Construction Progress Monitoring Using BIM and QR Code

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Abstract

BIM is widely used in the design and the planning phase of projects, but it is not effectively utilised during the execution phase (Davies, *et al.* 2013). This study examines the possibility of integrating BIM into a project management framework to monitor construction progress and thus, improving the current method of progress monitoring on site. A workflow involving collection of as-built data is implemented in a live construction project and this data is stored on a BIM-based platform. The project progress is monitored with the help of a project management application which utilises sensing technology (QR code) for data collection. The technology is kept economically viable and easy to use by using equipment like wireless QR code printers and smartphone sensors (camera). The project status is updated in a cloud-based database, which can also be retrieved by scanning the QR codes printed on-site. The QR code is utilised as a simple data storage method which can hold data like location, element IDs, task IDs, status etc., which can bring in a context-aware sense to the devices like a smartphone. This data is represented using a BIM-based platform. Complex data can be easily visualised at any instant, by using this method. This enables the various stakeholders to be at the same level of understanding about the project status.

Keywords: Progress monitoring, BIM, sensing technology, QR code, visualisation

1. Introduction

Construction Progress Monitoring is a highly complex task. It involves measuring, recording and analysing the construction works most of which are done manually (Zhang, et al. 2009). It is essential for the companies to keep track of the immense amount of data generated in this process in order to ensure that the required quality of work is attained. Unrealistic planning is one of the common reason for delays. Even for a well planned construction project delays can happen and are likely to impact the project costs and schedule. These delays can be accounted for unforeseen events (Rebolj, et al. 2008). Timely action must be taken to minimise the impact of these events. A proper construction progress monitoring system must bring the information from the site to the decision makers at the right time.

Recently, Building Information Modelling (BIM) has become popular among architects and design engineers. BIM is a framework for storing several layers of information about the building that can be shared and used throughout its life cycle i.e. design, scheduling, construction, operations and demolition (Pishdad-Bozorgi, et al. 2018). It is an information centric framework where all the different stake holders can view or update the data. Although, BIM is widely used in the design and the planning phase of the project, it is not completely utilised during the execution phase of the project. In particular, the methodology to incorporate site data into a BIM model is not well developed (Davies, et al. 2013).

Automated or semi-automated data acquisition is a solution for obtaining data with good accuracy and available in a timely manner. Many scanning based techniques can be utilised to collect actual data from the construction site (Mayer, et al. 2018). Technology such as barcodes and RFID have been available in an economic way in the market. The increasing amount of data in construction sites require streamlined and automated information flow. QR codes and RFID can deliver this in an efficient manner without the loss of quality (T. Omar, et al. 2016). A similar tracking system involves April tags, which are a type of fiducial marker which are placed at fixed locations in the building, whose locations are marked as per the 3D model previously generated (Nahangi, et al. 2018). In a study conducted using RFID as a technology to improve management efficiency, it was used to collect data which was later interpreted statistically. A web based facilities management system in Taiwan was studied in this work and the application of RFID was validated. It was found that RFID helped improve the efficiency (Ko, 2017). The RFID tags having GPS capabilities to easily identify the location of the tags are also available but tend to be costly due to the added benefits of better range, no line of sight required and durability (Akinci, et al.2006).. For a general user of a smart phone the easiest method to update data by phone is by scanning QR codes (Pan, et al. 2017). The collected data can be regulated within an IT framework and used for decision making (El-Omari, et al. 2011).

Photogrammetry, Laser scanning and computer vision technology have been utilized to make quality as-built models. These techniques integrated with BIM have been proven to be very useful (H. Omar, et al. 2018). In another study conducted, improving the construction management capacity using a three phase approach was done. It includes three systems each for identification of location, monitoring the work progress and visualization & statistical analysis. Bluetooth Low Energy beacon is utilized for collecting the location information from each worker. The BLE is an IoT technology which can be used for collecting location data even in complex environments like a construction site. This data is used to create heat maps and is compared with the construction progress data for analysis and decision making (Han, et al. 2017). Several studies for monitoring construction projects using image recognition based activity tracking system are being conducted (Senthilvel, et al. 2017). In a study conducted, the author presents the system as a solution to ensure flow of information. The data is collected on site and is converted to information on-time which has helped improve project performance. The image based system tries to compare the as built and planned models of the project. by extracting 3D geometry using photographs from multiple cameras. The images help in representing one-to-one, one-to-many, many-to-one, as well as many-to-many relations with the BIM and different stages of the activity as per the schedule (Rebolj, et al.2008). In a similar study a new automated approach for collecting data using unordered photos and BIM is used (Golparvar-Fard, et al. 2011). The author brings to the point that the current method of data collection brings in significant amount of data but are inefficiently presented, which results in poor decision making. The author suggests that monitoring must be effective, of low or no cost, automated and be represented in a feasible format which can be read and understood by all personnel involved (Golparvar-Fard, et al. 2015). Project management applications are being used extensively in construction projects where smartphones and PDA are utilised for progress monitoring (Kimoto, et al.2005). A construction site where the as-built data is collected using a project management application is selected for the study. Although the data was centralised and accessible for the stakeholders, the cloud based application could not provide location awareness to the users. The sensing technology is utilised for providing this accessibility and thereby improving communication.

