Construction Quality Management System Based on BIM and Mobile Positioning

Ma Zhiliang Cai Shiyao Yang Qiliang Mao Na

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Abstract

This study develops a construction quality management system based on Building Information Modeling (BIM) technology and indoor mobile positioning technology for construction quality acceptance in building projects, aiming to address issues such as missed inspections and secondary data transcription that exist in the current implementation of specifications during construction quality acceptance. Starting from the relevant specifications for construction quality acceptance, this study analyzes the standardized processes and requirements of construction quality acceptance, and based on this, designs system functions and establishes a system architecture. It then proposes key technologies and methods such as a BIM-based acceptance task generation algorithm and mobile positioning integration method, and develops a prototype system for construction quality management. Finally, the prototype system was trialed in actual construction projects, verifying the feasibility of the system.

Full Text

Construction Quality Management System Based on BIM and Mobile Positioning

Ma Zhiliang Cai Shiyao Yang Qiliang Mao Na

(Department of Civil Engineering, Tsinghua University, Beijing 100084)

Abstract This study, based on Building Information Modeling (BIM) technology and indoor mobile positioning technology, develops a construction quality management system for quality acceptance in building engineering construction, in order to solve problems currently existing in the standardized implementation process of construction quality acceptance, such as missed inspections and secondary transcription of data. Starting from the relevant standards for construction quality acceptance, this study analyzes the standardized process and requirements of construction quality acceptance, and on this basis designs the system functions and establishes the system architecture. It then proposes key technologies and methods such as a BIM-based acceptance-task generation algorithm and a mobile-positioning integration method, and develops a prototype system for construction quality management. Finally, the prototype system is tested in an actual construction project, verifying the feasibility of the system.

Keywords construction quality management; Building Information Modeling (BIM); mobile positioning technology; Industry Foundation Classes (IFC)

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1 Introduction

The construction stage is a key stage that determines the quality of building projects, and construction quality acceptance is an important link in ensuring project quality and requires strict management. At present, China already has many specifications and standards that provide detailed regulations on the methods and contents of construction quality acceptance. However, some problems still exist in the implementation process, such as: the large number of acceptance items and the relative insufficiency of inspectors' professional knowledge, which lead to missed inspections or incorrect inspections and even fabricated data; original paper records are not easy to preserve or consult; and secondary transcription of data into document management software results in low work efficiency, all of which bring hidden risks to project quality.

In order to improve the level and efficiency of construction quality management, in recent years scholars in China and abroad have used BIM, mobile computing, augmented reality, and other information technologies to propose a number of ideas and methods. Kwon et al. developed a quality-defect management system, divided into two parts: an image-matching subsystem and an AR (Augmented Reality) subsystem. The image-matching subsystem can automatically compare the two-dimensional views of the BIM model with photos taken at corresponding positions and viewing angles on the construction site, thereby obtaining defects such as dimensional deviations and construction omissions; the AR subsystem can associate the two-dimensional views of the BIM model with AR markers. Construction personnel attach the markers at designated positions on the construction site and then take photos using mobile devices; the system can identify the AR markers and superimpose the corresponding BIM views onto the actual images, so as to discover quality defects[^1]. However, this system is applicable only when the appearance quality has obvious defects, and it does not consider inspection items such as concrete strength, rebar installation, or precise dimensional deviations (such as verticality). Tsai et al. proposed a BIM-based construction quality inspection method that supports users in determining, before acceptance, the execution locations and requirements of acceptance tasks based on BIM, and in generating corresponding images and construction information templates. During acceptance, these images can be viewed on the construction site, and the construction information templates can be used to fill in and submit acceptance data, thus avoiding omissions in acceptance tasks and greatly reducing requirements on inspectors[^2]. However, in actual acceptance, the number of acceptance tasks is large and repetitive, and it is time-consuming and labor-intensive for users to add them one by one. In addition, because the system is built on Revit, it is not compatible with BIM models from other software. Kim et al. proposed several methods for applying mobile devices in construction quality management: deploying surveillance cameras on the construction site so that the images returned from each monitoring point can be viewed on mobile devices, thereby realizing remote monitoring; adding acceptance tasks on mobile devices, assigning acceptance personnel, and marking the locations of task points on an electronic map; and enabling multiple users to share drawings, so that operations performed by one user on the drawing, such as zooming and rotation, can be synchronously displayed on the devices of other users[^3]. However, the needs for functions such as remote monitoring and adding acceptance tasks are mainly on the computer side; although they can also run on mobile devices, they are not the most critical functions when mobile computing technology is applied to construction quality management.

