Enfoque basado en BIM-GIS alineado con ISO 9001 para la Gestión de Calidad

BIM-GIS base approach for quality management aligned with ISO 9001

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RESUMEN

La gestión de la calidad durante la construcción garantiza el cumplimiento de los estándares legales y del proyecto, pero a menudo depende de procesos manuales ineficientes. Esta investigación propone una herramienta de gestión de calidad alineada con ISO 9001:2015, integrando Building Information Modeling (BIM) y Geographic Information Systems (GIS). La herramienta permite digitalizar datos de inspección de calidad en obra y automatizar el intercambio de información entre software. Aplicada a la construcción de muros de hormigón armado, se demostró su funcionalidad y valor práctico. Investigaciones futuras pueden explorar casos más complejos, así como aumentar el nivel de automatización.

ABSTRACT

Quality management during construction ensures compliance with project and legal standards but often relies on inefficient manual processes. This research proposes a quality management tool aligned with ISO 9001:2015, integrating Building Information Modeling (BIM) and Geographic Information Systems (GIS). The tool digitizes on-site quality inspection data and automates information exchange between software, improving efficiency. Applied to reinforced concrete wall construction, the tool demonstrated correct functionality and practical value. Future research can explore complex case studies, increase automation, and evaluate user feedback to further improve the tool's capabilities.

PALABRAS CLAVE: Gestión de Calidad, Control de Calidad, BIM, ISO 90001, GIS.
KEYWORDS: Quality management; Quality control; BIM; ISO 9001; GIS.

1. Introduction

In the Architecture, Engineering, and Construction (AEC) industry, quality can be understood as the characteristics inherent to the fulfillment of requirements, and customer satisfaction [1]. On the other hand, quality management is a fundamental aspect that allows guaranteeing the delivery of high-quality, safe, and functional construction projects [2]. It aims to ensure that the products or services meet or exceed the customer's requirements and expectations, thus complying with current regulations and the technical specifications of the Project [3]. Building projects are characterized by a large number of activities running in parallel, a large number of stakeholders, and high budgets [4]. This highlights the importance of having a good Quality Management System (QMS) [5]. Conventional methods used for quality management are characterized by paper-based collection and recording of data, together with the storage and management of information on platforms without access to all stakeholders [6]. This often results in redundancies, subjective control, lack of efficiency, and information fragmentation that does not allow having a clearly defined quality management for the stakeholders [7]. Consequently, the probability of quality errors could increase causing large associated costs, that can amount to up to 25% of the total project cost [8]. Standards have been developed to promote the development of a QMS, including its certification. The International Organization for Standardization (ISO) through the ISO 9001:2015 standard, provides a framework for organizations to implement and maintain effective quality management practices [9]. It is based on compliance with seven principles: customer focus, leadership, people involvement, process approach, continual improvement, factual approach to decision-making, and relationship management [10]. It is one of the most widespread quality standards in the construction sector, with an increasing number of companies seeking to have such certification, since these standards guarantee a good QMS [11].

One of the most widely used methodologies in construction project management is Building Information Modeling (BIM) [20]. BIM is characterized by offering a collaborative approach that consists of the use of a multidimensional parametric model throughout the entire project life cycle [12]. Its use improves the way in which project quality information is managed, as it has the potential to improve stakeholder collaboration [3]. Despite its potential, the use of BIM in project quality management has been sparse [13], showing uses at the design stage to avoid quality defects in later phases [14]. On the other hand, the implementation of Geographic Information Systems (GIS) tools allows the management of geospatial information of the elements that make up the structure, as well as the resources involved in its execution [15]. Specifically, during the construction stage, this geo-referencing capability has been used to identify hazardous areas, plan safe routes, as well as optimize the logistics of delivery of materials and equipment, providing quality management data such as reports, photographic records and drawings, and all quality-related activities and decisions that can be managed in an accurate way [16]. The use of GIS in conjunction with BIM can be quite useful for recording data related to quality during construction [17]. Studies proposing the combined use of these two technologies for quality management have been focused on prefabrication projects, and construction of road projects. However, there is no research addressing the joint use of BIM and GIS for the quality management of building projects.