This paper examines the possibility of integrating BIM with a data collection framework to enable timely communication and visualisation. A new workflow has been developed in which the progress monitoring data is collected using QR code scanning and is represented in a BIM based platform. The workflow is tested out in a live construction site to improve the existing progress monitoring process using QR codes to collect construction progress data.

- Testing the feasibility of a BIM and QR code integrated workflow on-site.
- Identification of issues and challenges faced in the implementation.

1.1 Current Practice

The current practice as observed at the selected construction site (hereon referred to as construction site), is depicted in Figure 1.

1. A site engineer from the contactors side looks after the activities at the worker level.

2. When an activity is completed, the site engineer applies for a Request for Inspection (RFI) through the project management application.
3. Once the RFI is posted the quality engineer from the client side gets a notification in the application.
4. He has to then go inspect the corresponding request and approve or reject it using his mobile application.

In large projects, the inspection task will be tedious as identification of the corresponding element is really hard.

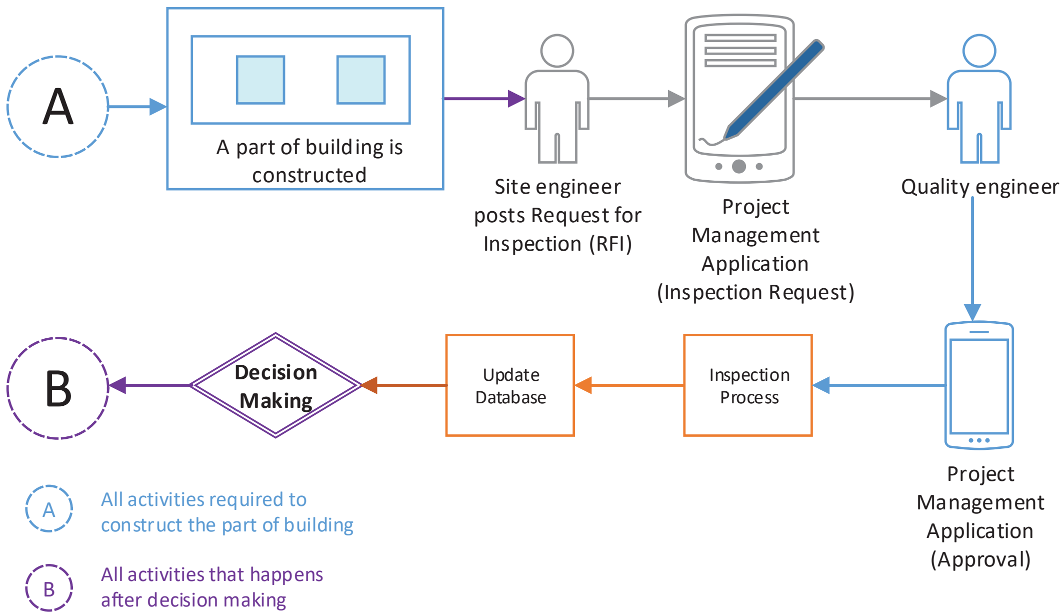


Figure 1: Current workflow practiced on-site

The following are observed at the selected construction site.