The above studies propose methods for improving the level of construction quality management from different perspectives. However, these methods are mainly based on construction

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Author profile Ma Zhiliang (1963-), male, professor, doctoral supervisor. Main research direction: application of information technology in civil engineering.

from the perspective of the constructor, without considering the quality-management requirements of the supervisor and the owner or information exchange among the various participants, and does not pay sufficient attention to the management and integration of original acceptance data; thus, complete acceptance documentation cannot be formed. Judging from the current situation in China, the above methods still differ substantially from the requirements of China' s standards for construction-quality acceptance.

The main objective of this study is, on the basis of BIM technology and indoor mobile-positioning technology, and starting from the requirements of China's relevant standards for construction-quality acceptance, to develop a construction-quality management system based on BIM and mobile positioning. The system is intended to support an information-based construction-quality acceptance process involving multiple participants, including the owner, contractor, and supervisor, and to improve the quality-management level of building projects.

2 System Analysis and Design

2.1 Analysis of Standard Requirements and System Functions

This study is based on relevant national and local standards such as the *Unified Standard for Construction Quality Acceptance of Building Engineering*, the *Code for Acceptance of Construction Quality of Concrete Structures*, the *Code for Acceptance of Construction Quality of Building Ground Engineering*, and the *Quality Evaluation Standard for Construction Engineering of Building Structures—Great Wall Cup*. It analyzes the management methods, management objects, and management content in construction-quality management.

According to the *Unified Standard for Construction Quality Acceptance of Building Engineering*, building projects for which construction-quality acceptance is to be carried out must be divided level by level into unit projects, divisional projects, sub-divisional projects, and inspection lots. Among these, the division of unit projects, divisional projects, and sub-divisional projects has been clearly specified in the standard, while inspection lots must be divided according to the actual project, by floor, construction section, etc., on the basis of construction and quality-control requirements and discipline-specific acceptance requirements. For samples in an inspection lot—that is, inspection points—full inspection or sampling inspection according to a sampling scheme must be carried out in accordance with the requirements of the standards [4]. The *Code for Acceptance of Construction Quality of Concrete Structures* provides specific provisions for the type of inspection lot, the corresponding inspection items, and sampling requirements [5].

After each construction process is completed, the contractor shall conduct self-inspection; only after the result is qualified may the next process continue. Among them, relatively important processes must also be re-inspected by the supervisor. In the process of self-inspection and re-inspection, each organization must fill in the corresponding acceptance documents. The management personnel of the owner are entitled to supervise and view acceptance status at any time.

Based on the above acceptance requirements, system users should include the contractor, supervisor, and owner; their main responsibilities are self-inspection, re-inspection, and supervision, respectively. The system should assist users in performing the following tasks: before acceptance, automatically generate construction-quality acceptance tasks in the BIM model according to the requirements of the acceptance standards, including inspection lots, inspection items, and inspection points; during on-site acceptance, support inspectors from all parties in using mobile positioning in combination with mobile devices and the BIM model to carry out on-site construction-quality acceptance and management, such as filling in on-site acceptance record forms; after acceptance is completed, automatically generate construction-quality acceptance results that conform to the standards. Here, it is assumed that the BIM model is provided in the format of IFC (Industry Foundation Classes), the internationally mainstream BIM data-exchange standard. The system function list and descriptions are shown in Table 1.

2.2 System Architecture and Development Environment

This study uses BIMserver as the BIM model management platform. This platform is an open-source BIM server platform initiated by TNO, a Dutch non-profit organization, and developed with voluntary participation by many programmers. It can support three-dimensional display and management of BIM data in IFC format.

With reference to the Spring MVC open-source framework, and on the premise of invoking BIM data-related services from BIMserver, this study establishes a system architecture [6], as shown in Figure 1.

The system adopts a Web-based B/S architecture and supports cross-platform use. From bottom to top, the system consists of four layers: the data layer, model layer, control layer, and view layer. The functions and development environments of the layers are as follows.

(1) Data layer. This layer stores all types of data required by the system, mainly including IFC data, standard data, and various table-document data. Data management is performed using the MySQL database management system.

(2) Model layer. This layer implements computational expression and information organization for various types of data in the data layer. It is developed in Java.