This research proposes the integration of BIM and GIS, aligned with ISO 9001:2015 standard, to develop a tool that supports quality management in construction projects of building projects. The developed tool was implemented through a case study, which consists of the construction of reinforced concrete walls of a house.

2. Research methodology

This research proposes a tool based on the integration of BIM, GIS and aligned to ISO 9001:2015 requirements, in order to improve traceability and storage of quality management data during the construction phase.

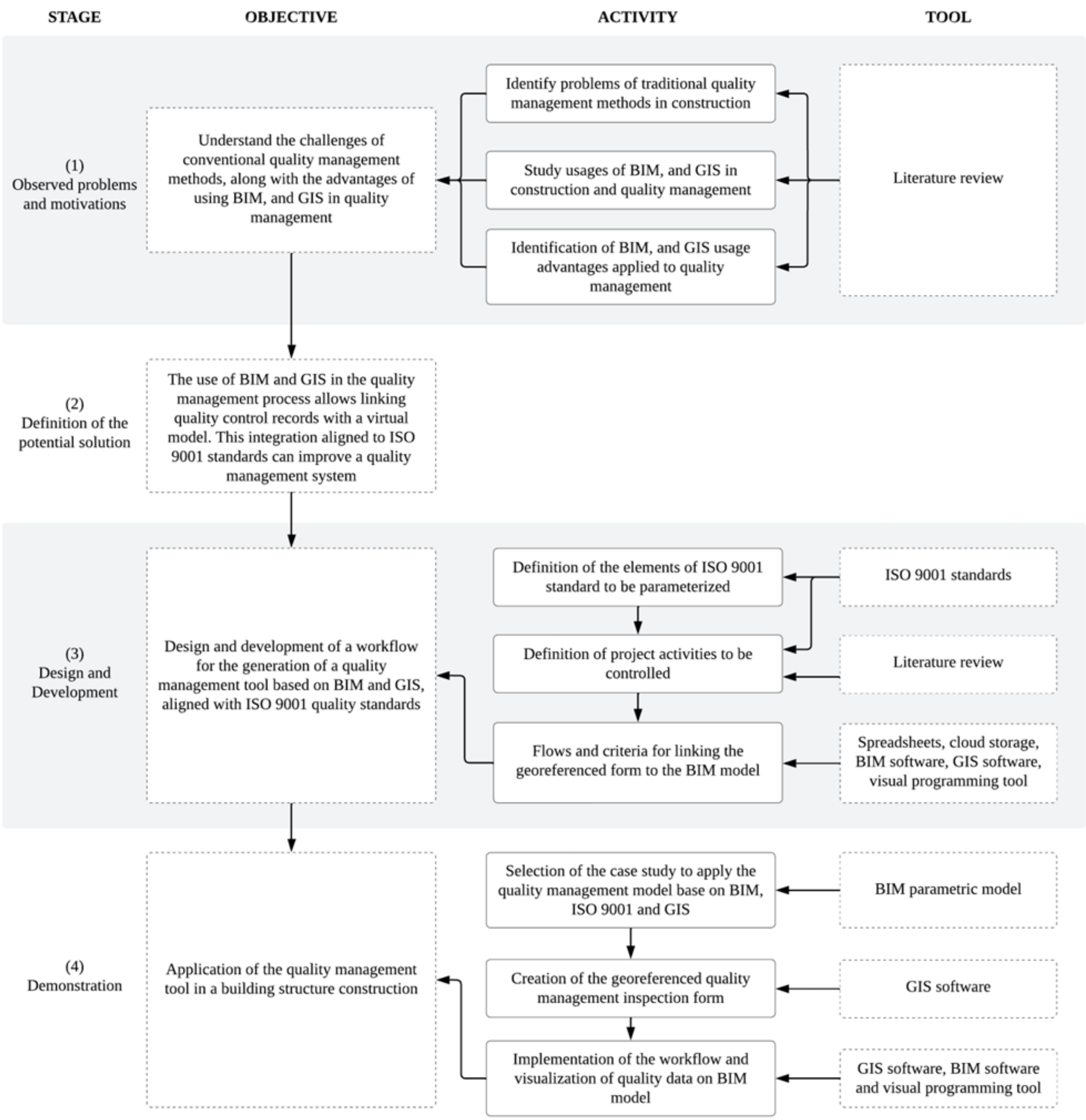

Figure 1. Research methodology.

The work follows the Design Science Research Method (DSRM) which seeks to solve an identified problem through an artifact proposal and its validation. The adaptation of DSRM to this work is organized in four stages as presented in Figure 1.: (1) identification of the observed problems; (2) definition of objectives for a possible solution; (3) design and development; (4) demonstration [18]. In the first stage, a literature review was carried out based on Scopus and Web of Science repositories, together with a review of existing standards and quality regulations. Here the purpose was to identify the status of the application of new technologies, with a special focus on BIM, GIS, and ISO 9001:2015 in QMS. In addition, the various current uses of BIM in the AEC industry, as well as the problems and challenges regarding the current methods, were reviewed.

