain platform is divided into the technology layer, which includes block chain layer and core application, and the service layer that has side chain and user application as shown in Table 4 (Yoo, 2018). One of the most popular applications developed using a blockchain platform is 'Smart-Contract' in financial industry as detailed in section 4.2. Emergence of this blockchain platform has made the technology more compatible with various tasks in different industries, and integration efforts in the construction industry are expected be focused on the use of this platform blockchain.

4. Existing Applications of Blockchain Technology

4.1 Blockchain Applications in the Construction Industry

In this study, existing blockchain applications are analyzed based on the construction project lifecycle. First, in planning phase, smart contracts and construction coins are the most noticeable movements of integrating blockchain into a construction project. Smart contract has been identified as one of the most effective blockchain-based applications in the construction industry by many experts; one says "It is the most effective blockchain technology that can solve many of endemic problems in the construction industry." (Construction Economy Newspaper, 2018). This technology can not only be utilized in the planning phase but in all phases of construction project lifecycle upon successful development. Construction Coin is now just a payment currency but it has much broader implications by storing all the transaction information and history in blocks which preventing forgery and alteration of information. Some construction coins are in the development stage including Hyundai BS&C's Hyundai Pay (HDAC), and they are expected to be commercialized in the real future.

In relation to the design phase, exploratory attempts are taking in place such as blockchain-based BIM, CAD management platforms, and so on. Blockchain-based BIM is aimed to improve the reliability issues of the BIM digital model, and some are being developed such as BIM COIN and BIM CHAIN. The CAD management platform is expected to mainly improve materials management, and examples include EOS-based CAD management platform named 'CADEOS' (CADEOS, 2018).

Smart City and logistics are well-known fusion applications of emerging technologies including blockchain and many attempts can be noticed in the construction and operation/maintenance (O&M) phase. Pilot projects have actively utilized IoT to effectively collect and manage construction data and various forms of blockchain technology are expected to be incorporated in the construction and maintenance of smart cities. Some blockchain applications in the logistics industry have already been implemented especially in customs and distribution management.

However, most of the existing blockchain applications in the construction industry are at early development or pilot-test stage. To expand the applicability of blockchain technologies in the construction industry, it is deemed necessary to expand development

Table 5. Blockchain Applications by Industry Sector

Industry type	Application content	Blockchain platform
Network (Information Communication)	- Webjet uses Etherium for online travel payment services.	EBass (Etherium Baas)
	- Northern Trust company applies IBM blockchain to ensure clarity transaction.	IBM Blockchain
Distribution	- Wal-Mart uses Hyperledger for tracks the entire distribution.	Hyperledger
	- The United Arab Emirates uses it to improve the tracking efficiency in exporting goods.	
	- Provenance company uses Etherium blockchain to track supply chain.	Etherium
	- BHP Billiton company uses Ethereum to manage real-time shipping data.	
Medical treatment	- MedRec company uses Etherium to manage and share accesses to medical records.	Etherium
	- Dentacoin company uses the Ethereum feature of data sharing and utilization to collect and share data.	
Energy	- Gird Singularity company develops distributed energy data trading platforms based on Etherium.	Etherium
	- Solar Coin-Solar Coin uses the Etherium platform to reward solar energy.	
Finance	- IBM develops banking solutions.	Hyperledger

Table 6. Smart Contract Applications in the Financial Industry

Blockchain platform	Application	Developer
Corda	Smart contracts between financial companies	Barclays Bank
	Trade, finance	R3CEV
Hyperledger	Trade, finance	Bank of America
	Payment between financial companies	Credit Mutuel Arkea Bank
	Trade, finance	Union Bank of Switzerland (UBS)
EBaas	Foreign exchange transaction	Continuous Linked Settlement Bank International (CLS)

efforts centered on technologies with high utilization potentials such as smart contracts and construction coins.

4.2 Blockchain Applications in Non-Construction Industries

In the global non-construction industries, more vigorous efforts of integrating blockchain technologies can easily be found. Logistics, distribution, medical, energy, and finance industries are the ones that have been leading this blockchain convergence activities. Some global leading IT companies including Microsoft™ and IBM have rigorously developed blockchain platforms such as Etherium and Hyperledger. Some applications developed based on these platforms are already commercialized as listed in Table 5 (Financial Security Institute, 2017).

