

# BIM- and Mobile-Based System for Supporting Facility Maintenance Management

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## Abstract –

Facility maintenance tasks require extensive historical data and information to be stored, retrieved and managed. Although several mobile-based devices have been proposed to access the maintenance information from three-dimension (3D) building information model (BIM) environment, these devices are deficient in simultaneously updating the maintenance information both in the field and the BIM. This study proposes a BIM- and mobile-based system that integrates BIM model, MySQL database, Microsoft Access database, and Android App modules for supporting facility maintenance management. The Android App module consists of the functions of 3D visualization, information inquiry, and view/edit maintenance work orders. While MySQL stores all the BIM information and work order databases, the manager can then update the BIM model. Allowing to update maintenance information in the BIM model in a cloud environment improved the existing relevant systems. Thus, by updating all the information in a cloud environment, it can then update the maintenance information simultaneously both in the field and the BIM with simple mobile-based devices.

In this study, it applied BIM-and Mobile-Based System for Supporting Facility Maintenance Management on a case project. In this project, it demonstrated how this system worked in a project. The results of the case project show that the maintainers in the project can immediately update the latest information and so reduce not only the time that takes but also the potential mistakes that may happen. To sum up, the efficiency of Maintenance Management boosted significantly.

## Keywords –

Building information modeling; Facility maintenance management; Mobile devise; Android App.

## 1 Introduction

Considering the importance of building maintenance and a rise in BIM technology all over the world, many are paying more attention towards the study of maintenance management systems. A NIST study suggested that by improving interoperability and efficiency during facility operation and maintenance, a total of \$15.8 billion annual cost could be significantly reduced [1]. In order to have a successful facility management (FM), managing information about facilities will be a major contribute [2].

Recently, building information model (BIM) have been a trending topic regarding the implementation and potential applications of BIM into the whole building lifecycle [3]. More importantly, BIM is increasingly considered as an Information Technology (IT)-enabled approach that allows design integrity, virtual prototyping, simulations, distributed access, retrieval and maintenance of the building data [4]. With the vast amount of information in BIM model, intra-disciplinary collaboration and multi-disciplinary collaborations will be needed to be able to efficiently utilize these information [5].

Currently, to develop a BIM-based maintenance management system, several mechanisms must be present. First, a BIM-based 3D model is developed using commercial BIM software (such as Bentley MicroStation or Autodesk Revit). Second, information in the BIM model will need to be exported and stored externally, since information could not be retrieved straight from the BIM model file format. Third, a maintenance management system developed on a selected platform (such as website based, API based, or mobile based) for users to retrieve information.

However, the current maintenance management systems are limited in that they do not fully integrate BIM into the maintenance management system. That is, other systems utilize the information exported from BIM model as if it is an independent entity from the BIM model. Though this allows a much better flexibility with the usage of information, such as 3

inserting or deleting information, but it doesn't fully tackle the problem of information exchange in BIM, since it lacks the information exchange from the maintenance management back to the BIM model.

To improve the BIM's integration with maintenance management systems, this work develops a maintenance management system that enables information to be synchronized from the management system and BIM model. The proposed system processes the information in different way. By separating the model and information to two, the proposed system can then apply on mobile computing, and for the information, it will be processed and stored in the cloud database. Applying mobile computing and cloud database technology into the system allows instant information sharing and retrieving.

## 2 Review of Current Studies

This section reviews current studies of maintenance management systems that address issues regarding building maintenance management. Previous researches have tried several ways of integrating BIM with maintenance management systems and had come up with some very interesting results. Unfortunately, information exchange between software still remains a crucial issue when it comes to BIM based maintenance management systems. Many provided methods to link information, once it had been exported out, but rarely talked about how to import information back into BIM model. It should be noted that this research believes BIM model collects and holds vital information throughout the building lifecycle, and that it should continue to do so when used in operation and maintenance phase.

### 2.1 Building Maintenance Management

To define the term building maintenance, according to Seeley (1976) [6] building maintenance is work undertaken in order to keep, restore or improve every part of a building, its services and surrounds, to a currently accepted standard, and to sustain the utility and value of the building.

While others proposed a list of objectives to define building maintenance, as listed below [7].

