https://doi.org/10.36375/prepare_u.iei.a158

Conceptual Model of Quality Management Based on Blockchain in Construction Industry

Atul Kumar Singh[1], V.R. Prasath Kumar[1*]

[1]Department of Civil Engineering, Faculty of Engineering and Technology,

SRM Institute of Science and Technology, Kattankulathur – 603203, Tamil Nadu, India.

*Corresponding Author: prasathv@srmist.edu.in

Abstract

Poor quality in construction could lead to the cash flow disruption, project delays, profit loss in projects due to rework, and some time to the property damage or human loss due to accidents. In order to ensure the quality of work, quality control (QC) departments inspect the construction work compliance with best practices, defined procedures, and specifications. These inspections rely on manual procedures, post-construction evaluation, document-based, and are carried out through a supervisory manner approach from top-down. However, this top-down control-oriented approach does not provide enough motivation for quality control managers, operators, and workers to voluntarily follow quality procedures and specifications. Besides, document-based quality specification compliance assessments have limitations that are difficult to determine whether the required specifications have actually been implemented and are not reliable to measure their real performance as well. In this regard, this study proposes a conceptual framework for Blockchain-based quality management at construction sites, which could ensure security and reliability of information generated through while implementing quality-related specification and procedures by managers and workers using Distributed Ledger Technologies (DLT) and also to encourage them by establishing a compensation structure through performance assessment for activities of each task. The Block chained quality management approach would greatly help shift the traditional top-down and passive quality control process to bottom-up and voluntary manner. It might open a new innovative value-chain structure in the construction quality domain which provides securing reliability of activities required for quality assurance procedures and specification implementation.

Keywords: Blockchain, Distributed Ledger Technologies (DLT), Construction Quality, Defect Management.

1. Introduction

Rework of poor-quality construction work is regarded as a non-value adding activity that is utterly affecting the productivity and performance in construction projects that spend inessential enormous costs, materials, time, and manpower [1]. Many

https://doi.org/10.36375/prepare_u.iei.a158

researches have extensively focused on construction defect management to enhance the poor quality in construction. Previous studies revealed that 5% to 15% of costs in construction projects are caused due to poor-quality work [2].

The rework does not only costs but might charge additional expenses due to delay in the project, and sometimes consume those resources which are allocated to other parts of the project. Poor quality does not only affect costs but also severe accidents. In the case of Korea, accidents due to poor quality of construction work have been reported in many projects such as the collapse of Pyenogtaek international bridge and the fall of the exterior wall of the National University Museum, both of which cause many deaths. Also, the number of dispute related to defects in apartment buildings are increased from 69 cases in 2010 to 3,880 cases in 2016.

