BIM-based Construction Quality Control: A BIM-QRC-ACQCR System Development and Validation (Part - II)

Rana Muhammad Irfan Anwar[1], Muhammad Usman Hassan[2], Salman Azhar[1]

[1] Auburn University, Auburn AL 36830, USA
[2] National University of Sciences and Technology, Islamabad 44000, Pakistan
sza0001@auburn.edu

Abstract
The construction industry is becoming more technologically advanced daily, and digitalization and automation strategies play a significant role. Accuracy, efficiency, and reliability are essential for a successful construction project. Throughout the project, various quality control onsite and offsite laboratory tests and inspections are conducted to maintain the highest standards. These reports and responses are kept as records, which can pile up and span volumes over time, making it challenging to handle and store all the reports. This research was conducted to introduce automation in the construction process via BIM. The completed work is presented in two parts: Part 1 focuses on developing the research aim, objectives, and framework, whereas Part 2 focuses on developing and implementing the system based on the framework, case study, and feedback. This article was aimed at the development of the system based on the proposed framework in Part 1. The QRC part of the system to generate QR codes was developed on the Autodesk Revit platform using the tools Dynamo and Dyno Browser. The ACQCR system was developed on a web-based platform which was comprised of a web page for user interaction and a Wamp server-based backend database. The completed developed system was first tested on a demo project and later on, for validation purposes, it was implemented in a public sector building as a case study and was evaluated by industry experts. Overall the system was well received and believed to be a promising step in the right direction.

Keywords
Building Information Modeling (BIM), Automation, Quality Assurance (QA), Quality Control (QC), Construction Industry.

1. Introduction

The construction industry contributes significantly to a country's GDP but lacks quality standards and poor quality control (Bakar et al., 2011). It is an information-intensive industry as a massive amount of information is transferred and exchanged (Y. Chen & Kamara, 2011). The ineffective use of technology can lead to increased rework in a construction project due to uncoordinated information gathering, reporting, and management, resulting in wasted time, cost overruns, and errors (P. E. d. Love, 2002). Managing project-related information can be challenging for organizations due to differences in size and technological capabilities (P. E. D. Love & Irani, 2003). Defining quality can be a complex and challenging task (Barrett, 2000). It can be defined as the process of evaluating and ensuring that work meets predefined standards, which is crucial to the success of any construction project. (Battikha, 2002). During construction, quality control is an essential process that involves inspection and testing of the materials and products being used, reporting any nonconformance, and taking corrective action to address any issues that come up (Chin et al., 2004). Field inspections are critical in ensuring that the contractor's workmanship, materials, and equipment meet the design specifications and standards. These inspections help identify and correct any deficiencies early on, minimizing the risk of costly rework and delays. By adhering to strict quality control procedures, construction projects can be completed safely, efficiently, and to the client's satisfaction (L. Chen & Luo, 2014). Ensuring the required quality standards in construction projects has been a challenge to manage consistently. The lack of effective quality management methodologies has resulted in the wastage of monetary capital and crucial resources such as manpower and materials in many observed cases (Arditi et al., 2015).

Construction quality control systems can be costly, involve multiple stakeholders, and generate excessive paperwork (Griffith, 2000). Traditional construction quality control methods based on site visits and 2D design drawings are often time-consuming, laborious, and prone to errors (Akinci et al., 2006). Laboratory engineers and staff typically create quality test reports through manual documentation. Additionally, the traditional method of tracking a specific report or inspection certificate is through manual paper-based record management. However, this conventional system of quality reporting has several inefficiencies that make it unreliable, inaccurate, and resource-intensive (Wang, 2008). Numerous studies suggest that the current quality control methods are not efficient. These ineffective methods are used to generate and interpret data, which ultimately leads to a waste of time and causes delays in the project schedule. As a result, project managers are unable to access complete and accurate information. This, in turn, affects the proper management and control of construction projects, as manual data interpretation is often used, which is not always reliable (Akinci et al., 2006). Real-time quality control is vital for reducing delays and cost overruns in construction projects. Robotics and automation can help detect defects early on (Martinez et al., 2019). Advanced construction technologies have the potential to significantly enhance the quality management of construction projects (Tam et al., 2000). The automated document management system can help in managing project-related documents efficiently (Eloranta et al., 2001). The computer program simplifies and speeds up data capture in comparison to the paper-based reporting system currently in use (Fernandez et al., 2003).

This research aims to develop a BIM-based system that introduces automation in construction quality control reporting and a repository for real-time information collection and processing. Moreover, three objectives designed to be achieved for this study are: (1) To identify issues and inefficiencies in traditional practices of construction quality control reporting and repository, (2) To devise a BIM-based framework for integration of automation in construction quality control reporting and repository, (3) Validation of developed framework using case study and (4) Evaluation of the developed system by industry experts. The article presenting "Part 1" of this research focuses on objectives 1 & 2, whereas the second article "Part 2" of the research focuses on objectives 3 & 4.

