Building Engineering 2024, 2(1), 1132.
https://doi.org/10.59400/be.v2i1.1132

Article

Digital transformation of quality management in the construction industry during the execution phase by integration of building information modeling (BIM) and cloud computing

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CITATION

Shaban M, Al-Hassan B, Mohamad AS. Digital transformation of quality management in the construction industry during the execution phase by integration of building information modeling (BIM) and cloud computing. Building Engineering. 2024; 2(1): 1132. https://doi.org/10.59400/be.v2i1.1132

ARTICLE INFO

Received: 28 February 2024
Accepted: 25 March 2024
Available online: 17 April 2024

Abstract: The quality of construction projects significantly impacts social and economic development. However, low quality and project failure often result from factors such as lack of quality procedures, poor communication, task coordination, and inefficient progress monitoring. This research aims to improve the efficiency of the construction phase by creating quality control checklists for processes and enhancing quality management through a collaborative digital environment integrating building information modeling (BIM) and cloud computing. Expert constructive interviews were first conducted to define a construction process quality control procedure to be linked to the 3DBIM model and then transition to a collaborative cloud environment (Autodesk Construction Cloud). An actual instance in Latakia City (Syria) demonstrated that the proposed methodology improves the efficiency and effectiveness of quality management during the implementation phase. It does so by offering a robust database, enhancing on-site quality information extraction from BIM models using smartphones, documenting defects and entering inspection data directly into a shared digital environment, and making it easier to track corrective actions and feedback. This facilitates constant and organized access to current data, reducing errors and rework, saving money and time, and enhancing decision-making speed and effectiveness. The search recommends the necessity of strict laws to adhere to quality procedures and the importance of providing infrastructure for digital transformation in quality management.

Keywords: construction projects; quality management; digital quality management; quality control; building information modeling (BIM); cloud computing

1. Introduction

Construction project success is largely dependent on quality management since timely and cost-effective project execution depends on an effective and efficient management procedure. All phases of the project lifecycle should incorporate quality management [1]. However, the execution process is thought to be the most complex because it accounts for the majority of project costs (70%–80%), making quality control and management during this phase one of the most difficult tasks [2]. Accurate and consistent information gathering, processing, and stakeholder engagement are necessary for high-quality project management.

Engineering facilities in Syria suffer from quality deficiencies, often failing to achieve the desired results and incurring high rework costs. The main reasons for this include the absence of quality procedures during the execution phase, lack of cooperation and communication between project participants, poor task coordination between team members, inefficient progress monitoring, limited ability to track changes, lack of strict supervision, and the inability to document problems and track their resolution. This is attributed to the limited sharing of information through traditional paper-based methods in conventional construction quality management approaches. The current practice of quality management in the construction industry involves issuing quality inspection checklists, conducting site inspections and testing, documenting non-conformity reports, and implementing corrective actions. However, there is no systematic method for recording the data that has been inspected, making it impossible to determine the quality status of the construction [3]. The revolution in computer systems and information technology has had a significant impact on the global community, as the construction sector or industry is now linked to information technology to increase construction efficiency. The construction industry has undergone a tremendous transformation thanks to building information modeling (BIM) technology, which covers all project phases and improves efficiency [4]. As BIM aims to change the way facilities and infrastructure are viewed and managed, it is seen as a gateway to technical innovation and helps to deliver projects successfully at a lower cost and higher quality [5]. According to Saad et al. [6], its benefits include increasing efficiency, facilitating competitive advantage, enhancing sustainability, streamlining complicated operations, and improving performance.

The rapid adoption of building information modeling (BIM) in the fields of architecture, engineering, and construction (AEC) has brought new and emerging challenges for collaborative practices related to the significant amount of BIM data that must be managed and controlled [7]. Because remote collaboration is not allowed and real-time construction information cannot be reported, participants must meet in person around a computer to discuss a particular building program using BIM files [8].

Cloud-based building information modelling, or cloud BIM, is a growing area of investigation for the architecture, engineering and construction (AEC) sector [9]. The problem of storing too much BIM data can be solved by increasing the capacity of cloud storage. Because cloud storage services make cloud-based BIM easily accessible to users in many locations, organizations can quickly expand the system without having to purchase expensive servers. This allows project team members to collaborate and coordinate more effectively in real time [8].

On building sites, mobile devices like iPads, tablets, and smartphones are now often used because cloud-based BIM systems like BIMXtra, A360, and others improve communication between office personnel and site workers. Through wireless networks, site teams may now view and address issues immediately from their mobile or cloud devices [10]. This has a direct and positive impact on the quality management of the site.

2. Research objective

Enhancing the efficiency of the construction phase in construction projects by:

1) Conducting constructive interviews with experts to develop checklists for quality control of construction processes.
2) Developing a methodology to enhance quality management by providing a collaborative and shared digital environment through integrating BIM and cloud

computing.

3. Literature review

Hartmann and Fischer [11] described how the project team of the Fulton Street Transit Center project in New York City utilized 3D/4D models for knowledge communication and generation during the constructability review process. The management team effectively communicated generated knowledge to non-engineers, suggesting an integrated process for efficient 3D/4D model usage in construction projects.

According to Sears et al. [12], an essential procedure in construction project management is a constructability review, which assesses design and construction plans to find possible problems or difficulties. Within the limitations of time and money, it seeks to guarantee that the design is workable, efficient, and practical. In order to reduce risks and improve the quality and efficiency of projects, stakeholders such as contractors, engineers, and architects work together to evaluate design documents.