However, in the domestic non-construction industry, most blockchain technologies are still in R&D stage, with only a handful of applications reaching to the commercial stage. MSIT (MSIT and Korea Institute of S&T Evaluation and Planning, 2018) announced a plan, "Blockchain Technology Development Strategy", to actively promote and accelerate development of blockchain convergence technologies especially targeting financial, medical, content, public, logistics, distribution and energy sectors. These governmental moves are only expected to grow to other industries including the construction as technological advances and industry-level interests increase.

Smart contract, initiated in the financial industry has great potentials in the construction industry considering various industry entities and its complex transaction structure. Smart contract is a decentralized blockchain platform-based application that can substantially enhance efficiencies during the contract negotiation and formation process. Many advantages include saving time, saving transaction cost, and increasing reliability and security. Although it has initiated in the financial sector, its applications are quickly broadened in a number of other industrial sectors as shown in Table 6 (Financial Security Institute, 2015).

5. Applicability of Blockchain in the Construction Industry

5.1 Identification Potential Blockchain Application Tasks

In order to identify areas in which blockchain can be effectively used, this study employs two criteria. One is the construction lifecycle, production stages of a construction project, comprised of planning, design, land acquisition, procurement, construction, and maintenance. There are various tasks in each stage, and level of efforts may differ project by project. In this study, 'Construction Manual' developed by city of Seoul (Seoul Metropolitan Government, 2014) is used as a standard in defining this construction tasks corresponding to the project lifecycle. Tasks required in each stage of a construction project is listed in Table 7. Among 23 tasks in four phases of a construction project, this study tries to prioritize them in terms of the blockchain applicability using a survey.

Table 7. Tasks in Construction Lifecycle

Phase	Task
Planning	Preliminary feasibility study
	Feasibility study of technical services
	Main feasibility study
	Master plan
	Investment strategy study
	Budget plan
	Selection of bidding method
Design	Project procurement strategy development
	Composition of evaluation committee
	Basic design
	Design review
	Detailed design
	Value engineering
	Procurement evaluation
Compensation & order	Land acquisition
	Contract evaluation
	Contract bidding and formation
Construction & maintenance	Construction management
	Project cost / change management
	Official completion
	Construction participant management
	Post-evaluation
	Operation and maintenance

Project management areas are used as the second reference in evaluating possibilities of blockchain application. 'PMBOK GUIDE' which is published by Project Management Institute (PMI) presents ten knowledge areas for project execution. The knowledge areas presented are integration management, scope

Table 8. Knowledge Areas for Project Execution

Knowledge area	Contents
Integration management	Project management plan, Communication process
Scope management	Project scoping, Design change
Schedule management	Project planning, Project management
Cost management	Construction cost calculation, Construction Cost, Payment · Management
Quality management	Quality standard, Testing method, Test result
Resource management	Material resources such as supplies·equipment, Human resources such as team·group
Communications management	Communication information between participants
Risk management	Identify Risks, Risk occurrence history
Procurement management	Order management, Contract·agreement, Successful bid document management
Stakeholder management	Project Charter development, Project manager disposition information

management, schedule management, cost management, quality management, resource management, communications management, risk management, procurement management, and stakeholder management. Main tasks in each of ten knowledge areas in 'PMBOK GUIDE' are summarized as shown in Table 8.

5.2 Applicability of Blockchain in Construction Tasks

Applicability of blockchain technology to the specific construction tasks are evaluated using a survey questionnaire based on the structure explained in section 5.1. The survey participants include general contractor, engineering companies, public institutions, and research institutions. The survey contents include the possibility of convergence of blockchain technology in the construction industry, and the applicability of blockchain technology to construction tasks based on the project lifecycle and project knowledge areas. Among popular blockchain technology applications including smart contracts, securities, digital currency,