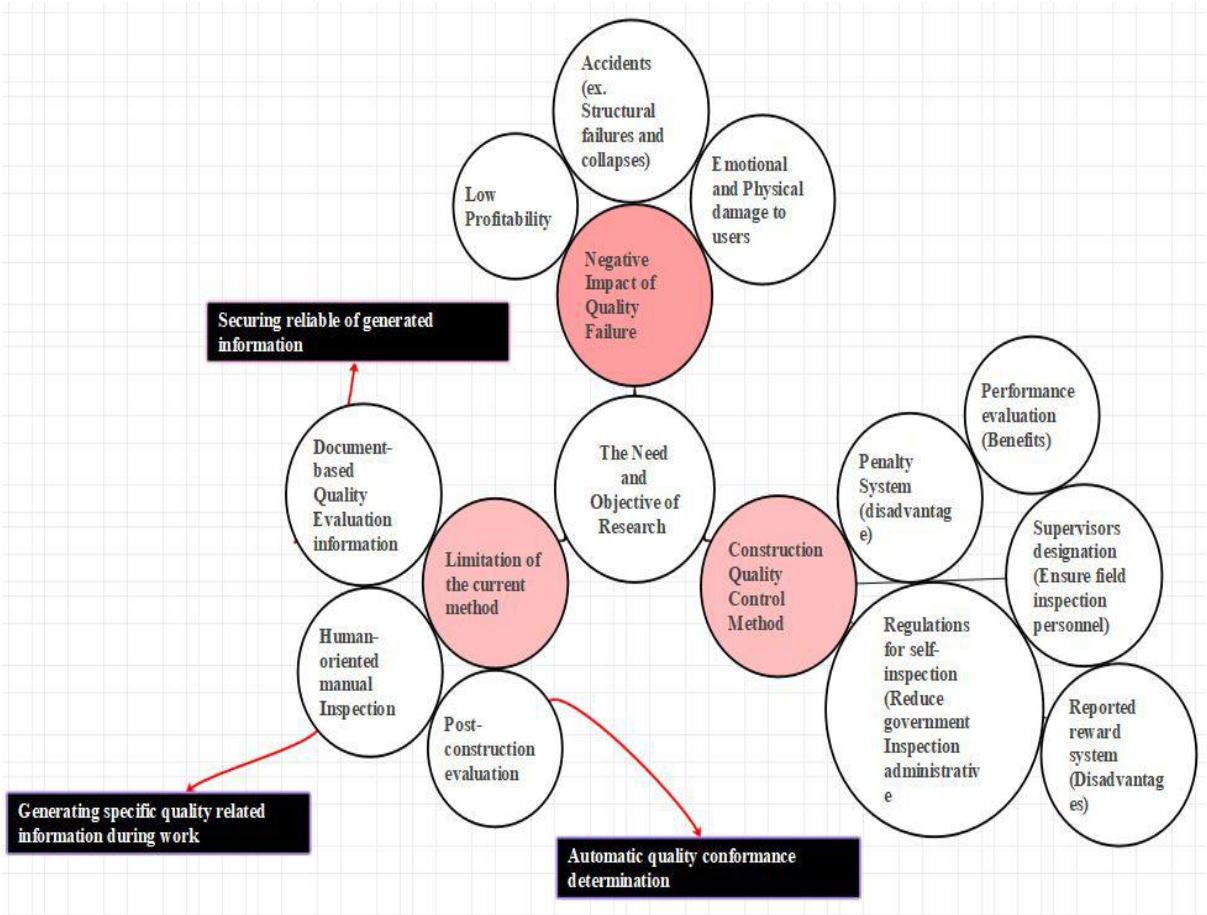

Figure 1: Limitation in Current Quality Management System and research objectives

Generally, in construction, to make sure the quality of work and prevent defects, the manager inspects the completed work, identify the defects if any, and records them with information of drawings and locations or in the form of documents such as checklist and punch list. After identifying defects in the field, they discuss the quality of work with the subcontractors and instruct them for actions such as repair or rework. This cycle of

rework and quality inspection continue until to gain the defined level of quality conformance advised by the agreed quality specification document between stockholders.

On the contrary, documentary evidence of events, activities, and tasks carried out to ensure the quality of work are often prepared for the purpose of responding to quality inspections by the management, and it is difficult to determine the authenticity of the actual acts and events being done to make sure the quality of work. Previous studies revealed that the capacity of government agencies responsible to ensure the quality of construction work is limited to 400,000 sites per year in Korea, which is unable to cover the total projects.

Moreover, the data shows that 67% of projects had experience in missing inspection work due to excessive workload or shortage of personnel, even if professional quality control personnel are deployed to inspect the sites. It is practically impossible to inspect all work steps for the required quality conformance events at each site, thus, there is high probability to have post- work inspection in a supervisory manner (top-down approach).

Even though various quality management systems are currently in practice to ensure the quality of construction work. However, there are several inherent limitations in the current practice such as physical inspection of work, manually observing and recording the quality-related events and activities, data loss during communication between the office and field, reactive approach for rework. The top-down approach, in which the quality inspector/auditor enforce the standards and specification to achieve certain quality conformance level using supervisory manner is another significant limitation of the current practice.

1.1 To address this, the following systemic approaches are required:

1) The construction information related to quality conformance of work can be produced at the worker level performing the actual work.
2) The quality-related information generated during the course of work is automatically determined by the system, not by inspector.
3) The reliability of the generated information can be secured at the same time. Therefore, this study aims to propose an innovative quality management system model that utilizes blockchain technology, which has a lot of interest in the construction field.