Table 1 System Function List

Function name	Function description
Import and browse three-dimensional models	Supports importing BIM model files in IFC format; supports browsing and interaction operations for three-dimensional models, including rotation, movement, and scaling; and supports viewing models by floor and component, facilitating rapid locating of inspection points.
Generate inspection lots, inspection items, and inspection points	According to the principles for inspection-lot division and sampling rules specified in the construction-quality acceptance standards, and in combination with the user' s division of construction sections, automatically generates inspection lots, inspection items, and inspection points before construction, helping formulate the acceptance plan and assisting on-site acceptance.
Fill in customized forms and take photographs on site	Supports users in using mobile devices to fill in construction-quality acceptance record forms and supports photographic records.
Indoor mobile positioning on the construction site	Supports positioning of mobile devices and can display the position of users on the construction site in the BIM model.

Figure 1 System architecture

Figure 1: Figure 1 System architecture

Function name	Function description
Automatically generate inspection-lot quality acceptance forms	Automatically generates inspection-lot quality acceptance forms that conform to the standards according to the original record forms.

Figure 1 System Architecture

(3) **Controller layer.** Implements the business logic of the system' s various functional modules; calls the basic interfaces of BIMserver to complete model-related application functions; and calls the relevant interfaces of the indoor positioning system to complete positioning functions. It is developed using Java.

(4) **View layer.** Provides three-dimensional model display and the display and interaction of other functional interfaces. The user interface must be compatible with computer browsers and mobile-device browsers. It is developed using HTML, JavaScript, jQuery, and other languages.

3 Key Algorithms and Technologies

3.1 Algorithm for Generating Acceptance Tasks Based on BIM

According to the above specifications, it can be seen that the key to determining an acceptance task is to: determine the acceptance lot, associate the corresponding inspection items with the acceptance lot, and obtain inspection points by sampling within the acceptance lot. Therefore, this study extracts relevant information about components from the BIM model and establishes an algorithm for generating acceptance tasks, that is, for generating acceptance lots, inspection items, and inspection points.

The IFC standard expresses BIM data using an object-oriented method. For entity elements such as columns, beams, and slabs, the IFC standard provides a series of definitions for object types, object properties, and relationships between objects, and at the same time includes abstract concepts such as storeys and axes. This algorithm combines the principles for acceptance-lot division and inspection-point sampling stipulated in the specifications, and generates acceptance lots, inspection items, and inspection points based on IFC data, as shown in Figure 2 [7].

In this algorithm, the system first traverses the IFC data, obtains the relationships among the abstract properties needed for dividing acceptance lots, such as

Figure 2 Algorithm flow for generating acceptance lots, inspection items, and inspection points

Figure 2: Figure 2 Algorithm flow for generating acceptance lots, inspection items, and inspection points

storeys and axes, and separately returns an entity set, an entity-type set, spatial-information sets such as storeys and axes, and attribute-information sets such as material and area. Since acceptance lots need to be divided according to the actual construction workflow stages, the user must add the construction workflow-stage attribute information of the components at this point, and the system then reorganizes the data according to the acceptance-lot division rules and returns the acceptance-lot set.

Figure 2 Algorithm Flow for Generating Acceptance Lots, Inspection Items, and Inspection Points

Then, the system associates inspection items with the acceptance lots and samples within each acceptance lot according to the construction-quality acceptance specifications, thereby obtaining the inspection-point set. The system marks the inspection points in the BIM model. After the acceptance lots and inspection points are generated, each entity element in the BIM model is assigned an acceptance-lot or inspection-point attribute and saved to the database. When construction-quality acceptance personnel use mobile devices to conduct on-site acceptance, the system can retrieve and display acceptance-lot, inspection-item, and inspection-point information from the database.

3.2 Indoor Mobile Positioning Technology and Its Integration

This system integrates an existing mobile positioning module to realize indoor mobile positioning. The module adopts a positioning method that combines geomagnetic information and Wi-Fi, enabling positioning on the construction plane with a positioning accuracy of approximately 2–3 m.

The positioning algorithm adopts the design idea of using Wi-Fi received signal strength to assist geomagnetic fingerprint matching. First, a geomagnetic fingerprint database is established offline, and then geomagnetic fingerprint matching and positioning are performed online. Establishing the geomagnetic fingerprint database offline means using the geomagnetic sensor carried by the mobile terminal to collect geomagnetic-field information and its characteristics in the personnel activity-space environment, and establishing a database of geomagnetic information and corresponding positional coordinates. During online matching and positioning, the system uses Wi-Fi signals for preliminary positioning, forming candidate matching areas.

area, and then uses geomagnetic fingerprints for precise positioning. It compares the current geomagnetic feature values and historical geomagnetic feature values with the geomagnetic feature data of each point in the geomagnetic fingerprint database of the area to be matched, thereby obtaining the position coordinates of the mobile terminal.