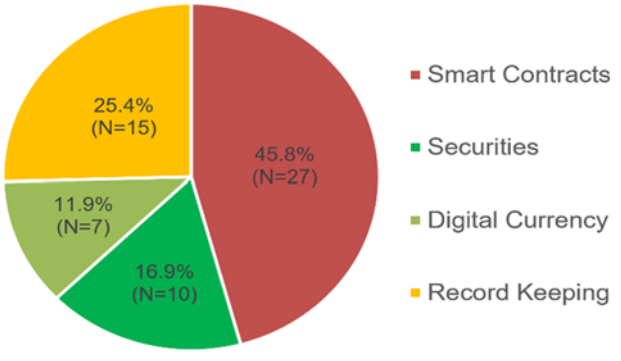

Fig. 5. Possibility of Convergence with Blockchain Technology

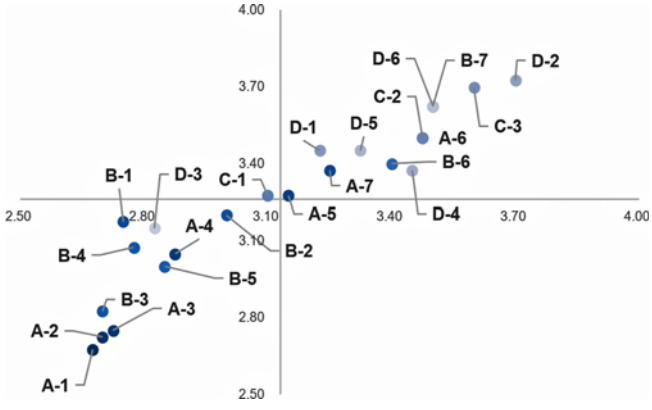

Fig. 6. Applicability of Blockchain Technology to Tasks

Table 9. Applicability of Blockchain Technology to Tasks

Task	No.	Applicability	Impact	Task	No.	Applicability	Impact
Preliminary feasibility study	A-1	2.68	2.68	Value engineering	B-6	3.40	3.40
Feasibility study of technical services	A-2	2.73	2.75	Procurement evaluation	B-7	3.10	3.28
Main feasibility study	A-3	2.88	3.05	Land acquisition	C-1	3.10	3.28
Master plan	A-4	3.15	3.28	Contract evaluation	C-2	3.48	3.50
Investment strategy study	A-5	3.48	3.50	Contract bidding and formation	C-3	3.60	3.70
Budget plan	A-6	3.25	3.38	Construction management	D-1	3.23	3.45
Selection of bidding method	A-7	2.75	3.18	Project cost / change management	D-2	3.70	3.73
Project procurement strategy development	B-1	3.00	3.20	Official completion	D-3	2.83	3.15
Composition of evaluation committee	B-2	2.70	2.83	Construction participant management	D-4	3.45	3.38
Basic design	B-3	2.78	3.08	Post-evaluation	D-5	3.33	3.45
Design review	B-4	2.85	3.00	Operation and maintenance	D-6	3.50	3.63
Detailed design	B-5	2.85	3.00				

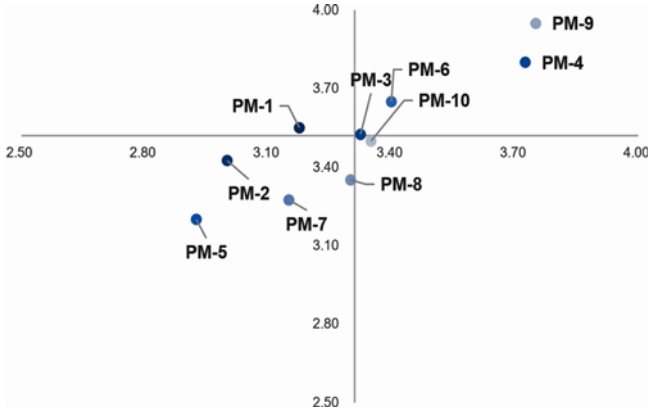

Fig. 7. Applicability of Blockchain Technology to Knowledge Areas

Table 10. Applicability of Blockchain Technology to Knowledge Areas

Knowledge area	No.	Applicability	Impact
Integration management	PM-1	3.18	3.55
Scope management	PM-2	3.00	3.43
Schedule management	PM-3	3.33	3.53
Cost management	PM-4	3.73	3.80
Quality management	PM-5	2.93	3.20
Resource management	PM-6	3.40	3.65
Communications management	PM-7	3.15	3.28
Risk management	PM-8	3.30	3.35
Procurement management	PM-9	3.75	3.95
Stakeholder management	PM-10	3.35	3.50

and record keeping, 'Smart Contract' is identified as the application which have the most potentials with the response rate of 45.8% (Refer Fig. 5).

In identifying application areas of blockchain technology, IPA analysis is employed by considering 'technology applicability' and 'impact of technology utilization'. This analysis is conducted twice; one based on the construction tasks defined in construction project lifecycle and the other based on the tasks in project management areas. In relation to the construction project lifecycle, 'Project Cost/Change Management', 'Contract Bidding and Formation', and 'Procurement Evaluation' are emerged as top three candidates for blockchain application with high applicability and impact as shown in Fig. 6. Comprehensive assessment of the applicability and impact of the blockchain technology is summarized in Table 9 based on the project life cycle.

