BIM-based Meticulous Construction Management for Metro Station Projects: A Case Study

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Abstract
In addition to difficulties in collaboration and information sharing, each of the participants in Hedong metro station in Guangzhou, China, has special BIM-based management requirements during construction. Based on a detail field investigation of different requirements from different participants, a series of methods including integrating different parametric 3D models, establishing the construction schedule and the 4D model by attaching each 3D component with a region attribute, and the order sheet method for construction process control were proposed to achieve meticulous construction management for this project. Then, a BIM-based multi-platform construction management system was developed for the owner, the engineering consultant and contractors. The application results show that the proposed methods and system reduced project cost, shortened construction duration, and ensured the safety of construction by contributing to the real-time communication and data exchanges within construction process and enabling tracking project updates and rapidly updating the data of construction activities.

Keywords: Construction management, collaboration, BIM, metro station, case study

1 Introduction

Construction is a typical collaborative work, which means that information should be exchanged and shared between the construction main bodies and different workers (Soibelman et al. 2011). Nevertheless, although being considered one of the major problems that causes project delays and cost overruns (Davidson & Skibniewski 1995), paper-based method is still the mainstream for construction data collection on site (Tserng et al. 2014), resulting in ineffectiveness in construction management which needs collect and update information in real time (Young et al. 2011).

Many efforts have been devoted to facilitate the collaboration in the Architectural Engineering and Construction (AEC) industry. Among them, Building Information Modeling (BIM) technology which includes all the processes that define, manage, apply and adapt a digital model of a facility (König et al. 2012), has received much attention, i.e., of combining a BIM-based 3D model and a project schedule (which represents the fourth dimension of time) into a 4D model (Wang et al. 2014).

Faghihi et al. (2014) demonstrated a novel approach to develop construction sequencing for the installation of the project elements by retrieving enough information from BIM. Moon et al. (2014) proposed a BIM-based 4D model to verify workspace conflict. Chen & Luo (2014) adopted 4D BIM in construction quality management. As for developing BIM based tools to support coherent production management on site, the effort is far from enough (Sacks et al. 2010).

In this study, as a case study in the construction of metro project, the Hedong metro station of Guangzhou-Foshan metro line, located in the center of Guangzhou (the capital of Guandong Province in China) adopted BIM to achieve meticulous construction management, showing positive potentials in facilitating effective construction in high-quality.

2 Related works

Many practices have demonstrated that BIM technology does facilitate the construction process. Based on BIM and 4D modeling protocols, Zhang & Hu (2011) proposed an approach for conflict and safety analysis during construction through the integration of construction simulation, 4D construction management and safety analysis. Giretti et al. (2011) developed an automated system that helped the construction companies by providing real progress information of the work. Nader et al. (2013) investigated the potential of exploiting mobile BIM technology that enhanced the existing processes and workflows. Lin (2015) developed a web Construction BIM-based Interface Management (ConBIM-IM) system for engineers to enhance interface information sharing and efficiency tracking in construction projects. Goedert & Meadati (2008) extended the digital model by documenting 3D as-built model and construction progress information to capture and store construction documents for the owner in a child development center project. Trebbe et al. (2015) provided an empirical case-based evidence for the benefits of applying 4D CAD models to plan construction on a major railway station renovation project in the Netherlands.

BIM was also adopted in the construction process of underground or railway projects. Based on BIM and mobile web service technology, Le & Hsiung (2014) developed a novel mobile web-based information system to illustrate the improvements of safety management to adjacent structures and tested it in urban underground construction projects. Cho et al. (2011) developed a BIM-based construction management integrated system which was mainly made up of full-range 3D information models and web-based 5D system models, and applied it to the construction of a high-speed railway project in safety management, virtual equipment operation, cost adjustment and construction management. Ding et al. (2012) used nD system to integrate the latest information to help the owner in making decisions comprehensively.