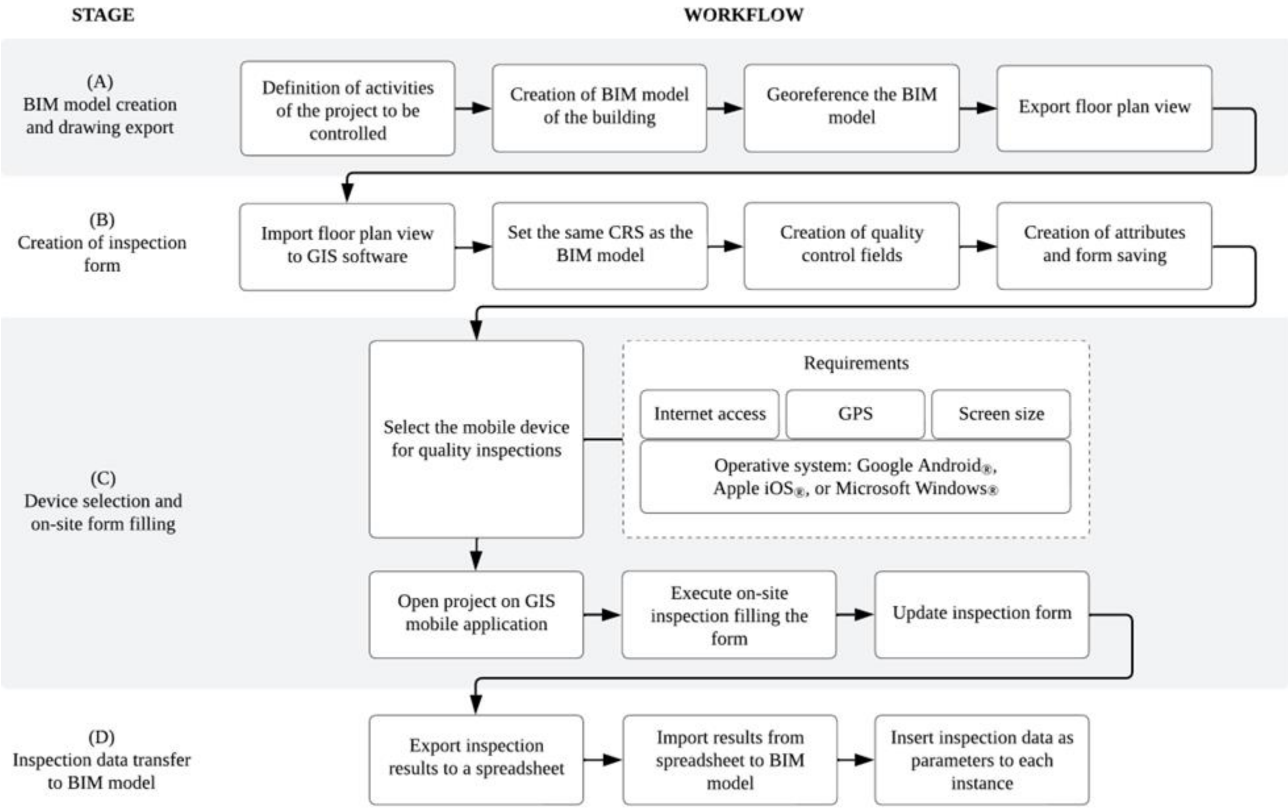

Figure 2. Workflow for the development of the quality management tool.

In the second stage a potential solution is presented, consisting of the implementation of BIM, GIS and ISO 9001:2015 to improve construction quality management. In the third stage, the quality management tool design and development was performed. In the fourth stage, the quality management tool was implemented in a case study, visualizing the results on a BIM model.

3. Developed method

The development of the tool focuses on supporting the fulfillment of requirements present in ISO 9001:2015, for the definition of a QMS [9]. For this, three fundamental aspects have been defined on which the development of the quality management tool is based, these are: (1) a defined workflow for quality inspection, (2) the digitization of inspection data collected in the field, and (3) the use of GIS and BIM models in the storage, management and visualization of quality information. The proposed quality management tool provides a prototype that links the status and progress of quality controls during the construction phase of building projects, with a parametric BIM model. It consists of the use of a geo-referenced quality inspection form, used to verify the correct execution of the supervised activity, visualizing the results in a virtual replica of the building. The quantity and order of the quality controls for each element will depend on its own type and its specific requirements, being considered as completed when the element has been submitted to all controls required for each activity related to its completion. Figure 2 shows the flow of the four stages to carry out the development of the proposed tool: (A) BIM model creation and drawing export; (B) Creation of inspection form; (C) Device selection and on-site quality inspection; and (D) Inspection data import to BIM model.