According to Love et al. [13], BIM can boost full life-cycle asset management, lower construction costs, lessen the likelihood of modified orders, integrate project systems, data, and teams, and improve the quality of design information and interoperability.

Wang et al. [14] discussed an integrated system of BIM and Light Detection and Ranging (LiDAR) to obtain real-time quality information on-site and process it for construction quality monitoring. The results show that the system is capable of efficiently identifying potential construction defects and supporting real-time quality control.

Lin et al. [15] introduced a BIM-based defect management (BIMDM) system for on-site quality managers in Taiwan during construction. The system integrates web and BIM technologies, enabling real-time visualization and analysis of defect information. The study shows its effectiveness in improving defect management efficiency and facilitating easy quality inspection in a 3D BIM environment.

Ma et al. [16] proposed a system that integrates BIM and indoor positioning technology, allowing inspectors to easily link the actual targeted element they are inspecting on the construction site with the corresponding BIM element by simply clicking on it to input inspection data on a mobile device. The inspection data is then uploaded to the server, and checklist forms are printed and signed.

Cheng [17] developed a preliminary model for a quality control system in the construction phase using Autodesk Revit API, which can record quality defects on-site immediately and display the three-dimensional elements including the defects. This quality control model can be uploaded to the cloud and provide real-time information. Users can also print quality control reports using this system.

Alhassan et al. [18] proposed a methodology for knowledge acquisition during public building maintenance using BIM and DYNAMO applications. Parametric models store information centrally, while visual programming enables processing, extraction, classification, and data export from the BIM model to enhance knowledge management.

In another study [4], a comprehensive approach to quality management through the integration of BIM and augmented reality (AR) technologies was proposed. The results emphasize that objectives such as reducing delays, improving quality, and lowering costs can be achieved through the proposed quality management system, as the web-based checklist facilitates access to updated information by enhancing communication among stakeholders.

In a study by AA and Varghese [3], a 4D model was developed for project quality management using Revit software to link foundation elements with their quality parameters. The researcher concluded several benefits of using BIM in quality management: better visualization of construction activities, improved communication among project stakeholders, a robust database, better understanding of quality requirements, continuous flow of information, time savings, and cost savings.

Using a point cloud and as-designed BIM features, Bassier et al. [19] introduced an innovative way to quickly assess built objects on building sites. Periodic remote sensing opens up new opportunities for comprehensive evaluations. This technique computes positioning errors, detects building flaws early on, and reduces failure costs dramatically. The program offers a user-friendly positioning accuracy meter and is integrated into native BIM software.

The research of Dahbi et al. [20] aims to integrate AR, BIM, and cloud computing technologies into a mobile application called "CollaBIM" to improve construction sector practices. This open-source solution aids in digital transition, providing visualization of models on 2D plans and 3D virtual models, enabling better building analysis throughout their life cycle. Collaboration is central to the research.

Qinghe et al. [21] developed a BIM management platform that improves visualization, data integration, safety, quality, collaboration, and emergency response in bridge projects by utilizing cloud computing, internet of things, and BIM technologies. The way these technologies work together for intelligent project management is demonstrated by this integration.

Irene [22] examined how a collaborative Cloud-BIM tool was used on the North Vancouver LGH ACF project, emphasizing how it improved interdisciplinary cooperation, design visualization, and project comprehension. Change management, file upload problems, and inadequate training are among the challenges that have been discovered.

In the research of Omran and Shaban [23], an integrated system for managing change orders electronically was developed that aligns with the expectations and ambitions of the construction industry through the integration of building information modeling (BIM) technology and cloud computing technology.

4. Methodology

1) Creating quality checklists: In this study, quality control checklists for construction execution processes were developed by conducting constructive interviews with 23 experienced engineers working in the construction industry in Syria for at least 20 years, in addition to relying on observation by reviewing work procedures.
2) Creating a quality-loaded BIM model: A 3D model of the case study building was created using the Revit software, as shown in **Figure 1**, and then quality

control procedures obtained from field surveys were added and linked to the corresponding elements in the model.

Figure 1. The BIM model (The Youth Housing Project).

3) Transition to a collaborative cloud-based environment: The transition was made to the Autodesk Construction Cloud (ACC) platform, a cloud-based platform designed by Autodesk for effective integrated management of construction projects. This platform includes a suite of BIM-based tools and project management capabilities designed to centralize all building information and related processes, improving communication, collaboration and coordination between stakeholders through a single online platform.
4) Verification through a case study: The Youth Housing Project in the city of Latakia (Syria) was chosen as a case study. It is a residential building consisting of a ground floor and nine repetitive floors with an area of 350 square meters, where each floor contains four identical apartments. On-site, the PlanGrid application, which is part of the ACC platform, was used. Users can upload, organize, and share project documents through this application. The teams can view high-resolution drawings and 3D models (BIM) on smartphones and tablets smoothly. Team members can collaborate on drawings and provide comments and feedback directly within the application. Changes to drawings and documents can be tracked and version history is maintained to ensure the use of the correct versions.

   It allows for documenting quality issues, safety concerns, and other problems at the worksite with the ability to attach photos and notes. In addition, the notification feature ensures real-time communication between the field team and the office team, significantly reducing the need for team feedback on unexpected problems. **Figure 2** shows the research approach chart.

