THE STUDY OF BIM-BASED MRT STRUCTURAL INSPECTION SYSTEM

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ABSTRACT: The Taipei MRT (Metropolitan Rapid Transit) system has been operated since 1996. Facing the challenge of safety and sustainability of MRT, it is urgent to develop a structural inspection strategy and maintenance system based on the concept of life cycle management. In the mean while, Building Information Modeling (BIM) has become an emerging technology in the architecture and construction industries. BIM utilizes the 3D CAD objects to simulate the real word building elements and with the ability to maintain life cycle information for a building. BIM is an ideal tool and platform for developing an inspection and maintenance system. The goal of this research is to establish a MRT structural inspection system concept based on BIM and life cycle management.

In this study, a BIM model of shield tunnel was established to demonstrate the integration of 3D CAD with inspection records. A MRT structural maintenance database, which includes structural deterioration types, inspection records, and repair methods, was designed to interact with the BIM. An inspection prototype system was designed and implemented to perform the MRT structural inspection. The proposed system was designed with mobile-side and server-side systems. The mobile-side system was designed to perform on mobile devices such as tablet computer or smart phones with the ability to mark defects on BIM, as well as to fill in inspection sheets and photos; the server-side system can assign inspection tasks, maintains all inspection records, automatically output inspection reports, and analyze the database to prioritize all maintenance tasks.

Keywords: *Building Information Modeling, Metropolitan Rapid Transit System, Shield Tunnel, Facility Management, Structural Inspection*

1. INTRODUCTION

The Taipei MRT (Metropolitan Rapid Transit) system has been operated since 1996. Most of the MRT structures are usually constructed by reinforced concrete or steel material. Different construction materials will deteriorate over time and have limited service life. In order to ensure the safety and reliability of MRT structure and extend its service life, regular inspection, monitoring and evaluation as well as maintenance have become critical issues. In the mean while, Building Information Modeling (BIM) has become an emerging technology in the architecture and construction industries. BIM utilizes the 3D CAD objects to simulate the real word building elements and with the ability to maintain the life cycle information for a building[1]. Most of the BIM applications at Taiwan right now are mainly focused on either design phase or construction phase; only few applications are focused on maintenance phase. BIM is an ideal tool and platform for developing an inspection and maintenance system. Therefore, the goal of this research is to design and implement a BIM-based inspection management system for Taipei MRT system. The current inspection procedures were discussed to analyze the functionality of proposed system. The framework of BIM-based inspection system was established. A system prototype was then developed with five core modules implemented in a Web-based system. The advantages of this new technology over traditional system were also discussed.

2. DISCUSSION OF CURRENT MRT INSPECTION PROCEDURES

Facility life-cycle maintenance and management for MRT system is a complicated cross-discipline work involving expertise such as engineering, management, and information technology. To simplify the research work, this research was mainly focusing on the inspection procedure for structural facilities.

Figure 1 demonstrates the general concept of facility inspection. Inspection can be categorized into three different types based on the level of detail and scenarios. Routine inspection is the simplest and most frequent inspection, which usually performs in a daily, weekly, or monthly basis. The regular inspection is a more detailed inspection, which usually performs in an annual or semi-annual basis. The special inspection usually performs when special event, such as earthquake or typhoon, occurs to quickly evaluate the safety of facilities. The inspection can be done in vision or with the assist of equipment and instruments. The main purpose of inspection is to identify potential defects of structural components. When defects were identified, it is critical to qualify the level of severeness to determine the follow-up maintenance actions. Minor defects can be resolved in routine maintenance works. In terms of medium level of defects, some may require setting up sensors to monitor the deterioration trend or real-time conditions, while some may need a specific repair plan. For serious defects, a more detailed inspection is required and also need to evaluate safety of the facility.

For all three types of inspection, the execution procedure shall be similar. Figure 2 shows a proposed routine inspection procedure, which is based on the current inspection procedure with a minor adjustment.