These tools and systems mostly focused on construction management and were developed for the contractor. The objective of these tools was mainly for decision-making support rather than real-time onsite process control. With the BIM technology gradually popular in infrastructure projects, there's a demand for a novel construction management system for information sharing among owners, contractors and engineering consultants at the same time for better controlling the detail activities within the whole construction process.

3 Introduction to the Hedong metro station project

The project in this study is a 9034 m^2 metro station named Hedong metro station, which is a part of the Guangzhou-Foshan metro line in Guangzhou, China. It is a two-storey underground island station with 109.7 m long and 29.5 m wide. Figure 1 shows the location and satellite imagery of Hedong metro station.

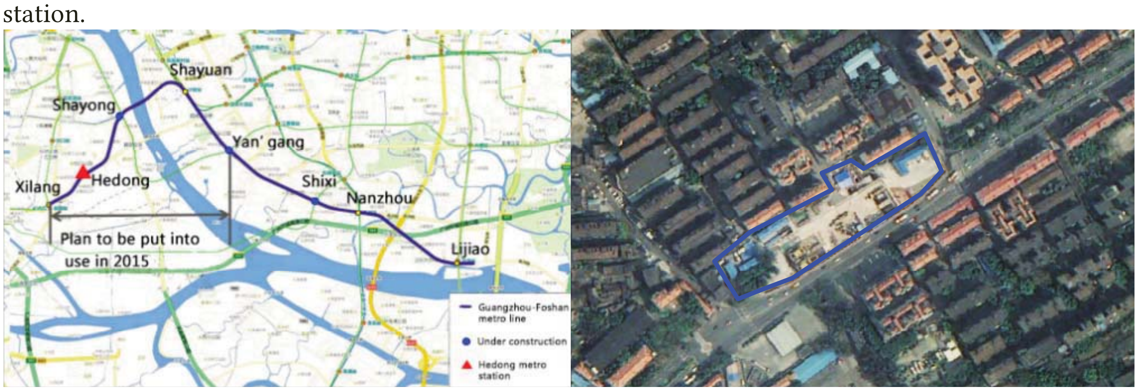

Figure 1 Location and satellite imagery of Hedong metro station

The study is implemented during installation of electromechanical equipment and decoration of the metro station. Three different kinds of participants are involved: the owner, the contractor and the engineering consultant while the actual investors of the project are the owner and the engineering consultant. Each of the participants has different BIM-based management requirements during the construction. Hence, a detail field investigation is a prerequisite work. The BIM project for the station started in Jun. 2014. By forming a 6 people group from the owner, the engineering consultant and the BIM executor, gathering investigation and expert's information consultation feedback, and theoretic analysis and so on for about 2 months' time, 2 reports for demand analysis and implementation plan respectively, were finalized in Aug. 2014. The general demands are discussed below.

The owner (the Guangzhou Metro Corporation) is responsible for the construction and operation of Guangzhou metro and related management activities. One typical demand of the owner for BIM is the collaboration. Based on BIM technology, this study creates a multi-scale model by integrating designing, construction, operation and maintenance information, which helps everyone working on the project coordinate and communicate seamlessly. Then it is also used to realize dynamic managements for construction scheduling, resource utilization, quality controlling, and safety inspection with the help of visualization methods. As-built information transformation is another demand of the owner. A typical as-built information model includes files transferred from the contractor at the end of the project in a number of file drawers or boxes. The information is marginally useful for an owner since it is difficult to extract the desired data within these files. This study creates a four-dimensional as-built model, which is implemented on a BIM database. Construction process information is attached to the model for the owner to use after construction. With the help of this enhanced as-built model, information can be fully retrieved.

According to the Construction Supervision Scheme adopted in China, the role of the engineering consultant (the Guangzhou Mass Transit Engineering Consultant Co., Ltd.) is to enhance construction supervision by introducing checks and control at various construction stages on behalf of the clients (Tam et al., 2004). In the project of Hedong metro station construction, the engineering consultant has a strong demand for meticulous management and real-time tracking of on-site activities to achieve the project objectives: in time, low cost, high quality, safety and so on. Intelligent schedule management is utilized by visualizing schedule data in a 4D-BIM model. Quality controlling is achieved by adopting an order sheet method, which will be discussed later, for supervising the detail construction activities, and even every workers onsite, so as to ensure the quality and safety of the project. And real-time construction process controlling is realized by mobile devices in an electronic communication mean.

