A BIM-BASED FRAMEWORK FOR AUTOMATION IN CONSTRUCTION QUALITY CONTROL REPORTING AND REPOSITORY

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THESIS ACCEPTANCE CERTIFICATE

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DEDICATED

TO

MY LOVING PARENTS, SISTERS AND FRIENDS

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LIST OF ABBREVIATIONS

Building Information Technology	BIM
Architecture, Engineering, Construction and Owner	AECO
Quality Management System	QMS
Recurrent Neural Network	RNN
Long Short-Term Memory	LSTM
Quality Control	QC
Quick Response Code	QRC
Comma Separated Values File	CSV
Geographic Information System	GIS
Radio Frequency Identification	RFID
Automated Construction Quality Control Repository	ACQCR
Database Management System	DBMS
Relative Database Management System	RDBMS
Structured Query Language	SQL
Light Detection and Ranging	LiDAR
Indoor Positioning System	IPS
Application Programming Interface	API

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ABSTRACT

The recent modernization of the construction industry throughout the world has made quality control a key aspect. In any construction project, many onsite and offsite laboratory tests and inspections are carried out to ensure quality. Traditionally, responses and reports are kept in as records yielding huge bundles and spanning volumes. This can further lead to issues such as poor data maintenance, loss of information, difficulty in information update and sharing, etc. Due to advances in computing such as Building Information Modelling (BIM), the construction industry has leaped forward tremendously through automation. In today's technologically advanced world, the use of automation strategies has become an integral part of any field of study. Automation makes the whole reporting, recording, and visualization process effective and efficient saving useful time and cost. This thesis proposes a new system "Quality Information Management based on Building Information Modeling (QIM-BIM)" for automation in traditional practices of construction quality control (QC) reporting and repository using BIM. The system generates QR-Codes using 4D BIM for laboratory testing of concrete cylinders and stores all the produced results in a SQL-based database. It further aids in visualizing the failed concrete elements via BIM model. This study enhances the process of data collection and information management in construction quality control. It demonstrates how the developed system's integration makes the quality control process more accurate and efficient.

Chapter 1

INTRODUCTION

Definition of quality is a complex matter (Barrett, 2000). The assessment and conformance of any work to the given or preset standards is known as "Quality" which is crucial for the successful completion of any construction project (Battikha, 2002). The conformance to the required standards of quality in a construction project has been a problematic issue to overcome. The lack of efficient and in many cases no quality management procedures has led to the wastage of not only financial capital, but also much-needed resources be it human or material (Arditi, & Gunaydin, 2015). To be successful, it is vital for any Quality Management System (QMS) to consider paperwork and management of quality records (Ahmed et al., 2005). Quality test reports are generally rendered by the lab engineers and staff in manually documented reports. In addition, the traditional methods of tracking any kind of reports and inspection certificates are based totally on manual paper-based record management. This traditional system of quality reporting has many inherent inefficiencies. It is unreliable, inaccurate at times, and most importantly resource-intensive (L. C. Wang, 2008a). According to previous studies, approaches for quality control and surveying have not been efficient. These ineffective strategies infer data that is only specific to time and location. After data acquisition, manual techniques are used to generate and interpret acquired data which is time-consuming resulting in ineffective project schedule and design. Project managers use these design schedules and cannot provide accurate and complete information in the workplace. Manual data interpretation limits the ability to properly manage defects and actively control construction projects (Akinci et al., 2006). Methods containing their own technological and economic backgrounds should be used in developing countries to improve the quality of construction projects (Abdel-Razek, 1998). Advanced construction technology such as mechanization and industrialization which could revolutionize the process of quality management depends on various factors. These, among others, include the coordination among various operators and work components, allocation of responsibility, sequence of different activities, time taken from system setup and its use, and the sheer quantity of operators and their respective qualification (Tam et al., 2000).

1.1. PREVIOUS WORK

BIM with the integration of LiDAR can be used for the collection of quality information and its processing for construction quality control in real-time (J. Wang et al., 2015a). IPS with the help of BIM can be used for effective and integrated management of construction quality control (Ma et al., 2018). A BIM-based coordinated quality administration system that consolidates ideas, can be used to decrease the quality defective events on construction projects and reduces quality defects in construction projects which in result reduce cost, better resource utilization, fewer delays, and improved quality of construction projects (Achkar, 2017a). Using Autodesk Revit API, a system can be developed which will display onsite quality defects in the 3D model, and such a system will improve information sharing and will efficiently document construction quality defects (Y.-M. Cheng, 2018a). The BIM 360 field is an advanced technology that could enhance the success of construction project quality administration and is another technique to control project quality in Vietnam to replace the conventional methods. A system for contractors that makes sure the successful quality assurance is elegantly and simply. With help of this innovative system project quality administration and update of the project, progress should be possible at the time and place of choice. Further, it can improve effective management, be less expensive, and increased competition (Nguyen et al., 2018a). A BIM-based framework can be an effective tool for the management of construction data, choosing the information related to the project quality, and doing information selection and rejection. Utilizing word cloud visualization and cluster analysis and converting unstructured data into structured data. Also utilizing Recurrent neural networks and long short-term memory RNN-LSTM to anticipate the quality issues of the construction project, for example, steel bars, formworks, concrete, and brickwork (D. Wang et al., 2018). A BIM-based quality control system prototype can record onsite quality defects and utilizing the Autodesk Revit API they can be visualized. It is an approach to detecting, recording, and displaying onsite quality defects in a 3D model. The system can efficiently store all the data which can be later printed or can be used to share information making communications better (Y.-M. Cheng, 2018b) A mobile device-based system can be used for the management of construction sites with two main purposes of sharing information and work management. The system can also link information with the location and is very efficient and effective in terms of communication among various construction site personnel on their own mobile devices. (C. Kim et al., 2011). BIM is very dominant in monitoring real-time progress, using software such as BIM 360 Field, which is quite effective. A BIM-based tool provides real-time progress and is very helpful in monitoring time, cost, and quality management (Matthews et al., 2015). There is huge potential for BIM in construction quality management with the adoption of an integrated approach of using a relational database and IFC-based system adoption, this increases the overall performance of the BIM model and database in construction quality control (Xu et al., 2018).

This research is aimed at utilizing BIM and its supported visual programming software i.e., Dynamo with the help of a web-based database for improving inefficiencies in traditional construction quality control repository.

1.2. PROBLEM STATEMENT

Construction quality control systems are quite expensive, they are affected by the involved stakeholders, and they tend to create a lot of paperwork (Griffith, 2000). Traditional construction quality control methods based on on-site visits and 2D design drawings are time-consuming, laborious, and prone to errors (Akinci et al., 2006). Quality test reports are normally created by lab engineers and staff in manually documented reports. In addition, the traditional ways of tracking a specific report or inspection certificate are completely manual paper-based handheld record management. This traditional system of quality reporting has quite some inefficiencies which are unreliable, inaccurate, and are resource-intensive (L. C. Wang, 2008b). Many studies indicate that current approaches for quality control are not efficient hence these ineffective methods are utilized to generate and interpret data which result consumes more time and delays the project. Project managers do not have complete information hence handheld manual data interpretation restricts the proper management and control of construction projects (Akinci et al., 2006).

In a construction project, quality control and early defect detection are important to reduce delays and cost overruns by integrating robotics and automation for real-time quality control (Martinez et al., 2019). To improve the construction projects' quality control, techniques should be utilized which are technologically strong (Abdel-Razek, 1998). Advanced technologies in construction quality control can vastly improve the quality management of construction projects (Tam et al., 2000). An automated document management system can facilitate a project (Eloranta et al., 2001). The computer program simplifies and reduces the time of data capture compared to the currently used paper-based reporting system (Fernandez et al., 2003a). The studies discussed here have tried to overcome the issues of traditional practices adopted in construction quality control with techniques like integration of robotics and automation with real-time monitoring, automated document management system. In brief, BIM is an emerging technology with vast field of application, and it has not been used to integrate automation in construction quality control reporting and repository.

Hence the question arises “Can BIM help in automation and improvement of construction quality control reporting and repository by catering for incurring issues and inefficiencies in traditional practices”.

1.3. OBJECTIVES

- To identify the inefficiencies in traditional construction quality control repository.
- To develop a BIM-based framework for automation in a quality control repository.
- To evaluate the developed framework.

1.4. SIGNIFICANCE

Pakistan is a country where construction quality has been neglected over decades, but now the trend is shifting as people are getting aware of the need for construction quality implementation on site. As construction quality cost is very high in Pakistan and there are limited interactive methods to effectively engage construction workers to improve project quality. This study undertaken would help our construction quality industry to automate the construction quality control process more effectively in terms of performance and efficiency.

1.5. THESIS OVERVIEW

In this thesis, Chapter 1 includes the introduction in detail, the problem statement with the research gap, the objectives of this research, and the significance of this thesis in our industry. Chapter 2 consists of the theory behind the proposed methodology. It includes all the details of the theory involved in this thesis and the enlisted issues and inefficiencies that occur in our traditional practices of construction quality control reporting and repository. Chapter 3 involves the methodology adopted to acquire the data involving the experimental paradigm and workflow and the development of the framework with the complete working of the framework. Chapter 4 describes the developed system which is based on the devised framework. Also, the complete working of the system. Chapter 5 consists of the evaluation and results and the analysis of results obtained, and a discussion in detail. Chapter 6 consists of a conclusion and briefly explains the future work.

Chapter 2

LITERATURE REVIEW

The development of any country depends upon various major contributors and the construction sector is one of them (Nawaz et al., 2013). All the construction projects are novel since they provide us with the business creation and fulfillment of human fundamental needs (Khelifi & Hesham, 2016). The development of the construction industry depends on the quality of construction projects (D.Ashokkumar, 2014).

2.1 CONSTRUCTION QUALITY

The construction quality can be defined as the fulfillment of sets of rules and requirements provided by the owner and designer (Rajiv & Harinath, 2018). In the successful completion of any construction project, proper quality management is essential (Nguyen et al., 2018a). The construction project quality directly impacts the steady turn of events and adequacy of the financial components of the public economy (Quyen et al., 2017). In construction projects, quality management must be adopted throughout the construction for better and complete quality control (L. C. Wang, 2008a). In many construction projects, there are issues like delays in schedule and cost overruns, they can be minimized and mitigated if proper quality control is performed. (Martinez et al., 2019).

2.2 CONSTRUCTION QUALITY CONTROL

Construction quality control can be defined as a set of processes that make sure if compliance with the defined standards is being met (Hendrickson, 2008). The act of conveying information through documents containing quality control data can be described as a quality control report. Traditional approaches for construction quality reporting are not helpful, as they provide location-specific data and the time of work taking place, also the produced information and data are interpreted by labor and are not linked with the project design model and project schedule. As a result, project and quality control do not get total and precise data about work set up. This does hinder their capabilities to easily recognize and manage construction quality defects, and effectively control and manage construction projects (Akinci et al., 2006).

2.3 ISSUES AND INEFFICIENCIES

In any country there are substantial contributors towards its Gross Domestic Product and construction industry is one of those major sectors and as time is passing by it is getting bigger and bigger quickly but unfortunately, it encounters various issues like uncertainty, less productivity, inappropriate quality, and lack quality standards (Bakar et al., 2011). Construction quality systems are accused to be very costly, affected by involved parties and they have a huge potential for creating spanning volumes of paperwork (Griffith, 2000). There is a huge amount of information sharing and transfer that takes place during the construction of a project as it is an information-intensive industry (Chen & Kamara, 2011).

In a construction project information collection, its reporting and managing it becomes quite difficult as multiple re-drawing and re-keying of information take place. In the end, all of this results in wastage of time, unpredicted costs, various errors, and miscommunication, and thus rework takes place, which is one of the main factors of time and cost overruns in construction projects (P. E. D. Love, 2002). In the construction industry information technology (IT) is not being utilized effectively in information communication and sharing which increases the amount of rework (P. E. d. Love, 2002).

Construction organizations are of various categories with different capabilities in the workforce, machinery, and technology hence it becomes difficult to manage construction project information especially information related to costs. Many of these construction organizations do not have any system to collect or process cost-related information (P. E. D. Love & Irani, 2003). Normally in construction practices, there are some methods for construction quality assurance, but they are dependent upon site visits, comparison of designs drawings, validation of specifications, etc., do consume time, require more labor, and are error-prone (Akinci et al., 2006).

Issues identified from the literature are illustrated below in Table 1 Reported Issues:

Table 1 Reported Issues

Sr. No.	Issues	Reported Frequency	Authors
1	Paper-based data and manual work	22	Bai, 2013; Becerik-gerber et al., 2012; Cheng, 2018b, 2018a; Chin-Keng, 2011; East et al., 2013; Eloranta et al., 2001; Fernandez et al., 2003; Griffith, 2000; Haupt & Whiteman, 2004; Lin et al., 2014; Lin & Su, 2013; Ma et al., 2008, 2018; Matthews et al., 2015; Nguyen et al., 2018; Roh et al., 2011; Zhiliang et al., 2005; Zhou & El-Gohary, 2016)
2	Lack of conceptual reporting knowledge and unreliable methods	14	(Akinci et al., 2006; Y.-M. Cheng, 2018a; Chin et al., 2004; Chin-Keng, 2011; Lin & Su, 2013; P. E. D. Love & Irani, 2003; Ma et al., 2008, 2018; Mani et al., 2009; Matthews et al., 2015; Roh et al., 2011; L. C. Wang, 2008b; Zhiliang et al., 2005)
3	Inefficient and difficult information update	10	(Becerik-gerber et al., 2012; Eloranta et al., 2001; Lin et al., 2014; Lin & Su, 2013; Ma et al., 2018; Nguyen et al., 2018b; L. C. Wang, 2008b; Zhou & El-Gohary, 2016)
4	Labor intensive and bulking documents	21	(Achkar, 2017; Becerik-gerber et al., 2012; Y.-M. Cheng, 2018a;

			Y. M. Cheng, 2018; Chin-Keng, 2011; East et al., 2013; Eloranta et al., 2001; Fernandez et al., 2003; Griffith, 2000; Haupt & Whiteman, 2004; Lin et al., 2014; Lin & Su, 2013; Love & Irani, 2003; Ma et al., 2008, 2018; Mani et al., 2009; Roh et al., 2011; Wang, 2008; Zhiliang et al., 2005; Zhou & El-Gohary, 2016;Roh et al., 2011)
5	Prone to Errors	11	(Chin-Keng, 2011; East et al., 2013; Haupt & Whiteman, 2004; Lin et al., 2014; Lin & Su, 2013; P. E. D. Love & Irani, 2003; Ma et al., 2008, 2018; Mani et al., 2009; Matthews et al., 2015; Roh et al., 2011)
6	Paperwork yields less quality	8	(Akinci et al., 2006; Bai, 2013; Eloranta et al., 2001; Fernandez et al., 2003b; Lin et al., 2014; Lin & Su, 2013; P. E. D. Love & Irani, 2003; Roh et al., 2011)
7	Complexity is more	6	(Bai, 2013; Chin-Keng, 2011; Eloranta et al., 2001; Fernandez et al., 2003b; Mani et al., 2009; Roh et al., 2011)
8	Poor information sharing and communication	9	(Bai, 2013; Y. M. Cheng, 2018; Chin et al., 2004; Chin-Keng, 2011; Eloranta et al., 2001; Lin et al., 2014; Lin & Su, 2013;