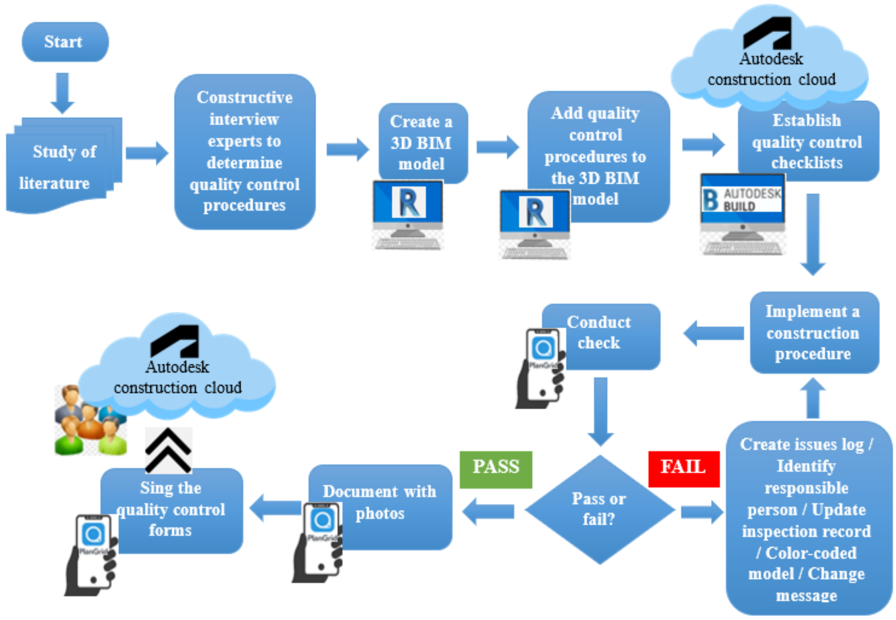

Figure 2. Research approach chart.

5. Results and discussion

1) After conducting constructive field interviews with experts, quality control checklists for executing earthworks and construction operations for structural elements (formwork, reinforcement, and pouring) were developed. As indicated in Appendix.
2) Through the digitization of quality management by integration of (BIM) and cloud computing, researchers have been able to address the most common issues in traditional quality management approaches by:

5.1. Collaboration and communication

The digitization of quality management helps to share information transparently and centrally between project members. As project participants are added to the platform, companies can invite their employees to join and define permissions for each member. This allows them to determine what they can see and do on the platform based on their responsibilities and project needs, as shown in **Figure 3**. This approach helps to organize and coordinate work more effectively, ensuring that participants are committed to the tasks assigned to them and that appropriate access to data and information is granted to each individual.

To facilitate access and organization of project information, the platform centrally stores crucial documents and files. These include blueprints, digital models, schedules, photos, and other project-related files. The stored data encompasses change orders, backups, and various document versions. This centralized repository allows for efficient comparison of different document versions, tracking change dates, and identifying responsible parties. As a result, companies can respond promptly and effectively to changes, ensuring the quality execution of their processes. **Figure 4** illustrates the centralized file storage within the platform.

Figure 3. Add members to the platform with their company identification, their job roles and their permissions.

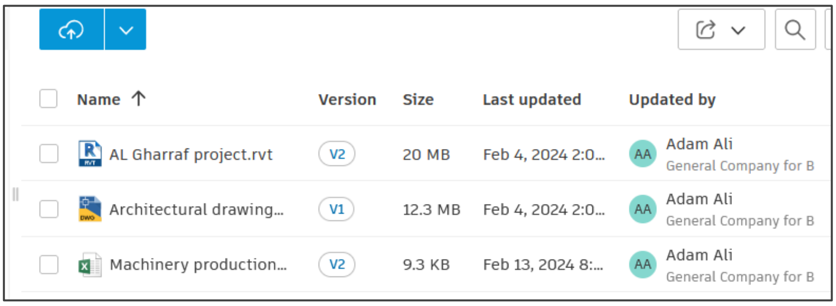

Figure 4. Centralized file storage.

5.2. Providing a repository for quality data

The proposed methodology establishes a highly centralized repository for quality data. This data is seamlessly integrated into the building information modeling (BIM) model using REVIT software. By incorporating a set of special parameters, REVIT allows for the inclusion of quality-related information. Specifically, each 3D element within the model is linked to these parameters, ensuring that alongside the geometric details, process-specific quality data is associated with each element. Refer to **Figure 5** for a visual representation of this integration.

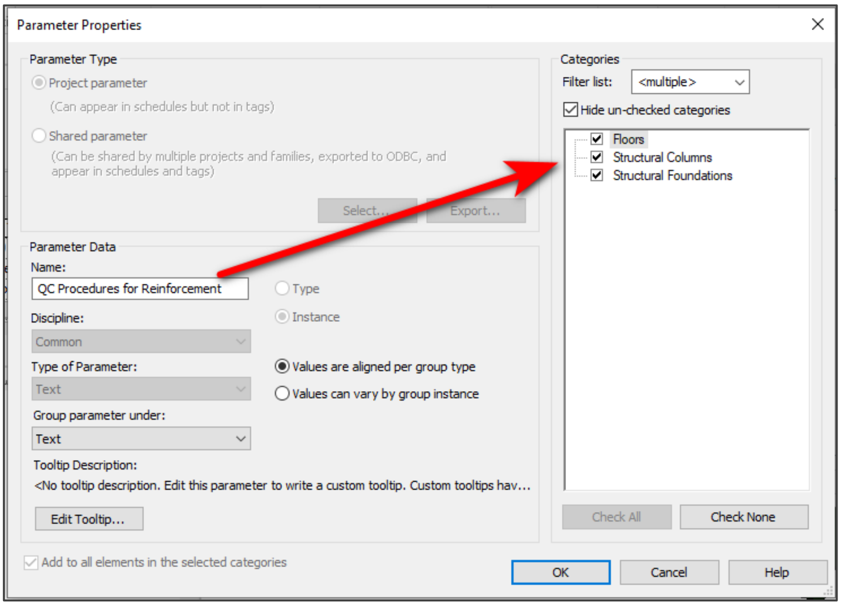

Figure 5. Adding parameters for reinforcing work quality control procedures.