Beside the general contractor, four subcontractors are involved for mechanical, electrical and plumbing (MEP) installations, and decoration. They have three main demands, one for better site management of equipment, material and workers, one for operation process visualization of crucial positions to reduce construction errors, the other one for collaboration with each other to share information and reduce construction conflicts. In order to meet these demands, three kinds of applications, including a desktop application (CS Client), which was extended on the authors' previous work, the 4D-GCPSU system (Hu & Zhang 2011), a web application (BS Client) and a mobile application (MS Client), are developed based on the same BIM database. These applications allow contractors to track project updates and rapidly update digital records of work completed during the construction phase.

According to all the requirements, the BIM-based platform with three clients was developed and gradually put to use from Feb. 2015. Since Apr. 2015, the platform has been running for more than 2 months smoothly.

4 BIM-based meticulous construction management technologies

4.1 Integration of different parametric 3D models

In this project, subcontractors were responsible for 3D modeling and adopted different parametric 3D modeling tools including Revit, Tekla, Microstation, MagiCAD, Tfas6 and CATIA to conduct the detail design. In order to manage all the components, all these objects should be integrated in the BIM-based construction management platform. Hence, a 3D modeling standard was firstly released to provide guidelines for subcontractors in level of details for different models, principle of component encoding, naming strategy for model files and coordination mechanism. Then a model interface based on industry foundation classes (IFC) was developed to import data from the above tools. Figure 2 shows that the IFC-based model interface fully integrates all the models in different modeling tools and forms a complete model.

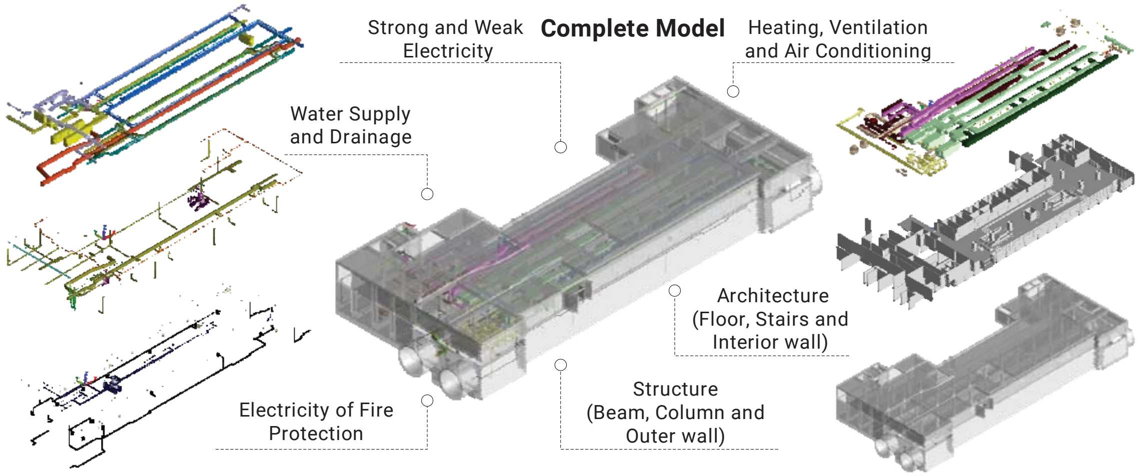

Figure 2 Integrate different models to establish a complete BIM model

4.2 Establishing the construction schedule and the 4D model

The schedule planning processes were still based on 2D drawings before introducing the 4D-BIM tool (Zhang & Hu 2011) in this project. Considering cost, resource and safety, 4D simulation was conducted to help the general contractor and subcontractors establish a reasonable construction schedule in pre-construction.