- To ensure that the buildings and their associated services are in a safe condition;
- To ensure that the buildings are fit for use;
- To ensure that the condition of the building meets all statutory requirements;
- To carry out the maintenance work necessary to maintain the value of the physical assets of the building stock
- To carry out the work necessary to maintain the

quality of the building.

In maintaining a building, there are usually several strategic options available to management, and many alternative decisions to be considered. There is, for example, the possibility of reducing the demand for maintenance by addressing the actual cause of failure and identifying its consequences. Therefore, we could also define building maintenance by dividing it into three strategies [8]: Reactive/Corrective Maintenance.

Corrective maintenance is the simplest type of maintenance, where a component of a building is used until it breaks down, meaning that the component no longer performs its required function. When this happens we perform corrective maintenance to repair or replace this broken component to restore the component to its original functioning state. This type of strategy is also referred to as reactive maintenance because it happens when a component had already broken down, in which the maintenance crew then reacts to this failure in building component. Even though corrective maintenance can be expensive, it is still an important management strategy because it is how we collect vital predictive information. Corrective maintenance can be extremely expensive because of two reasons:

1. The failure of the component can cause large amount of consequential damage to other components in the building.
2. The failure of a component is unpredictable and may occur at a time when it's inconvenient to both the user and the maintaining authority.

### 2.2 BIM-based Maintenance Management System

Recently all over the world, scholars are starting to pay more attention towards the study of BIM-based management systems. Scholars are researching on how to integrate the cloud into BIM-based management systems, so in this section we would be reviewing what other scholars have achieved throughout the years First we'll review the study regarding using BIM to construct a building facility management system [9]. Second, Chuang (2011) [10] constructed a webpage providing 3D visualization while also showing construction progress. Third, Lin and Su (2013) [2] developed a maintenance management system through Navisworks API. Jian (2011) [9] constructed a BIM-based management system on a webpage, providing users the ability to search, insert, delete, and edit component information exported from Autodesk Revit. This system also utilizes the Autodesk browser plugin to provide users with 3D visualization of the BIM model through the constructed webpage. His research used ODBC export function to export information into Microsoft

SQL database, then by using ASP.NET to create webpages.

Lin and Su (2013) [2] believes that the performance of facility maintenance management can be enhanced by using web technology for information sharing and communication. They proposed quite an innovative system regarding BIM-based facility maintenance management. Unlike what other scholars had proposed, this research constructed a facility maintenance management system through Autodesk Navisworks API which enables the user to operate the 3D BIM model in Autodesk Navisworks while integrating cloud computing to retrieve maintenance related information

The main reason that the system they proposed is unique is because it stores all the information in an independent database, instead of storing the information in BIM model. In the management layer, the maintaining authority edits the BIM model and then export it into NWD file for Navisworks to read and open. When the user opens this read-only BIM model (NWD file), the system will start data mapping all the components in BIM model to all available information in FMM database. This means that all the crucial information regarding maintenance will be stored in the FMM database instead of the BIM model. The reason behind this setup is because the author believed that the amount of maintenance information stored will increase over time if all FMM pieces of information are recorded in the BIM model. Since BIM models cover a wealth of building information, central BIM models storage space should be reserved for crucial information, such as spatial information, facility ID and name of facility, facility location, and other critical information. In order to keep the system performance at an acceptable level, the information derived by other applications should be stored in an external location [2].

Though this is the most thorough system compared to others, the fact that it was constructed on Navisworks API still causes problems. This means that the user will need to use a tablet or light weighted notebook in order to actually use this system because it needs to be able to operate Autodesk Navisworks. In order to truly enhance and promote the benefits of cloud computing, a system that works on something more convenient, something that everyone would carry wherever they go need to be constructed.

### 2.3 Interoperability of BIM and Maintenance Management Systems

The main exchange format for BIM files is Industry Foundation Classes (IFCs). However, the initial problem with IFCs is that they are not intended to store and carry all relevant data for all multi-featured construction processes. Furthermore, not all relevant

data can be structured in a single super schema [11]. Many BIM software provides IFC conversion when exporting files, but there are still some issues when implementing IFC which was stated in Redmond's research. For example, IFC information models use schemas represented in EXPRESS (data modelling language).