			Nguyen et al., 2018a; L. C. Wang, 2008b)
9	Paperwork consumes time	15	(Y. M. Cheng, 2018; Chin et al., 2004; Fernandez et al., 2003b; Lin et al., 2014; Lin & Su, 2013; P. E. D. Love & Irani, 2003; Ma et al., 2008, 2018; Mani et al., 2009; Matthews et al., 2015; Nguyen et al., 2018a; Roh et al., 2011; L. C. Wang, 2008b; Zhiliang et al., 2005; Zhou & El-Gohary, 2016)
10	Inconvenient and hard data maintenance	4	(Y. M. Cheng, 2018; Y.-M. Cheng, 2018a; Lin et al., 2014; Lin & Su, 2013)
11	Difficult to refer information due to conflicts and errors in documents	5	(Bai, 2013; Lin et al., 2014; Lin & Su, 2013; Matthews et al., 2015; L. C. Wang, 2008b)
12	Inadequate, ineffective, and unable to present complete information	11	(Akinci et al., 2006; Y. M. Cheng, 2018; East et al., 2013; Eloranta et al., 2001; Lin et al., 2014; Lin & Su, 2013; P. E. D. Love & Irani, 2003; Mani et al., 2009; Roh et al., 2011; L. C. Wang, 2008b)
13	Inefficiency and errors in information extraction	5	(Akinci et al., 2006; East et al., 2013; Haupt & Whiteman, 2004; Mani et al., 2009; Zhou & El-Gohary, 2016)

14	Data loss and difficult data re-entry	6	(Bai, 2013; East et al., 2013; Fernandez et al., 2003b; Lin et al., 2014; Lin & Su, 2013; L. C. Wang, 2008b)
15	Increased cost	7	(Bayazit & Karpak, 2007; Griffith, 2000; P. E. D. Love & Irani, 2003; Mani et al., 2009; Matthews et al., 2015; Zhou & El-Gohary, 2016)

2.4 LITERATURE SCORE AND RANKING OF ISSUES

The above table of issues and inefficiencies was scrutinized and analyzed for their literature score as the data was obtained both in qualitative and quantitative form and the results that were obtained are given in Table 2 Compilation and literature analysis of issues explained below.

Table 2 Compilation and literature analysis of issues

Rank	Issues	Total Literature Score	Normalized Score	Cumulative Normalized Score
1	Paper-based data and manual work	1.46667	0.189003	0.189003
2	Labor Intensive and bulking documents	0.84	0.108247	0.297251
3	Inefficient and difficult information update	0.66667	0.085911	0.383162
4	Paperwork consumes time	0.6	0.07732	0.460481
5	Poor information sharing and communication	0.6	0.07732	0.537801

6	Lack of conceptual reporting knowledge and unreliable methods	0.56	0.072165	0.609966
7	Increased Cost	0.46667	0.060137	0.670103
8	Prone to errors	0.44	0.056701	0.726804
9	Inadequate, ineffective, and unable to present complete info	0.44	0.056701	0.783505
10	Complexity is more	0.4	0.051546	0.835052
11	Data loss and difficult data re-entry	0.4	0.051546	0.886598
12	Paperwork yields less quality	0.32	0.041237	0.927835
13	Difficult to refer information due to conflicts and error in documents	0.2	0.025773	0.953608
14	Inefficiency and errors in information extraction	0.2	0.025773	0.979381
15	Inconvenient and hard data maintenance	0.16	0.020619	1

2.5 AUTOMATION IN MANUAL WORK AND DATA

In a construction project, efficient quality assurance and effective quality control are among the major factors that reduce the number of project delays and cost overruns. With the integration of automation and robotics in construction, quality control is becoming more effective and reliable with real-time monitoring. (Martinez et al., 2019). Building information modeling is relatively a new concept with a lot of capabilities and is helping in the construction of more complex projects (Kalyan et al., 2016). An automated document management system can facilitate the process of construction management (Eloranta et al., 2001). The systems that are digital and computer-based are making the work easy and reducing the time of data capture when compared with traditional practices of paper-based reporting systems (Fernandez et al., 2003a).

2.6 BENEFITS OF AUTOMATION AND BIM

The application of newer technologies like automation and BIM in construction industry yield various benefits. An extensive literature review was carried out for benefits identification of introducing automation and BIM in traditional practices of construction quality control reporting and repository. The benefits identified from the literature are illustrated below in Table 3 Benefits Reported Frequency.

Table 3 Benefits Reported Frequency

Sr. No.	Benefits	Reported Frequency
1	Web-based system	14
2	Electronic Data	11
3	Can present Multi-dimensional Data	9
4	Multi-disciplinary collaboration	9
5	Automatic generation of documents	9
6	Efficient Information Utilization	8
7	Reduces Errors	8
8	Effective tool	8
9	Ease of Information Update	7
10	Ease of Visualization	7
11	Information Generation	7
12	Integrate Data during Construction	6
13	Increased speed and accuracy	6
14	Improves Productivity	6
15	Data Maintenance	6
16	Increased Efficiency and Precision	6
17	Better Performance than manual work	6
18	Management of Construction Data	6

19	Integration with other technologies like GPS, RFID etc.	6
20	Information Sharing	5
21	Project Participants Interaction/Communication	5
22	Less Error and Omissions	5
23	Improved Decision Making by Project Management	5
24	Precise and Consistent Information	5
25	Integration of Virtual and Real World	5
26	Real-time	5
27	Reduces Rework	4
28	Data Simulation and Optimization	4
29	Interoperability	4
30	Eliminates Conflicts	3
31	Minimize waste	3
32	Time Sequence	2
33	Time Saving	2
34	Less work force required	2
35	Reduces Cost	1
36	Lower Risk	1

2.7 ISSUES VS BENEFITS MATRIX

The identified benefits of introducing automation and BIM in traditional practices of construction quality control were compared with the issues and inefficiencies of traditional practices to check if the strategy to be adopted will address the incurring issues and inefficiencies. They were then scored with the number of issues and inefficiencies they were minimizing and mitigating in the reported literature. The scored benefits are given in Table 4 Scored Benefits.

Table 4 Scored Benefits

Rank	Benefits	Score
1	Electronic Form (Automated Data)	11
2	Eliminates Conflicts	3
3	Reduces Rework	4
4	Efficient Information Utilization	8
5	Can present Multi-dimensional Data	9
6	Time Sequence	2
7	Web-based system	14
8	Information Sharing	5
9	Integrate Data during Construction	6
10	Ease of Information Update	7
11	Multi-disciplinary collaboration	9
12	Project Participants Interaction/Communication	5
13	Increased speed and accuracy	6
14	Ease of Visualization	7
15	Improves Productivity	6
16	Less Error and Omissions	5
17	Information Generation	7
18	Data Maintenance	6
19	Reduces Cost	1
20	Improved Decision Making by Project Management	5
21	Increased Efficiency and Precision	6
22	Reduces Errors	8
23	Lower Risk	1
24	Data Simulation and Optimization	4
25	Better Performance than manual work	6
26	Effective tool	8
27	Time Saving	2
28	Automatic generation of documents	9
29	Precise and Consistent Information	5

30	Integration of Virtual and Real World	5
31	Interoperability	4
32	Management of Construction Data	6
33	Less work force required	2
34	Minimize waste	3
35	Real-time	5
36	Integration with other technologies like GPS, RFID, etc.	6

2.8 RANKING OF BENEFITS

The identified benefits of introducing automation and BIM in construction quality control were analyzed and were put against the issues and inefficiencies of traditional practices of construction quality control, and it was found out that all the major issues and inefficiencies are being covered by these realized benefits. Then the benefits were ranked in the order in which the benefits covering most issues and inefficiencies were given priority. The accordingly arranged benefits are given below in Table 5 Ranked Benefits.

Table 5 Ranked Benefits

Rank	**Benefits**	**No. of Issues Covering**
1	Web-based system	14
2	Electronic Form (Automated Data)	11
3	Can present Multi-dimensional Data	9
4	Multi-disciplinary collaboration	9
5	Automatic generation of documents	9
6	Efficient Information Utilization	8
7	Reduces Errors	8
8	Effective tool	8
9	Ease of Information Update	7
10	Ease of Visualization	7
11	Information Generation	7

12	Integrate Data during Construction	6
13	Increased speed and accuracy	6
14	Improves Productivity	6
15	Data Maintenance	6
16	Increased Efficiency and Precision	6
17	Better Performance than manual work	6
18	Management of Construction Data	6
19	Integration with other technologies like GPS, RFID etc.	6
20	Information Sharing	5
21	Project Participants Interaction/Communication	5
22	Less Error and Omissions	5
23	Improved Decision Making by Project Management	5
24	Precise and Consistent Information	5
25	Integration of Virtual and Real World	5
26	Real-time	5
27	Reduces Rework	4
28	Data Simulation and Optimization	4
29	Interoperability	4
30	Eliminates Conflicts	3
31	Minimize waste	3
32	Time Sequence	2
33	Time Saving	2
34	Less work force required	2
35	Reduces Cost	1
36	Lower Risk	1

2.9 BUILDING INFORMATION MODELLING

2.9.1 What is BIM?

Building Information Modeling (BIM) is a digital representation of the physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is a collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder (NIBS, 2012).

In the architecture, engineering, and construction (AEC) industry, building information modeling (BIM) is one of the most recent and encouraging developments. Using the building information modeling, a precise virtual model of a building can be made (Azhar, 2011).

BIM can be used for visualization of the model, creation of drawings, construction code reviews, forensic analysis, facility management, estimation of cost, sequencing of construction, clash detection, etc (Azhar, 2011).

2.9.2 Benefits of BIM

There are various benefits of BIM. As mentioned by (Khan et al., 2008) building information modeling can provide faster more effective processes, better design, controlled whole-life costs, and environmental data, automated assembly, better customer service, and lifecycle data. Visual description of benefits is shown in Figure 1 (Reizgevičius et al., 2018).

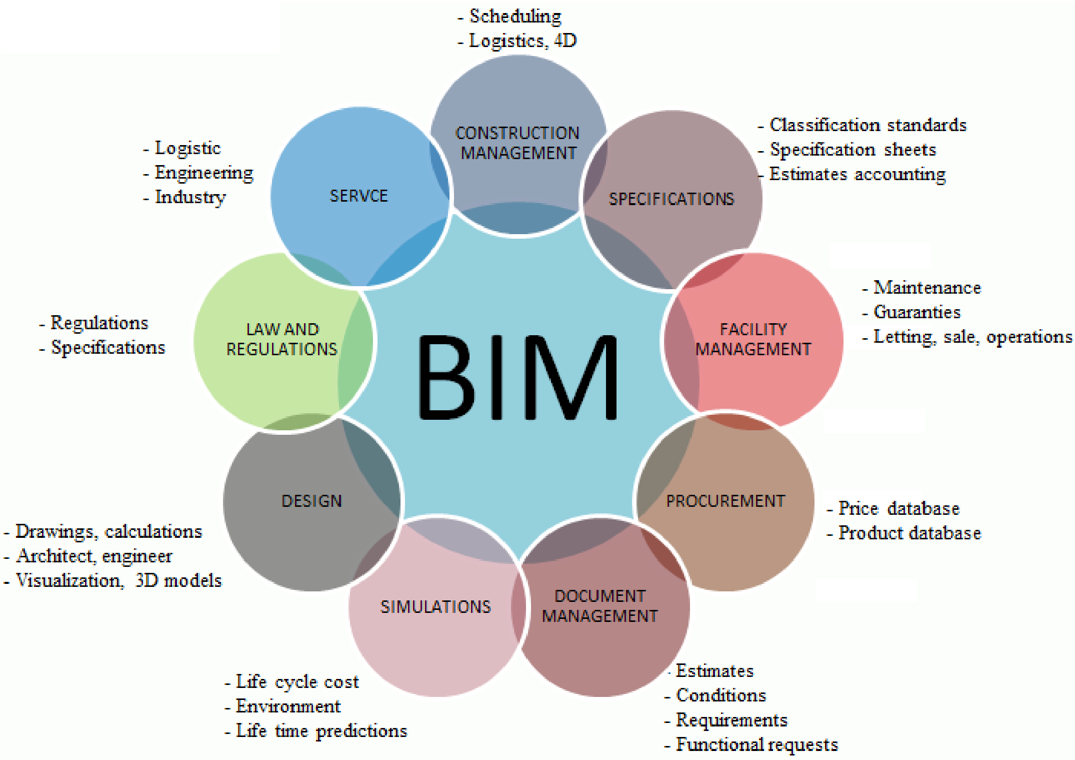


Figure 1 Building Information Modelling

2.9.3 BIM & Construction Quality

Real-time dynamic information management and quality control have recently been studied in several recent research projects. In these studies, dynamic management or control was determined as a flexible, fast, and efficient response to the control of different activities on construction sites. Also, that can be information modeling (Infrastructure BIM) based, internet browser-based, independent of different terminals, and utilizes wireless and mobile information transfer (Kivimäki et al., 2015). BIM can be used in the creation of multidimensional models with space constraints, time, costs, materials, design, and manufacturing information, finishes, etc., and support real-time information sharing and collaboration. This information can be also be used with other technologies like augmented reality, virtual reality, radio-frequency identification (RFID), and even with 3D printers (Lester, 2014). Building information can be utilized in reducing the manual re-entering of data to a minimum and enabling the consequent re-use of digital information, laborious and error-prone work is avoided, which in turn increases productivity and quality in construction projects (Borrmann et al., 2018)

BIM technology-based quality management framework is the focus of the platform to achieve the function, which is combined with AR technology to promote the construction quality control (Lou et al., 2017). In BIM, the model is a digital representation of a complex construction product and contains precise product information data, BIM model can also be used to obtain construction-oriented data and linking information that is crucial to manufacturing and quality control and assurance (Martinez et al., 2019). A quality control system using LiDAR-based real-time tracking, and integrated BIM-based real-time checking can automatically collect data, perform comparisons between the as-built data and as-planned BIM model, and assess construction quality on-site (J. Wang et al., 2015b). The utilization of BIM in the construction stage combines it with quality management to develop innovative approaches and improve the performance efficiency of the quality management system (Y. M. Cheng, 2018).

2.10 SOFTWARE AND TOOLS USED IN RESEARCH

There are various software and tools that have been used during the performed research and this thesis and they are described here in detail.