Next step was to link 3D components with schedule. However, this was a hard work because not only it required a great deal of effort and time, but the building elements were not correctly or even segmented according to the construction activities assigned in the schedule plan as well. In this case study, the authors suggested an easy method by attaching each 3D component with a region attribute as shown in Figure 3. Firstly, horizontal (X, Y) and vertical (Z) axis were created. Then by choosing two X axis, two Y axis and two Z axis, an axis-parallel box region was created so that the center of a 3D component's bounding box could be calculated to judge whether it belonged to the region or not. Finally, the schedule was assigned to a region so that it would be linked to 3D components automatically.

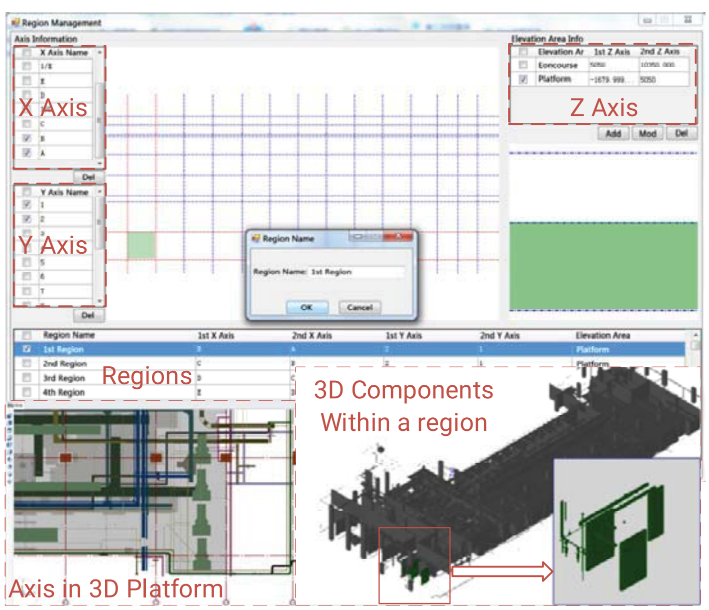

Figure 3 A region and its related 3D components

4.3 The order sheet method for construction process control

In order to achieve meticulous construction management beyond the activity level and even directly to all the workers onsite, the BIM-based order sheet method was proposed as shown in Figure 4. An order sheet for construction work consists of one construction task scheduled to be completed in one day. The contractor should fill in several order sheets with related 3D components, construction guides, materials and equipments, workers and so on for all the activities in the next day. Specifically, only inspection passed materials and equipments, and qualified workers can be selected when filling in the order sheet. Subsequently, only order sheet assigned workers can pass through the entrance gate into the construction site. In this manner, the construction quality and the safety onsite can be improved.

The order sheets are generated according to mainly the schedule and resource information in the BIM-based 4D model. Then they transfer between engineering consultants, contractors and workers to send or gather information. The collected construction process information and e-documents such as construction logs and supervision logs will be integrated into the BIM data repository automatically. An order sheet can be viewed or updated in all three applications. It also has an indirect linkage with the entrance control system of the construction site to prohibit all the unauthorized people from entrancing in, which means only workers authorized in on-going order sheets will be given this entry permission.