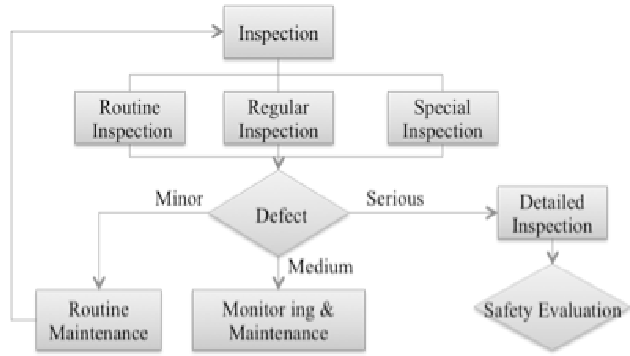

Fig. 1 General Concept of Inspection Task

The inspection processes include inspection task planning, inspection preparation, inspection execution, result evaluation, analysis & report, and prioritize maintenance tasks. Each inspection process will be discussed below.

a. Inspection Planning: In order to fulfill the frequency requirements established in maintenance guidelines and also to monitor the overall execution performance, it is necessary for manager to come out with an inspection plan for all facilities. The inspection plan shall create a serial of inspection tasks for all three types of inspections. The plan will cover all facilities and meet the frequency requirements. Each inspection task will be scheduled with start date and completion date, and assigned to a group of inspectors.

b. Inspection Preparation: When an inspection task is created and assigned, the assigned inspectors shall prepare the task in advance. The preparation will include the arrangement of essential equipment, preview of inspection checklists and drawings, review of past inspection records, review of past repair records, assurance of in-filed procedure, and plan for traffic control.

c. Inspection Execution: In the assigned inspection date, inspectors can perform the inspection in field. The crucial issue in inspection execution is to clearly and thoroughly record defects observed from the structural facility. The record shall cover the type of defect, the level of severeness, the exact location of the defect, and extent of defects. Photos or video of defect shall also be taken for every defect to supplement the record for future validation and evaluation.

d. Result Evaluation: After the in-field inspection is completed, a more experienced expert shall review the inspection data to validate the inspection results. A condition index for each component and the entire facility will be calculated based on the validated inspection result. Follow-up maintenance actions, such as repair methods and budget estimation, can also be recommended in this process.

e. Analysis & Report: For each inspection task, inspectors shall generate a task report after the result is validated. When the inspection plan is completed, the manager shall summarize the result with statistics analysis and come out an inspection report for future planning.

f. Prioritize Maintenance Tasks: Due to the limitation of maintenance resources, it is crucial to prioritize the maintenance urgency of defects based on the condition index of all components. The priority list will be utilized to generate the maintenance plan for follow-up actions. The maintenance plan will not be discussed in this study.

Fig. 2 Flowchart of Inspection Procedure

3. DESIGN AND IMPLEMENTATION OF BIM-BASED INSPECTION SYSTEM

Based on the inspection procedure discussed in previous section, this research proposed and implemented a prototype of maintenance management system for MRT structural facilities. The system structure overview is depicted in Figure 3. The proposed system is built on top of a BIM-based database. A structure facility inspection system, which includes basic information module, inspection management module, inspection execution module, analysis & report module, and maintenance module, was designed as the core functionality to interact with the BIM-based database. Other modules, such as GIS module, system parameter module, and monitoring module, were also planned.

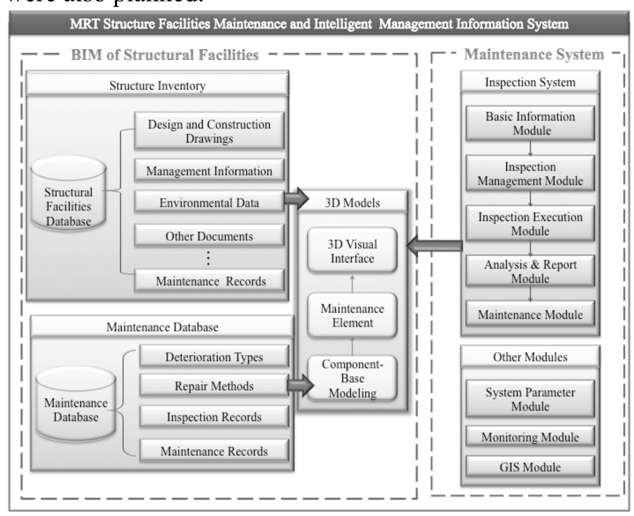

Fig. 3 Framework of Structural Facilities Maintenance Management System

The following will discuss the detailed concepts and implementation of the BIM-based database, which includes three major components.

a. Implementation of 3D Models: 3D model is the fundamental component of a BIM. To establish the 3D model of a facility, a hierarchical component decomposition chart of structural facility was identified first[2]. A naming or numbering principle was created to generate unique code or ID for each component. The 3D model for each component was created and gathered together to form an element library. This element library can be modified and reused to construct the 3D models for other structural facilities. For instance, a section of shield tunnel is composed of many rings, while each ring can be decomposed into several segments. 3D models for each segment was created and integrated to form a ring, and then extended to form a section of shield tunnel (Figure 4 & Figure 5). In this research, Autodesk Revit is utilized to create the 3D models, while elements are designed in Autodesk Inventor or AutoCAD 3D.