1.2 Issues in current quality management systems

One of the critical components in a successful construction project management is quality management [3]. In construction, the occurrence of quality non-conformance is

comparatively high and can negatively affect the firm's profit and its competitiveness [4]. Poor quality is the consequence of non-conformance to the quality standards and specifications during construction work, which results in additional time and cost to all in a project [5].

In order to sort out the issue, this area is being extensively studied by many researchers. However, the problem of data loss, reactive approach, and substantial workload still exist. For instance, the process of manual observation and recording the non-conformance or defect information at the site and re-putting to the computer in the office for discussion is cumbersome and could be less accurate due high chance of data errors, omission and miswrite [6]. Quality conformance inspection consumes a major portion of construction manger's work efforts, which is accounted for around 38 percent of their total work [7]. To reduce the workload of the construction managers in checking quality conformance, radio frequency (RF) technology [8], personal digital assistant (PDA) [9] and laser scanner [10] have been developed. However, these systems work with reactive approaches after non-conformance already been happened, and it is vital to control and apply all the required events and activities for quality conformance during the construction process so that to ensure the specified quality before the defect occurs.

Over the last decade, many researchers have devoted vital attention to enhance the quality management system in construction. Several concepts and their enabling technologies such as building information modeling (BIM) and augmented reality (AR) have been investigated for proactive and automatic quality inspection during the construction work. The augmented virtuality (AV) based tele-inspection system for non-conformance detection has been developed by Wang and Chen [11]. Similarly, Dong et al proposed a mobile-based telematic digital workbench system for construction quality management that integrates the location of visual information on the job site with the 3D model [12]. However, a categoric, transparent, and reliable approach is inevitable to solve the before mentioned issues in the current quality management system.

2. Blockchain technology applications in construction

Blockchain technology also known as distributed ledger technology (DLT) is considered to be capable of transforming many global industries, and the construction has no exception. Blockchain was introduced in 2008 as an underpinning technology for the verification tool of world's first cryptocurrency (bitcoin) transactions [13].

The significant features of block chain technology are:

(i) immutability (once blocks are chained then cannot be modified);
(ii) a peer-to-peer network made up nodes (computers) for decentralized operation;

https://doi.org/10.36375/prepare_u.iei.a158

(iii) reliability (all nodes have an same copy of the same blockchain in all nodes which is verified through an algorithm for any anomalies;
(iv) authentication (a Proof-of-Work mechanism validate transactions in the Blockchain) [14].

2.1 Previous research already been carried out to explore blockchain technology for multiple domains can be classified in seven use-categories:

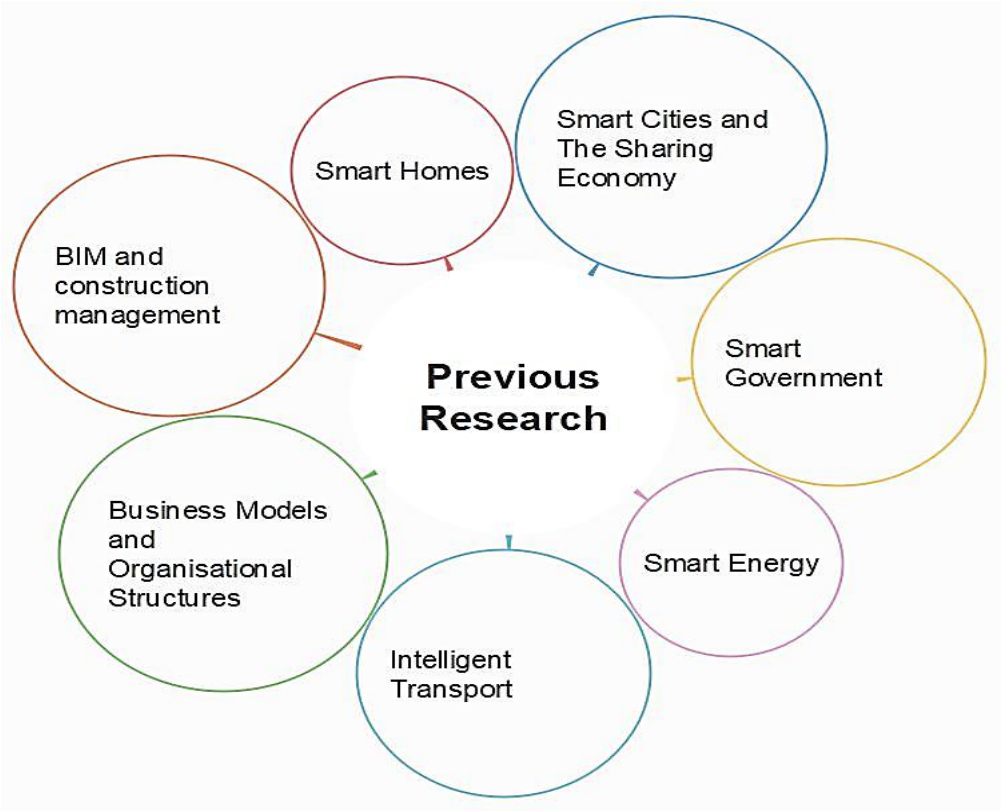

Figure 2- Previous Research on Blockchain technology for Multiple domain

The scope of the derived literature in this paper is limited to the previous efforts related to the buildings, energy and construction. Currently, many researchers are focusing on the applications of Blockchain technology in various construction industry areas such as energy transactions using distributed fields, Integration of IoT technologies with blockchain, BIM and blockchain-based approaches, and resolution of delayed payment to subcontractors' problems through a smart contract. Castellanos investigated the energy transactions generated from wind or solar sources using distributed ledger technology (DLT) [15]. To measure the inside temperature in the building using IoT based smart home devices, a hybrid approach of BIM and blockchain technology is applied for energy management and saving [16]. Wang proposed a smart contract-based blockchain method to solve the problem of wage payment to the construction worker [17]. Previous efforts regarding the blockchain in the construction domain revealed that most of the research was focused on smart contracts to enhance the transactions of payments.

https://doi.org/10.36375/prepare_u.iei.a158

However, some web articles have focussed on the conceptual adoption of blockchain in safety compliance and quality conformance in construction.

3. Blockchain-based quality management system framework

This study intends to develop an innovative system framework that utilizes blockchain technology for effective construction quality management. The main functions and utilization effects of this system includes three main attributes: (1) Implementing text mining, computer vision, internet of things (IoT), and augmented reality (AR) technology to determine the appropriate information generated by quality conformance activities, (2) Leveraging Distributed Ledger Technologies (DLT) in blockchain to ensure security and reliability of information generated during the specific quality-related events, tasks, and activities (3) Based on the report of on-site quality conformance activities being done by worker level, granting the contractor/partner quality conformance level assessment.

The proposed framework enables the categoric generation of construction information related to the quality of work at the bottom worker level that performs the actual work. However, the system instead of the person automatically determines the generated information and controls the reliability of the generated information.

The quality management-related stakeholders in a construction project can be grouped into four classes. Quality conformance events and activity information produced during the construction work is mainly generated by contractors and suppliers, and the generated information is stored in the quality management events and activities database (DB). The verification of the quality conformance of the stored information is evaluate d in rules-based or algorithm-based systems. To allow access of relevant participants to the project's information, the proposed system framework would adopt licensed blockchain protocols to only allow authorized participants to the network.

In the process of creating quality conformance events and activities information, checking and verifying the ledger, Hyperledger consensus algorithm can be used to check the author or viewer's authority to ensure the reliability of stored data and prevent unauthorized users from accessing the ledger. Unlike, other specific platforms to a particular business- models, Hyperledger can be universally adopted in several fields of industries. The Hyperledger is an open-source community of Linux foundation project focused on developing tools and libraries for blockchain deployments.