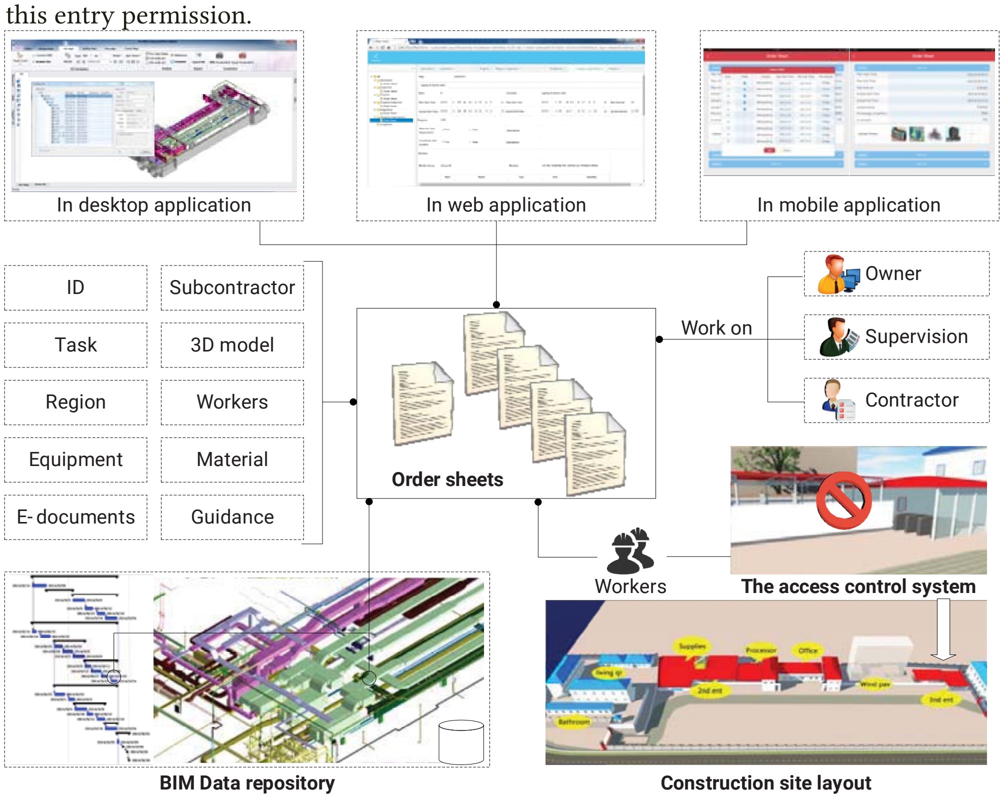

Figure 4 The order sheet model for construction process control

The order sheet is also useful for real-time tracking of work on construction sites. As a contractor or subcontractor prepares for, executes or completes a task onsite, the order sheet in the system transitions between different states in its lifecycle as shown in Figure 5.

In the preparation stage, an order sheet will be generated by the system if all prerequisites were satisfied. Then the contractor selects workers, materials and others that are necessary for completing the task contained in the order sheet before sending to an engineering consultant for confirmation. When the information were incomplete, the order sheet will be returned to the contractor. After it is approved, the contractor is allowed to execute the task. During the execute stage, the contractor reports the actual progress of the assigned tasks to the engineering consultant through the order sheet. Delay and rework needed will be reflected in the order sheet. When the task is finished, the engineering consultant and the contractor should upload related electronic documents which will be integrated into the BIM data repository to form the as-built model.

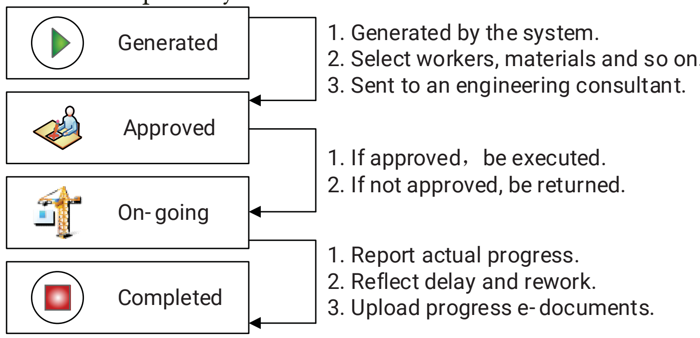

Figure 5 The lifecycle of an order sheet

5 System implementation and application results

5.1 System architecture and design principles

Based on the approach mentioned before, a BIM-based multi-platform construction management system for metro projects was developed and applied in this study. The system was developed based on an existing 4D-BIM platform developed by Zhang (Zhang & Hu 2011). The system consists of five logical components: a BIM data repository, a web server, a desktop application (CS Client), a web application (BS Client) and a mobile application (MS Client) as shown in Figure 6.