## 3 Proposed System

The key to developing the proposed system is to store and provide information indirectly from BIM model to the maintenance management system.

In this system, it consists of four parts: BIM model, MySQL database, Microsoft Access database, and Android App. The following sections provide detailed explanations of each part.

Figure 1 presents the framework of the proposed system; it shows the main relationship between four parts of the system and how the system cooperates with each other.

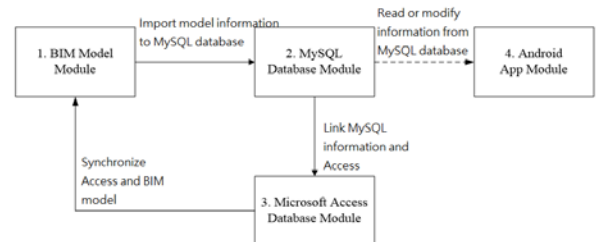


Figure 1. Framework of the System

As shown in figure 1, the proposed system divides the model and information into two, and links to two different parts, Microsoft Access Database (see section 3.3) and Android App (see section 3.4). Compare with other system, usually the information and model are unseparated, the proposed system can both read and modify the information on Android App devices.

### 3.1 BIM Model

Autodesk Revit is used to develop the BIM model owing to its popularity in Taiwan, and in case to implement the proposed system, a BIM model with level of detail (LOD) 300 is required.

A LOD 300 BIM model contains different objects such as columns, beams, walls, slabs, windows, and doors, along with these objects' information like sizes, shape, locations, orientation and geometric data (such as length, area, and volume). Also, non-geometric information/data (including the maintenance related data) are included in the 3D BIM objects.

To ensure this system work properly, some required fields in Autodesk Revit needs to be set up. The most crucial part of constructing a workable BIM model is to

make sure the information required in the maintenance system exist in Revit as component's custom parameters, and that it is exactly identical as to the name we presented, since the android application will be retrieving information from that specific column. These parameters created in the BIM model are determined by interviews conducted with the maintenance unit and through the system proposed by Wang et al. (2013) [12].

These maintenances related shared parameters were created manually in Autodesk Revit 2014 and can be separated into four main information categories: maintenance company information, inspection information, component's property information, and historical maintenance information. These four categories consist of all the information that will be retrieving through our android application all of them would be crucial regarding the backend usage for queries in MySQL database, below are the detailed explanations of what information are included in each category.

### 3.2 MySQL Database

In the system, MySQL database management system is used to store all of our information that will be used by the simple mobile devices application. There are several advantages for using MySQL database, for it is supported by different computer operating systems and it is also very user-friendly. But the main reason is due to MySQL is an open source system, in which it is convenient in searching for other users' shared experience and any other related information that helps with solving problems. In this section it will highlight on the setup of MySQL database management system for model data to be exported to and stored in. It includes two procedures; First procedure includes a total of five steps for installing WAMP and configuring the system settings. Second procedure includes Creating and editing MySQL databases.

### 3.3 Microsoft Access Database

The proposed system used Microsoft Access to enable synchronization of model data in MySQL back to BIM model in Revit, in order to tackle the problem regarding the inability of interoperability between MySQL and Revit BIM Model, see figure 2.

As shown in figure 2, the information between BIM model and Access Database is a double-side path. Compare with traditional application of BIM, since traditional works as a one-way path, the proposed system can both read and rewrite the BIM information,

which makes it possible for operators read and modify the information by their simple mobile devices immediately. Eventually, reduce the work time for transferring the information, and the potential mistakes that may happen.

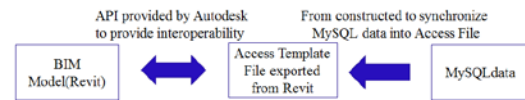


Figure 2. Information flow from Access

### 3.4 Android App

In order to create a convenient yet user-friendly platform for interacting with the data stored in MySQL database, android operating system is applied to build an android application. Two reasons explain why android system is applied. First, android is the most common operating system nowadays. Second, it is easy to obtain for most of the people.