5.3. On-site acquisition of quality data

In the proposed methodology, the BIM model loaded with quality data is viewed on site using a tablet or mobile phone to obtain all the necessary information about the elements on site as shown in **Figure 6**. **Figure 7** illustrates a virtual tour inside the building to facilitate the process of obtaining information about the internal elements. The site official can find the required elements in the BIM model using a smartphone or tablet by performing a filtering process for the elements through selecting the level, category and disciplines of the element as shown in **Figure 8**. The site official can also perform measurements directly on the model as shown in **Figure 9**.

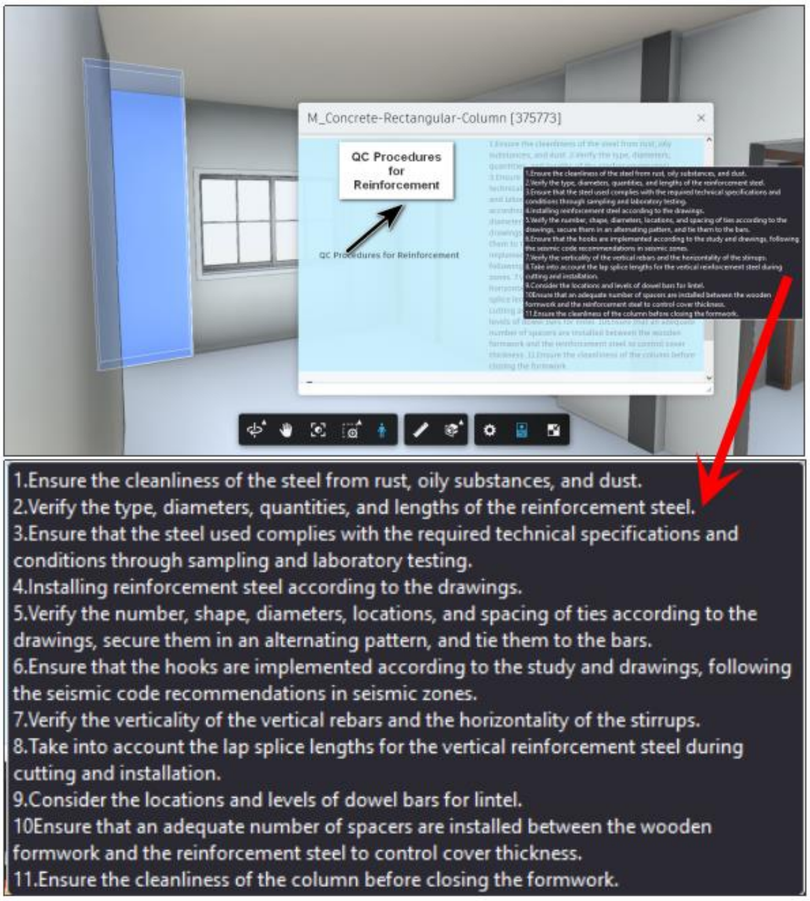

Figure 6. Quality control procedures for column reinforcement.

Figure 7. Virtual tour inside the building (The Youth Housing Project).

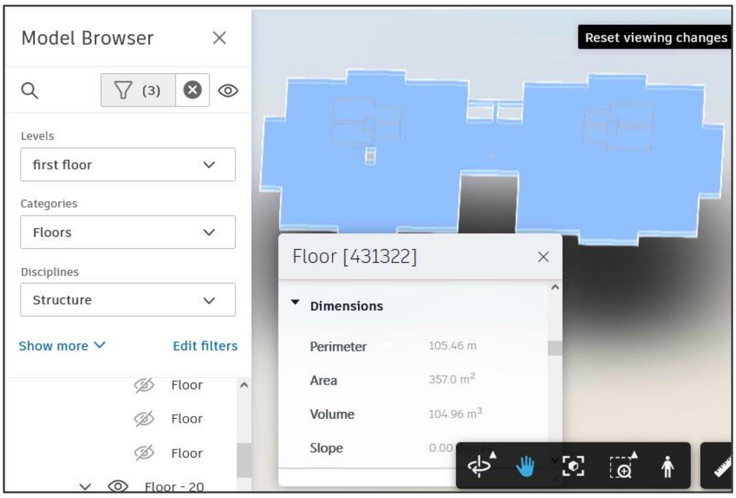

Figure 8. Filter elements.