Regarding the PMI's knowledge areas, 'Procurement Management' and 'Cost Management' are identified as the main blockchain application areas with high applicability and impact as shown in Fig. 7. 'Procurement Management' is analyzed to have an applicability of 3.75 and a potential impact of 3.95. The complete analysis result for each knowledge area is provided in Table 10.

In the construction industry, blockchain technology is just being introduced as most of the efforts remains at the theoretical and R&D stages. In order to maximize benefits of integrating this emerging technology, it is necessary to start focusing on the areas of high applicability and greater potential impact. According to the survey analysis, 'Smart contract' is identified as the one with highest potentials among existing blockchain applications. It may be somewhat expected result due to the

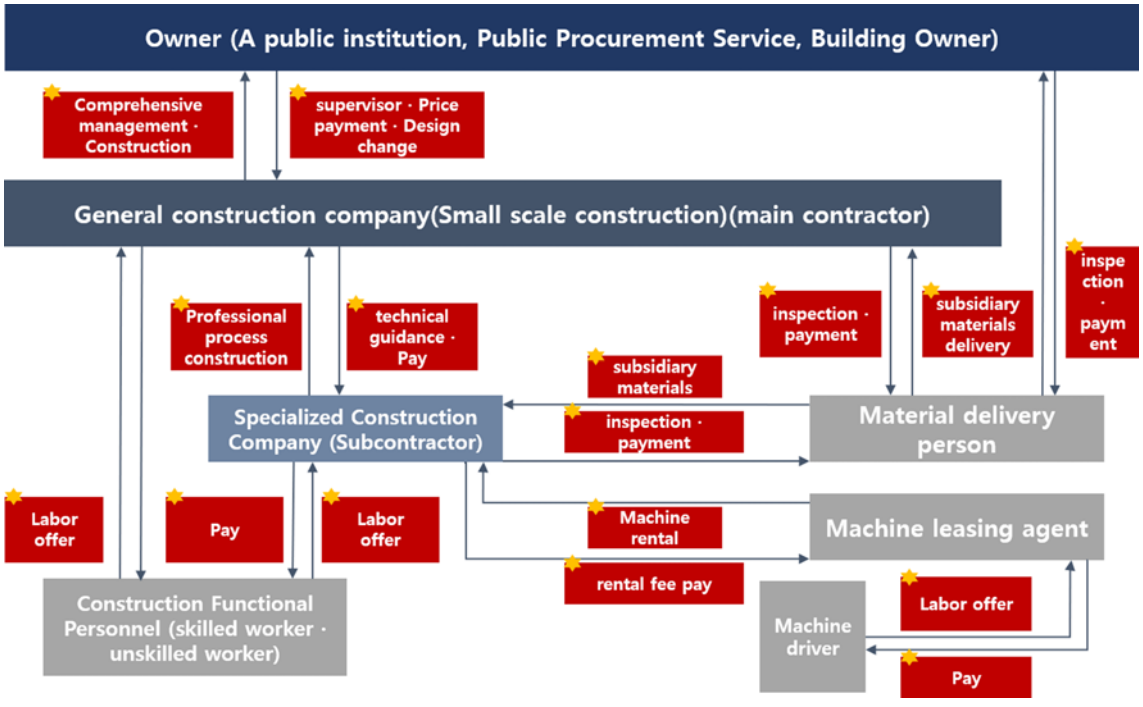

Fig. 8. Contractual Relationships in Construction

high volume and complexity of construction contracts as illustrated in Fig. 8 (Kim, 2015). In addition, all the identified specific construction tasks with high blockchain applicability and impact are related to 'Procurement', 'Contract', and 'Cost'. Therefore, it is reasonable to start focusing blockchain convergence efforts on these areas and then expand application areas as the technology matures.

6. Conclusions

In this study, a comprehensive analysis on blockchain is conducted to materialize potentials of this emerging technology in the construction industry. In doing so, not only a detailed technology overview is prepared, but also existing applications are thoroughly investigated in both construction and non-construction industries. In addition, a survey questionnaire is used to collect data on the technology awareness level and potential application area to further specify blockchain application areas in the construction industry.

It is obvious that much of technology fusion opportunities still remain in the construction industry and blockchain is one that has great potential to enhance industry practices. However, blockchain convergence is not as active in the construction industry compared to non-construction industries as described before. Most of blockchain applications are in R&D or pilot-study stages and not much literature is available focused on the technology. Despite of blockchain's great potentials such as excellent security, decentralization, and technological scalability, much efforts need to be come in both research and practical aspects.