2. The BIM-QRC-ACQCR System

The BIM-based Quick Response Codes (QRC) & Automated Construction Quality Control Repository (ACQCR) is a combined system developed based on the proposed framework. It consists of two parts:

(1) BIM-QRC. It is developed as a BIM-based plugin that generates QR codes with the required information encoded in them for the compressive strength testing of concrete, as shown in Figure 1.

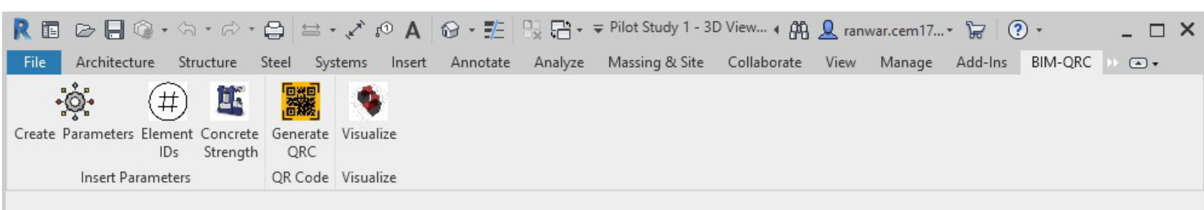

Fig. 1 BIM-QRC Plugin for Autodesk Revit

(2) ACQCR is the second part of the system. It acts as a database and a web-based tool that stores data for sharing information and visualization in the BIM model. The software used in the development is Autodesk Revit 2020, Dynamo, Dyno-browser, Primavera P6, Microsoft Excel, Microsoft Visual Studio Code, and SQL database.

BIM-QRC is an Autodesk Revit-based plugin that has been developed using Dyno Browser and Dynamo. A buttons panel was created in Autodesk Revit 2020 for easier tasking of the developed system. It consists of 5 interactable buttons that perform different tasks assigned to them that have been encoded through the dynamo. The buttons panel was developed using the Dyno-browser application.

There are various parameters predefined in Autodesk Revit which also allows the users to define more parameters as desired. The first button, *Create Parameters* inserts two parameters into the BIM model, which are *Element IDs* and *Concrete Strength.* The second button, *Element IDs* inserts Element IDs into the introduced parameter. The third button, *Concrete Strength* asks the user, as shown in 2, for the required concrete compressive strength to be inserted into the BIM model.

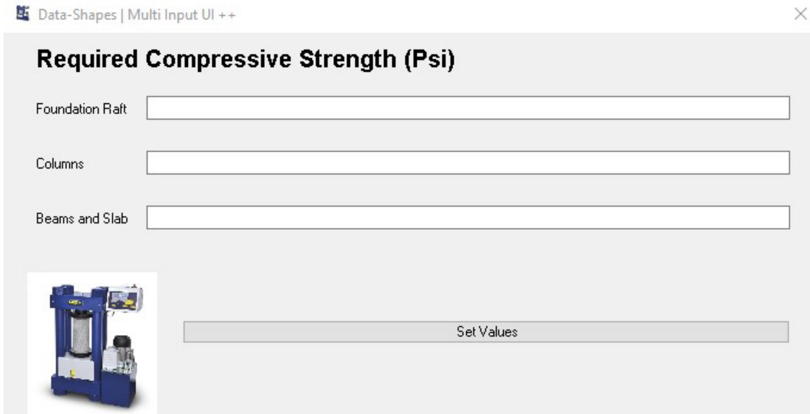

Fig. 2 Input Required Concrete Strength

After execution of both buttons, defined earlier, the required parameters appear in our project parameters in Revit under the assigned group of *Identity Data* as shown in Figure 3.

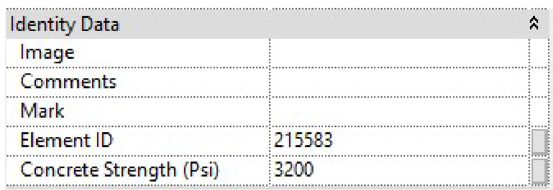

Fig. 3 Introduced Parameters i.e. Element ID and Concrete Strength (Psi)

The button *Generate QRC* when pressed asks for the project schedule Excel file as shown in Figure 6, after selecting the desired file when executed it generates the QR codes into a predefined folder already encoded.