https://doi.org/10.36375/prepare_u.iei.a158

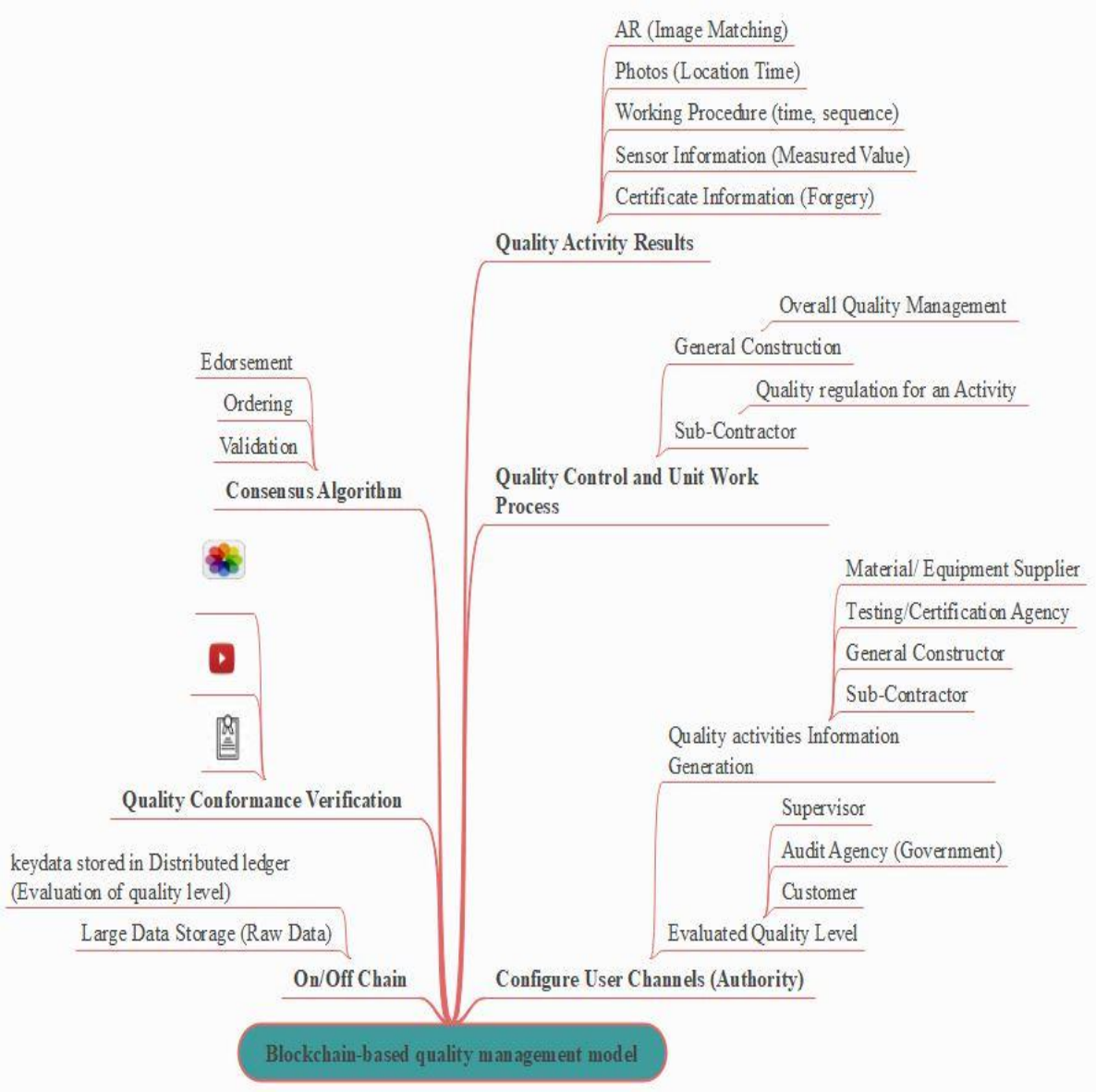

Figure 3: Process of proposed Blockchain-based quality management model

These tools and libraries are open source and can be written or modified based on requirements using common programming languages such as Java, Golang, Node.js, and could be further integrated with construction industry tools for BIM such as Revit, dynamo, grasshopper, as well as to other technologies such as IOT, image recognition, and text-mapping. The configurable module structure allows users to easily select and replace the functions they want to fit the business model of the desired company. In order to reduce data overload in a Blockchain network, the raw data in large amount with more size such as images, BIM files, sensor data, etc. could be stored in a separate database outside the blockchain, however, the generated hash and URL against each transactions would be recorded in a distributed ledger. Through channel separation and MSP (Membership Service Provider) function in Hyperledger, general contractor can

access the ledger of subcontractor's CH.2, but sub-contractor cannot be accessed by general contractor's CH.1.