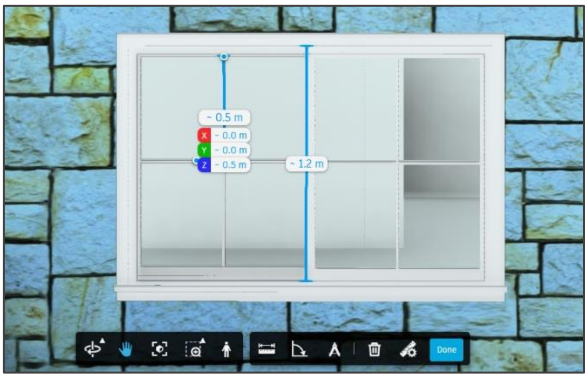

Figure 9. Taking measurements.

5.4. Track implementation and document quality issues

Digitizing quality management facilitates real-time monitoring of project progress by providing up-to-date data. This tracking and monitoring process offers a comprehensive view of process and quality performance through the analysis of data and key performance indicators. Companies can pinpoint areas that require improvement and development. Regular tracking enables effective data collection and analysis, allowing for the early identification of potential quality issues. Strategic decision-making can then address these challenges.

To streamline data collection, customized forms have been designed. These templates encompass various fields, including text, geographic location, weather conditions, electronic signatures, images, and dates. On-site personnel complete these forms using smart devices. The collected data serves as the foundation for customized reports, such as daily reports, progress updates, quality assessments, safety reports, and inspections (as depicted in **Figure 10**).

Digitizing quality management also facilitates the inspection process on-site through electronic checklists that are created as shown in **Figure 11**. The inspector fills out the checklists during the inspection process using a mobile phone and documents compliance cases with photos. In case of a violation, it is described and its location is identified on the 3D BIM model, and the responsible person is automatically notified through the platform and email with a message indicating the need for correction or rework. After completing the inspection process, the report is signed by the inspector and shared via the platform with relevant parties.

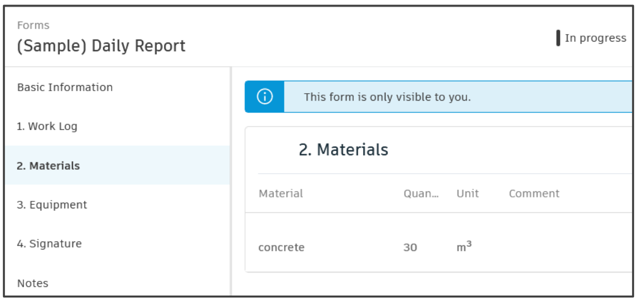

Figure 10. Daily report.

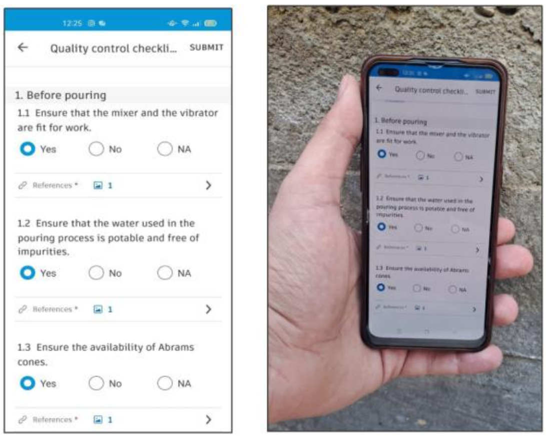

Figure 11. On-site form of quality control.

Quality issues that have arisen during the construction process have been visually documented in the BIM model, as have safety issues and the necessary accident prevention measures as shown in **Figure 12**. Cases of defects in materials or equipment used in the project are recorded with the responsible parties, and attachments of images, documents, notes, and rework messages are included as shown in **Figure 13**. The colored markings on the three-dimensional elements indicate a defect in the element, making it easier for responsible parties to note the location of defects and problems, helping to improve communication, simplify problem management, improve project quality, and manage it effectively.

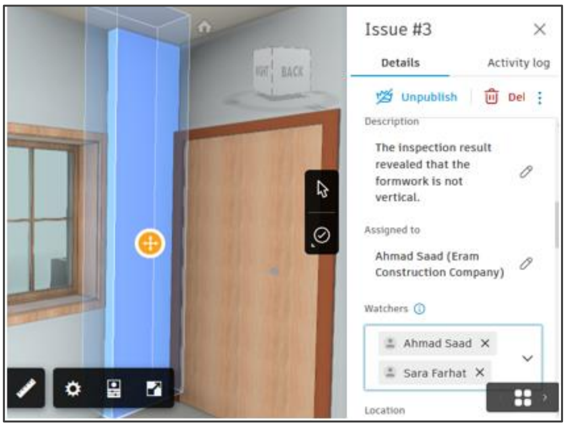

Figure 12. Documentation of a column issue in BIM model.

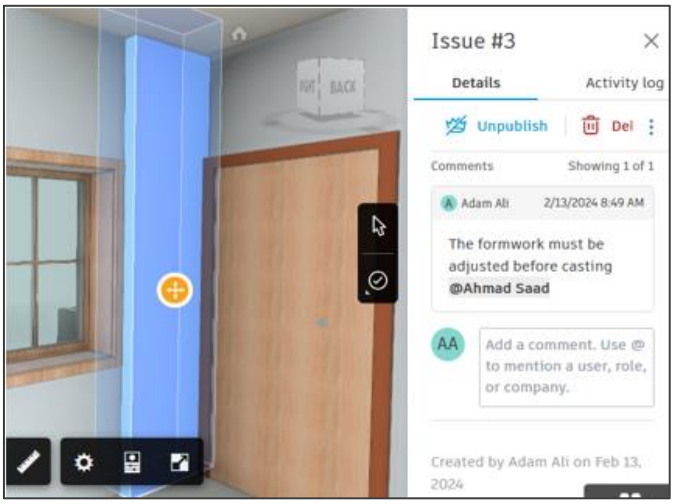

Figure 13. Fixing and reworking message from supervisor.