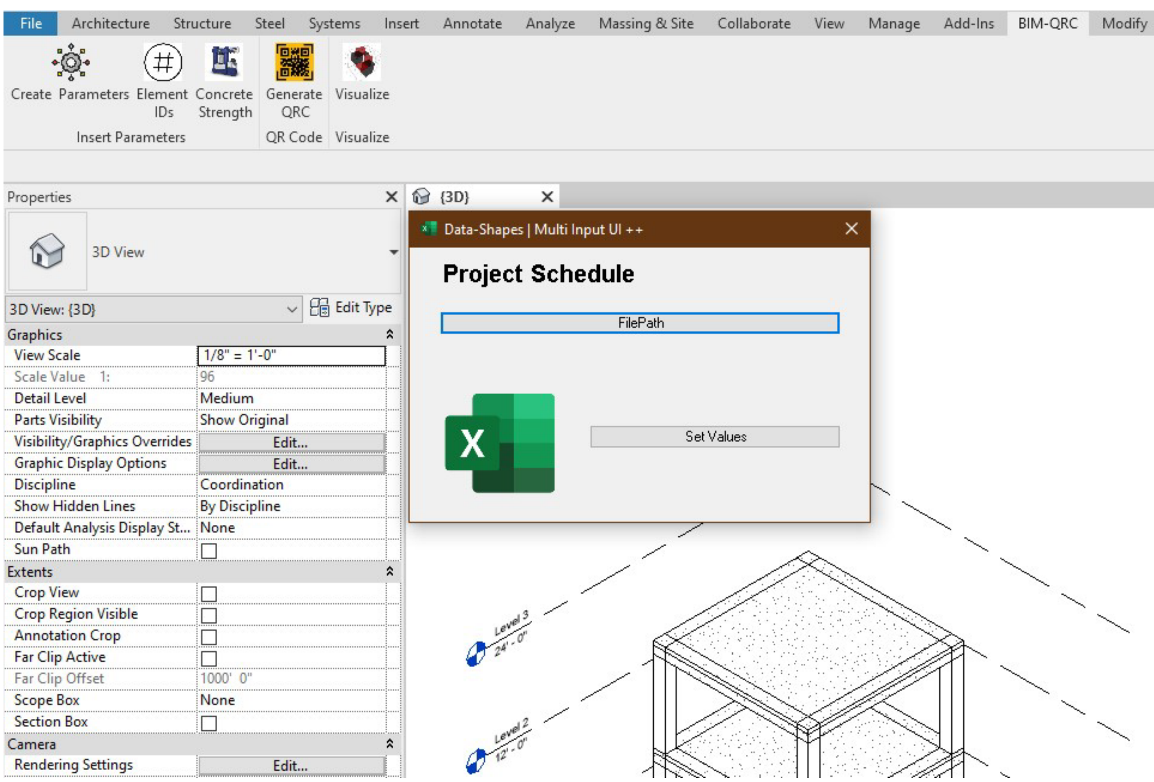

Fig. 4 Importing Project Schedule and Generating QR Codes.

The generated QR codes contain information i.e., the Element ID of the Concrete Elements, their Required Concrete Compressive Strength in Psi, their Pouring Dates, and a Web link for data collection from the testing which is connected to a Database. The fifth button *Visualize* when pressed asks for a database CSV output file that is generated in the second part of this system named ACQCR. When the desired file is selected, systems then analyze the data from the CSV file and the information already stored in Autodesk Revit. Upon analysis, the concrete elements that failed the cylinder compressive strength test in the laboratory are displayed in red for visualization purposes. ACQCR is a web-based system that was developed for data input and results uploading onto a database. It uses an SQL-based database, which makes it easier to access the results from anywhere. SQL stands for Structured Query Language, and it is used for relational databases. A database is an organized collection of structured information or data, which is usually stored electronically in a computer system. A database is typically controlled by a database management system (DBMS) which typically supports user-defined data types and can act as an extension of the storage system (Orlandic, 2000). When the generated QR codes are scanned via tablet, smartphone, or dedicated QR code readers the information stored in them appears. After clicking the stored web link a webpage opens, as shown in Figure 5, which asks for desired information about the results of concrete compressive strength testing.