Based on the survey results, contract management is identified as one area of blockchain technology application in the construction industry. Furthermore, much additional information such as cost data can be more effectively managed and analyzed by taking advantages of this emerging technology. As mentioned, a construction project is a full of contracts with various information and different entities which makes it a great candidate for blockchain technology convergence.

Blockchain technology will be widely used in various industries in the future and the usage in the construction industry will only grow as well. To enhance the industry's applicability to the developed technologies, this study attempts to comprehensively review the technology and identify potential application areas. It is envisioned that this study provides a good guidance to the researchers and practitioners who wish to attempt to integrate blockchain technology into the construction practices. Following studies focusing on the actual application development is required to gain tangible benefits from the technology.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2019R1A2C2087976).

ORCID

Kyeongbaek Kim https://orcid.org/0000-0002-5095-4596
Gayeoun Lee https://orcid.org/0000-0001-6968-3784
Sangbum Kim https://orcid.org/0000-0001-7988-5486

References

CADEOS (2018) Decentralized product management platform. Retrieved April 21, 2020, https://cadeos.io

Choi SI, Shim SB, Chun CJ, Kim CY (2018) Development of international trade system using block-chain technology and validation of utilization in construction industry. Korea Institute of Communication Sciences Publication, Seoul, Korea

Construction Economy Newspaper (2018) The construction revolution 'Blockchain 2.0 period' is coming (1). Retrieved April 21, 2020, http://m.cnews.co.kr

Financial Security Institute (2015) The trend of blockchain utilization in domestic and foreign financial fields. No. 2015-028, Security Research Department, Seoul, Korea

Financial Security Institute (2017) Development of blockchain application technology and case of introduction by industry. No. 2017-002, Security Research Department, Seoul, Korea

Guk KW (2019) Case study of application by blockchain technology and industry sector. Institute of Information & Communications Technology Planning & Evaluation Publication, Seoul, Korea

Iris B (2017) The architecture, engineering, and construction industry and blockchain technology. Proceedings of 2017 national conference on digital technologies in architectural education and DADA 2017 international conference on digital architecture, September 9-10, Nanjing, China, 279-284

Kang MS (2018a) Confidence crisis in blockchain. Weekly KDB Report, KDB Publication, Seoul, Korea

Kang SJ (2018b) Implication and development of blockchain technology and its implications. National IT Industry Promotion Agency Publication, Seoul, Korea

Kang TW (2018c) Blockchain-based BIM, smart contract and trend. Proceedings of communications of the Korean institute of information scientists and engineers, December 12-23, Seoul, Korea

Kim SI (2015) A Study on preventing the unfair practice among participants in construction works. Korea Research Institute for Human Settlements, Seoul, Korea

Kim JK (2018) Effects and implications of block chain on industry and international trade. Institute for International Trade Publication, Seoul, Korea

Kim Kh, Son SH, Kim SK (2019) A basic study of construction procurement management using block chain & big data technology. The Korea Institute of Building Construction Publication, Seoul, Korea

Korea Institute of Science and Technology Information (2018) Blockchain technology development strategy. KISTI Publication, Seoul, Korea

Lee HR (2018) Construction of a sensor network framework based on blockchain technology with enhanced safety and privacy security for construction workers. Architectural Institute of Korea Publication, Seoul, Korea

MSIT and Korea Institute of S&T Evaluation and Planning (2018) Blockchain's future. Ministry of Science and ICT and Korea Institute of S&T Evaluation and Planning, Seoul, Korea

Seo YH, Song JH, Kong YI (2017) Blockchain technology: Prospect

and implications in perspective of industry and society. Software Policy & Research Institute, Seoul, Korea

Seoul Metropolitan Government (2014) Construction manual. Seoul Metropolitan Government, Seoul, Korea

Wang J, WU P, Wang X (2017) The outlook of blockchain technology for construction engineering management. *Frontiers of Engineering Management* 4(1):67-75, DOI: 10.15302/J-FEM-2017006

Yoo GS, Kim KH (2018) Blockchain. Korea Institute of S&T Evaluation and Planning, Seoul, Korea

Ziga T, Rober K (2017) Potential of blockchain technology for construction management. *Procedia Engineering* 196(2017):638-645, DOI: 10.1016/J.proeng.2017.08.052