5.5. Corrective action tracking

Corrective action tracking plays a pivotal role in quality management. It serves several critical purposes. During the construction process, errors and issues inevitably arise. Corrective actions help identify these anomalies promptly. By addressing them, companies ensure the quality of operations, meet customer expectations, and safeguard their reputation.

Our proposed methodology establishes a detailed historical record of observed issues and non-compliances. Each issue is meticulously documented, including references to the responsible individuals. To streamline corrective actions, we employ a color-coded system within the 3D BIM model as shown in **Figure 14**. Each color corresponds to a specific stage of the corrective action process:

- Draft: Initial identification (Black).
- Open: Acknowledged and under review (Orange).
- Pending: Awaiting resolution (Blue).
- In review: Assessment by relevant parties (Purple).
- Closed: Successfully resolved (Grey).

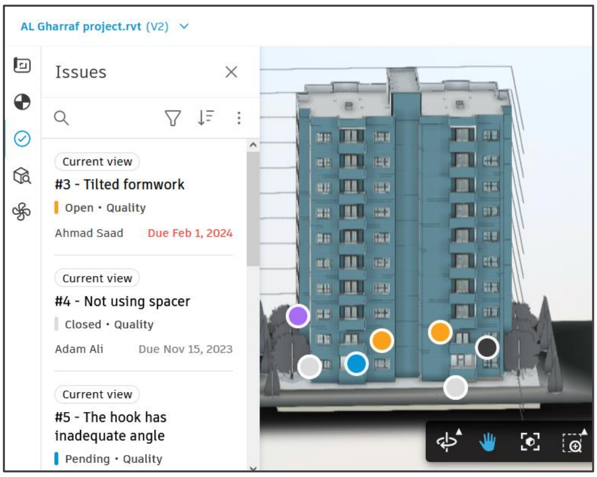

Figure 14. Visualization of the color-coded model, combined with historical record of the issues.

5.6. Feedback tracking

The proposed methodology serves as a comprehensive communication system for reporting, feedback tracking, review, and dissemination of lessons learned. It ensures a clear and consistent flow of information by providing feedback on documents, designs, and reports. Comments, notes, and direct changes are seamlessly incorporated into the documentation process.

Key components of this approach include feedback integration, detailed reports, team meetings, and efficiency enhancement. Stakeholders contribute feedback directly to documents, ensuring continuous improvement. The system generates detailed reports summarizing received feedback, serving as valuable insights for decision-making and process enhancement. Regular team meetings facilitate collaboration and knowledge sharing, identifying strengths and weaknesses in the construction process. Necessary actions are taken to improve work efficiency based on data analysis, ensuring adherence to quality standards and meeting customer needs.

6. Conclusions

This research aimed to improve the efficiency of the construction phase by creating quality control checklists for processes and enhancing quality management through a collaborative digital environment integrating building information modeling (BIM) and cloud computing. The effectiveness of the system was studied through a real-life case in Latakia City-Syria. The research found that the integrated use of BIM and cloud computing makes implementation phase quality management more efficient and effective by better understanding the design, providing a robust database, improving communication and collaboration between participants, enhancing on-site quality information extraction from BIM models using smartphones, documenting defects and entering inspection data directly into a shared digital environment, and facilitating the tracking of corrective actions and feedback. This enables continuous and structured access to up-to-date information and inspection results, thereby reducing defects, minimizing rework, saving time and cost, and improving the speed and efficiency of decision-making. Moreover, the color-coded model, combined with the historical record of the issues, gives an overview of the current quality status of the project both in qualitative and quantitative terms. The research recommended the need for strict regulations to adhere to quality control procedures, the need to provide technical infrastructure to move the construction industry to a collaborative digital environment, and the importance of conducting training courses for construction workers on the use of the new technology.

Author contributions: Conceptualization, MS, BAH and ASM; methodology, MS and BAH; software, ASM; validation, ASM; conducting interviews, ASM; data curation, MS, BAH and ASM; writing—original draft preparation, ASM; writing—review and editing, MS, BAH and ASM; supervision, MS and BAH. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors declare no conflict of interest.

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Appendix

Table A1. Quality control checklist for excavation.

Item number	Item description	Pass	Fail
1	Suitable excavation and relocation vehicles should be obtained after securing relocation sites.		
2	Accurately determine the drilling depth based on the soil mechanics report data.		
3	Identify the bench mark and fixed axes on the site.		
4	Determine the limits of the excavation based on accurate topographic surveys.		
5	Define of the outer boundaries of the buildings to be excavated.		
6	Check the groundwater level to ensure proper drainage if it is higher than the foundation level.		
7	Ensure that the land is free of gas pipes and electrical cables.		
8	Make sure that there are no materials or insects (some types of ants) that could damage the concrete.		
9	Check the type of soil.		
10	Random samples should be taken and tests carried out to observe changes in the classification and physical properties of the soil.		
11	Determine the type of temporary reinforcement for the sides of the trench where the ground is weak.		
12	The coefficient of swelling of the soil, which can be up to 20%, must be determined in order to determine the quantities of excavation and relocation.		
13	The soil settlement under the foundations must be leveled.		
14	Ensure that the excavated soil is not stored close to the pit to prevent the collapse of the sides.		