This mobile positioning module can send real-time planar positioning coordinates to the server and, through coordinate transformation, convert the positioning information on the plan into a certain floor plan in the BIM model for display. Mobile positioning technology can provide on-site acceptance personnel with real-time location information and help them determine their relative position with respect to components. It can play an important role especially in quality acceptance for complex buildings.

4 Prototype System Trial

Based on the above system design and key technologies, this study developed a prototype construction quality management system and carried out a trial application in the Science and Technology Building Block B project of Beijing Urban Construction Second Co., Ltd. The project is a scientific research office building, located in Chaoyang District, Beijing, with a raft foundation and frame–shear wall structure, 12 stories above ground (including 4 podium stories) and 4 stories underground, with a total building area of 34,012.10 m^2.

In this study, the Revit structural model provided by Beijing Urban Construction Second Co., Ltd. was used to export an IFC data file, which was then uploaded into the system. Before acceptance, the testing personnel selected components in the model and added the construction lot information to which the components belonged. They then clicked the button, and the system automatically generated the inspection lot, inspection items, and inspection points.

This trial covered self-inspection by the construction party. During the acceptance process, the testing personnel carried mobile Wi-Fi and a tablet computer with them and accessed the system through a browser. As shown in Fig. 3, the BIM model displays the user’ s position in real time. The user selects the inspection lot and inspection items in the tree diagram on the left, controls the showing and hiding of the corresponding components in the tree diagram on the right, selects inspection points in the model view, and clicks the table icon button in the area above the model to fill in the on-site acceptance record form as prompted, as shown in Fig. 4. The user can click the camera icon to take photographs of the corresponding part of the inspection point; after completion, the user can click the eye icon to view the photos.

The system automatically generates an inspection-lot quality acceptance record form that meets the requirements of the relevant specifications, based on the data in the on-site record form filled in by the acceptance personnel, as shown in Fig. 5. The user can directly print this form. In the inspection-lot quality acceptance record form, selecting an inspection item and clicking the corresponding inspection record allows the corresponding original data record to be viewed.

During the trial, the testing personnel collected data for four subprojects on

On-site acceptance model viewing (mobile device)

Figure 3: On-site acceptance model viewing (mobile device)

On-site acceptance form filling (mobile device)

Figure 4: On-site acceptance form filling (mobile device)

the second floor of Block B of the Science and Technology Building, covering a total of 12 inspection lots, and formed relatively complete acceptance materials for that floor. The trial results show that the system can avoid secondary data transcription and ensure that the original data can be traced. The next step will be to continue deepening the system trial.

Fig. 3 On-site acceptance model viewing (mobile device)

Fig. 4 On-site acceptance form filling (mobile device)

Fig. 5 Automatically generated quality acceptance record form

5 Conclusion

Through an in-depth analysis of acceptance specifications, this study established, based on BIM technology, an algorithm for generating inspection lots, inspection items, and inspection points; integrated the functional module for indoor mobile positioning; and designed and developed a construction quality management system that supports multiple participants, including the owner, contractor, and supervisor. The system was trialed in an actual project. The system complies with the requirements of the relevant specifications, can effectively reduce the workload of acceptance data personnel, improve the authenticity of acceptance data, and provide new methods and tools for solving existing problems in construction quality management. It helps improve the level and efficiency of construction quality management and expands new application points for BIM technology in the construction stage.

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Automatically generated quality acceptance record form

Figure 5: Automatically generated quality acceptance record form

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A Construction Quality Management System based on BIM and Indoor Positioning

Ma Zhiliang, Cai Shiyao, Yang Qiliang, Mao Na

(Department of Civil Engineering, Tsinghua University, Beijing 100084, China)

Abstract: This paper develops a prototype system for construction quality management based on Building Information Modeling (BIM) and indoor positioning, which is aimed to solve the problems in the traditional inspection process, such as omissions in quality inspection and second-hand manual entry of the original inspection data into the computer software. In this research, based on the national standards for construction quality inspection in China, the standard process and requirements of construction quality inspection are analyzed, and then the functions and architecture of the system are designed. Next, an algorithm for inspection task generation is proposed based on BIM and a prototype system is implemented by integrating an indoor positioning technique. Finally, the prototype system is tested at a real construction site to verify its effectiveness and efficiency.

Key Words: Construction Quality Management; Building Information Modeling (BIM); Indoor Positioning; Industry Foundation Classes (IFC)

Note: Figure translations are in progress. See original paper for figures.