- An IT infrastructure for monitoring the project is implemented at the construction site.
- BIM is provided by the architect but it is used only for generating construction drawings for the contractor.
- BIM is not utilised for scheduling, progress monitoring or visualising the information.
- The information exchange can be made effective by integrating BIM in the above activities i.e. scheduling, progress monitoring and visualisation. This can be achieved by:
  - Mapping BIM and current schedule
  - Using this mapped data for progress monitoring using the application
  - Visualising the collected data from site on BIM based platform

1.2 Implementing the new workflow

A new workflow has been developed for improving the monitoring of the construction process. The schedule mapped to the BIM model is utilised as an input for the new workflow. This data is updated in real-time using the project management application ***nPulse*** **(**http://nadhi.in/**)**.

Different tasks involved in the modified workflow are summarised in

Table 1. Key personnel involved in monitoring are listed in Table 2. Software modules used for creating the support framework for project monitoring is given in

Table .

Table 1: Framework for project monitoring

Sl. No.	Type	Tasks
1	Pre monitoring tasks	• Prepare BIM • Prepare schedule • Mapping of BIM element ID to tasks in schedule • Upload the mapping to nPulse database
2	Tasks during monitoring	• Construction activity completion • Posting of RFI and printing QR code • Approval / Rejection of activity • Update database
3	Tasks after monitoring	• 3D model based on BIM • Get data from updated database in real-time • Visual feedback of data in database • Decision making

Table 2: Personnel involved in the Progress Monitoring

Sl. No.	Role	Description
1	**Site Engineer**	• Contractor's engineer • Overlooks the construction task as per the drawings, specifications and schedule • Responsible for posting RFI and printing QR code on completion of the task using the nPulse site engineer module
2	**Quality Engineer**	• Owner's engineer • Responsible for the quality inspections • Overlooks the dimensional stability, material used, reports on strength tests • On approval using the nPulse Quality engineer module the accounts section approves the funds to the contractor

Table 3: Software required for collecting data from site

Sl. No.	Name	Description
	Postgre SQL	Database Management tool. Enable the developer to query data from the schedule stored in the database
2	Apache Tomcat	Create local server to enable communication between the

		mobile device and the database
3	Nadhi nPulse desktop	It enables the users to access the project information. The GUI enables the users to add, edit, analyse and visualise the data
4	Nadhi nPulse mobile application	The project management mobile application that has the QR code scanner. It communicates through the server to access the database whenever required

The equipment needed for implementing the workflow include the following:

1. A wireless pocket printer that can be connected to smartphone using Bluetooth technology for QR code printing. It is lightweight and can be carried to construction sites with ease.
2. A smart phone that can run nPulse project management application. The application provides the interface for scanning QR code using the phone camera.

A portable wireless printer is used for printing QR code. A sticker type of paper is used for printing. The QR code printed will be stuck on to the respective element corresponding to the task in hand. On scanning the QR code all the necessary details about the corresponding task can be seen by the engineer. Once the task details are approved by the engineer the as built BIM model will be updated.

Procedure:

1. Each task on a building element is completed by a group of workers under the site engineer.
2. The site engineer completes initial inspection and posts the RFI using the nPulse application. He prints the QR code and attaches it to the corresponding element.
3. This appears as a notification on the quality engineer's module. He then updates the inspection time and other instructions through the application.
4. The quality engineer comes to the site and scans the QR code. All the related documents of the corresponding element appear on the application, and he can begin the inspection.
5. On approval of the task, the schedule is updated and also the accounts department will be notified for initiating fund transfer to the contractor.
6. The site engineers and other authorised personnel could scan the QR code to find the current status of the element, the documents attached to it. If the task is not approved the list of rejected checklists can be viewed

The workflow is shown in Figure .