2.10.1 Autodesk Revit

A graphical user interface (GUI) is a computer program that enables users to communicate with a computer with the use of some visuals. There are various GUI software's to work with BIM and major ones are Autodesk Revit, Graphisoft ArchiCAD, and there is some software like Nemetschek Allplan, BricsCAD, Edificius that are worth mentioning (Bouška, 2016). Autodesk Revit is specifically built for building information modeling (BIM) providing a complete architectural design and documentation solution, supporting all phases of design and all architectural drawings and schedules required for a building project, from massing and conceptual studies through the most detailed construction drawings and schedules (Zurich et al., 2013). Analytical modeling in BIM has been introduced with the Autodesk Revit environment. Well-documented API (Application Programming Interface) allows for seamless integration with other software. Dynamo is an extensive software operated through Revit. It is an interface between the visual programming environment and Revit API (Salamak et al., 2018).

In our developed system, GUI enables a user to access the BIM software tool to get the desired QR-codes from the building model. A model screen will provide the user view of the project. Buttons have been incorporated into the tool for executing various programmed scripts for the user's ease.

2.10.2 Quick Response Code (QR-Code)

The Quick Response Code (QR-Code) is the most widely used two-dimensional barcode in the world, and it has been successfully applied in many applications in manufacturing and construction (Chou & Wang, 2020). A Quick Response Code (QR-Code) is a type of matrix bar code or two-dimensional code designed to be read by smartphones. The code consists of black modules arranged in a square pattern on a white background. The information encoded may be text, a URL (Uniform Resource Locator), or other data [71][72]. The larger amount of information QR-Code contains, the greater the number of pixels. It must also have a minimal resolution performance to allow pixel dis-crimination to recognize pixel patterns. QR-Code allows users to enter a variety of information, but depending upon the information, the number of pixels required will also increase proportionally. Therefore, if high-capacity information is entered into the QR-Code, a high-resolution device is required to recognize the QR-Code. Conversely, the minimal information required for object recognition reduces the number of pixels in QR-Code. The recognition rate of the QR-Code increases if the number of pixels used is less [73].

2.10.3 Wamp Server and MariaDB (RDBMS)

WampServer is a Windows web development environment. It allows you to create web applications with Apache2, PHP, and a MySQL database. Alongside, PhpMyAdmin allows you to easily manage your database (WampServer).

RDBMS stores data in the form of tables, with most commercial relational database management systems using Structured Query Language (SQL) to access the database (Relational Database Management System). MariaDB is developed as open-source software and as a relational database, it provides an SQL interface for accessing data (MariaDB Server).

This chapter describes the literature about construction quality. Importance of construction quality in the construction industry of any country. Construction quality comprises of two parts quality assurance and quality control. This chapter describes What construction quality control is and what does it do, how important it is in the construction industry. It describes the issues of construction quality and construction quality control. After that, it describes the identified issues and inefficiencies reported in the literature. The identified issues and inefficiencies have been ranked according to their literature score. After that benefits of introducing automation and BIM in construction quality control, reporting and repository were identified. Later a cross matrix was prepared of issues and inefficiencies vs benefits. It was performed to check if the introduction of automation and BIM in the traditional benefits will mitigate the identified issues and inefficiencies. Based on the above-realized benefits a methodology and framework will be devised in the next chapter.

Chapter 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter describes the methodology for achieving the objectives which are described in Chapter 1. The research is designed in compliance with the detailed research process (including literature review, framework development, validation, and evaluation).

3.2 RESEARCH DESIGN

With the formulation of a basic workflow chart research gap analysis was initiated, the study of existing knowledge was carried out, after a critical review of literature a research gap was identified. The problem statement was defined, and topic selection was performed. With the help of a preliminary study, research objectives were formulated. the methodology of this research is given in Figure 2 Methodology.

For the first objective of our research, a detailed literature review has been carried out from several research articles to identify the issues that exist in our construction quality control repository. The obtained issues have been grouped due to their overlapping nature and have been ranked according to their total literature score.

We studied the construction quality control repository and issues that occur in the traditional process and in the literature to eradicate the inefficiencies identified in the first phase. To achieve the second objective, the elements of the framework are to be decided following the construction quality control repository. The contents shall include construction quality control repository, BIM, and automation. These features will be sub-divided in detail on basis of the construction quality control repository procedure.

To achieve the last objective this framework will be evaluated by implementing the designed model on a construction site and obtaining the difference between the traditional and automated reporting procedure and getting experts' opinions on the developed system. The identified inefficiencies in the conventional construction quality control repository as literature review was performed and then the benefits of automation in construction quality reporting were identified with the extensive literature review. After comparing and analyzing both the issues and benefits a comparison matrix was formed and it was found out that most of the identified issues and inefficiencies can be covered successfully with the help of realized benefits.

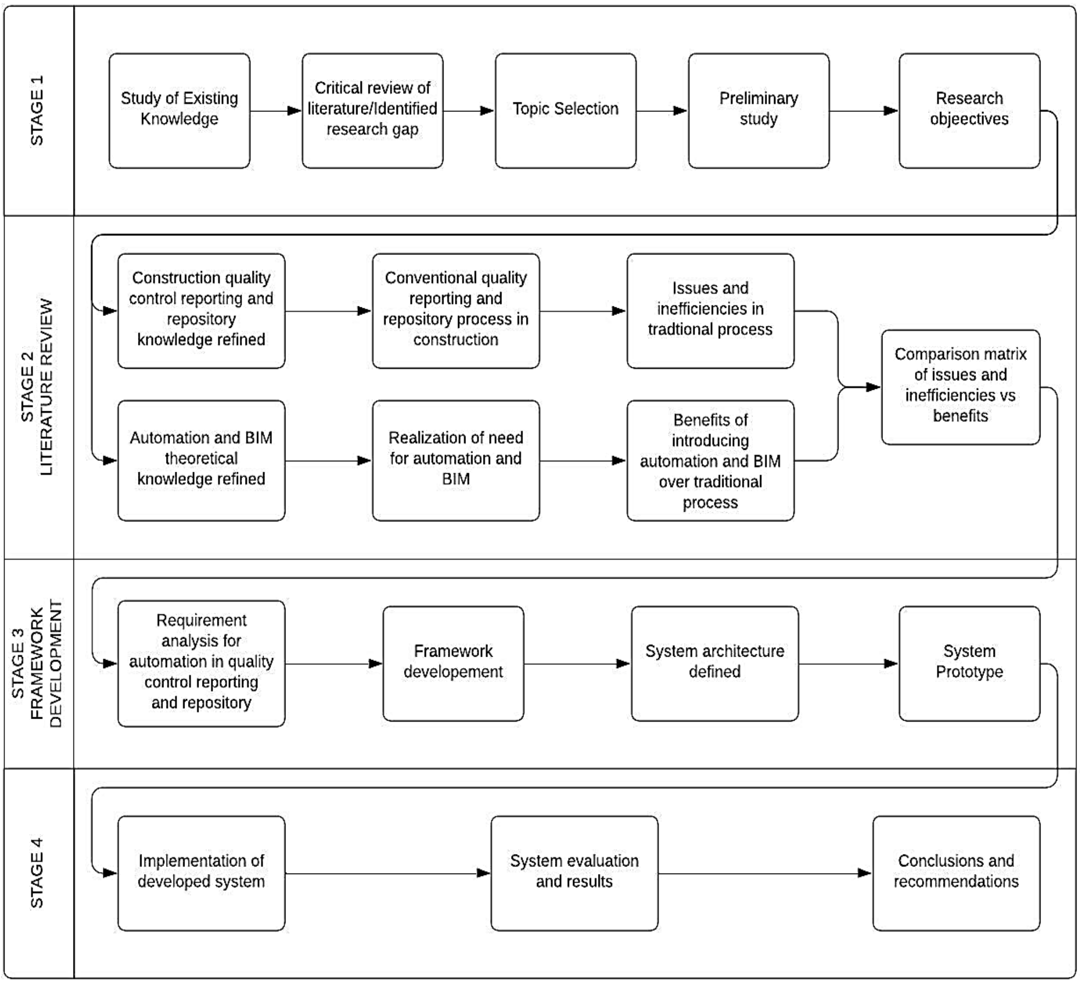


Figure 2 Methodology

3.3 FRAMEWORK

To achieve automation in the construction quality control reporting and repository a BIM-based framework has been developed which is given in Figure 3 Framework. The developed framework is a BIM-based framework for smart and better working of our system. When a construction project begins, its virtual model is made for visual purposes and its schedule is made for a better understanding of the project timeline.

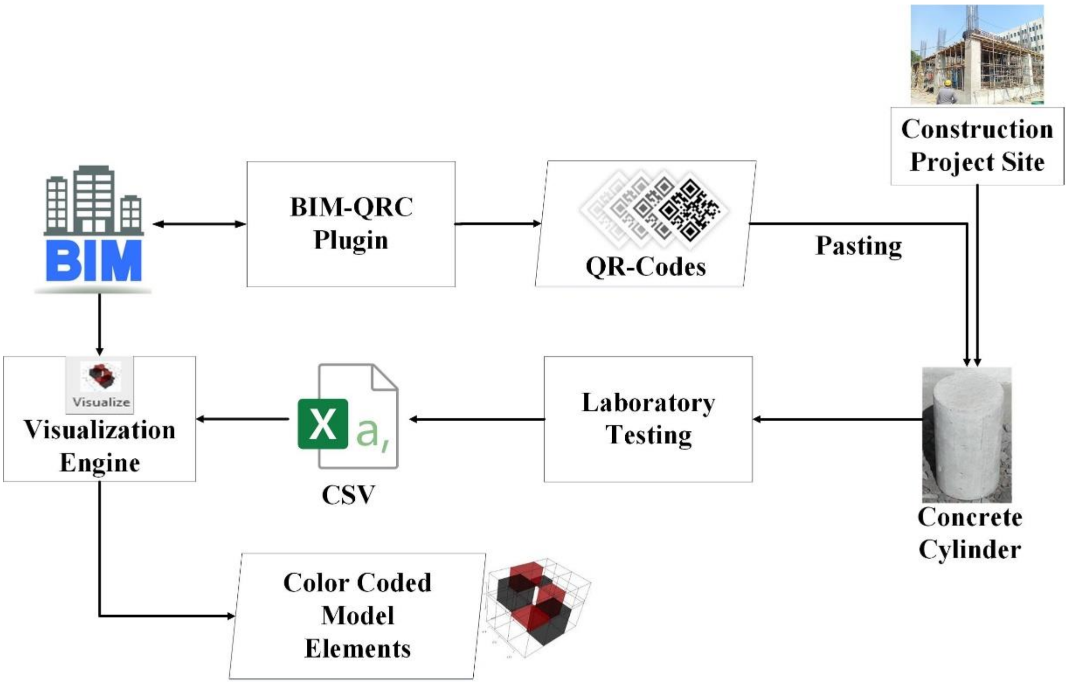


Figure 3 Framework

BIM-QRC Plugin

The developed framework starts with a 3D BIM model of a project. The scope of our work is strictly restricted to major concrete elements which are foundation raft, column, beam, and slab. Hence the model only contains these elements. What the system does is that it collects all the concrete elements from the model and makes groups of them level-wise.

QR-Codes

After the grouping, it then arranges them according to their level number and makes a list of them so that it can be used in the generation of QR codes. The system then asks for a project schedule excel file. From the project schedule, it filters the concrete activities according to their date of pouring, and then it generates its list based on the dates in which it groups them like the groups of the concrete elements from the model previously. Then it combines the generated list of schedules with the list of concrete element groups and inserts it into the QR code generator which then generates the QR codes of those groups with the respective date of their use and exports them to a selected folder.

Concrete Cylinder

The generated QR-Codes are then printed and the pasting of QR-Codes on the concrete cylinders begins. The QR-Codes are pasted onto concrete cylinders according to their dates of pouring, as QR-Codes are present in the folder with the date of their respective pouring of concrete element as shown in Figure 4. The system then takes the next step of taking data from the laboratory.

Figure 4 Dated QR-Codes

Laboratory

In the next step, cylinders are taken to the library where tests will be performed on them. First, they are scanned with a QR-Code reader that could be a smartphone or a computer-based QR-Code reader. Then after reading the code the data appears which was stored into the QR-Code. Concrete compressive strength tests are performed on the concrete cylinders, the laboratory technician then inputs the results obtained from laboratory tests into the webpage interface which was opened earlier by scanning QR code. When all the data is put on the webpage interface it then uploads it to the backend SQL-based database. Which then stores all data provided. And it can be very useful in retrieving that data when and where needed. The results can also be viewed on a dashboard that is linked to the database and can export data as a CSV file containing all the information.

Visualization

After generation of the Database CSV file, it is then inserted into the developed BIM-based Visualization engine which then displays all the failed concrete elements in a Red color-coded form, and they can be easily visualized in the BIM Model.

This chapter describes the methodology adopted for the research work in detail and describes the adopted framework, its formulation, and its working in detail with the briefing of each section in detail. In the next chapter, we will develop a system based on the devised framework from this chapter.

Chapter 4

SYSTEM PROTOTYPE

4.1 INTRODUCTION

This chapter aims to describe the system prototype QIM-BIM. It has been created following the proposed framework in Chapter 3. All the system prototype functions are developed based on a/the system framework. A tool was integrated in Autodesk Revit 2020 with the help of supplementary software such as Dynamo and Dyno-browser. A web-based application was also developed using Personal Home Page (PHP), Structured Query Language (SQL), and Relational Database Management System (RDBMS). The prototype QIM-BIM consists of two parts:

- BIM-QRC (BIM-based Quick Response Code)
- ACQCR (Automated Construction Quality Control Repository)

4.2 BIM-QRC

A BIM-QRC tool was developed in Autodesk Revit 2020 with the help of supplementary software Dynamo and Dyno Browser based on Figure 5 BIM-QRC Framework.

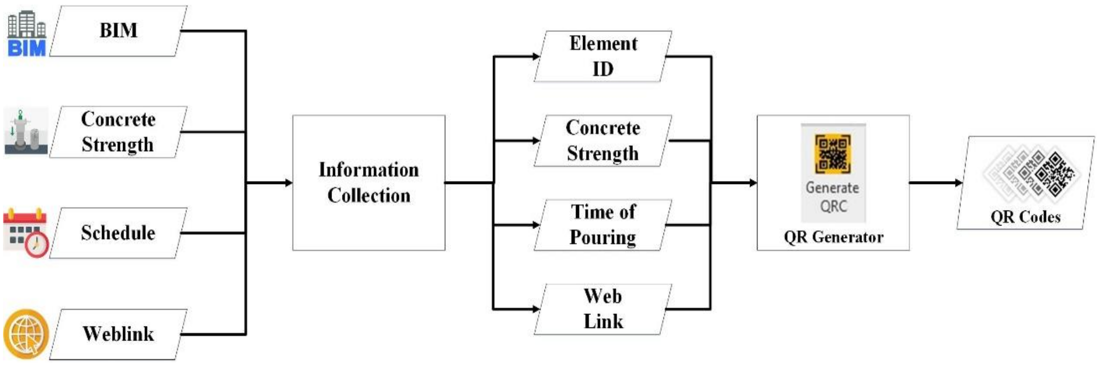


Figure 5 BIM-QRC Framework

4.2.1 Create Parameters

In Revit, some project parameters are predefined in the system, and it is open to the user to define some more parameters as desired. Using Dynamo visual programming a script was developed as shown in Figure 6 Dynamo script - Create Parameters.