In addition, the audit agency, and supervisor can grant the participation access to CH.1 and CH.2 for reviewing the quality conformance level of construction companies recorded on the blockchain.

4. Implementation Scenarios

In order to ensure quality of work, the quality conformance events and activities needs to be checked for each work step, and the generated information during each step is automatically checked by the system, not the person, for compliance with quality-related regulations and procedures.

To further elaborate the idea of the study, four case scenarios are selected and detailed as under. Missing struts when install shoring system: For instance, inspecting the struts when installing the shoring or shielding system in an excavated site, the manger takes images of each job-step during work progress. The augment reality (AR) based image matching techniques check the installation status and accuracy of the struts, any discrepancies could be recorded and sent to the database.

The blockchain system could generate a hash for each generated record and will save on the server. Checking waterproofing work procedures: In waterproofing work, there are various layers of different materials to be painted and finished on the surface with specific time intervals. The manger captures the images after finishing the primary layer and before starting the second layer, the rule-based engine analyzes the images with corresponding time reference and record the hash against each transaction in the blockchain.

Testing Compressive Strength of Concrete: Calculating compressive strength of concrete is very critical in construction of structural works. Initially, the quality inspector in the lab take image of concrete molds during curing under water. Then the inspector captures the compressive strength results after 3, 7 and 28 days by doing experiment on universal testing machine (UTM). The system can then generate the hash against both the images and will be saved in the block chain, other data such as images or documents will be stored in the external database.

Material test report Registration: Similarly, equipment or machinery fitness and material quality is also significant to ensure quality of work. In order to have reliable quality and fitness to use information, the document certificate made against each particular inspection for the concerned equipment or materials could be uploaded to the blockchain system.