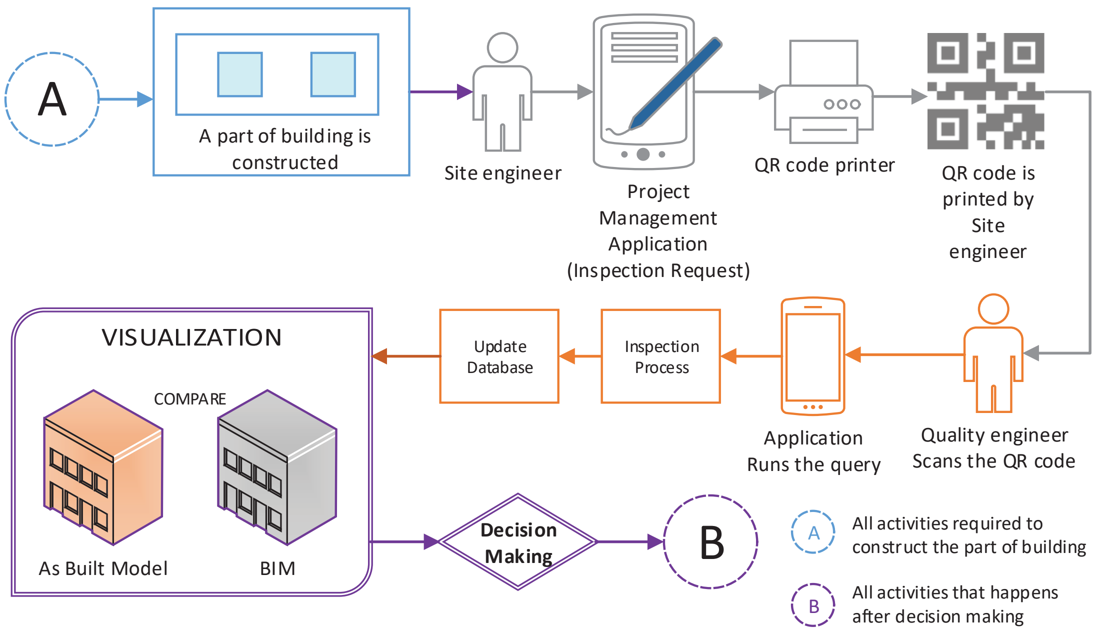


Figure 2: Workflow using QR code technology

2. Evaluation

The framework was evaluated on an actual construction site. The selected project is a commercial building situated at Porur in Chennai, India. The building is being developed by ***Company A*** (client and quality engineer) with the help of ***Company B*** (architect), ***Company C*** (contractor) and ***Company D*** (project manager). ***Company B*** provides the design details and BIM. ***Company C*** is bound by a design and build contract to ***Company A***. ***Company D*** provides the project management support and the IT infrastructure for progress monitoring and communication among the stakeholders.

Company B and ***Company D*** operates remotely whereas ***Company A*** and ***Company C*** have setup fully fledged site offices to carry out the construction and monitoring activities.

The client insisted on a thorough monitoring system for the purpose of creating a good accounting database. The transfer of funds for a particular activity only happens when the quality engineer approves of the construction activity in the project monitoring device. This updated information is instantaneously visible for the client's accounting team and fund transfer will be initiated.

2.1 Progress monitoring at selected construction site

The workflow for the Project Monitoring was designed after collecting observations and recommendations from users for 10 days. The new workflow was implemented and was tested for two weeks. The parameters listed in Table were collected in order to evaluate the performance of the monitoring system.

Table 4: Table showing the distribution of points for various parameters

Parameters	**4**	**3**	**2**	**1**	**0**
	very good	**good**	**Ok**	**bad**	**no result**
Functionality	worked in first try	worked 2-4 tries	worked after few tries	worked after many tries	did not work

Scanning distance	> 2.0	1.0 - 2.0m	0.5 - 1.0m	< 0.5	nil
Environment	sunny day	cloudy	Rainfall	heavy rainfall	NA
Durability	> 24 hours	24 hours	8 hours	1 hours	can't be used
Lighting	> 200 lux	200-101 lux	100-51 lux	50-11 lux	< 10 lux
Network	very good	good	Ok	bad	no network
UX	very good	good	Ok	bad	did not work

All the readings were taken for the foundation level activities and therefore the QR codes were exposed to the exterior environmental forces. This led to readings showing low durability, when compared to readings taken in an indoor condition. Similarly, the lighting parameters have low values and are subject to large variations, as all the elements selected are exposed to the outdoor conditions. There was no fluctuation in the network during the period of the experiment.

The functionality aspect will be high or low depending on the errors in the application, hardware or network. The users in the selected construction site are already familiar with the nPulse application. The quality engineers were asked to carry the QR code wireless printer in order to print it. The user experience was collected at the end of the experiment as per the Table 5.