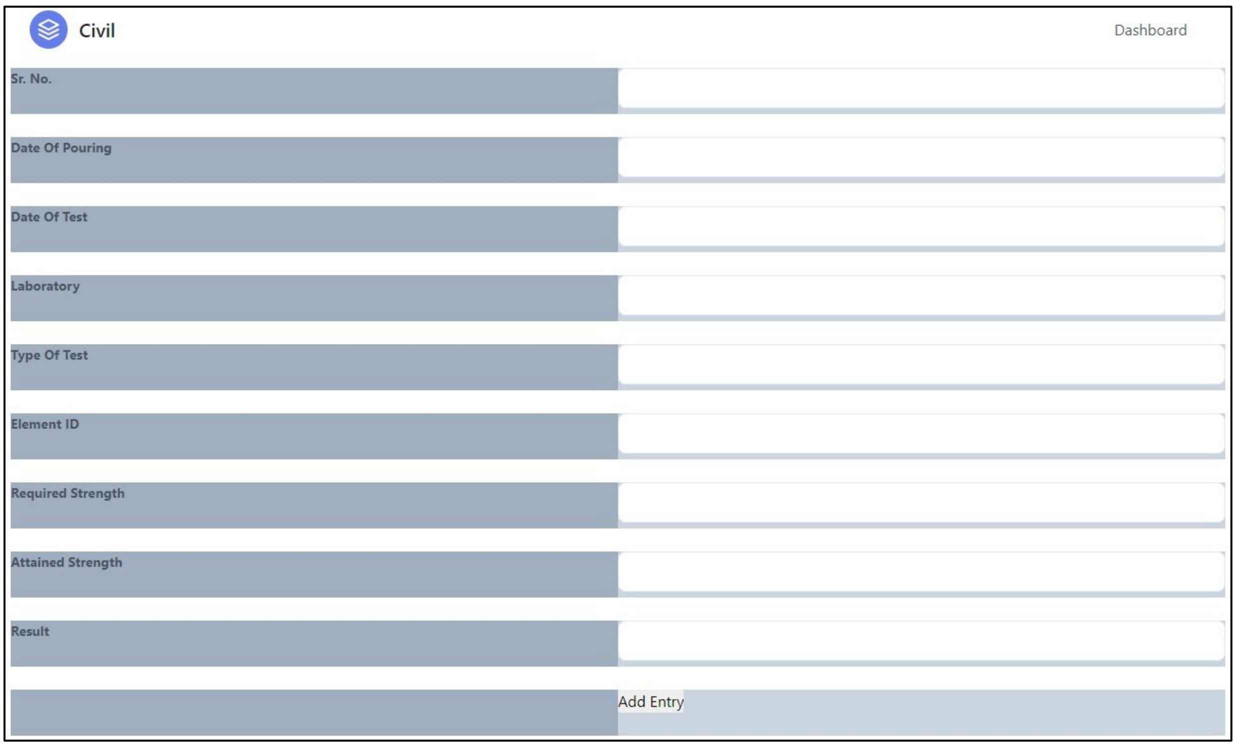

Fig. 5 Input Testing Results

When the data is put into the page and *Add Entry* button is pressed it then stores the data into the linked database. Results can be viewed inside the database and a separate dashboard page has also been developed for easier visualization of stored data. The dashboard button is present on the webpage as shown in Figure 6.

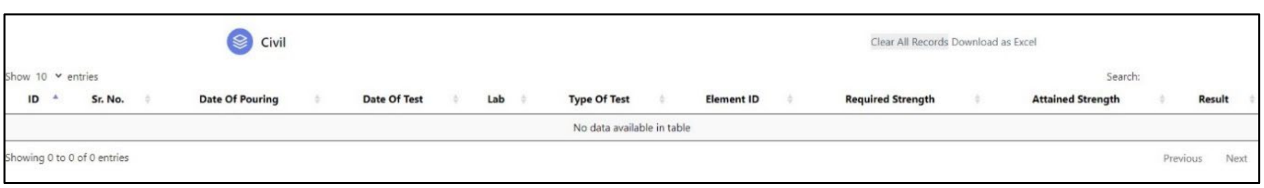

Fig. 6 Dashboard

The dashboard we've developed is depicted in the provided figure. It elegantly displays all the entries, each tagged with a unique system ID and serial number for easy identification and tracking. For user convenience, there's a 'Clear All Records' button that, when pressed, erases all the data within the dashboard, providing a fresh start. Additionally, users can export the data through the 'Download as Excel' button. This feature generates a CSV file, which is then saved to the predefined download folder on the user's computer. This CSV file encompasses all the records meticulously stored in the database, ensuring no data loss during the transfer. The visualization component is a key aspect of our system, designed specifically to analyze failed concrete elements. Upon clicking the 'Visualize' button within our BIM-QRC panel, the system prompts the user to select a database CSV file. Once a file is chosen, it's uploaded into the system. The system then analyzes the data and visualizes the failed concrete elements by marking them in a distinct red color-coded manner. This feature is critical for quickly identifying and addressing areas of concern, as vividly illustrated in the accompanying Figure 7.