4. Results

4.1 Case study

The case study selected corresponds to a house located in Curauma, Valparaíso, Chile. Its configuration is a single level with a surface of 96 m2, and its design is based on the construction of a reinforced concrete wall system. The quality controls considered in the case study correspond to the construction of all the reinforced concrete walls of the house. In order to establish the quality requirements for these activities, the specifications from [19] were used, which details construction methods based on Chilean standards. In particular, three quality control phases were considered. The first phase includes quality controls carried out prior to concrete pouring. The second phase includes the quality controls performed during the pouring of concrete. The third phase includes the checks carried out after the concrete has been poured into the walls. In case of non-compliance with the quality requirements within the control phases, the necessary corrective actions will be recorded to consider a compliance status.

4.2 Creation of the BIM model and drawing exporting

With the quality controls already defined, the BIM model of the house was generated. The modeling was performed using the information available in the drawings.

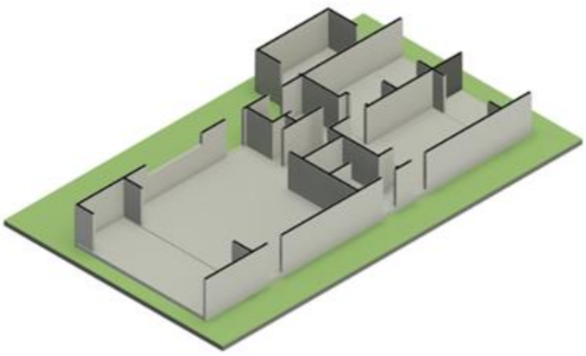

Figure 3. 3D model of the case study.

Since the quality controls will be performed on structural walls, the modeling was performed on the structural discipline within Revit. Figure 3 presents a 3D view of the modeled Project.