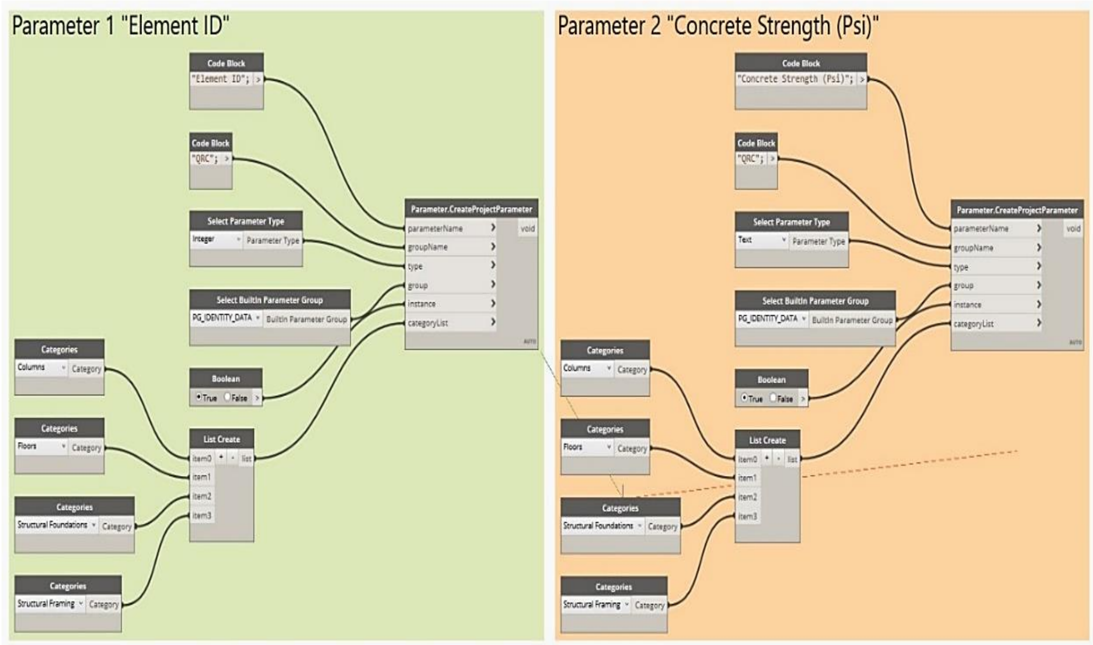


Figure 6 Dynamo script - Create Parameters

This script inserts “Element ID” and “Concrete Strength” as parameters into the project. For user ease a button named “Create Parameters” is developed using dyno browser which runs the desired dynamo script as shown in Figure 7 Insert Parameters.

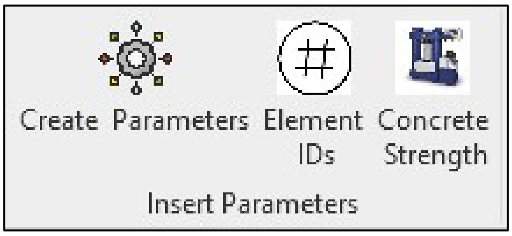


Figure 7 Insert Parameters

When the user inserts the desired parameters and their values, the system then displays the inserted parameters into the identity data tab as shown in Figure 8 Parameters.

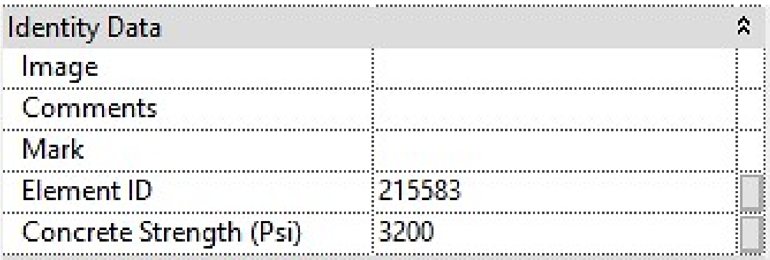


Figure 8 Parameters

4.2.2 Element IDs

In Revit, metadata (i.e., data of data, such as Element ID) is defined for each of the building objects, and thus the object data (such as geometry and materials) of every object is identifiable in the game engine. A Revit plugin was made that transfers all the required data and corresponding metadata to a QR Code. QR Code shows that for each selected key in metadata (in our case we used Element ID), the complete object data is accessible, such as the position and materials of the object with the given Element ID (Du et al., 2018). Every element has an element id which is assigned by Revit itself. Anyone can see the element id of the desired element by selecting it and going to the Manage tab and then clicking the “IDs of Selection” button as shown in Figure 9 IDs of Selection.

Figure 9 IDs of Selection

It reveals the element id of the selected element. So, to make it more convenient a dynamo script is developed with which we can insert element ids into the “Element ID” parameter, so element id is available in the properties where all other parameters are available. The parameter can be seen in Figure 8 Parameters with the element id of some element from the model. The dynamo script is available in the following Figure 10 Dynamo script – Element IDs.

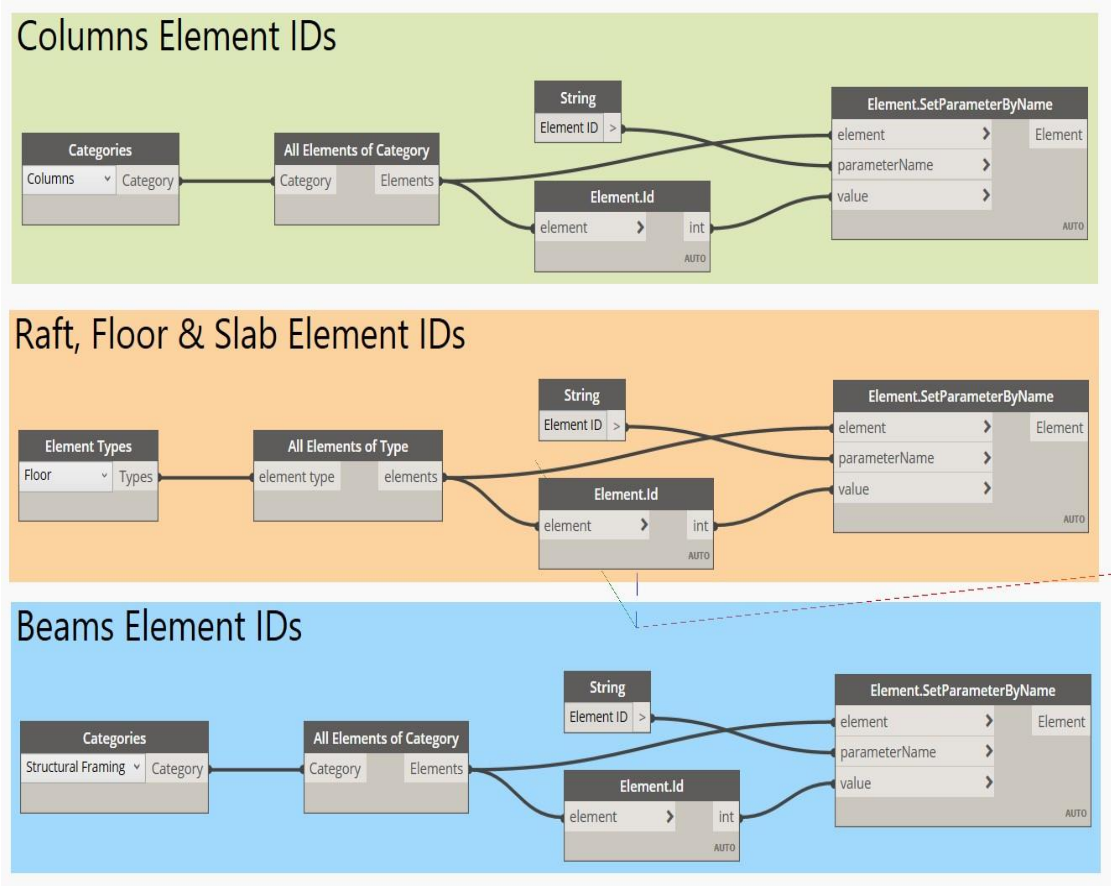


Figure 10 Dynamo script – Element IDs

4.2.3 Concrete Strength

To introduce concrete compressive strength into concrete elements in Revit a dynamo script is developed which adds a parameter named "Concrete Strength (Psi)" into Revit. Concrete elements in every project have desired compressive strength depending upon various factors i.e., type of project, load, etc. Depending upon the type of concrete element in the project its strength is kept as required in the project. Users can add required concrete compressive strength, in psi, into the concrete elements depending upon the project requirements. So, a dynamo script is developed to insert the concrete compressive strength into the model elements of BIM and the script is given in following Figure 11 Dynamo script - Insert Concrete Strength (Psi).

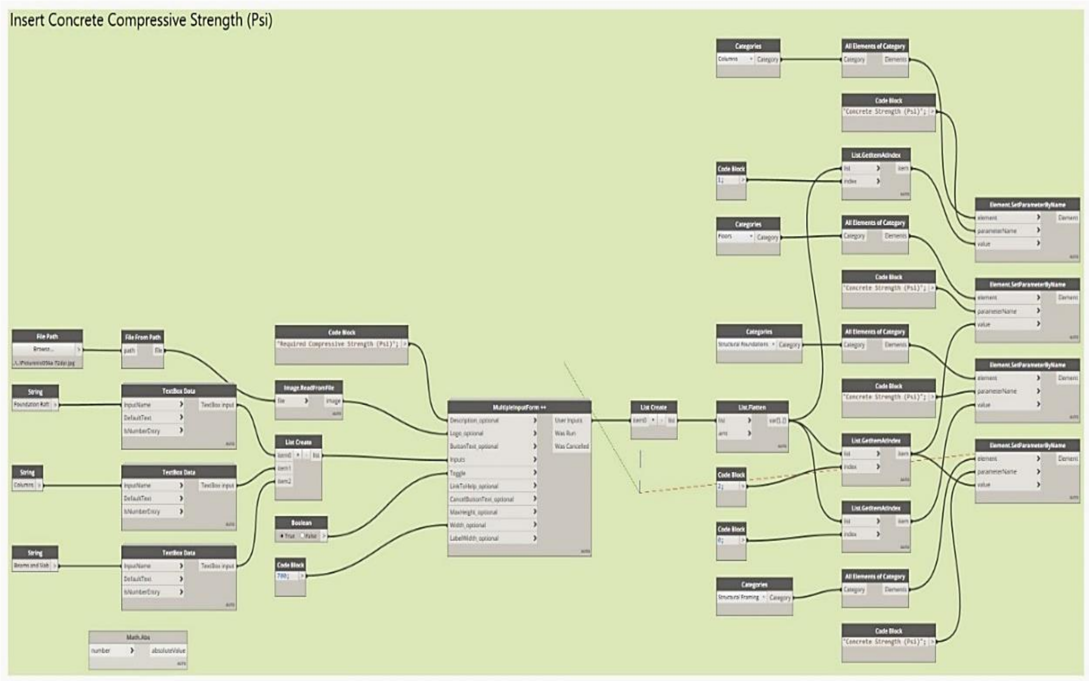


Figure 11 Dynamo script - Insert Concrete Strength (Psi)

The dynamo script is linked up with a button, this button has been developed using dyno browser, which allows the user to enter required concrete strength into the elements as required and it is shown in Figure 12 Required Concrete Strength. The user will enter the required concrete strength of the model elements in Psi and the user will have the ability to enter the separate values for the foundation raft, columns, beams, and slabs. When the user will press the set values button the system will automatically assign the concrete strength values to the model elements.

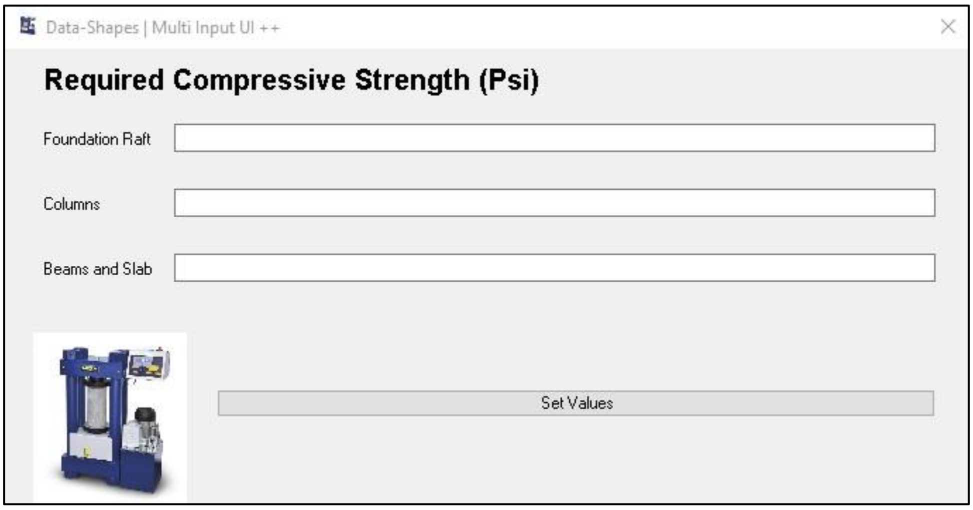


Figure 12 Required Concrete Strength UI

4.2.4 Generate QRC

A Quick Response Code (QR-Code) is a type of matrix bar code or two-dimensional code designed to be read by smartphones as shown in Figure 13.

Figure 13 QR-Code

The code consists of black modules arranged in a square pattern on a white background. The information encoded may be text, a URL (Uniform Resource Locator), or other data [59][60]. The larger amount of information QR-Code contains, the greater the number of pixels. It must also have a minimal resolution performance to allow pixel dis-crimination to recognize pixel patterns. QR-Code allows users to enter a variety of information, but depending upon the information, the number of pixels required will also increase proportionally. Therefore, if high-capacity information is entered into the QR-Code, a high-resolution device is required to recognize the QR-Code. Conversely, the minimal information required for object recognition reduces the number of pixels in QR-Code. The recognition rate of the QR-Code increases if the number of pixels used is less. [61].

A dynamo script is developed which generates the QR Codes of the grouped concrete elements according to the project schedule concerning the pouring dates of concrete and is shown in Figure 14 Dynamo script - Generate QR-Codes. First, the system asks for the project schedule file and then generates the list of QR codes, respectively.