By developing an android application, the proposal aims to provide users with a more user-friendly platform in accessing data through the cloud. Any person with an android operating system mobile device would be able to open up this application and view or update the BIM information in MySQL database.

The main profit that Android app offer is convenience, and since AR (Augmented Reality) tech is imported in this app, users can view the model through AR by the markers. Compare with traditional 2 dimensional blueprint, viewing the model in AR makes it more intuitive for the users. About AR function, it will be fully introducing in section 4.1.

## 4 Application Selections of Android App

In the application, it consists of three different modules. First, 3D Model Visualization Module, providing users with the function to view the desired 3D model. Second, Information Inquiry Module, providing users with function to search for component information in four different ways while also providing instant updating capabilities regarding the information acquired. Last, Maintenance Work Orders Module, providing users with the function to generate maintenance work orders upon the selected components and to review previous generated maintenance work orders. Figure 3 shows the framework of application functions, and the following sections will introduce the three modules step by step in detail.

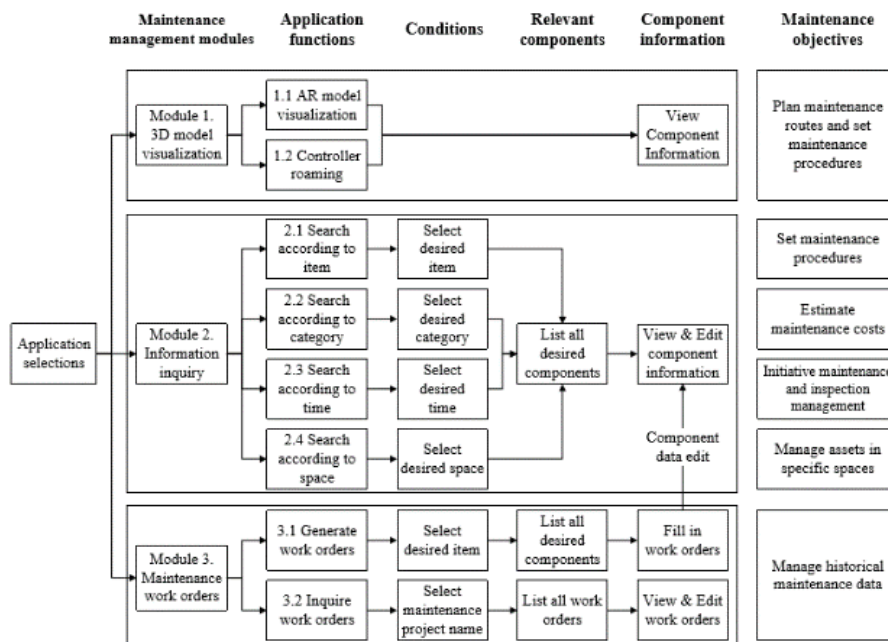


Figure 3. Framework of application function

#### 4.1 3D Model Visualization Module

In 3D model visualization module, it can divide into three parts; 3D model, mobile screen, and QR code markers. 3D model's information is stored in MySQL database, and will be presented on mobile screen by scanning the QR code markers.

In this module it provides two types of unique functions; AR model visualization and controller roaming. Users are allowed to view 3D models created by Revit and stored in MySQL database through this module with AR technology or with controller roaming function. Both functions will be able to acquire information from MySQL database by pressing the component on the mobile screen, which is accomplished by querying the information through component element ID generated by Revit.

In the proposed system, both functions put emphasis on offering users a much more convenient operating environment. As figure 4 shown, users can view the information and model by scanning the AR markers. And for figure 5, it shows that the users can also use controller roaming function to travel around in the model by SMD. Before the proposed system, users had to carry lots of devices or papers for operation, however, the proposed system overcomes these inconveniences.