4.3 Creation of the inspection form

For the creation of the inspection form for the control of concrete walls, the first step was adding a layer of type points, assigning it the name “Quality form”. Within it, the fields corresponding to the type of information to be collected in the field through the quality controls were created. Seven fields were considered. (1) Quality control supervisor: text field to enter the name of the professional in charge of performing the quality inspection. (2) Status: text field to enter the quality compliance status, based on the requirements for the controlled activity. (3) Responsible: text field to enter the name of the professional responsible for the quality assurance of the controlled activity. (4) Comment: text field to enter additional comments to the compliance status when performing quality controls. (5) Date: date field to enter the day, month, and year when the quality inspection of an activity is performed. (6) East coord: field of type integer, which stores the East coordinate (CRS WGS 84) of the location where the quality inspection point is located. (7) North coord: integer type field, which stores the North coordinate (CRS WGS 84) of the location where the quality inspection point is located. Each of the fields created was used to create an attribute adapted to the activity to be controlled, forming three groups of attributes according to the control phases defined for wall concreting. The previously created attributes were assigned to each group, where the fields “Status”, “Responsible”, “Comment” and “Date” are repeated as many times as activities are contemplated within each control phase. For attributes that include the “Status” field, three options were established to determine compliance. Using the “Value Map” attribute customization option, the entries “Complies”, “Does not comply” and “Corrected” were predefined. These options will be stored in the attribute, to be selected from a drop-down list when entering the information in the form.

4.4 Execution of quality control inspection

For the field inspection, the Samsung® Galaxy Tab S6 Lite tablet was used, whose features meet the necessary requirements for the adequate visualization and management of the information. The QField application was installed on the device and a stable internet connection was ensured through the Wi-Fi network available at the construction site.

Once the document has been synchronized within QField, the floor plan of the house is displayed in the application interface.

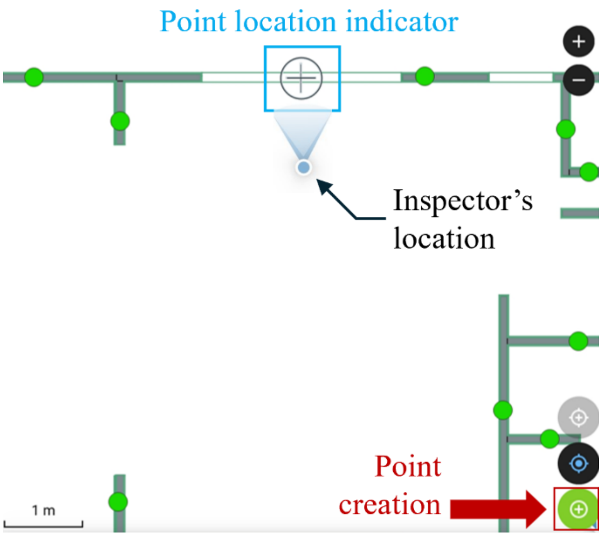

Figure 4. Creation of control points on QField app.

Thanks to the GPS integrated in the device, the inspector can at all times visualize an icon with his location and orientation with respect to the plan, allowing him to easily locate the wall in front of him. In this instance, the inspector activates the layer editing and adds the point by tapping on the floor plan (Figure 4).

Once the point is created, the quality inspection of the wall is performed according to the corresponding control phase, within the pop-up window containing the inspection form. Figure 5, shows the completed form, once the inspection of the "During concrete pouring" phase is finished.