https://doi.org/10.36375/prepare_u.iei.a158

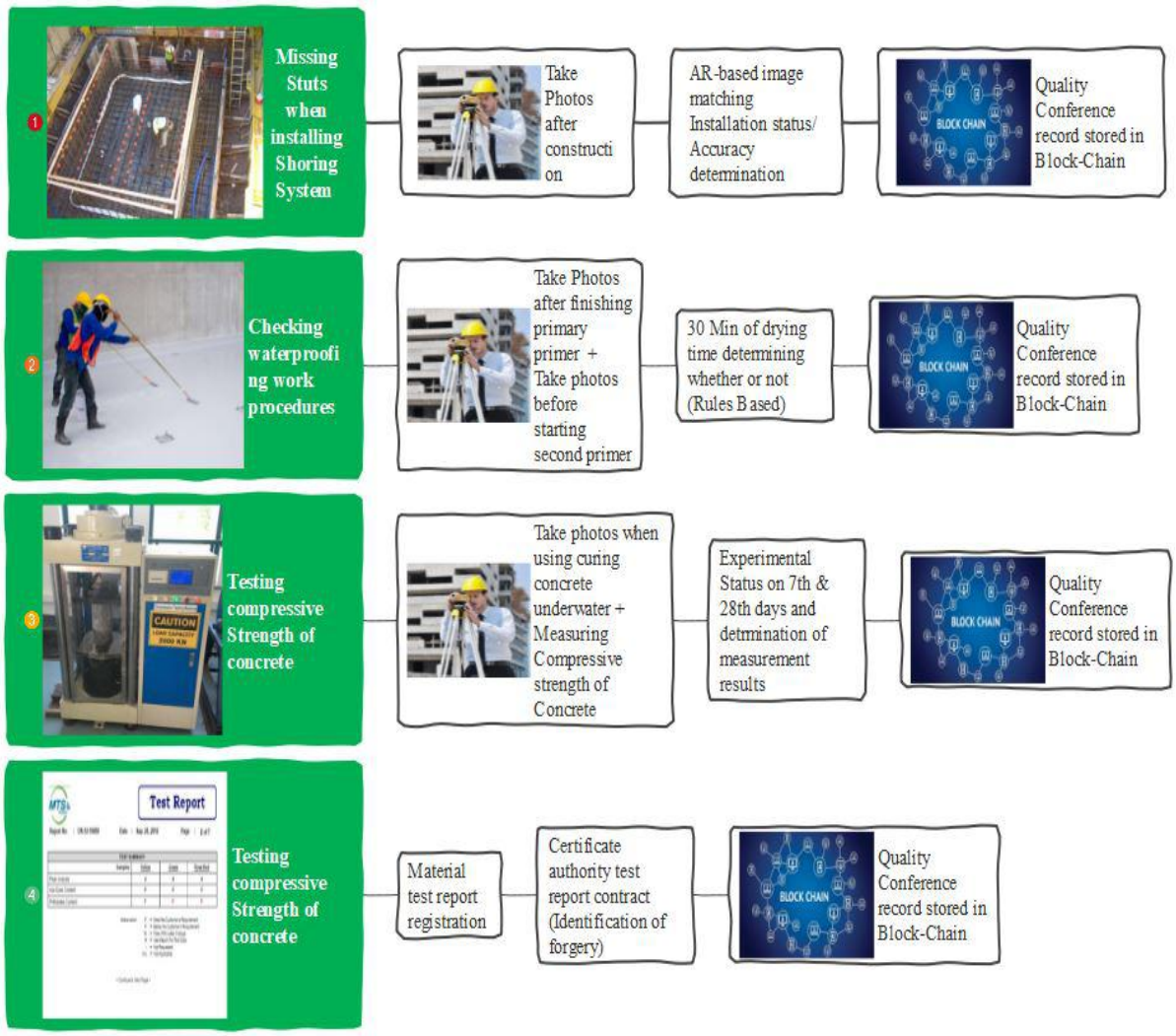

Figure 4: Implementation scenarios for the proposed Quality Management Model

The images of the documents can be converted to the text using optical character recognition technology (OCR) or text mining, then the required relevant important information such as date, time, location and fitness etc. can be extracted, and their corresponding hash along with URL could be stored in the blockchain.

5. Discussion on Expected Results

The core intention of the study is to develop a framework for a system that automatically evaluate and examine the quality conformance events and activities grading level based on the information generated during the process of performing quality control events, activities and tasks by the manager or workers. The system based on the proposed framework is expected to be beneficial and alternate for Inspection agencies and prospective users or occupants (considering apartments case), as it

provides reliable, transparent, and verified information required for quality conformance, without even physically visiting the site.

The rules for quality conformance can be defined from quality management regulations and quality inspection cases. The integration of advance technologies with blockchain such as image recognition, image matching and IoT based sensors could determine the accurate and secure information pertaining to quality conformance. In addition, the determined quality related information and verification data can be recorded on the blockchain to gain security and reliability, and using channel-specific access rights, users can be provided with reliable quality management activity information at any time.

Additionally, this study proposed a quality management process innovation for shifting the traditional quality management process from top-down approach to bottom-Up approach that can efficiently measure the quality conformance level during the actual work (proactively) before the failure occurs, rather than detecting the defect after the completion of entire work, which is reactive approach.

6. Conclusion

To ensure the quality of work in construction, the quality control (QC) departments inspect the work compliance with best practices, defined procedures, and specifications. These inspections rely on post-construction evaluation, document-based, and are carried out through a supervisory manner approach from top-down.

Apart from that, the traditional quality management system is unable to acquire the job step events/activities information pertaining to the standard and best practices required to produce a qualitative work. To address this issue, this research proposed a conceptual framework for Blockchain-based construction quality management system.

This proposed framework utilizes Hyperledger fabric protocols to store key information of quality related events and activities using blockchain technology. It also proposed the application of various technologies, including image recognition, image matching, text mining, and IOT sensors, to verify the suitability of safety activities. It is expected that the Block chained quality management approach will contribute to shift the traditional top-down to passive quality control process to bottom-up and voluntary manner. It might open a new innovative value-chain structure in the construction quality domain which provides securing reliability of activities required for quality assurance procedures and specification implementation.

References

[1] S. Alwi, K. Hampson, S. Mohamed, Non Value-Adding Activities: A Comparative Study of Indonesian and Australian Construction Projects, Proc. 10th Conf. Int. Gr. Lean Constr. (2002).

[2] P. Netscher, The true costs of poor quality construction | LinkedIn, (n.d.). https://www.linkedin.com/pulse/true-costs-poor-quality-construction-paul-netscher/ (accessed June 22, 2020).