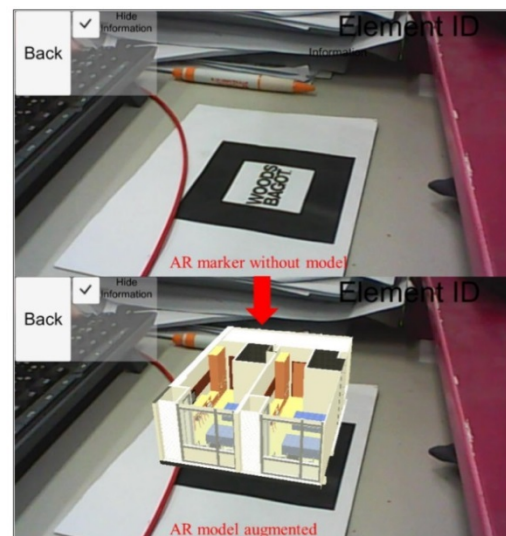


Figure 4. Markers and AR model augmented



Figure 5. Controller roaming function



## 4.2 Information Inquiry Module

There are two types of information that would be displayed in application. The first type of information is the basic information. It includes type name, component dimensions (width x height), serial number, location (space number), level, construction cost (direct cost), net width and height, room area, and material names.

This type of information is linked with the model directly, so the users are unable to modify the information by app (mobile devices), but are able to view the information.

The second type of information is the maintenance information in which the data are changeable by users. Including maintenance company name, person in charge, installation date, previous and next inspection date, previous maintenance cost, condition, general and detail category, all the information can be change on the app which the users are using.

Since the proposed system consists of two databases, it guarantees that the information changed from app can imported back to BIM model, compare with other systems, the BIM model and database are setted up together, people can only view the information yet are not able to modify it. For the second type of the information, which just mentioned, can then be able to change on the app in the proposed system.

To search for the desired component and its information, the information inquiry module provides two types of inquiry functions, namely, search according to item and category. Shown in Figure 6 and described as follows

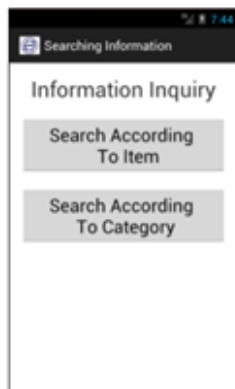


Figure 6. Information Inquiry

- Search according to item: This function lists the six types of components in the spinner for users to choose. For example, if a user knows which door to search for, then the user would only need to choose the component type to be "door" and then search through all the doors to acquire information regarding the desired door, see Figure 7.

- Search according to category: This function provides two spinners for users to choose the general and detail category of maintenance work. General category is the architectural construction, and detail category includes maintenance work for masonry finishes, paint finishes, water leakage, doors and windows, room partitioning, metal materials, plumbing fixtures, and ceilings. These detail category describes several maintenance projects that components would undergo.



Figure 7. Demo of search according to item

## 4.3 Maintenance Work Orders Module

In Maintenance work orders module, it consists of two parts. The first part is Generate work orders. By selecting desired item, it will then list all the desired components which the users can fill in the work orders. After filling the work orders, the users can both View & Edit component information. The second part is Inquire work orders. By selecting maintenance project name, users are able to view and edit the work orders.

The main purpose of this module is to allow the users generate and search for work orders at any time and any place. The other purpose of this module is to help users manage historical maintenance work orders, with all the maintenance work orders stored in MySQL, maintenance work orders database, the users will be able to effortlessly manage this historical data. Additionally, each maintenance work order was created based on a component, meaning that this one to one relationship between work order and a component will decrease any uncertainties when users are reviewing work orders.

Since all the work orders are stored in MySQL database, the information of the work orders will also be able to store back in the model.

- Generate Maintenance Work Orders: Generate maintenance work orders based on a selected component.
- Inquire Maintenance Work Orders: Inquire maintenance work orders based on the selected maintenance project name

## 5 Case Study

The proposed system is applied to a building project of a national research center located in northern Taiwan. This building built with reinforced concrete (RC), including four upper-structure floors and two underground-structure floors, which is a multi-purpose building that provides guests with accommodations, parking spaces, several event venues or spaces to host conferences and meetings, and a dining hall.

All of the 75 housing rooms in this building include various types of furniture components, which can be further divided into several categories including, beds, closets, cabinets, electronic devices (TV and refrigerators), tables, and chairs. These added up to more than a hundred of components to be managed.