Table A2. Quality control checklist for backfilling.

Item number	Item description	Pass	Fail
1	Ensure that all types of insulation are completed.		
2	Ensure that the backfill material is a suitable soil, clean and free of organic residues, preferably sandy soils or rocky residues.		
3	Take into consideration the sieve analysis if the backfill material is gravel.		
4	Conduct laboratory and field density and moisture tests periodically and in random areas to achieve the physical requirements of the backfill material.		
5	Document the amount of aggregate to be used, taking into account the compaction coefficient, which may reach up to 20%.		
6	Ensure that the backfilling is done in layers according to the soil report, with an average thickness of no more than 20–25 cm.		
7	Ensure that the backfill layer is completely submerged in water for 24 h, in particular for sandy soils.		

Table A3. Quality control checklist for foundation formwork.

Item number	Item description	Pass	Fail
1	Ensure the proper installation of excavation sides (temporary shoring) and verify their completion in a correct and durable manner.		
2	Match the axes of the foundation with the correct survey axes.		
3	Matching the axes of the foundation with the correct survey axes.		
4	Check the dimensions and heights of the foundations.		
5	Ensure the perpendicularity of foundation angles by measuring the diagonals of each foundation to ensure that the foundation is square or rectangular and does not deviate.		
6	Ensure the stability of the formwork sides and their ability to withstand the force generated by pouring the concrete mass inside.		

Table A3. (*Continued*).

Item number	Item description	Pass	Fail
7	Properly close the sides of the foundations together and seal any gaps between the wooden panels.		
8	Verify the locations of openings and paths for plumbing and electrical installations, etc.		
9	Thoroughly wet the formwork with water before pouring if it is wooden to avoid absorbing concrete water.		
10	Check the horizontal level of the foundations pouring with each other and the rest of the foundations with a mercury scale.		

Table A4. Quality control checklist for foundation reinforcement.

Item number	Item description	Pass	Fail
1	Ensure that the steel is free from rust, oil, dust, or any material that will prevent good adhesion to the concrete.		
2	Check the type, number, and length of rebar diameters.		
3	Ensure that the steel used complies with the required technical and conditional specifications through sampling and laboratory testing.		
4	Ensure that the reinforcing steel is placed in the correct position according to the drawings.		
5	Ensure that the foundation rebars are horizontally leveled without any inclinations.		
6	Securely tie the steel and cut any excess binding wire.		
7	Install the rebar chairs to raise the top mesh steel according to the attached drawings.		
8	Ensure adequate cover thickness on all sides in accordance with code requirements, and place spacers on foundation sides and under bottom mesh steel.		
9	Check the diameter, number, and length of column dowel bars in accordance with code requirements.		
10	Check the position of the column dowel bars and connect them to the stirrups, ensuring that they do not move during the pouring process.		
11	Ensure that column dowel bars are properly anchored inside the foundation.		

Table A5. Quality control checklist for column formwork.

Item number	Item description	Pass	Fail
1	Ensure the dimensions of the column section are correct.		
2	Align the axes of the columns with the correct survey axes.		
3	Ensure the wood is clean from any debris.		
4	Ensure proper sealing of joints and openings (for pouring, etc.).		
5	Ensure horizontal and vertical bracing is securely in place to prevent any movement or tilting during pouring.		
6	Verify the verticality of the column before, during, and after pouring using available surveying equipment or traditional methods (plumb bob, mercury).		
7	Make sure that there is no deviation.		
8	Thoroughly wet the wooden formwork before pouring.		
9	Leave enough space between the wooden panels to prevent them from swelling when watering.		
10	Check the pouring level and determine the height of the column door.		
11	Leave a hole in the column formwork to check the pouring level.		

Table A6. Quality control checklist for column reinforcement.

Item number	Item description	Pass	Fail
1	Ensure the cleanliness of the steel from rust, oily substances, and dust.		
2	Verify the type, diameters, quantities, and lengths of the reinforcement steel.		
3	Ensure that the steel used complies with the required technical specifications and conditions through sampling and laboratory testing.		
4	Installing reinforcement steel according to the drawings.		
5	Verify the number, shape, diameters, locations, and spacing of ties according to the drawings, secure them in an alternating pattern, and tie them to the bars.		
6	Ensure that the hooks are implemented according to the study and drawings, following the seismic code recommendations in seismic zones.		
7	Verify the verticality of the vertical rebars and the horizontality of the ties.		
8	Take into account the lap splice lengths for the vertical reinforcement steel during cutting and installation.		
9	Consider the locations and levels of dowel bars for lintel.		
10	Ensure that an adequate number of spacers are installed between the wooden formwork and the reinforcement steel to control cover thickness.		
11	Ensure the cleanliness of the column before closing the formwork.		

Table A7. Quality control checklist for slab formwork.