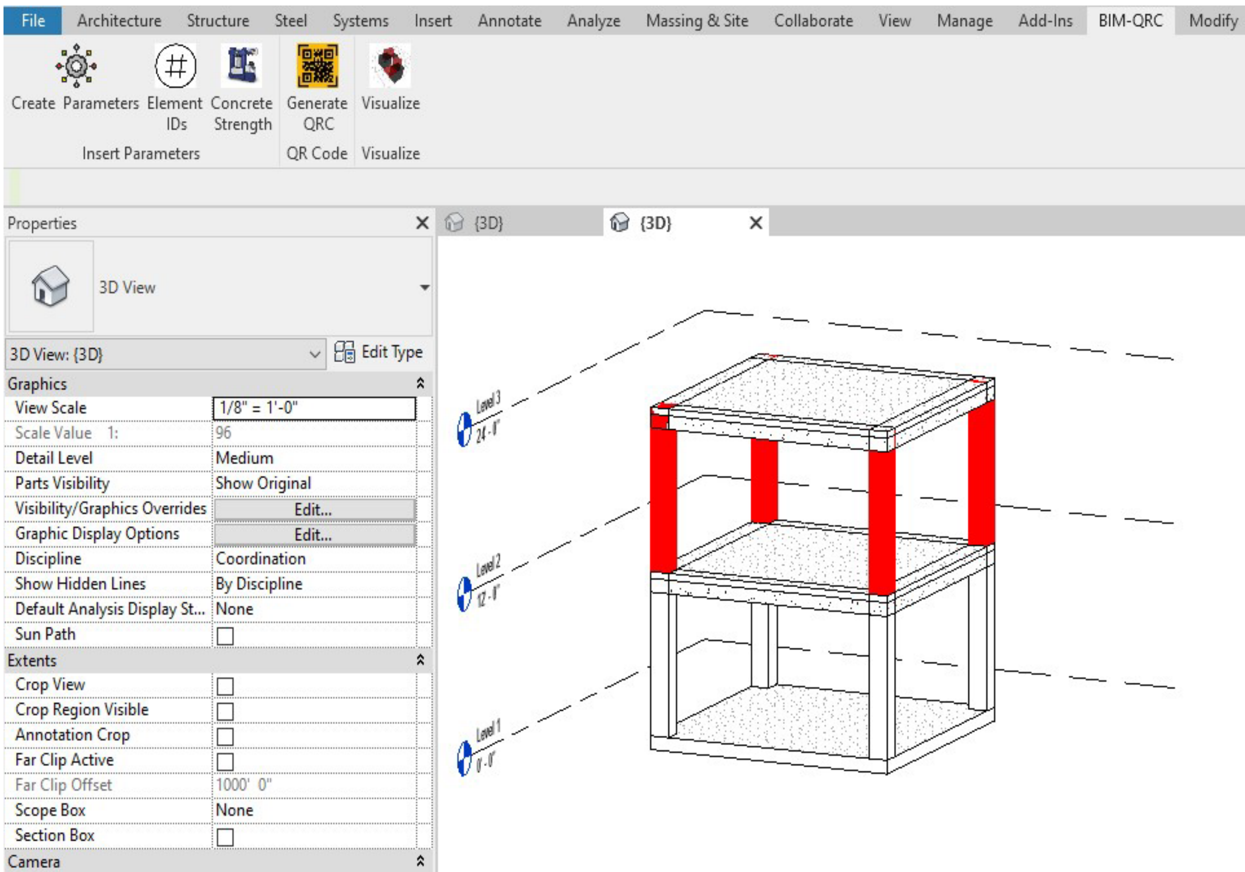

Fig. 7 Results Visualization

3. Case Study

A public sector office building project was selected as a test case model project due to the availability of data and information. Also, it is preferable to demonstrate BIM features to various stakeholders on public sector projects for their implementation (Ali et al., 2018). The system that was developed for this case study was tested successfully after its implementation. The BIM model of the project was created using Autodesk Revit 2020, as depicted in Figure 8. Our scope was limited to the major concrete elements, which include Foundation rafts, Columns, Beams, and Slabs.

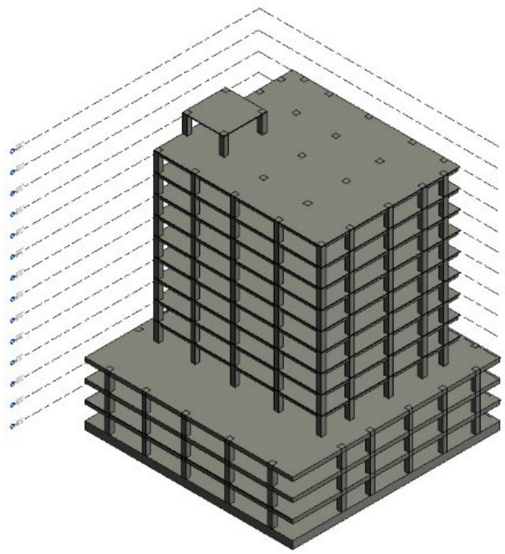

Fig. 8 The Case Study BIM Model

After the model development, the system was initiated through the Autodesk Revit panel named *BIM-QRC*. First, the required parameters were inserted into the BIM model using our plugin *Create Parameters* button. After the creation of parameters, the values were added using the next two created buttons, *Element IDs* and *Concrete Strength* as shown in Figure 9.