[3] H. Abdul-Rahman, Some observations on the issues of quality cost in construction, Int. J. Qual. Reliab. Manag. 14 (1997) 464–481. https://doi.org/10.1108/02656719710170693.

[4] H. Abdul-Rahman, P.A. Thompson, I.L. Whyte, Capturing the cost of nonconformance on construction sites: An application of the quality cost matrix, Int. J. Qual. Reliab. Manag. 13 (1996) 48–60. https://doi.org/10.1108/02656719610108314.

[5] Y.A. Olawale, M. Sun, Cost and time control of construction projects: Inhibiting factors and mitigating measures in practice, Constr. Manag. Econ. 28 (2010) 509–526. https://doi.org/10.1080/01446191003674519.

[6] C.S. Park, D.Y. Lee, O.S. Kwon, X. Wang, A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template, Autom. Constr. 33 (2013) 61–71. https://doi.org/10.1016/j.autcon.2012.09.010.

[7] J.Y. Lee, O.S. Kwon, J.S. Choi, C.S. Park, A study on construction defect management using augmented reality technology, 2012 Int. Conf. Inf. Sci. Appl. ICISA 2012. (2012). https://doi.org/10.1109/ICISA.2012.6220933.

[8] L.C. Wang, Enhancing construction quality inspection and management using RFID technology, Autom. Constr. 17 (2008) 467–479. https://doi.org/10.1016/j.autcon.2007.08.005.

[9] Y.S. Kim, S.W. Oh, Y.K. Cho, J.W. Seo, A PDA and wireless web-integrated system for quality inspection and defect management of apartment housing projects, Autom. Constr. 17 (2008) 163–179. https://doi.org/10.1016/j.autcon.2007.03.006.

[10] S.N. Yu, J.H. Jang, C.S. Han, Auto inspection system using a mobile robot for detecting concrete cracks in a tunnel, Autom. Constr. 16 (2007) 255–261. https://doi.org/10.1016/j.autcon.2006.05.003.

[11] X. Wang, R. Chen, An Empirical Study on Augmented Virtuality Space for TeleInspection of Built Environments, Tsinghua Sci. Technol. 13 (2008) 286–291. https://doi.org/10.1016/S1007-0214(08)70163-9.

[12] A. Dong, M. Lou Maher, M.J. Kim, N. Gu, X. Wang, Construction defect management using a telematic digital workbench, Autom. Constr. 18 (2009) 814–824. https://doi.org/10.1016/j.autcon.2009.03.005.

[13] D. Vujičić, D. Jagodić, S. Randić, Blockchain technology, bitcoin, and Ethereum: A brief overview, in: 2018 17th Int. Symp. INFOTEH-JAHORINA, INFOTEH 2018 - Proc., Institute of Electrical and Electronics Engineers Inc., 2018: pp. 1–6. https://doi.org/10.1109/INFOTEH.2018.8345547.

[14] J. Li, D. Greenwood, M. Kassem, Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases, Autom. Constr. 102 (2019) 288–307. https://doi.org/10.1016/j.autcon.2019.02.005.

[15] J.A.F. Castellanos, D. Coll-Mayor, J.A. Notholt, Cryptocurrency as guarantees of origin: Simulating a green certificate market with the Ethereum Blockchain, in: 2017 5th IEEE Int. Conf. Smart Energy Grid Eng. SEGE 2017, Institute of Electrical and Electronics Engineers Inc., 2017: pp. 367–372. https://doi.org/10.1109/SEGE.2017.8052827.

[16] A. Dorri, S.S. Kanhere, R. Jurdak, Towards an optimized blockchain for IoT, in: Proc. - 2017 IEEE/ACM 2nd Int. Conf. Internet-of-Things Des. Implementation, IoTDI 2017 (Part CPS Week), Association for Computing Machinery, Inc, 2017: pp. 173–178. https://doi.org/10.1145/3054977.3055003.

[17] J. WANG, P. WU, X. WANG, W. SHOU, The outlook of blockchain technology for construction engineering management, Front. Eng. Manag. 4 (2017) 67. https://doi.org/10.15302/j-fem-2017006.