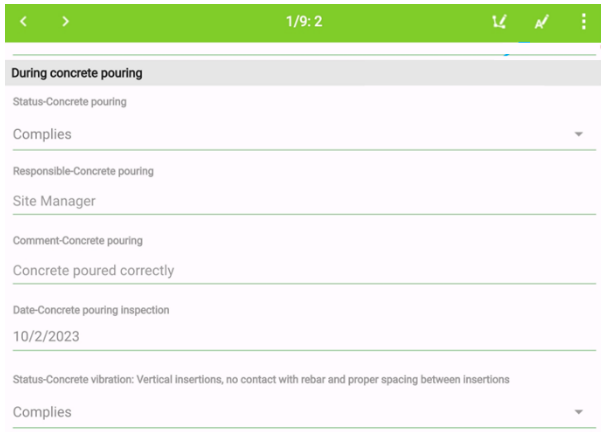

Figure 5. Completed inspection form for concrete pouring phase.

Once the inspection is completed at each point created, a green indicator is displayed, allowing the operator to visually locate the inspections previously performed. Once the quality inspection is completed, the changes are uploaded by the inspector to the virtual storage.

4.5 Linking quality inspection results to BIM model

The process of importing data into the BIM model was structured in five steps, which include groups of functions generated in Dynamo. These steps are: (1) Quality form data import, (2) Creation of shared parameters, (3) Creation and assignment of cube family, (4) Filling cubes parameters, and (5) Filling walls parameters. Figure 6 presents a view of the complete routine, that contemplates the five steps.

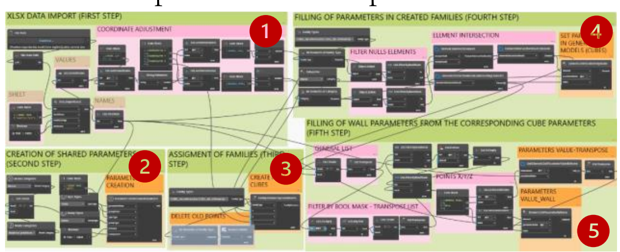

Figure 6. Dynamo routine.

Step (1) starts with reading the data from the XLSX file generated in QGIS, which is located in the local storage of the computer. From these, Dynamo extracts and separates into three individual lists the data corresponding to attribute names, coordinates of the field control points, and attribute values. Then, the value of the coordinates is adjusted, to be assigned to the X and Y axes within the model. In step (2), shared parameters were created and named according to the existing fields in the inspection form. Step (3) consists of the creation of generic families of cube type, whose function is to assign them the coordinates corresponding to the control points in the field. In this way, each instance of this family was assigned a location that corresponds to the location of a wall that has been inspected. Additionally, a routine has been generated that eliminates instances of existing cubes in the model, prior to the generation of new cubes. The purpose of this is to avoid duplication of elements in the model, which have an identical location. In this way, every time a Quality inspection data update is performed, the existing cubes (pink colored) will be replaced by new copies. In step (4), the sharedparameters previously created were filled with the attribute values for each control point. That is, each cube present in the model will obtain the parameters corresponding to the control point of its location. Then, the intersections between the walls of the model and the cubes were identified. From these intersections, two lists were generated, one containing the identification of the cubes and the other containing the identification of the walls corresponding to each cube. Finally, in step (5), the shared parameters are copied from each cube to each corresponding wall, based on the intersection. In this way, each wall subject to the quality controls will have the attributes of the inspection form inserted as parameters within it. As each wall progresses through the quality controls, the parameters associated with these inspections will be completed. To effectively appreciate the overall progress of the project in terms of quality, it is possible to use the visualization tools incorporated in Revit. In this way, the data captured in the field, being now as parameters within the model, can be managed and sorted for interpretation and visualization in the 3D model of the house. Figure 7, shows an example, where graphical display filters were configured to show the status of the walls, indicating in red color those that remain pending, and in green color those with completed status.