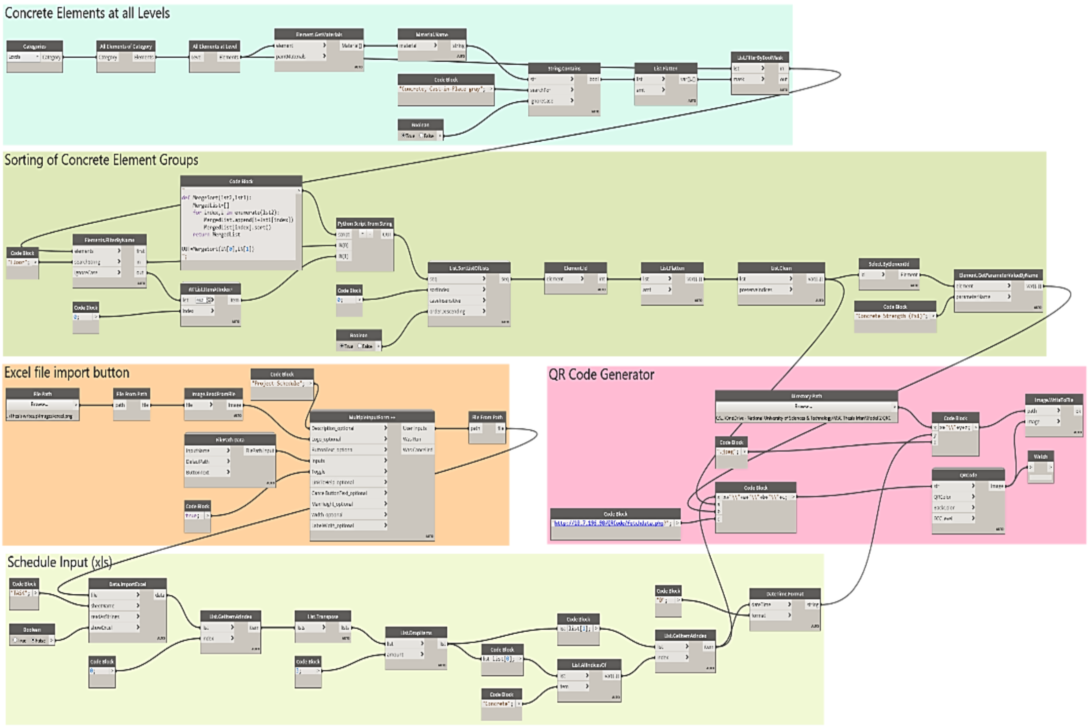


Figure 14 Dynamo script - Generate QR-Codes

This script linked up with a button using dyno browser as shown in Figure 25 BIM-QRC. When Generate QRC button is clicked it opens a UI that asks for the project schedule file as shown in the following Figure 15 Generate QRC UI.

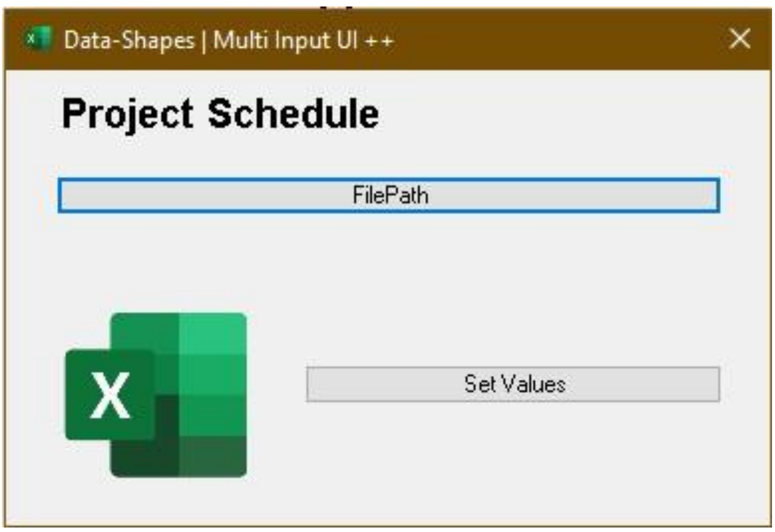


Figure 15 Generate QRC UI

In our project QR Code contains information such as Element ID, timestamp, compressive strength of concrete, and a link for a web-based application that uploads data into the database which will be discussed later in the chapter.

4.3 ACQCR

ACQCR is the second part of our developed prototype, and it is based on a devised framework which is given in Figure 16. This part of the system prototype deals with the laboratory part of our project. The tests performed in the laboratory produce data, ACQCR deals with that data and storage of that data.

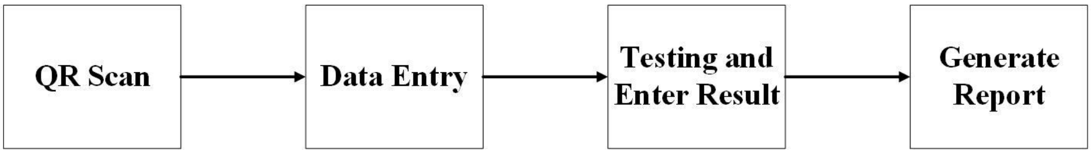
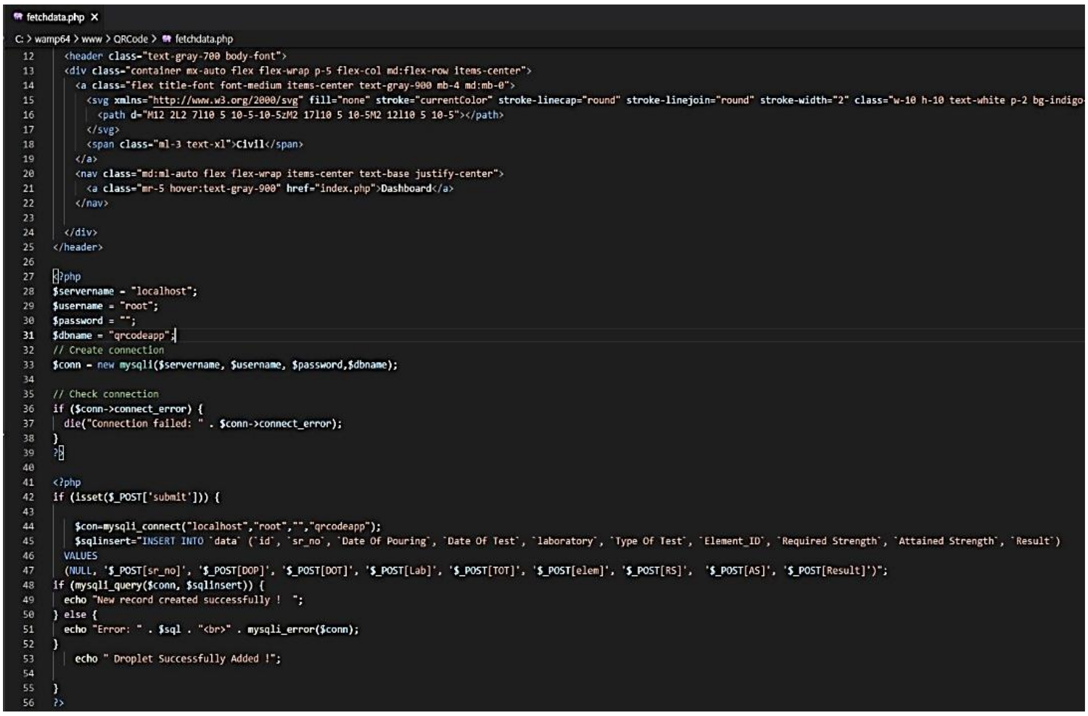


Figure 16 Laboratory - Framework

The data is entered into a webpage and after uploading, it stores the entered data into the database. This database is suitable for remote access and gets rid of burdensome paperwork. This webpage interface is developed on Visual Studio Code with back-end programming of PHP, for visual purposes only some part of the code is shown in Figure 17 PHP Programming.



```
fetchdata.php
C: > wamp64 > www > QRCode > fetchdata.php
  <header class="text-gray-700 body-font">
  <div class="container mx-auto flex flex-wrap p-5 flex-col md:flex-row items-center">
    <a class="flex title-font font-medium items-center text-gray-900 mb-4 md:mb-0">
      <svg xmlns="http://www.w3.org/2000/svg" fill="none" stroke="currentColor" stroke-linecap="round" stroke-linejoin="round" stroke-width="2" class="w-10 h-10 text-white p-2 bg-indigo-
        <path d="M12 2L2 7l10 5 10-5-10-5zM2 17l10 5 10-5M2 12l10 5 10-5"></path>
      </svg>
      <span class="ml-3 text-xl">Civil</span>
    </a>
    <nav class="md:ml-auto flex flex-wrap items-center text-base justify-center">
      <a class="mr-5 hover:text-gray-900" href="index.php">Dashboard</a>
    </nav>

  </div>
</header>

<?php
$servername = "localhost";
$username = "root";
$password = "";
$dbname = "qrcodeapp";
// Create connection
$conn = new mysqli($servername, $username, $password,$dbname);

// Check connection
if ($conn->connect_error) {
  die("Connection failed: " . $conn->connect_error);
}
?>

<?php
if (isset($_POST['submit'])) {

    $con=mysqli_connect("localhost","root","","qrcodeapp");
    $sqlinsert="INSERT INTO `data` (`id`, `sr_no`, `Date Of Pouring`, `Date Of Test`, `laboratory`, `Type Of Test`, `Element_ID`, `Required Strength`, `Attained Strength`, `Result`)
  VALUES
  (NULL, '$_POST[sr_no]', '$_POST[DOP]', '$_POST[DOT]', '$_POST[Lab]', '$_POST[TOT]', '$_POST[elem]', '$_POST[RS]',  '$_POST[AS]', '$_POST[Result]')";
if (mysqli_query($conn, $sqlinsert)) {
  echo "New record created successfully !  ";
} else {
  echo "Error: " . $sql . "<br>" . mysqli_error($conn);
}
    echo " Droplet Successfully Added !";

}
?>
```

Figure 17 PHP Programming

A webpage interface is developed, from this code, for ease of use as shown in Figure 18 Webpage Interface. It is used to record results from the laboratory testing after scanning of QR-Code from Concrete Cylinder which will provide us with the stored information. After opening the weblink the developed webpage interface will appear where the user will enter the data.

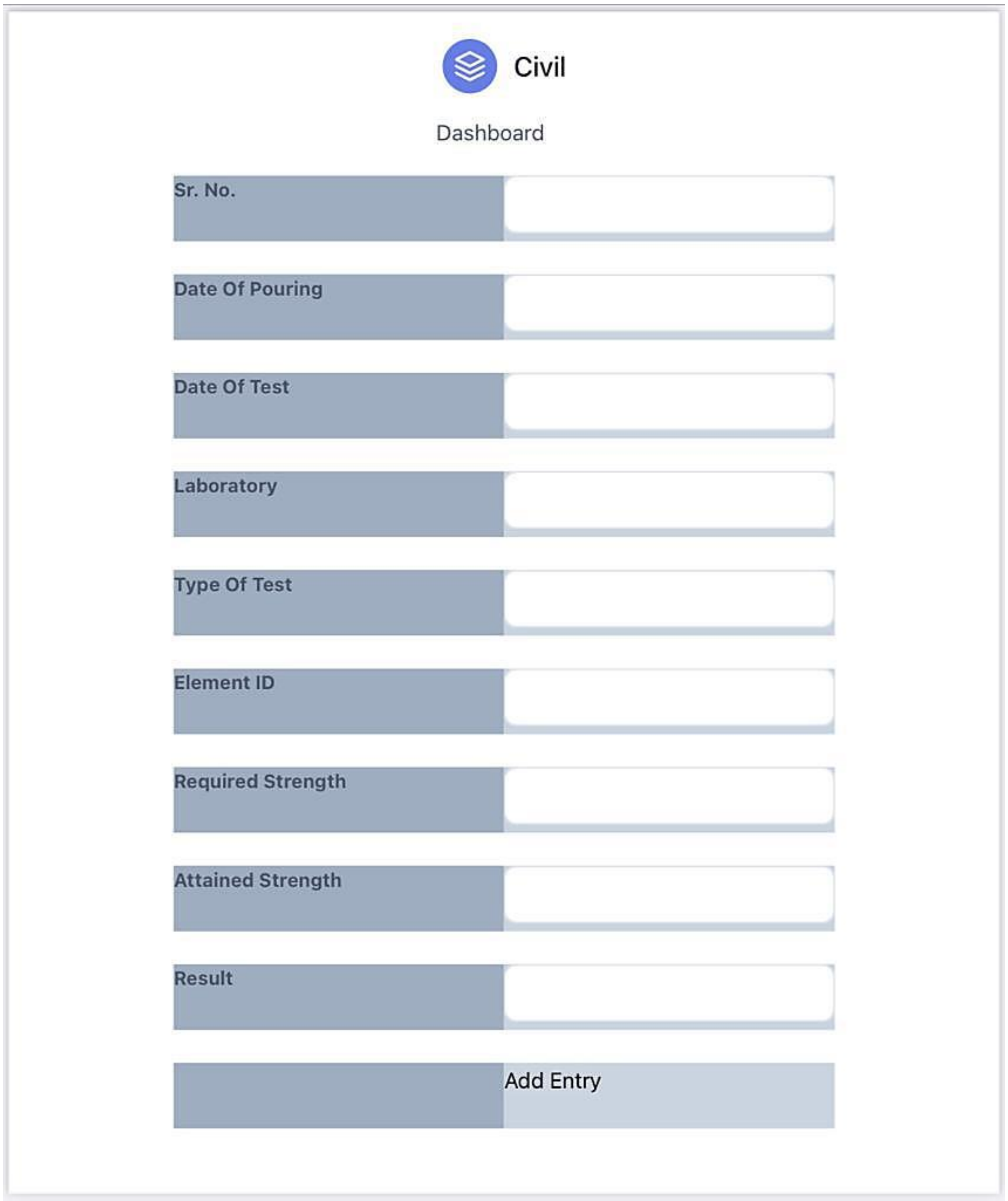


Figure 18 Webpage Interface

It can be used to take data as input from laboratory or testing sites where concrete compressive strength tests will be performed. The selection of required elements to be put into the webpage has been made from studying various lab reports and some other have been added like “Element ID” which were must for our system to work effectively. Users can input information in the webpage interface such as serial number, dates, laboratory, type of test performed, element id, required concrete compressive strength in psi, attained concrete compressive strength in psi, and result. Values of some of these are readily available in the QR code information when it is scanned like timestamp, element id, required concrete compressive strength in psi, and webpage link.

The Add Entry button is also present which stores the data into the database (RDBMS) based on MariaDB as shown in Figure 19. Users can also view all the results by clicking the “Dashboard” button as shown in Figure 18. It then takes the user to the next interface of the dashboard as shown in Figure 21.