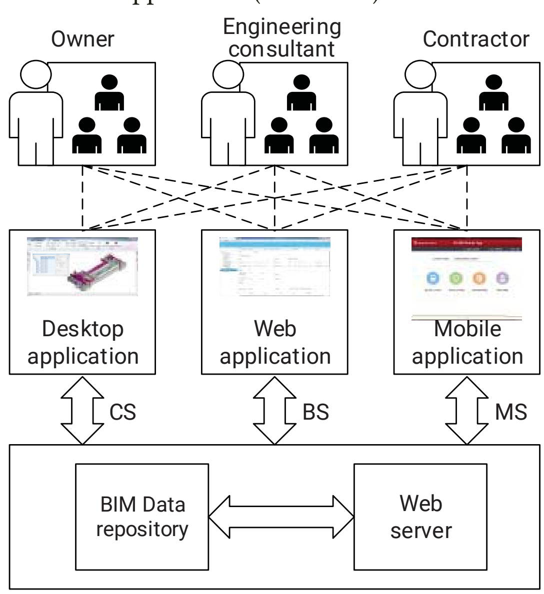

Figure 6 System logical components

The BIM data repository is responsible for storing all the multiple project information of the metro station project, including the geometric information and the corresponding technical information of all the works. It provides a solution to keep the construction management data consistent and correct. The BIM data repository consists of a primary Microsoft SQL Server 2008 database that is placed onsite.

The web server runs on Microsoft Windows Server 2008 with an Internet Information Server (IIS). The web server contains web services that are remotely called from the web and mobile applications to retrieve the required information from the data repository. The request message is sent to the server via the lower network protocol (i.e. HTTP) after the client encapsulates it with Extensible Markup Language (XML) using Simple Object Access Protocol (SOAP). On receiving the SOAP request, the web server parses the request, executes the corresponding service and returns the result to the client with SOAP.

In order to meet the demand for real-time tracking of work both on construction site and in head office, three system clients are involved in the platform. The CS client with an OpenGL-based 3D graphic platform (Zhang et al. 2014) runs on Microsoft Windows 7 or above and it is developed by using Microsoft Visual C# .NET. The CS client focuses on BIM data management and presentation, such as IFC model imports, 4D simulation and progress analysis. The BS client can be used via web browsers such as Microsoft Internet Explorer or Mozilla Firefox. It is developed using ASP.NET, which is easily incorporated with HTML and JavaScript technologies. The MS client runs on iOS 7 or above, as well as android platform. The BS client and the MS client focus on BIM data collection, field construction instruction, usual construction management, such as viewing work lists and uploading construction drawings. By these three kinds of applications, the platform offers six main functional modules to meet different demands. These modules were comprised of the 3D browser and display module, schedule management, resource management, quality control, safety management, evaluation management and workflow management.

When designing the platform, three mechanisms including data-caching mechanism, access control mechanism and server-push mechanism were considered. The data-caching mechanism is used to reduce the network time of data transmission as BIM data such as geometric data of building elements are stored in local cache files and do not need to be retrieved every time queried from the BIM server. The access control mechanism defines which user has the permission to read or write which part of BIM data so as to ensure the security of important data. For example, the subcontractor has no authority to modify work orders which have gotten past the engineering consultant. The server-push mechanism ensures the job alert and related BIM data will be pushed to those who need them initiative.

5.2 Field applications

In this project, except for the establishment of 4D model, construction simulation, schedule and resources management, etc., the meticulous construction management utilizing order sheet method should be emphasized. Through order sheets governed by the system rather than papers or lots of e-documents, collaboration and data exchange between engineering consultants and contractors became easier, more efficient and consistent. Accurate process data were collected and delivered to the unique BIM data repository. These data made it possible to analyze resource consumption accurately and timely, which did help in project cost control, as well as quality and safety control. Besides, based on states of order sheets and relationship between 3D components with order sheets, a colored 3D model could be rendered with a unique color for each order sheet state as shown in Figure 7. It helped subcontractor better understand others' construction progress and adjust his own construction schedule to coordinate with them.