ElementID	East coord.	North coord.	Final status	Finishing date
Completed				
1hB7eHvOr8hfNSjXp1$j6J	259654.99509534	6332363.22445745	Completed	10/30/2023 12:00:00 AM
1hB7eHvOr8hfNSjXp1$jD9	259668.138493988	6332363.22445745	Completed	10/30/2023 12:00:00 AM
1hB7eHvOr8hfNSjXp1$jA8	259655.345928469	6332357.3488961	Completed	11/2/2023 12:00:00 AM
1hB7eHvOr8hfNSjXp1$jtA	259662.735221401	6332358.94973809	Completed	11/2/2023 12:00:00 AM
1hB7eHvOr8hfNSjXp1$js9	259661.82982195	6332359.91240796	Completed	11/2/2023 12:00:00 AM
1hB7eHvOr8hfNSjXp1$jnU	259660.879888094	6332359.04766396	Completed	11/2/2023 12:00:00 AM
1hB7eHvOr8hfNSjXp1$jz8	259664.180858125	6332362.34185968	Completed	10/30/2023 12:00:00 AM
1hB7eHvOr8hfNSjXp1$jvb	259665.822377545	6332363.2300791	Completed	10/30/2023 12:00:00 AM
1hB7eHvOr8hfNSjXp1$jbK	259661.667984217	6332362.572347	Completed	10/30/2023 12:00:00 AM
1hB7eHvOr8hfNSjXp1$jau	259656.074450575	6332362.67353655	Completed	10/30/2023 12:00:00 AM
1hB7eHvOr8hfNSjXp1$inW	259663.134858611	6332358.28509738	Completed	11/2/2023 12:00:00 AM
3QQ1u4qZ12UP4og4kQHS8f	259653.949469956	6332362.70164476	Completed	10/30/2023 12:00:00 AM
3EdjW$WEDCtx3vtHRBASIS	259656.052763804	6332357.89410368	Completed	11/2/2023 12:00:00 AM
0YDgMS3yz37RTPSimxS$WX	259662.218905119	6332361.76283057	Completed	10/30/2023 12:00:00 AM
0YDgMS3yz37RTPSimxS$cC	259661.960309594	6332362.03266938	Completed	10/30/2023 12:00:00 AM
0YDgMS3yz37RTPSimxS$rR	259661.468593659	6332358.68251747	Completed	11/2/2023 12:00:00 AM
0iu$q00KDCEO9e7Yw0AG2T	259659.902788676	6332363.23570074	Completed	10/30/2023 12:00:00 AM
0iu$q00KDCEO9e7Yw0AG6U	259658.151157513	6332357.36381385	Completed	11/2/2023 12:00:00 AM
Pending				
1hB7eHvOr8hfNSjXp1$j14	259664.199300544	6332364.29778044	Pending	
1hB7eHvOr8hfNSjXp1$j1v	259665.770263071	6332365.24156879	Pending	
1hB7eHvOr8hfNSjXp1$jql	259668.078532929	6332360.49622168	Pending	

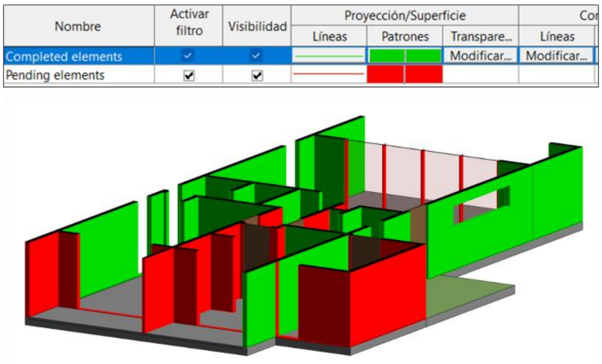

Figure 7. Visualization of quality status on BIM model elements.

5. Discussions

This research proposes a new approach that integrates tools widely used in construction to define a workflow. This flow is based on satisfying organizational and process requirements present in ISO 9001:2015. Its implementation offers the incorporation of technological support, which uses BIM as a quality information management center. This represents a particularly useful alternative for organizations that are in the process of certifying their QMS, and that have the tools used in the method of this study.