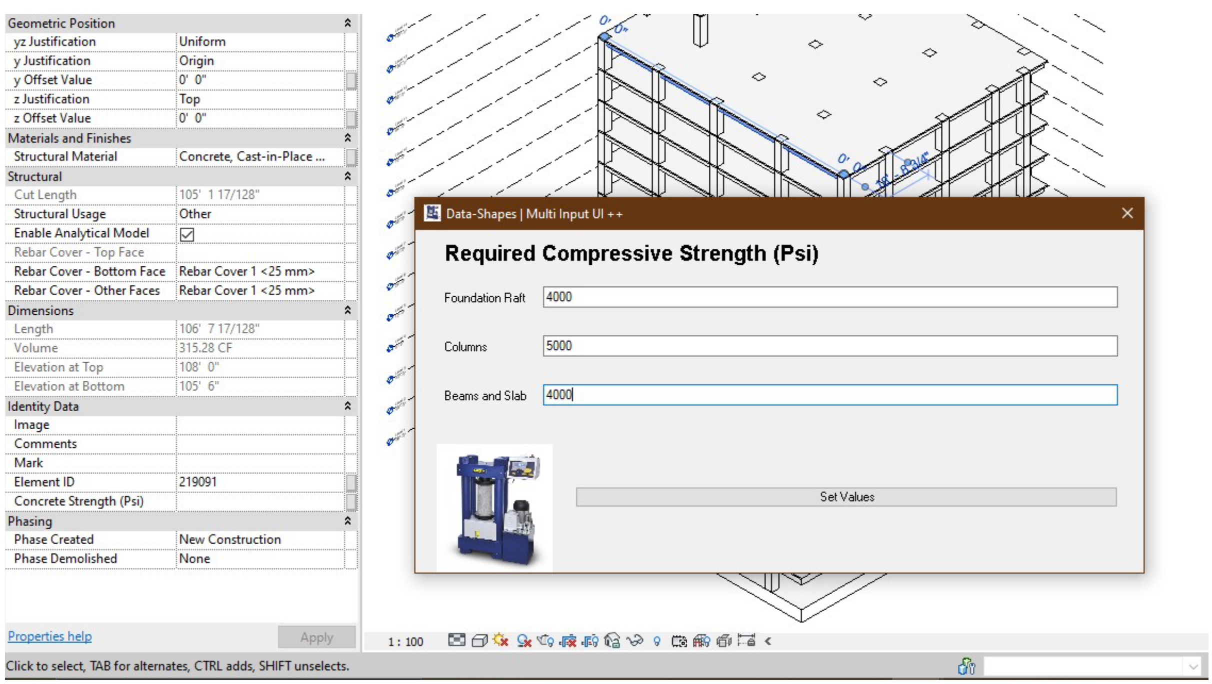

Fig. 9 Inserting Required Concrete Strength for the Project.

The case study was successful, as it ran into no issues. None of the compressive strength tests failed, and all of the provided test samples exceeded the required strength.

4. Results

Evaluation of our developed system BIM-QRC-ACQCR was completed through experts' review, as done by (Shen & Marks, 2015) for their research. The system was evaluated by conducting semi-structured interviews with 15 experts, including industry experts and laboratory engineers. Experts were provided with the implementation of BIM-QRC-ACQCR on real project models as test cases. A ratio of 60:40 was adopted between several industry experts and laboratory engineers. The results of the expert's review sessions are discussed in the following subsections. The expert's response via semi-structured interviews was collected for questions related to the need for BIM-QRC-ACQCR in the construction industry, the usability of the interface, possible implementation, and overall efficiency to improve traditional practices of construction quality control repository. A total of 15 experts' responses were collected, out of which 6 are laboratory engineers, and 9 are industry experts.

As Figure 10 indicates, in response to the question of "Need," a dominant 80% (47% strongly agree and 33% agree) thought that such a system is needed in the construction industry, while 20% remained undecided. Encouragingly, none of the experts disagreed with its need in the construction industry. Also, the figure indicates, in response to the question of "Usability," 60% of the experts (20% strongly agree and 40% agree) believed that such a system is useable in the construction industry, while 7% remained undecided and 33% disagreed with its useability.

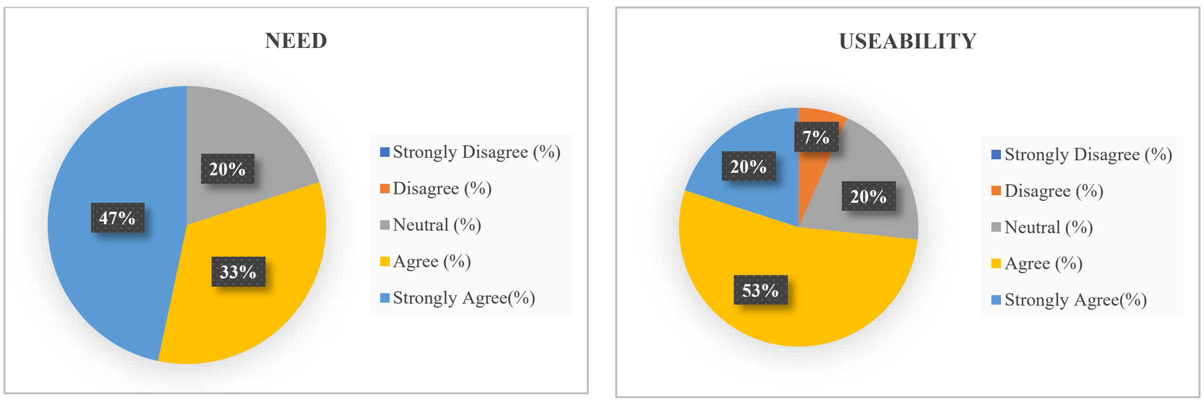

Fig. 10 Need and Usability of the BIM-QRC-ACQCR system.