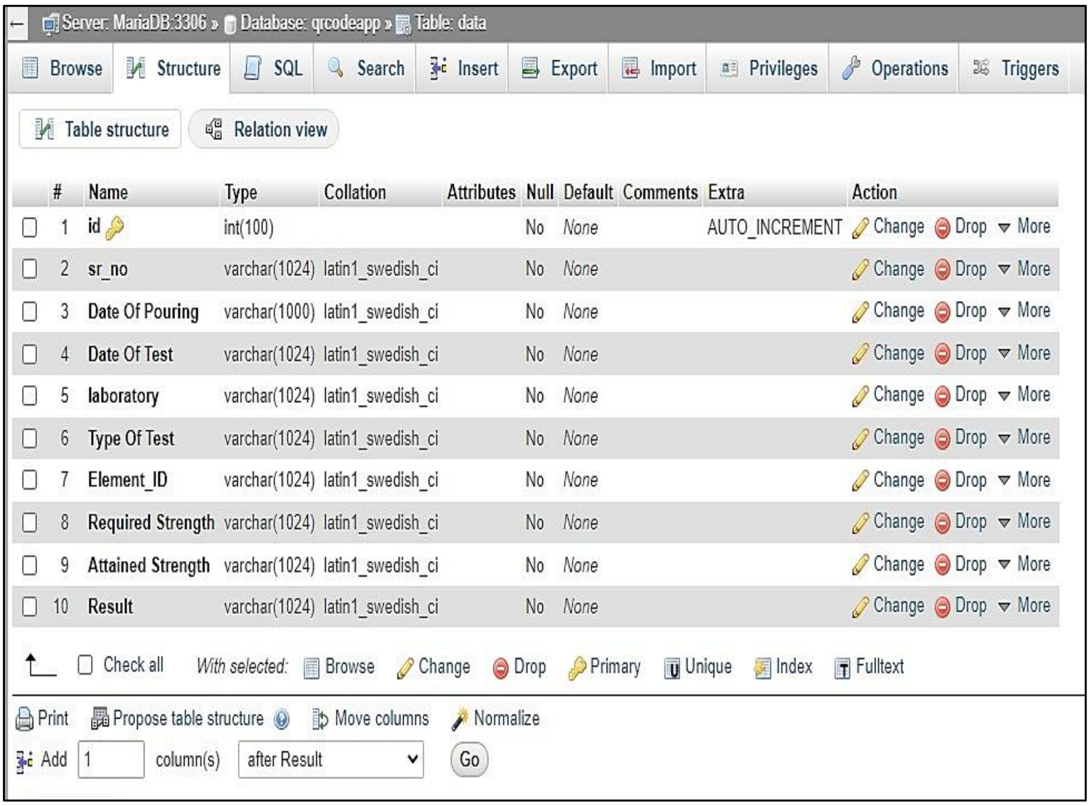


Figure 19 Database

MariaDB is an advanced form of MySQL which uses RDBMS instead of Database Management System (DBMS). To view data from the database a second webpage interface is known as “Dashboard” is also developed using Visual Studio Code with back-end PHP programming as shown in Figure 20. The developed “Dashboard” from this code can be seen in the Figure 21.

```
index.php ●
C: > wamp64 > www > QRCode > index.php
<!DOCTYPE html>
<html>
  <head>
    <meta charset="UTF-8">
  <meta name="viewport" content="width=device-width,initial-scale=1">
  <link href="https://unpkg.com/tailwindcss@^1.0/dist/tailwind.min.css" rel="stylesheet">
  <link rel="stylesheet" type="text/css" href="https://cdn.datatables.net/1.10.21/css/jquery.dataTables.css">
  <script type="text/javascript" charset="utf8" src="https://cdn.datatables.net/1.10.21/js/jquery.dataTables.js"></script>

  <link rel="stylesheet" type="text/css" href="https://cdn.datatables.net/1.10.19/css/jquery.dataTables.min.css">
  <script type="text/javascript" language="javascript" src="https://code.jquery.com/jquery-3.3.1.js"></script>
  <script type="text/javascript" language="javascript" src="https://cdn.datatables.net/1.10.19/js/jquery.dataTables.min.js"></script>
  <script type="text/javascript" class="init">$(document).ready(function() {$('#table_id').DataTable();});</script>

    <title>Civil</title>
  </head>
  <body>
  <header class="text-gray-700 body-font">
  <div class="container mx-auto flex flex-wrap p-5 flex-col md:flex-row items-center">
    <a class="flex title-font font-medium items-center text-gray-900 mb-4 md:mb-0">
      <svg xmlns="http://www.w3.org/2000/svg" fill="none" stroke="currentColor" stroke-linecap="round" stroke-linejoin="round" stroke-width="2" class="w-10 h-10 text-white p-2 bg-indigo-
        <path d="M12 2L2 7l10 5 10-5-10-5zM2 17l10 5 10-5M2 12l10 5 10-5"></path>
      </svg>
      <span class="ml-3 text-xl">Civil</span>
    </a>

      <nav class="md:ml-auto flex flex-wrap items-center text-base justify-center">
     <form action="" method="post">
       <input type="submit" name="clear" value="Clear All Records" />

       <a href="downloadcsv.php?table=tbl_vfm">Download as Excel<a/>
         </form>

    </nav>

    </div>
</header>
<table id="table_id" class="display">
    <thead>
      <tr>
```

Figure 20 PHP Programming

Civil

Clear All Records Download as Excel

Show 10 entries Search:

ID	Sr. No.	Date Of Pouring	Date Of Test	Lab	Type Of Test	Element ID	Required Strength	Attained Strength	Result
88	1	12-06-2021	10-07-2021	Field Laboratory	Concrete Cylinder Compression Test	218857	5000	5308	Pass
89	2	12-06-2021	10-07-2021	Field Laboratory	Concrete Cylinder Compression Test	218857	5000	5379	Pass
90	3	12-06-2021	10-07-2021	Field Laboratory	Concrete Cylinder Compression Test	218857	5000	5697	Pass

Showing 1 to 3 of 3 entries

Previous 1 Next

Figure 21 Dashboard

Its purpose is to serve as the platform for viewing data and can be called a Dashboard. This dashboard takes the results from the database (RDBMS), and it can export all data as a CSV file by clicking on the "Download as Excel" button, which can be used in the BIM-QCR for visualization of failed concrete elements in the Revit Model.

4.4 VISUALIZE

Visualization is the key function of our system. Its framework is given in framework on which the visualization engine will be developed.

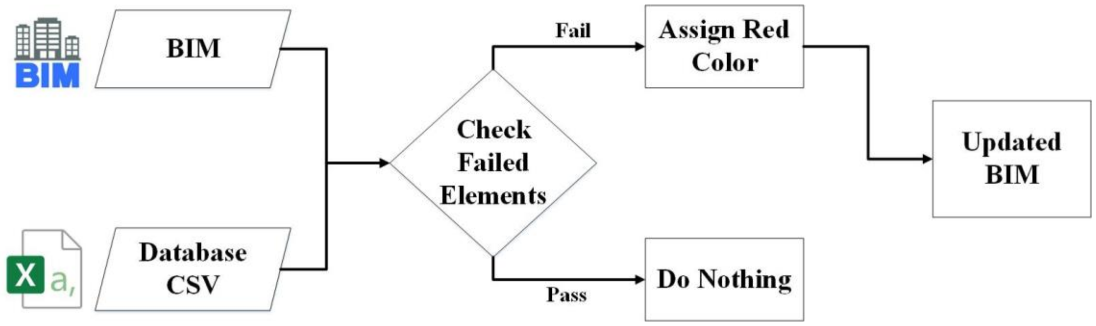


Figure 22 Visualization Framework

To visualize the failed concrete elements in the compressive strength test, a dynamo script is developed which is shown in the following Figure 24 Dynamo script - Visualization. This script takes the database CSV file as input from the desired location, as shown in Figure 23 Visualize button UI, selected by the user, and then after comparing the test results with the required values of concrete strength stored in the model previously, the engine then color-codes the elements into red which have failed to meet the required concrete compressive strength criteria and then updates the BIM model.

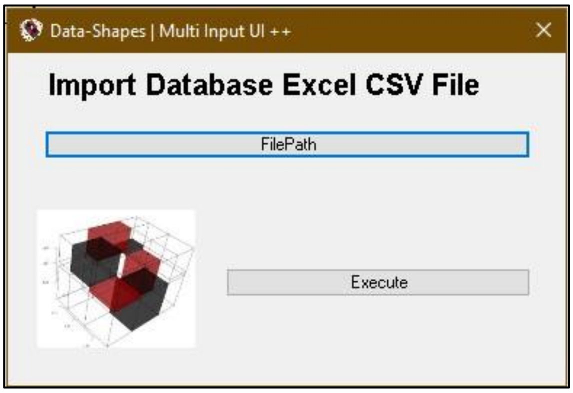


Figure 23 Visualize button UI

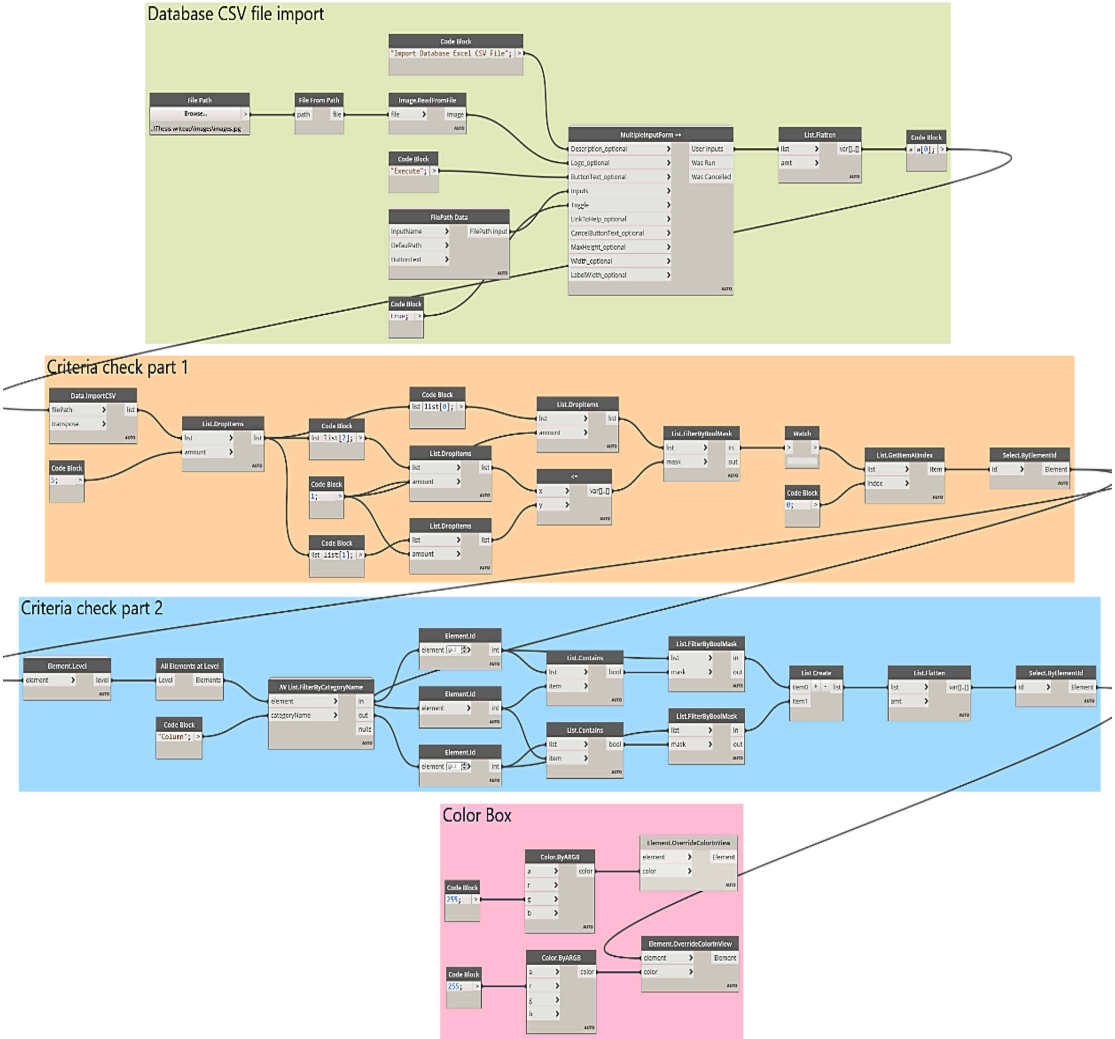


Figure 24 Dynamo script - Visualization

This script is linked up with a button that is made using dyno browser as shown in Figure 25. When this button is clicked opens a dialogue box that asks for the database file to run the script on it and shows the results in the Revit model.

4.5 BIM-QRC TOOLBAR

A toolbar was made in Autodesk Revit named “BIM-QRC” with the help of Dynamo and Dyno-browser, to access the functions of the system and it is shown in Figure 25 BIM-QRC. Dynamo has been used to do the background visual coding and its scripting and Dyno-browser has been used to develop the buttons, assign them names and icons. Separate groups of buttons were also made in the ribbon for an easier understanding of tasks to be performed via the tool. The first group named “Insert Parameters” contains buttons for the creation of parameters and inserting the required values in them. The second group named “QR Code” contains buttons that create QR Codes. The third group named “Visualize” contains buttons that help in the visualization of failed elements. All the buttons that were created are explained below.

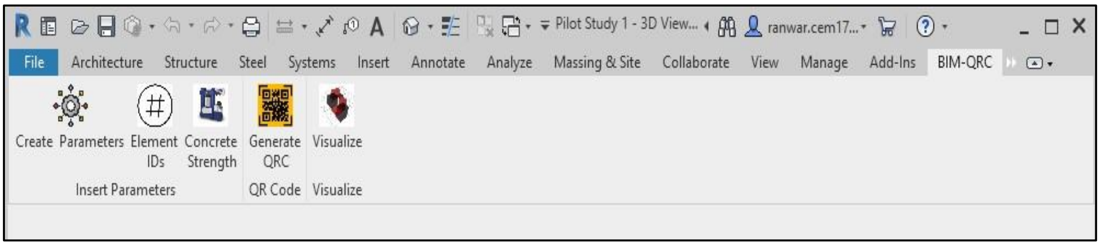


Figure 25 BIM-QRC toolbar

Dynamo was used for Visual programming purposes that were provided with the back-end Python programming. Only the nodes available in the open-source packages were used to achieve the desired outcome.

In brief, the whole system works in a stepwise fashion where every button performs a specific function. The first button creates the required parameters. The second button inserts element IDs as a parameter. The third button inserts required concrete strength in model elements. The fourth button generates the QR codes of concrete elements. After scanning QR codes, the results are put into the web-based developed system. Then using the last button failed concrete elements can be visualized in the BIM model.

Chapter 5

EVALUATION AND RESULTS

5.1 CASE STUDY

For the validation and evaluation of this system, we took two case studies. The validation was done with the case study and later the system was evaluated using the opinion of field experts and laboratory engineers. All the results are explained in this chapter. A public sector office building project of Pakistan (Pakistan Engineering Council, Regional Office Lahore, Punjab) was targeted as a test case model project. It is preferable to demonstrate BIM features to stakeholders on public sector projects, for its implementation [78].

The system was initiated with the development of the BIM model as shown in Figure 26 Case Study BIM Model and it has all the details as required by our designed framework whose scope is to basic concrete work and major basic elements of concrete i.e., Foundation raft, Column, Beam, and Slab. The model of the case study was developed according to the predefined scope of our work in Autodesk Revit.