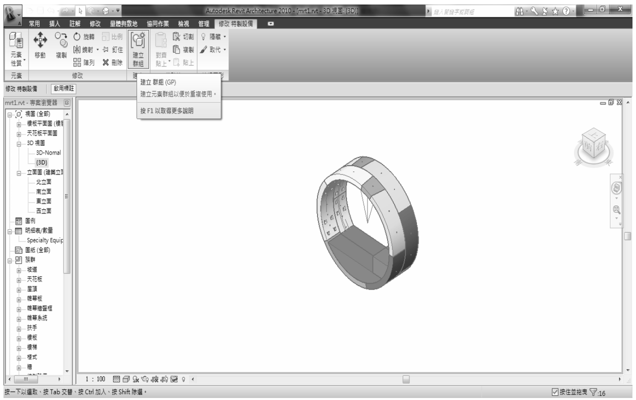

Fig. 4 Creation of 3D Model – example of components

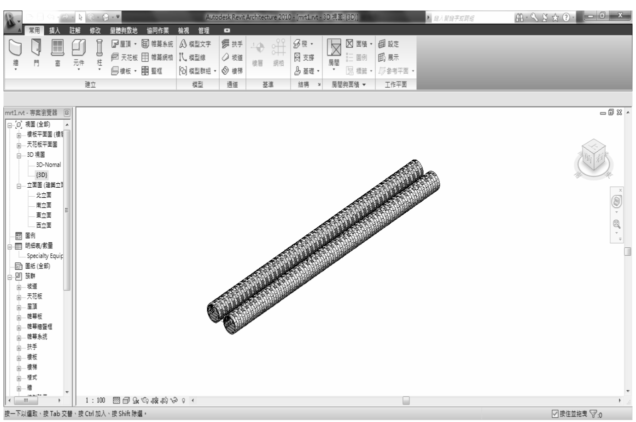

Fig. 5 Creation of 3D Model – example of shield tunnel

b. Inventory of Structural Facilities: The 2nd component of the BIM-based database is the inventory of facilities. The collection of inventory data was based on the concept of life-cycle management. Therefore, the inventory will include design drawings and documents, construction drawing sand documents, as well as completion drawings[3]. Other information such as management data, environment data, and photos were also collected. For the inventory data, some information, such as dimension data and design criteria, can be saved as data fields directly within the 3D models; some other information, such as documents and photos that cannot be stored directly inside the 3D models, can be saved in a separate database connected with links （Figure 6).

Fig. 6 Creation of Inventory Data

c. Maintenance Database: With the inventory data collected and linked to the 3D models, the final piece of the BIM-based database is the maintenance database, which includes the inspection records and maintenance records. The database was too complicated to store directly in the 3D models, therefore, was designed in a separate database (see Figure 3). The maintenance database and 3D models can be referenced through the component IDs. In addition to the inspection and maintenance records, the deterioration types and associated repair methods for all elements were also collected and categorized in advance （Figure 7). These data are crucial to create inspection checklist and condition evaluation.

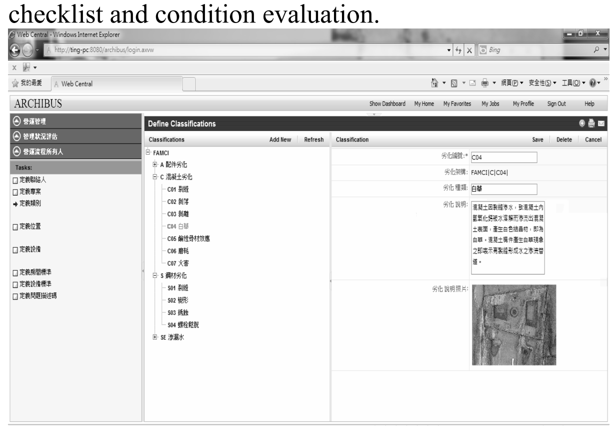

Fig. 7 Management of deterioration types

The three major components of the BIM-based database are 3D models, facility inventory database, and maintenance database as discussed above. With the database established, the maintenance management system, as depicted in the right-hand side of Figure 3, is implemented to interact with the database to support the inspection tasks. The functionalities of each module will be discussed below.

a. Basic Information Module: The main functionality of this module is to interact with the inventory database. This module can construct the structure component decomposition tree-view, display the 3D views of structural components, and manage the inventory data.

b. Inspection Management Module: The main functions of this module include scheduling of inspection tasks, task assignment for inspectors, and inspection preparation for inspectors. The task manager can setup an inspection task by choosing target facilities and assign the start and completion date, then assigned to a group of inspectors. The inspectors can then study the assignment in advance, review the past inspection records, and maintenance records within this module.

c. Inspection Execution Module: This module is design to assist inspectors to execute the inspection tasks on-site. This module is designed to perform on a mobile device such as smart phone or tablet computer. The inspector can login to this module on-site and found the task assignment. Target components are listed with guides to go through all of them (Figure 8). Inspection of each component will need to complete the inspection checklist, record defects, and taking photos for defects. The inspection results will be uploaded wirelessly to the remote server.