In addressing the topic of "Implementation," according to the data presented in Figure 11, a significant portion of the experts have shown support for the system's applicability within the construction industry. Specifically, 7% of the experts strongly agreed, and 67% concurred with the feasibility of implementing such a system. Meanwhile, 13% were undecided, and an equal percentage expressed disagreement regarding its implementation in construction. When examining the aspect of "Efficiency," Figure 11 reveals that a substantial majority, 73%, of the experts view the system as efficient. Nonetheless, a notable portion, 27%, posited that the system's implementation might not necessarily translate to enhancements in the overall performance and efficiency of the construction quality control repository.

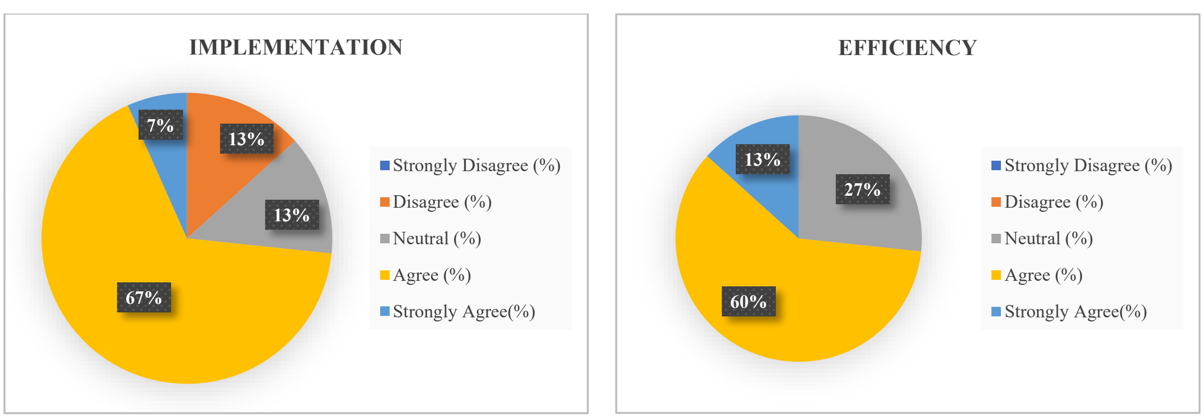

Fig. 11 Implementation and Efficiency of the BIM-QRC-ACQCR system.

Experts evaluated the system BIM-QRC-ACQCR by rating its effectiveness in addressing certain issues and inefficiencies on a 5-point Likert scale. This scale ranged from 1 ('Strongly Disagree') to 5 ('Strongly Agree'), based on their comprehension of the system's capabilities. The average of these scores was calculated to determine a Relative Importance Index (RII) for each issue or inefficiency. These indices were then ranked to illustrate their significance, as detailed in Table 1.

Table 1. Ranked Issues and Inefficiencies

Rank	Issues and Inefficiencies	RII Value	Mean Score
1	Inefficient information update & sharing	0.933	4.667
2	Time-Consuming	0.920	4.6
3	Poor data maintenance	0.907	4.533
4	Malpractice	0.853	4.267
5	Hectic Paperwork	0.827	4.133
6	Increased Cost	0.693	3.467
7	Prone to Errors	0.693	3.467
8	High complexity	0.587	2.933

5. Conclusion

The highlighted inefficiencies in the results, such as inefficient information update and sharing, time-consuming processes, and challenges in data maintenance, can be significantly enhanced through the implementation of a new automated framework. Experts in the industry have noted that malpractice is a common issue in traditional methods, yet this can be substantially reduced with the introduction of the proposed system. The conventional approach to managing a construction quality control repository is fraught with inefficiencies, which can be effectively minimized by adopting the new automated framework for construction quality control repositories. This paper enriches the discourse on the potential application of BIM in enhancing construction quality control, thereby addressing a notable gap in existing literature regarding BIM's role in construction quality control reporting and repositories. Through an exploration of BIM's implementation in quality control, this study proposes an integrated solution aimed at refining the current quality control repository process via the BIM working environment. This advancement is poised to facilitate a deeper comprehension of quality control among project stakeholders and foster more efficient collaboration through the use of visualization techniques.