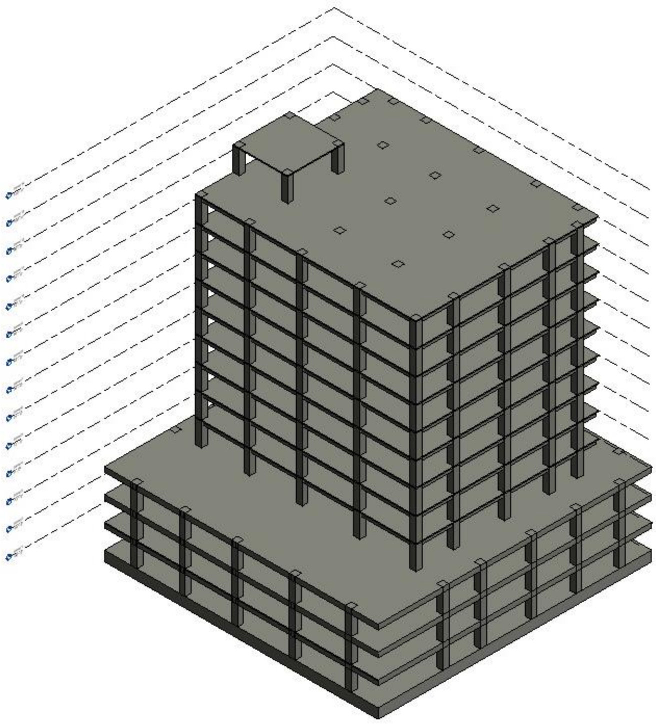


Figure 26 Case Study BIM Model

In the BIM-QRC plugin first parameters were created, using the “Create Parameters” button present on the ribbon in the “Insert Parameters” group, which is required for the plugin. The parameters are named “Element ID” and “Concrete Strength (Psi)” as shown in Figure 8. After that using the plugin element IDs were inserted into the parameter using the insert “Element IDs” button as defined in the previous chapter in detail. Required concrete compressive strength was put in according to the project requirement as shown in Figure 8, using the “Concrete Strength (Psi)” button present in the ribbon. In the first case study the required compressive strength of concrete for foundation raft, beam, and slab is 4000 psi and for columns is 5000 psi as shown in Figure 27 Inserting Concrete Strength and Figure 28 Inserted Concrete Strength.

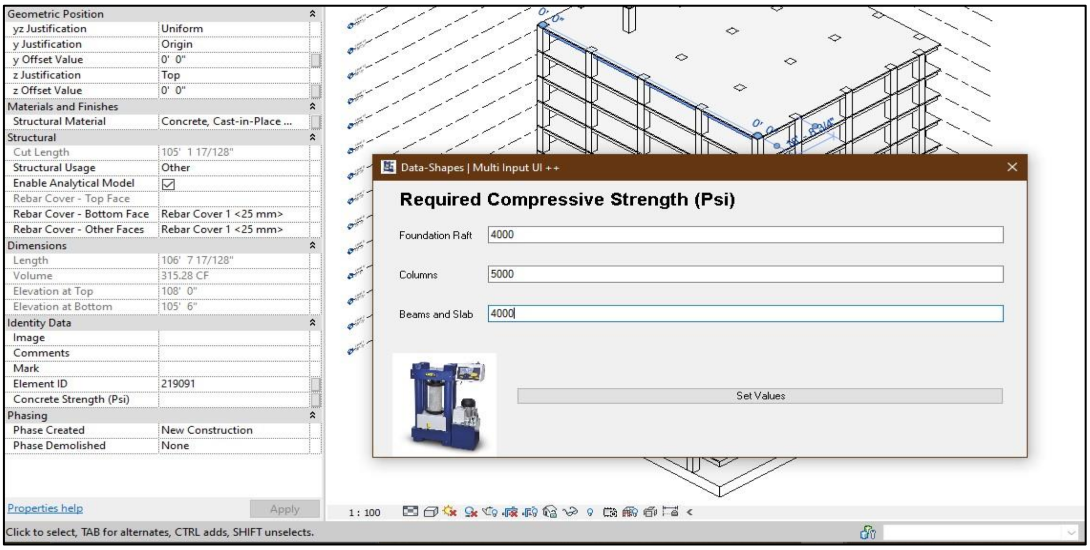


Figure 27 Inserting Concrete Strength

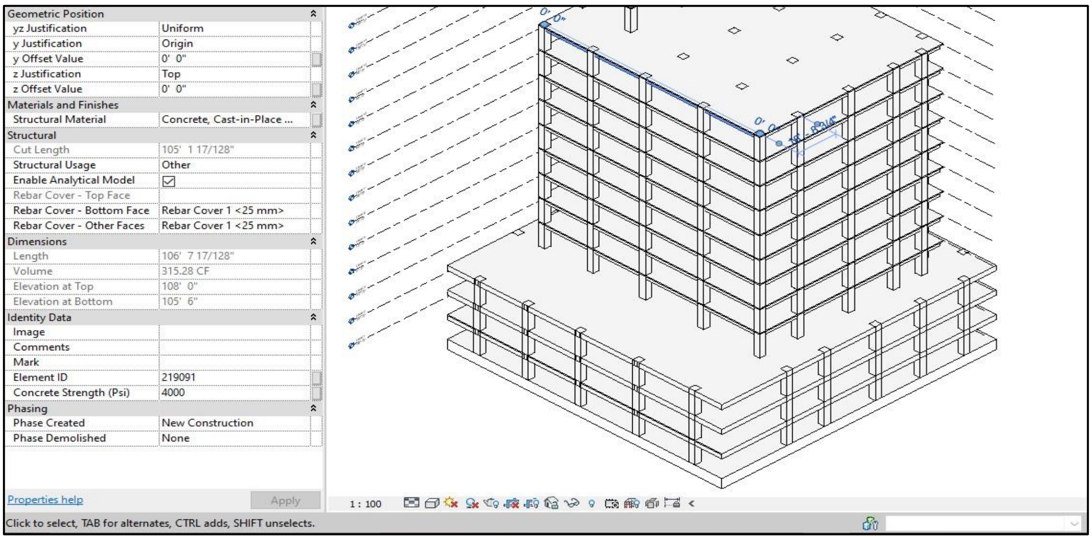


Figure 28 Inserted Concrete Strength

To generate the QR-Codes, a button named “Generate QRC” was clicked. It opened a UI that asked for the project schedule excel file as shown in Figure 29, the system generates QR codes in the predefined folder as shown in the following Figure 30.

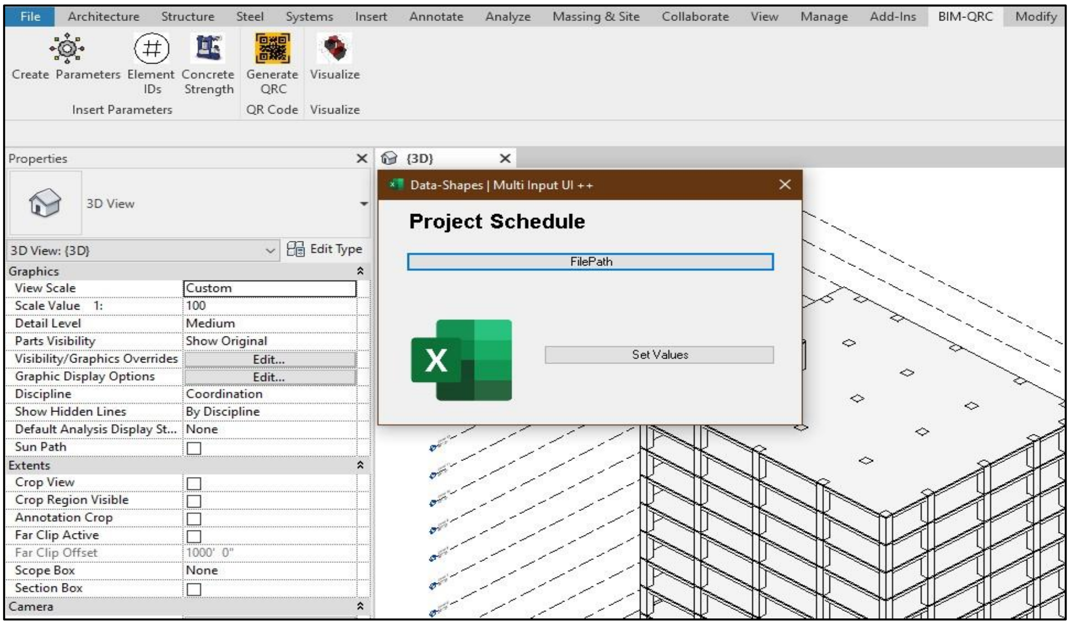


Figure 29 Inserting Project Schedule

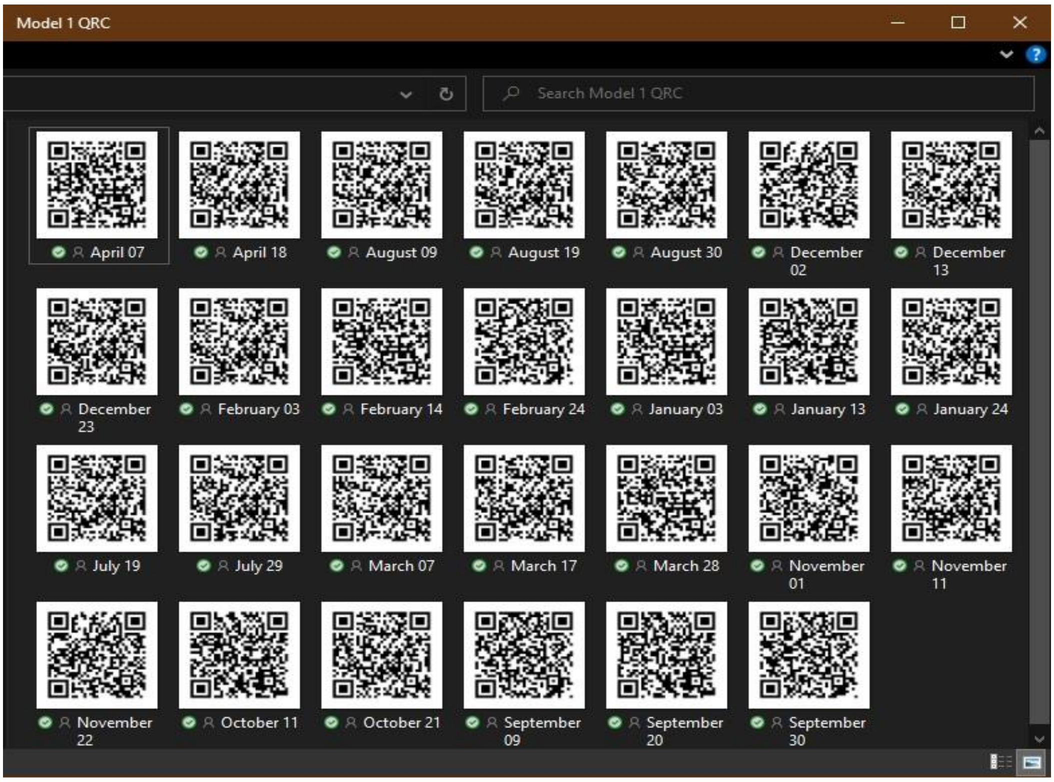
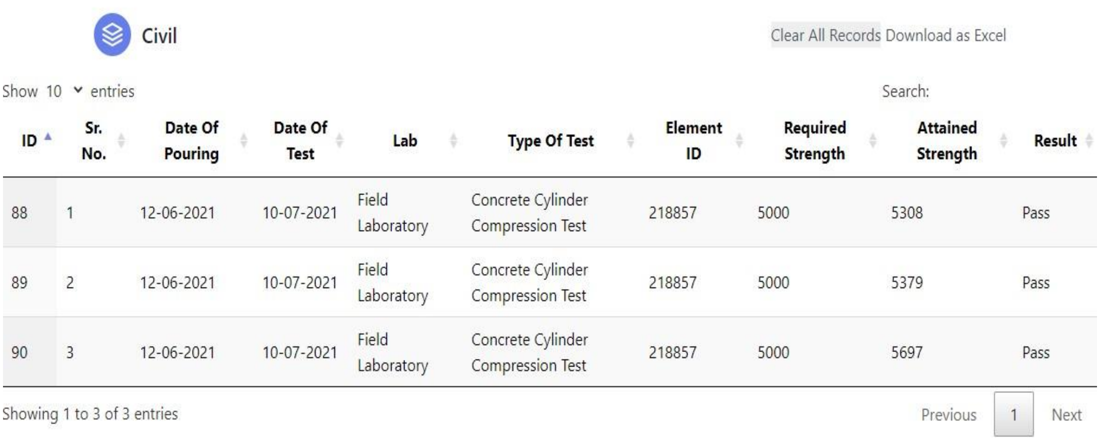


Figure 30 Generated QR codes

After the generation of QR codes, they were pasted onto the concrete cylinders, and then the QR codes present on them were scanned in the laboratory. After scanning them and clicking on the link appeared it opened a webpage. The webpage asked for the information required as shown in Figure 18. After putting up all the results into the webpage and clicking on "Add Entry" it then stored it onto the database. Some of the tests were performed and results were put on the database following the same procedure. All the results uploaded for the case study can be seen in the dashboard as shown in the following Figure 31.



ID	Sr. No.	Date Of Pouring	Date Of Test	Lab	Type Of Test	Element ID	Required Strength	Attained Strength	Result
88	1	12-06-2021	10-07-2021	Field Laboratory	Concrete Cylinder Compression Test	218857	5000	5308	Pass
89	2	12-06-2021	10-07-2021	Field Laboratory	Concrete Cylinder Compression Test	218857	5000	5379	Pass
90	3	12-06-2021	10-07-2021	Field Laboratory	Concrete Cylinder Compression Test	218857	5000	5697	Pass

Figure 31 Dashboard

For visualization of the failed concrete elements, the database was exported into a CSV file using the button "Download as Excel". It then exported the database file as CSV into the predefined folder.

After clicking on the "Visualize" button in the Revit QRC tab it then asked for the database CSV file as shown in Figure 32.