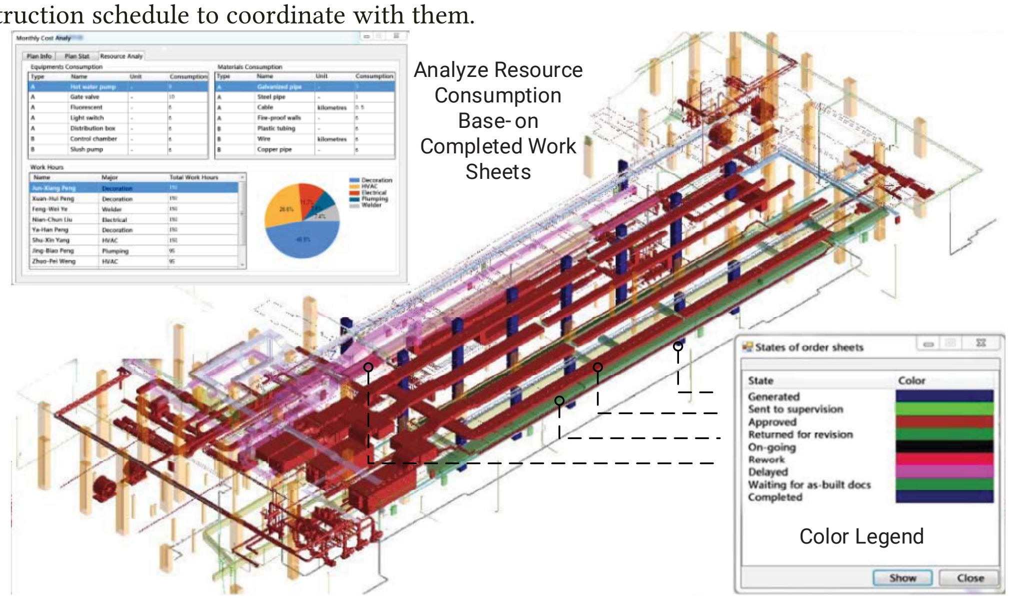

Figure 7 The colored 3D model reflecting order sheet's state and resource consumption statistics

During the MEP installations and decoration period of Hedong metro station, about 142 project participants including owner, engineering consultant, contractor, subcontractor and workers were involved in this study. 4 system workshops were held on construction site to demonstrate how to use the BIM-based multi-platform construction management system. Besides the guide for 3D modeling, 5 other guides were suggested for BIM tools selection, schedule compiling, material management, as-built model delivering and QR Code management. In the past 2 months, 206 order sheets were generated and traced by engineering consultant, contractor and subcontractor with the help of the three clients. Figure 8 shows a screenshot of the 3D model related to an order sheet for the installation of a fire box and a photo on site after the work was completed.

According to the feedback, the system shortened the construction duration by more than 3 weeks and totally save the cost about 400,000 RMB. During the construction phrase, more than 2000 collisions and construction conflicts were found and avoided, indicating that there was a significant improvement in construction process control and collaboration between different subcontractors.

Figure 8 A screenshot of the 3D model related to an order sheet for the installation of a fire box and a photo on site after the work was completed

6 Conclusions and future works

In the case study of adopting BIM technology to the meticulous construction management in Hedong metro station project, some key issues including integration of different parametric 3D models, establishing the construction schedule and the 4D model, and the order sheet method for construction process control were discussed. A 4D-BIM construction management system with 3 clients was developed based on the same BIM database. Application results showed that the proposed methods and system contributed to the real-time communication and data exchanges within construction process, enabled project participants to track project updates and rapidly update the data of construction activities, and ensured the quality and safety of the construction, thus meeting most of the demands from the owner, the engineering consultant and contractors.

In the future, the system will be revised according to more participants and then applied to many other on-going metro projects in Guangzhou. Further studies will be required in the complete as-built model and data delivery from the construction period to the operation and maintenance period in metro projects.

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