Table 5: Points distribution for the different readings taken from the construction site

Sl No.	Element	Task	Unique BIM_ID	User	Functionality	Scanning distance	Environment	Durability	Lighting	Network	UX
					Points (0-4)	*meters*	*Points (0-4)*	*Points (0-4)*	*Points (0-4)*	*Points (0-4)*	*Points (0-4)*
1	Column	Concreting	1610340	self	4	0.5	4	4	1	4	NA
2	Column	Concreting	1610323	self	4	0.5	4	4	1	4	NA
3	Raft	Concreting	1216823	self	3	0.5	1	2	4	4	NA
4	Raft	Concreting	1216823	self	0	NA	4	4	4	4	NA
5	Pile Cap	Reinforcement	2579828	self	4	0.5	4	4	4	4	NA
6	Pile Cap	Reinforcement	2580645	self	4	0.5	4	4	4	4	NA
7	Slab	Formwork	887860	self	4	0.5	4	4	4	4	NA
8	Pile Cap	Reinforcement	2593830	self	4	0.5	4	4	4	4	NA
9	Pile Cap	Formwork	2669725	self	4	0.5	4	4	4	4	NA
10	Pile Cap	Reinforcement	2594911	self	4	0.5	4	4	4	4	NA
11	Pile Cap	Formwork	2593937	self	4	0.5	4	4	4	4	NA
12	Column	Concreting	1604237	self	4	0.5	1	0	1	4	NA
13	Column	Concreting	1610601	self	4	0.5	1	0	1	4	NA
14	Column	Reinforcement	2577186	self	0	NA	1	0	4	4	NA
15	Column	Formwork	1608553	self	0	NA	1	0	4	4	NA
16	Column	Reinforcement	1608320	engineers	4	0.5	4	4	4	4	3
17	Column	Reinforcement	2573145	engineers	4	0.5	4	4	4	4	3
18	Pile Cap	Formwork	2592167	engineers	4	0.5	4	4	4	4	4
19	Pile Cap	Formwork	2592124	engineers	4	0.5	4	4	4	4	4
20	D-wall	Reinforcement	2052871	engineers	4	0.5	4	4	4	4	3

The summary of readings taken for the various activities are given as the following.

Functionality: The functionality parameter showed the highest working condition for most of the readings. It can be seen that three of the readings shows that the workflow did not work at all. This was primarily due to the bugs in the application. The testing also served as a method to find bugs in the nPulse application.

Scanning Distance: The scanning distance is 0.5 m for all the readings taken. Each of the readings taken are at closely accessible locations. It was tested and found that the camera was unable to scan the QR code beyond 0.5 m.

Environment: This parameter refers to the environmental condition. It is relevant to the experiment as the current on-going activities are all exposed to the external weather conditions. The observation table shows that the weather conditions were either sunny or rainy.

Durability: Durability was tested using custom modified QR code samples. The QR code was covered in a thin transparent plastic film to protect from rain and dust. It was observed that the paper stayed intact by using this method. But, the QR code became unreadable in 48 hours due to an induced chemical reaction between the printed ink and the glue used to stick the plastic film. Use of costlier, better quality paper could further improve the durability of QR code.

Lighting: The lighting aspect was tested using the light-sensor in the smartphone. It was seen that for the readings taken open to sky the lux values were high and was easily scanned by the smartphone camera. When the QR codes were under the shade the readings were below 50 lux. This problem can be easily tackled for smartphone cameras with built-in flash.

Network: There were no obstructions as the construction activities are still happening at the foundation level. However, network issues are expected to be a problem as soon as the superstructure begins to envelope the construction activities.

UX: The user experience was collected from the site personnel involved in the data collection.

2.2 On-site observations

Some images of using QR codes on site are shown in Figure 3. Several challenges that need to be overcome for successfully implementing project monitoring using QR code in a construction site were identified, including the following:

- Weather condition is a critical factor for durability.
- Low lighting condition did not affect scanning since built-in flash lights in the smart phones could be used, but locating the QR code was difficult.
- Several tasks and activities like concreting and reinforcement cannot be monitored, also activities involving inaccessible areas like overhead slab formworks.