### 5.1 Maintenance Practice of Case Project

The case study of this research focus on a new-built academic center (four upper-structure floors with RC), during construction stage, BIM model is built. The manager of the building is a team of construction from the owner. Usually the team focus on 3 different works. First, planning and constructing for the new building. Second, maintaining and repairing the existing build and facilities. Last, Space setting and numbering for the building. After starting the operation management stage, the owner proposes an operation management system in order for the convenience of the building in the future. This research helps the manager establish the operation management system.

### 5.2 Applications

Based on the information exported from the BIM model to the MySQL database, one can start using the application (maintenance management system) by first logging into the system by entering the correct email and password. The system will then go to the module selection page of the system.

Next, users can choose to visualize 3D models through AR or controller roaming functions. For example, a maintenance staff could be able to visualize the whole floor and identify each component located and seen on that model. This helps maintenance personnel with planning maintenance route, since they will be able to easily observe the whole layout of the floor in 3D. The users could also be able to have a better idea of where the component is located at and the difficulty of maintenance. Figure 8 shows a user using a mobile device to visualize the AR model of a room from the case study.

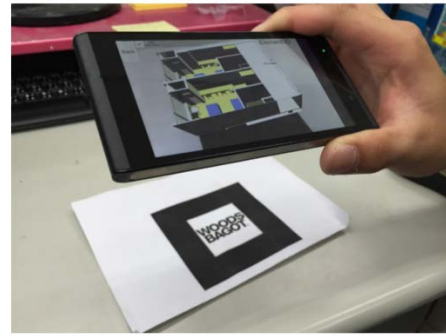


Figure 8. AR model application

Users can also quickly acquire information through Information Inquiry Module by using condition-based functions to find the component and view its information, as shown in figure 9 as an example. Users first select the conditions then choose the desired component from a list in order to view and modify information.

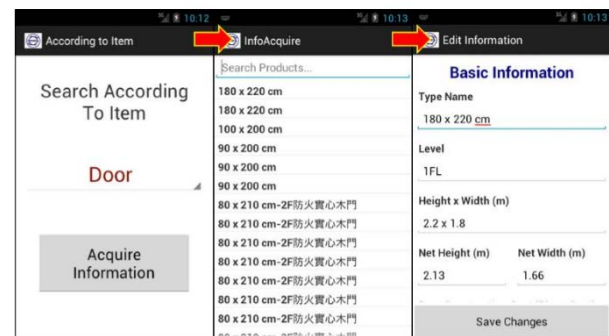


Figure 9. Steps for information inquiry

Lastly, the users will be able to generate and view maintenance work orders. The first function, generate maintenance work orders, let users create maintenance work orders targeted to one component, meaning each maintenance work order corresponds to a single component. The second function, inquire maintenance work orders, let users search for all the maintenance work orders by their maintenance project, which would list out all the components that belongs to a maintenance project.

## 6 Conclusions

This work demonstrated that integrating BIM based maintenance management system and mobile computing is feasible via the development of a mobile application. The integration provided by this system is significant in three aspects. First, BIM can support information exchange through the internet by providing BIM model information to MySQL database. Second,

the 3D model visualization module allows BIM model to be viewed through mobile devices with augmented reality technology. Third, a truly complete integration between BIM and maintenance management system in enabling data exchange from maintenance management system back to BIM model. Overall, the proposed system demonstrated its effectiveness in enhancing the current BIM-based maintenance management system applications.

Future research in this area may also include the following directions in expanding the proposed system. First, while the current system considers 6 popular component types, other types of components, such as MEP system components can be included. Second, implementation of this system towards various BIM software could be tested. Third, evaluation of maintenance companies or other analytical functions can be included into the application, to focus on how information can be used to help make better decisions. Last, the AR tech in this project imported markers, however, it is possible to make it mark-less, which enable that in future, operators no need to carry papers or find the markers that is hid in the structures.

## Acknowledgments

This research is financially supported by the Ministry of Science and Technology of Taiwan (Contract No. MOST 104-2622-E-009-021-CC3 and MOST 104-2221-E-009-175-MY3). We also like to sincerely express our appreciation to Ming-Wei Hung in Concord Tech Taiwan Company for his technical assistance. In addition, the valuable assistance and collaboration of several practitioners involved in the case study are greatly appreciated.

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