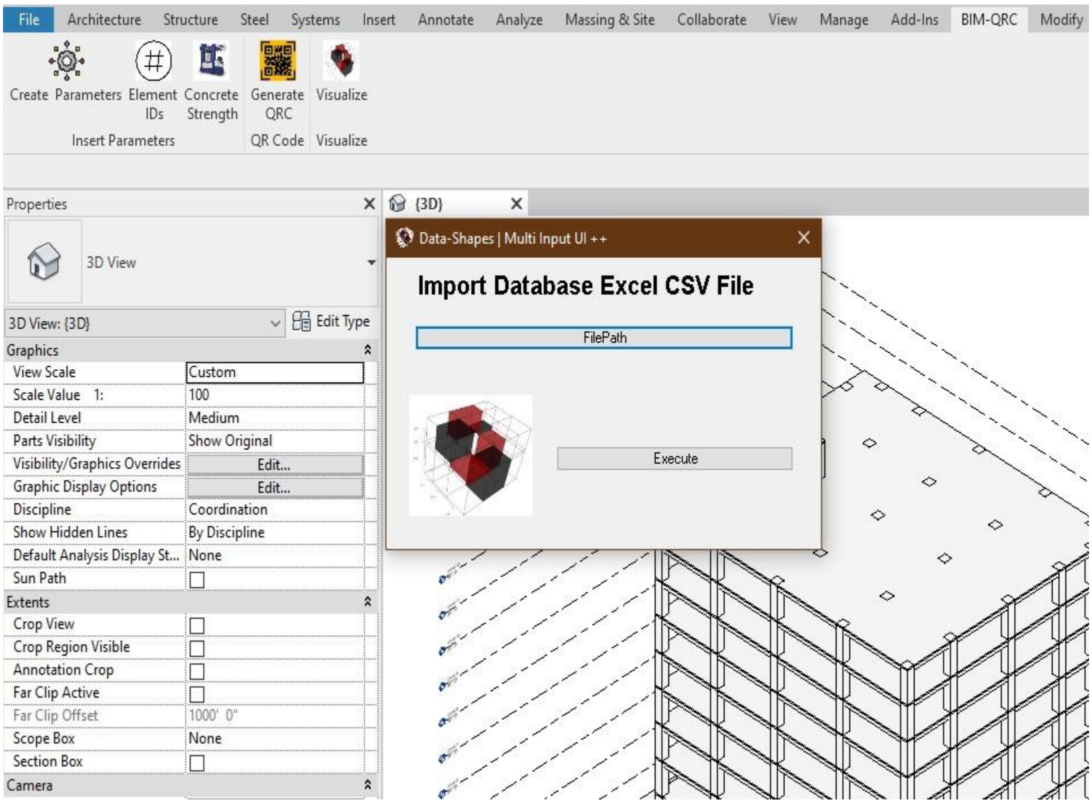


Figure 32 Visualize Case Study

Processing the data from the CSV file and the data from the BIM model it then decided which concrete groups have failed the predefined criteria. After accessing the data, the system then color codes them and displays them in the Revit model as shown in the following figure.

5.2 EVALUATION RESULTS

After successful testing of the working of the developed system prototype on two case studies, it was then evaluated using the opinion of field experts and laboratory engineers. Experts were provided with the implementation of BIM-QRC-ACQCR on real projects model as a test case. Semi-structured interviews were then carried out with 15 experts. A ratio of 60:40 was adopted between the number of field experts and laboratory engineers. Results of the expert's reviews sessions are discussed in the following subsections.

5.2.1 Results of Semi-Structured Interviews

The expert's response to questions related to the need of 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.

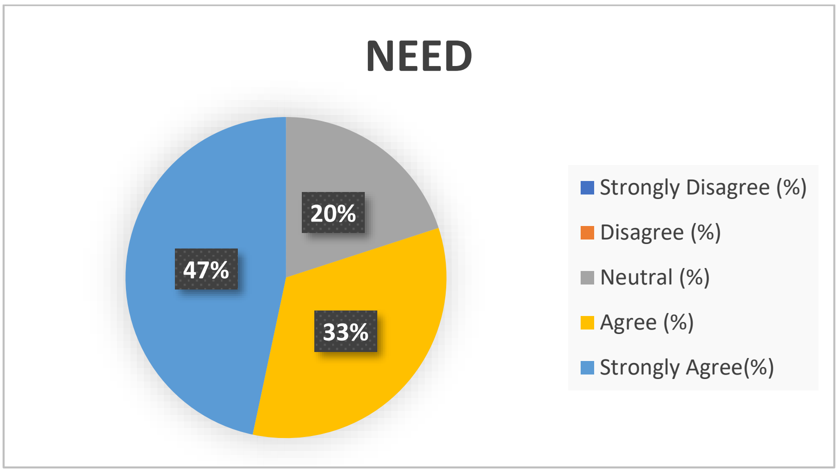


Figure 33 Experts' response on NEED

As shown in Figure 33, out of 15 experts, a dominant 80% (47% Strongly agree and 33% agree) thought that there is a need for such a technologically advanced system in the construction industry, while 20% of the experts remained un-decided. Encouragingly, none of the experts disagreed with its need in the construction industry.

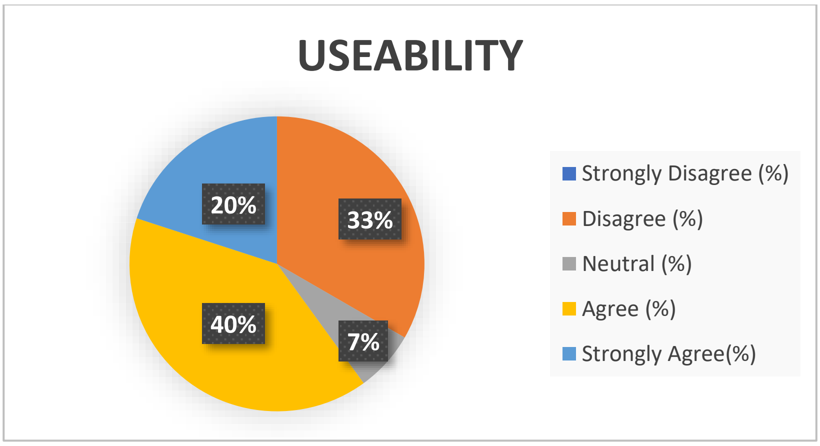


Figure 34 Experts' response on USABILITY

As shown in Figure 34, out of 15 experts, 20% Strongly agree and 40% agree that such a system in the construction industry would be easy to use, while 7% of the experts remained undecided. And 33% of the experts disagreed with its useability in the construction industry.

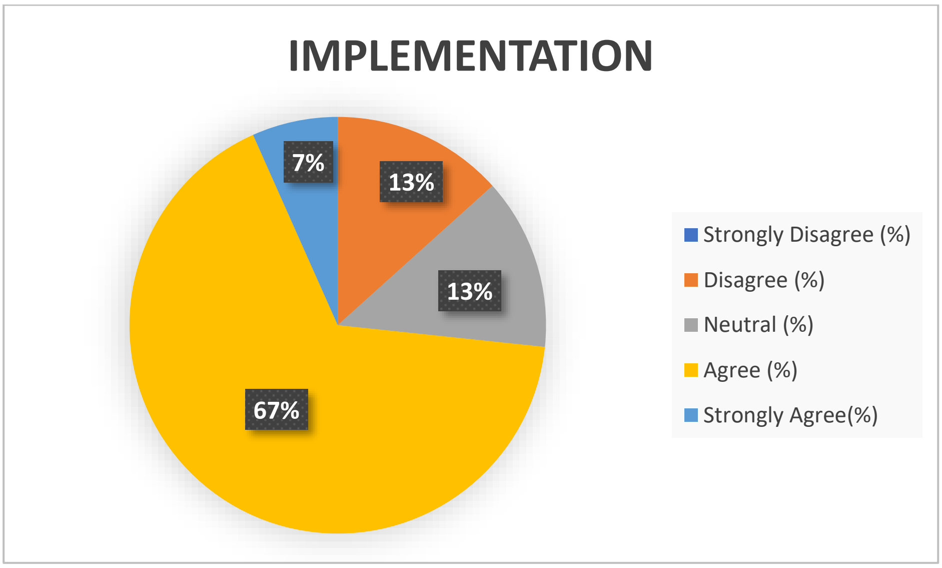


Figure 35 Experts' response on IMPLEMENTATION

As shown in Figure 35, out of 15 experts, 7% Strongly agree and a dominant 67% agree that such a system in the construction industry can be implemented, while 13% of the experts remained undecided. And 13% of the experts disagreed with its implementation in the construction industry.

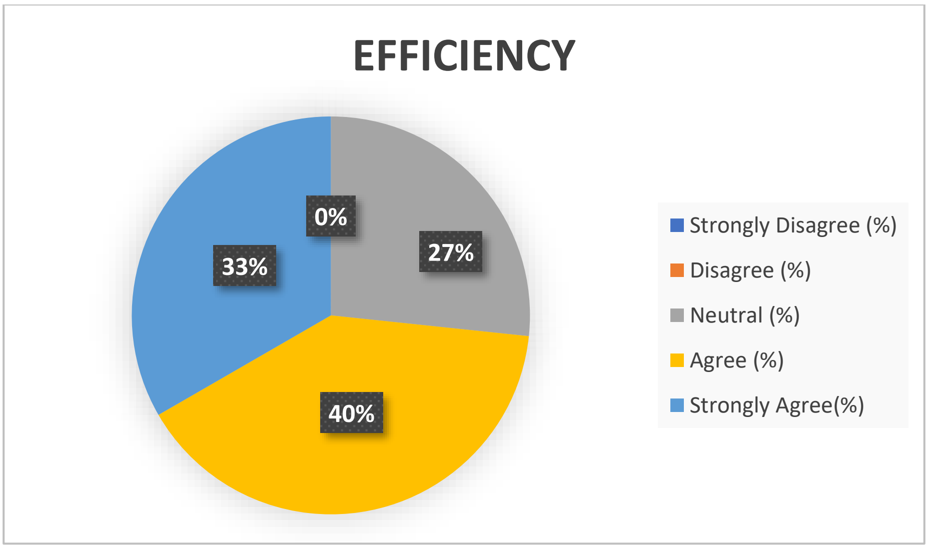


Figure 36 Experts' response on EFFICIENCY

As shown in Figure 36, a dominant 73% of experts considered it as an efficient tool to improve the EOT claim management process, however, 27% thought that if it is implemented it may or may not improve the overall performance of the construction quality control repository.

5.2.2 Experts Feedback on The System's Potential

Table 6 Scored Inefficiencies Groups shows the mean value, RII value, and ranking of the issues which can be effectively resolved using the developed BIM-QRC-ACQCR. It is obtained using the experts' opinion, collected on a 5-point Likert scale (with 1 representing 'Strongly Disagree' to 5 representing 'Strongly Agree'). The obtained score on a 5-point Likert scale was analyzed and their mean score was found out and based on which the Relative Importance Index (RII) value was found out for all issues and inefficiencies group as given in Table 6. After that, they were arranged according to their RII Value and given in Table 7.

Table 6 Scored Inefficiencies Groups

Sr.	Grouped Inefficiencies	Mean Score	RII Value
1	Hectic Paperwork	4.133	0.827
2	Prone to Errors	3.467	0.693
3	Inefficient information update & sharing	4.667	0.933
4	Poor data maintenance	4.533	0.907
5	High complexity	2.933	0.587
6	Time Consuming	4.600	0.920
7	Increased Cost	3.467	0.693
8	Malpractice	4.267	0.853

Table 7 Ranked Inefficiencies Groups

Rank	Grouped Inefficiencies	RII Value
1	Inefficient information update & sharing	0.933
2	Time Consuming	0.920
3	Poor data maintenance	0.907
4	Malpractice	0.853
5	Hectic Paperwork	0.827
6	Increased Cost	0.693
7	Prone to Errors	0.693
8	High complexity	0.587

5.2.3 Discussion on Experts Scores

During semi-structured interviews, the expert panel expressed their views on the stated inefficiencies. Key comments are discussed below:

In the *Inefficient information update and sharing* group, dominantly all the experts believed that this group of inefficiencies can be completely covered with the developed system due to its nature of being versatile in terms of usage of technologies like web-based systems. Overall, this group is ranked 1st. In a *time-consuming* group, experts highly believed that this group of inefficiencies can be largely covered with the developed system due to the integration of technologies like BIM and Web. They believed that time is an essential component in any construction project and saving time in any project would be of great success. The *Poor data maintenance* group is the 3rd group overall, and in this group, experts scored (strongly agree and agree), and results show they strongly believe that this inefficiencies group can be covered with the developed system. As per RII values, all the issues belonging to this group are reduced by more than 90%. In the *Malpractice* group experts highly believed that it can be covered with this developed system and would help in reducing the number of issues occurring due to this. This group is ranked 4th on the list. In the *Hectic paperwork* group, the average score of experts indicates most experts scored favorably (strongly agree and agree), hence BIM-QRC-ACQCR can considerably solve all documentation-related issues in the construction quality control repository. Overall, this group is ranked 5th and as per RII values, all the issues belonging to this group are reduced by more than 80%. In the *Prone to errors* group, the average score of experts indicates most experts scored (agree and neutral), which shows that some believed that the grouped inefficiencies can be covered with the developed system, and some cannot be covered with the developed system. Overall, this group is ranked 6th. In the *high complexity* group, experts' scores remained neutral and disagree. They believed that this inefficiencies group is hard to tackle with the developed system and needs to improve in decision-making capabilities. In the *increased cost* group, experts scored between agreeing and neutral which indicates that they believed this inefficiencies group can be covered partially and is ranked 7th. Overall, the developed system is highly appreciated by the experts.

Chapter 6

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

Construction quality is not given importance as other aspects of a construction project and especially automation in construction quality has been lacking behind always in underdeveloped countries like Pakistan etc. It is considered least important in our traditional culture and construction practices. In the contemporary world of global competitiveness, it is very important to endorse construction quality, its every step, and processes that take place during the whole construction quality assurance and quality control. Automation is being adapted globally in every aspect of human life and all the benefits it provides are making everything easy for everyone. Adapting automation in construction projects especially in construction quality control would be fruitful in improving time consumption, cost savings, and overall a clean procedure. Though several research have been made to highlight the importance of construction quality and inclusion of automation in construction quality to improve its performance and effectiveness, yet still it needs more adoption towards construction quality control. Automation in the construction quality control repository is an aspect of the whole quality control process that has been endorsed in this research to enhance the adoption of automation.

As scored by experts, the inefficiencies that can be effectively tackled with the application of the developed framework are **Inefficient information update and sharing**, **Time consuming, and Poor data maintenance.** Most of the field experts pointed out that **malpractice** is quite common in our industry, but it can be mitigated if the proposed system is adopted.

Automation will not only help reduce the number of issues that have been mentioned in this research which have been found in the reported literature but will also bring benefits. Construction quality following the compliance of all the international standards is of immense importance. Pursuing automation in quality control will not only reduce the shortcomings in the whole process but will also help in its adoption where it is given the least importance. The construction quality reporting process is not as clean as some might think it is in underdeveloped countries where results can be easily manipulated hence bringing automation to it will make it more resistant to such malpractice causing hindrance in them. The traditional construction quality reporting process yields less performance in every aspect as compared to the introduced automated framework of the construction quality control repository in this research. The major factors that have been highlighted in the results are time, information sharing, data maintenance, etc., which are improved with the adoption of a new automated framework. Thus, the system devised proves to be an effective one when compared with the conventional practices that are used in construction quality control repositories.

6.2 LIMITATIONS

First and foremost, this study was limited to specific material concrete because with the increase in the number of materials the complexity of system increases. Secondly, the prepared model of BIM did not include all the concrete elements as it becomes more complex with the increasing number of model elements and aligning schedule with them. At the end, this study was performed on local network due to difficult management of an online network.

6.3 FUTURE RECOMMENDATIONS

This research was focused on bringing automation into construction quality control reporting and repository with focused material i.e., concrete. Further research can include other materials. In this study QR codes were used, further research can include RFID tags. The developed system is aimed to deal with the execution phase of construction only. On the contrary, it can also be used for the design stage reporting i.e., borehole log reports and soil testing, etc.

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