a. QR codes fixed on the rebars

b. QR code placed near a newly cast concrete slab

Figure 3: QR codes on-site

2.3 User Interface for visualisation

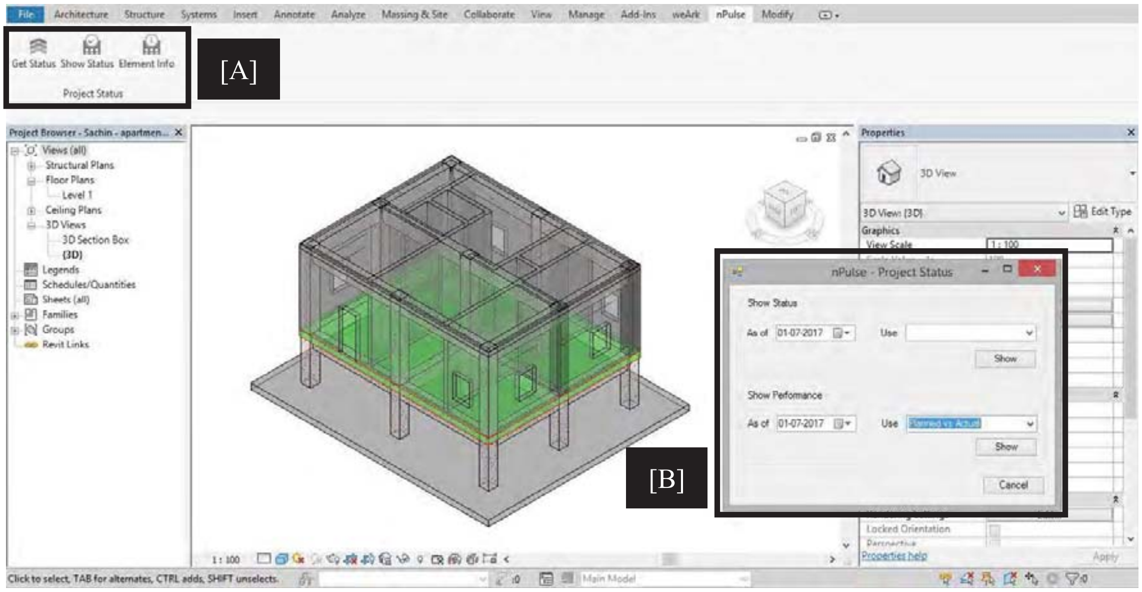


Figure 4: Graphical User Interface- developed as an addin for Autodesk Revit

The Graphical User Interface (GUI) implemented is shown as per the Figure 4. The plugin is developed using the Autodesk Revit API. The plugin links the online database with the BIM model. The graphical parameters are modified using the plugin to achieve the required results. The GUI has buttons to obtain user inputs, perform database queries and update 3D model.

For illustration, the visualization of project status is shown in Figure 5. The user can query any date within the project timeline and request to highlight the elements that have any task attached to it in any of the planned, actual or estimated dates. This functionality allows the user to visually understand the different activities that will happen at the construction site on a particular day.

The query with planned dates can be viewed throughout the project timeline. It is the baseline schedule that is prepared by the planning engineers. The actual dates will be able to show the construction works that was actually done for the selected day. This is a very relevant viewport for the different stakeholders, as this can show the real-time activities that have happened in the construction site.

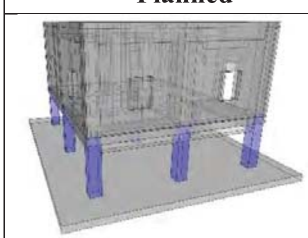
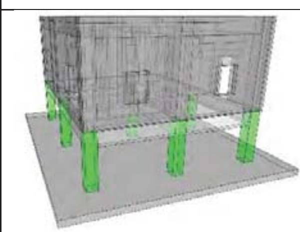
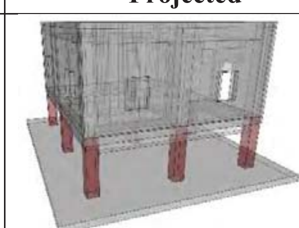
Planned	Actual	Projected
 Planned work for the selected date is highlighted as blue	 Actual work for the selected date is highlighted as green	 Projected work for the selected date is highlighted as brown

Figure 5: Visualising project status

3. Concluding remarks

This study tried to resolve few construction site challenges in a practical manner. In this research, a new framework for construction progress monitoring using existing technology like QR code and BIM has been developed and tested. The new workflow implementation has improved the efficiency at the construction site by making information easily accessible due to the location aware query feature.

Visualisation of data is given utmost importance in this study. The database is updated in real-time during the inspection process by scanning QR codes using the application. The project manager is able to obtain up to date information about the status of the project through the user interface. Clarity in communication leads to better project management.

The implementation on an actual construction site demonstrated the feasibility of applying the framework to complex construction projects. The study also brought out the limitations of the QR code technology.

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