Item number	Item description	Pass	Fail
1	Ensure the levelness of the slab before installing the formwork and take into consideration the thickness of the wood used.		
2	Ensure the dimensions of the structural elements to be poured and check for horizontal and vertical alignment.		
3	Verify the thickness of the slab in all areas.		
4	Use good quality wood without holes, protrusions, or defects.		
5	Ensure the safety of metal and wooden props and the distance between them and their height.		
6	Review the connection points of the props in case of high elevations and ensure the strength of the reinforcements at the joints.		
7	Ensure the installation of inclined props in both directions and secure them well with columns or walls.		
8	Ensure the stability of the slab under the props and its ability to bear the loads of the supports		
9	Avoid using blocks under the props and replace them with intersecting wooden battens.		
10	Ensure the presence of diagonal props.		
11	Ensure that the wooden formwork is flat and at a constant height.		
12	Ensure the adhesion of the wood panels to prevent concrete leakage during pouring.		
13	Ensure there are no protruding concrete pieces from columns due to poor execution.		
14	Verify the accuracy of the slab dimensions and the locations of any dropped beams if present.		
15	Review the dimensions and heights of any dropped beams.		
16	Review the vertical sides of the dropped beams.		
17	Check the accuracy of the angles of the slabs.		
18	Review the reinforcements when connecting application panels together and ensure proper jointing.		
19	Check that bathroom slabs drop below the level of other slabs.		
20	Review the locations and dimensions of electrical, plumbing, and HVAC openings.		

Table A8. Quality control checklist for slab reinforcement.

Item number	Item description	Pass	Fail
1	Ensure the cleanliness of the reinforcement steel and the absence of rust.		
2	Verify the type, diameters, quantities, and lengths of the reinforcement steel according to the design code.		
3	Ensure that the reinforcement steel is placed in its designated location as per the drawings, especially in the cantilever and the stair.		
4	Check the connections and lengths of the rebars according to the drawings.		
5	Place spacers beneath the bottom mesh steel and between the formwork and the beam sides.		
6	Ensure the dimensions of the beam's stirrups, their quantities, and their spacing are equal or as per the drawings.		
7	Ensure that the stirrups are interlocked alternately.		
8	Properly connect the upper and lower beam reinforcement steel with the stirrups.		
9	Ensure proper bending of beam reinforcement steel and ensure it is executed as per the drawings.		
10	Ensure the continuity of column ties within the beams (according to the plans and code instructions).		
11	Review the reinforcement steel of stairs and ensure dowel bars.		
12	Review the reinforcement steel of column capital.		
13	Review the lengths of column dowel bars and ensure their correct placement in case of reducing the column section.		
14	Ensure proper bending of column dowel bars in the last floor slab.		
15	Review the detailing of sanitary drop-downs.		

Table A9. Quality control checklist for hollow blocks distribution.

Item number	Item description	Pass	Fail
1	Review the dimensions and quality of the hollow block and avoid using broken blocks.		
2	Ensure that the hollow blocks meet the conditions and technical specifications by conducting fracture and loading tests.		
3	Ensure the distribution of the hollow blocks to guarantee the dimensions of the ribs and beams as shown in the drawings.		
4	Ensure that the ends of the hollow blocks row are completely closed to prevent concrete from leaking into the hollow blocks during the pouring process.		

Table A10. Quality control checklist for pouring.

Quality control checklist for pouring			
Before pouring			
Item number	**Item description**	**Pass**	**Fail**
1	Ensure that the mixer and the vibrator are fit for work.		
2	Ensure the quality of the concrete in accordance with project specifications: (mix temperature does not exceed 35 Celsius, fineness of cement, setting time not exceeding 45 min, mix consistency or water content in concrete, sieve analysis of the mix).		
3	Ensure the presence of a specified water content for concrete (in case of using semi-automatic mixers).		
4	Ensure that the water used in the pouring process is potable and free of impurities.		
5	The workability of the concrete should be suitable for the element being poured, according to specifications.		
6	Ensure the availability of Abrams cones (slump tests) and their readiness.		
7	Ensure an adequate number of concrete cubes/cylinders for sampling (not less than 3 samples per 100 cubic meters or as per requirements).		
8	Ensure that the wooden formwork is wet with water before pouring.		

Table A10. (*Continued*).

Quality control checklist for pouring			
Before pouring			
Item number	**Item description**	**Pass**	**Fail**
9	Review the sequencing of pouring stages with the responsible supervisor.		
10	Review the identification of casting joints, expansion and contraction joints, and settlement joints.		
11	Ensure that spacers are placed under the bottom mesh steel of slab, under the lower rebar of beams, between the sides of the formwork for the beams and the rebars to control cover thickness.		
12	Ensure that the pouring height does not exceed 3 m (preferably less—2 m) at maximum.		
13	Ensure that weather conditions are suitable for the pouring process.		
During pouring			
1	Review and ensure the accuracy of the mix proportions, especially the water to cement ratio.		
2	Ensure that the concrete is poured to the appropriate level without excess to avoid the need for demolition later on.		
3	Precisely monitor the scaffolding and props during the pouring process to prevent any unforeseen events.		
4	Use vibration in all stages of pouring all structural elements.		
5	Ensure that column rebars are not shaken or moved during the pouring process.		
6	Make sure that each part is properly compacted after pouring, especially beams, without allowing the mechanical vibrator to touch the reinforcement steel as much as possible.		
7	Ensure that the surface of the concrete is properly leveled for the finished part using appropriate tools (such as a helicopter trowel) according to the specifications.		
8	Continuously measure the thickness of the slabs and ensure uniformity of thickness.		
9	Remove excess concrete promptly before hardening and ensure that all surfaces are level and clean after pouring is complete.		
After pouring			
1	Ensure that the concrete continues to be cured by spraying and moistening it with water for at least seven days after pouring.		
2	Ensure that the formwork is removed correctly in terms of timing, location, and type of structural element.		
3	Monitor the results of breaking concrete cubes in a structured tracking table with dates.		