6. Future recommendations

The primary objective of this study was to explore the integration of automation within the construction quality control processes, with a particular focus on the laboratory testing of construction materials like concrete. In place of traditional RFID tags as they run into issues inert to them, the innovative use of QR codes was proposed. The system developed through this research is designed for application during the construction execution phase, offering significant improvements in efficiency and accuracy. However, its utility is not limited to this phase alone; it can also be beneficial during the design stage, enhancing processes such as borehole log reports and soil testing. Moreover, the scope of automation based on this research extends beyond these initial applications, presenting opportunities to revolutionize various facets of construction quality control, thereby setting a new standard for the industry.

References

Akinci, B., Boukamp, F., Gordon, C., Huber, D., Lyons, C., & Park, K. (2006). A formalism for utilization of sensor systems and integrated project models for active construction quality control. *Automation in Construction*, *15*(2), 124–138. https://doi.org/10.1016/j.autcon.2005.01.008

Ali, B., Zahoor, H., Mazher, K. M., & Maqsoom, A. (2018). BIM Implementation in Public Sector of Pakistan Construction Industry. *ICCREM 2018: Innovative Technology and Intelligent Construction - Proceedings of the International Conference on Construction and Real Estate Management 2018*, 42–51. https://doi.org/10.1061/9780784481721.005

Arditi, D., Arditi, D., & Gunaydin, H. M. (2015). Total quality management in the construction process Total quality management in the construction process. *International Journal of Project Management*, *7863*(AUGUST 1997), 235–243. https://doi.org/10.1016/S0263-7863(96)00076-2

Bakar, A. H. B. A., Ali, K. Bin, & Onyeizu, E. (2011). Total quality management practices in large construction companies: A case of Oman. *World Applied Sciences Journal*, *15*(2), 285–296.

Barrett, P. (2000). Systems and relationships for construction quality. *International Journal of Quality and Reliability Management*, *17*(4), 377–392. https://doi.org/10.1108/02656710010298409

Battikha, M. G. (2002). QUALICON: Computer-based system for construction quality management. *Journal of Construction Engineering and Management*, *128*(2), 164–173. https://doi.org/10.1061/(ASCE)0733-9364(2002)128:2(164)

Chen, L., & Luo, H. (2014). A BIM-based construction quality management model and its applications. *Automation in Construction*, *46*, 64–73. https://doi.org/10.1016/j.autcon.2014.05.009

Chen, Y., & Kamara, J. M. (2011). A framework for using mobile computing for information management on construction sites. *Automation in Construction*, *20*(7), 776–788. https://doi.org/10.1016/j.autcon.2011.01.002

Chin, S., Kim, K., & Kim, Y. S. (2004). A process-based quality management information system. *Automation in Construction*, *13*(2), 241–259. https://doi.org/10.1016/j.autcon.2003.08.010

Eloranta, E., Hameri, A. P., & Lahti, M. (2001). Improved project management through improved document management. *Computers in Industry*, *45*(3), 231–243. https://doi.org/10.1016/S0166-3615(01)00099-9

Fernandez, O., Labib, A. W., Walmsley, R., & Petty, D. J. (2003). A decision support maintenance management system: Development and implementation. *International Journal of Quality and Reliability Management*, *20*(8), 965–979. https://doi.org/10.1108/02656710310493652

Griffith, A. (2000). Integrated management systems: A single management system solution for project control? *Engineering, Construction and Architectural Management*, *7*(3), 232–240. https://doi.org/10.1108/eb021148

Love, P. E. d. (2002). Auditing the indirect consequences of rework in construction: a case based approach. *Managerial Auditing Journal*, *17*(3), 138–146. https://doi.org/10.1108/02686900210419921

Love, P. E. D., & Irani, Z. (2003). A project management quality cost information system for the construction industry. *Information and Management*, *40*(7), 649–661. https://doi.org/10.1016/S0378-7206(02)00094-0

Martinez, P., Ahmad, R., & Al-Hussein, M. (2019). Automatic Selection Tool of Quality Control Specifications for Off-site Construction Manufacturing Products: A BIM-based Ontology Model Approach. *Modular and Offsite Construction (MOC) Summit Proceedings*, *2017*, 141–148. https://doi.org/10.29173/mocs87

Orlandic, R. (2000). *A Layered Multi-Model Design Framework for DBMS Construction A Layered Multi-Model Design Framework for DBMS Construction**. https://www.researchgate.net/publication/259392121

Shen, X., & Marks, E. (2015). Near-Miss Information Visualization Tool in BIM for Construction Safety. *Journal of Construction Engineering and Management*, *142*(4), 04015100. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001100

Tam, C. M., Deng, Z. M., Zeng, S. X., & Ho, C. S. (2000). Quest for continuous quality improvement for public housing construction in Hong Kong. *Construction Management and Economics*, *18*(4), 437–446. https://doi.org/10.1080/014461900050024851

Wang, L. C. (2008). Enhancing construction quality inspection and management using RFID technology. *Automation in Construction*, *17*(4), 467–479. https://doi.org/10.1016/j.autcon.2007.08.005