Fig. 8 Screen Shot of Inspection Execution Module

d. Analysis and Report Module: This module can assist manager to review and validate inspection data and evaluate the structure condition based on the inspection results. This module can also perform statistics analysis based on defect types and volumes (Figure 9). This module can also automatically generate inspection reports or analysis reports (Figure 10).

Fig. 9 Analysis & Report Module – Search Result

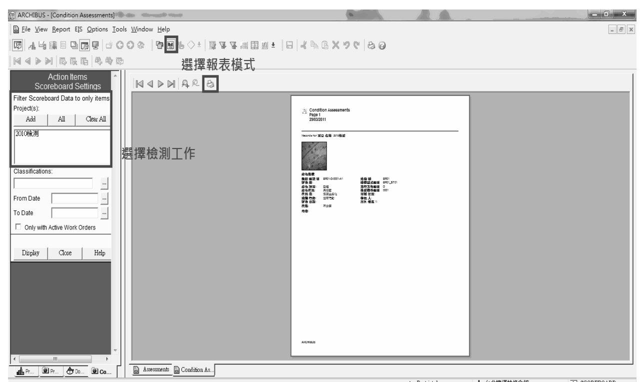

Fig. 10 Analysis & Report Module – Report Generation

e. Maintenance Module: This module can assist manager to recommend repair methods and file maintenance requests for deteriorated components, then monitor the status of maintenance works.

The five modules discussed above are kernel modules for the inspection management system. There are three other modules proposed in the system framework but yet to implement in the prototype in this study. The functionality of these modules will be discussed below.

f. GIS Module: This module will locate and displace facilities and associated inspection records in maps. This will provide the integration capability of this system to other existing GIS-based system.

g. Monitoring Module: This module is designed to manage and monitor sensors set up for critical structures.

h. System Preference Module: The system preference module is designed for the maintenance of system itself. The major functions include account and privilege management, parameter setting, and maintenance of item lists.

4. COMPARISION WITH CURRENT PROCEDURE

This research implemented a prototype of BIM-based inspection management system for MRT structural facilities, and conducted a field test in a small section of a shield tunnel. The introduction of BIM-based inspection can lead to some fundamental changes in data management and procedure execution. Table 1 summarizes the comparison between traditional system and BIM-base system.

Table 1. Traditional System vs. BIM-based System

	Traditional System	BIM-based System
Structural Components	Database-centric system with 2D CAD connection	3D-CAD-centric system supplemented by database
Inspection Execution	Record defects on paper in the field, then reproduce to digital form or database record afterward.	Record defects on mobile device with 3D view and location. Result can automatically upload to database.
Defect Recording	Plain text with photos associated with it	Mark on 3D CAD and link to text and photos
Inquiry & Report	Return with record from database. Can link to 2D CAD and photos.	Return with 3D models and link to records and photos

The study shows several advantages of BIM-based system over traditional system. Fist of all, the 3D models provide a new interface with strong visualization effect to enhance the overall comprehensiveness. Component information can store in 3D model directly or managed in a separate database. Secondly, the defects are directly marked on the 3D model to provide a more accurate record. With these marks record in 3D model over time, inspectors can easily compared past records and identify problems. Thirdly, the inspection execution module is designed to take advantage of the advanced hi-tech mobile devices with wireless communication capability, GPS sensor, and photo shooting lens, to assist inspection in the field. The system cannot only raise the in-field performance effectively but also increase the database integrity by avoiding redundancy and better accuracy.

5. CONCLUSION

This research studied the current Taipei MRT maintenance management procedures and proposed a BIM-based inspection management system. The BIM database is composed of 3D models, inventory database, and maintenance database. The inspection management system was designed with eight modules, while five kernel modules are implemented in the prototype system. The comparison of BIM-based system and traditional system shows several advantages in information storage and visualization. This research demonstrates the capability of BIM in maintenance phase from the prospective of life-cycle management. The proposed system can extend or integrate with other BIM applications in design and construction phases to form a total life-cycle management system.

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