On the one hand, the creation of digitized inspection forms has demonstrated that it is possible to adapt existing quality records. This solved the problem of paper-based documentation, with records that can be managed by more than one professional in a virtual cloud. These forms work from inputs in text, date, number, and coordinate formats, allowing to cover much of the data commonly used in quality inspection forms. Given the wide compatibility of QGIS and QFieldCloud with commonly used operating systems, the creation and application of these forms can be performed from virtually any mobile device with an internet connection. This gives a certain freedom to the organization to use existing equipment or acquire new ones, according to their needs.

On the other hand, the use of GIS has proven to be a useful tool for bidirectional data exchange between on-site inspections and a geo-referenced model. In this case, QGIS has its own tools and plugins, which allow in a few steps the import of CAD files, the creation of forms, and the synchronization of files in the cloud. The proposed method uses the creation of points on a georeferenced floor plan of the project. This way of proceeding proved to be effective in the case study, being able to access the inspection of all the walls presented in the house. However, there are limitations when trying to take this configuration to the inspection of elements that may not be clearly distinguishable in a floor plan. This is the case of the superposition of elements in the same vertical, as could be the case of windows, roofs, or floors. The same limitation would arise when seeking to record inspections of elements that are only visible in elevation, such as cladding or facades. In this case, the added points could have an overlap in the plan view, as they have the same location, which would result in problems in filling out the form on the mobile device, as well as in the subsequent assignment of data to the elements. Related to this, the effect of including the use of real-time location within QField, could imply an unknown margin of error in the precision with which the device is able to locate its exact position. This is because this margin is subject to internet connectivity conditions, the existing satellite signal at the construction site, and the magnitude of the inspected elements in the drawings. In the event that these three conditions are not favorable, the location of the element will only depend on the inspector's skill in interpreting the drawings.

Finally, the use of BIM models has shown to be a high-capacity alternative in the management and storage of quality data. Its use ensures the availability and traceability of information, which is stored in the form of parameters and assigned to each corresponding element. In this way, the information can be easily organized and visualized, facilitating the follow-up of non-conformities and the implementation of corrective measures. By using Dynamo, it was possible to facilitate the input of data from QGIS, avoiding potential errors linked to doing it manually. Limitations in the use of this tool again lie in the eventual overlapping of project elements. In this case, the cubes that are modeled according to the location of the inspected elements could be modeled overlapped, which could lead to errors in the identification of intersections and subsequent data assignment.

In summary, the proposed workflow includes the automation of a large number of tasks that are traditionally performed manually. These include the storage of inspection data, the transfer of this information to a BIM model, and the processing of the data for visualization in all quality control phases. However, the developed method does not contemplate the complete automation of the workflow, having to resort to manual tasks such as the synchronization of files in QFieldCloud, and the export of the XLSX file from QGIS, for the connection with Dynamo.

5. Conclusions

Quality management during the construction phase is essential to ensure compliance with requirements and improve project efficiency. The development of a good QMS can generate benefits for organizations, including the certification of their processes under international standards. This can be a showcase for the organization, opening the doors to the award of larger and more demanding projects. This study presented a quality management tool focused on the digitization of quality controls, which is aligned with quality requirements presented in ISO 9001:2015. A workflow was designed that includes the use of GIS, through QGIS and QField, as a tool for the creation and operation of georeferenced digital inspection forms. A BIM model generated in Revit was used for the storage and management of quality information on a virtual replica. The transfer of information between these tools was supported with the visual programming tool Dynamo, achieving the automation of most of the steps involved in the process. The tool was implemented in the construction process of reinforced concrete walls of a one-story house. The resulting model allowed the management of quality information for each element, improving accuracy and efficiency in the quality control process. With this, it was evidenced that the integration of widely used tools allows for improved quality management, promoting the standardization and certification of processes. The main limitations are associated with the low level of complexity of the study case used and the level of automation achieved. Therefore, future research on the subject presents opportunities in the complexity of case studies, increasing the levels of automation and evaluating improvements of the method by receiving feedback from users.

Acknowledgments

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