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建築資訊模型應用於營建工程知識與進度更新管理

Applications of BIM Technologies in Knowledge and As-built Schedule Management in Construction

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本論文係冉淑慧君（D94521007）在國立臺灣大學土木工程學系博士班完成之博士學位論文，於民國 103 年 1 月 17 日承下列考試委員審查通過及口試及格，特此證明

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摘要

工地管理一直都是營建管理成功重要關鍵因素之一，而在工地管理直接執行應用的知識管理(Knowledge Management)與進度管理(Schedule Management)是近年來在營建管理領域高度被探討的重要議題。目前知識管理與進度管理主要是以文字的模式作為資訊傳遞的方式，有時還是不易表達實際現場建物構件位置的進度與經驗知識，因此本研究利用建築資訊模型(Building Information Modeling, BIM)之視覺化效果特色建置 3D BIM-based 知識管理與 BIM-based 進度更新管理模式，有系統地彙整蒐集及管理工程在施工階段之知識分享與進度更新管理，以利提昇營建工地管理之效率與效益。利用 BIM 方法應用於 BIM-based 知識管理來彙整相關工程累積的知識與經驗，主要的好處在於能夠有效率地瞭解執行工程相關之知識資產，有效地彙整及管理工程專案的知識，同時應用 BIM-based 進度更新管理模式，能更有效地展現工程實際進度。營建工程未來應用 3D BIM 模式將成為工程專案執行控管之一種趨勢。本研究透過相關文獻收集分析及業界專家訪談，探討營建工程應用 BIM-based 知識管理與 BIM-based 進度更新管理模式之需求、模式及架構，建構出 BIM 模型管理模式、BIM-based 知識管理模式與 BIM-based 進度管理模式之流程與機制，主要分成四個部分進行研究：(1)首先探討 BIM-based 知識管理與 BIM-based 進度更新管理之問題及需求；(2)提出 BIM 模型管理模式、BIM-based 知識管理模式與 BIM-based 進度管理模式之流程與機制；(3)建置 BIM-based 知識管理與 BIM-based 進度更新管理雛型系統；(4)利用個案營造廠的實際工程應用 BIM-based 管理模式及系統，評估營建工程專案之知識管理與進度更新管理之成效及可能遭遇困難，提供未來營建工程工地管理之參考。

關鍵字: 建築資訊模型、進度管理、知識管理、BIM 模型管理

ABSTRACT

Various visual representations of a project management and associated information combined with visual representations of the project in progress, i.e. Building Information Modeling (BIM), can assist with these tasks of identifying effective construction strategies for managing a project's knowledge and schedule. The application of BIM integrated with as-built schedule management and the knowledge management for building projects during the construction phase is discussed in this work. To assist the general contractor in effectively and efficiently managing knowledge and schedule, this study proposes BIM model management model, BIM schedule management model, and BIM knowledge management model. Furthermore, this study presents novel prototype called the Construction BIM-assisted Schedule and Knowledge Management (ConBIM-SKM) prototype for general contractors in Taiwan. Finally, the ConBIM-SKM prototype is applied to a case study of a commerce building project in Taiwan to verify its efficacy and demonstrate its effectiveness during the construction phase.

During the process of BIM application during the construction phase, it is necessary to consider the process management regarding the BIM models. Before the applications of BIM models, all new BIM model or updated BIM models must be reviewed and approved. Only the approved BIM models can be published and deliver to related participants to apply BIM model.

Regarding to schedule management, there is a great deal of research focusing on the simulation of the 4D approach (3D and time simulations), although the idea of the 4D approach is not new. There are few studies on updating an as-built schedule using the BIM approach. Notably, the proposed approach retains information about changes and conditions to the as-built schedule in a digital format and facilitates easy and effective visual updating of as-built schedule information in the web environment. Furthermore, project participants can access and utilize the most recently updated as-built schedule integrated with the BIM application in practice during the construction phase. The case study results show that the ConBIM-SKM prototype provides users with centralized storage of all updates to the contents and status of the as-built schedule during the construction phase of a project, such that the project managers and project engineers can track and manage the visual status effectively. Overall, field test results indicate that the proposed ConBIM-SKM prototype is an effective and visual platform for the general contractor to handle construction work using an as-built schedule integrated with BIM model.

Regarding to BIM-based knowledge management, this work presented and developed the ConBIM-SKM prototype as a visual platform to improve construction knowledge sharing in building projects. Using the BIM technology, project managers and engineers can gain knowledge related to BIM and obtain feedback provided by jobsite engineers for future reference. Overall, field test results indicate that the ConBIM-SKM prototype is an effective and simple platform for construction knowledge management. The case study results demonstrate the effectiveness of a ConBIM-SKM-like system for KM during the construction phase.

Keywords: BIM, Building Information Modeling, Schedule Management, Knowledge Management, BIM Model Management.

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LIST OF ABBREVIATIONS

A/E/C: Architectural, Engineering, and Construction

AIA: American Institute of Architects

BIM: Building Information Modeling

BPMN: Business Process Mapping Notation

CAD: Computer-Aided Design

IDM: Information Delivery Manual

IFC: Industry Foundation Classes

ISO: International Organization for Standardization

MPS: Model Progression Specification

IPD: Integrated Project Delivery

LOD: Level of Development

RFI: Request for Information

1. Introduction

1.1 Motivation and Background

An as-planned schedule can be updated frequently, particularly as a construction project becomes larger and more complex. In the study, the as-built schedule reflects the actual start time, actual completion dates, actual duration of the specified activities during the process or final status. A general contractor typically requires access to as-built schedule information to control and manage construction projects. Updated as-built schedule management is essential to control and manage construction projects, particularly because it enhances communication and coordination among project participants. Promptly sharing the updated as-built schedule with other participants helps them make compatible decisions, which helps to minimize possible disputes. Therefore, updated as-built schedule monitoring and control among project participants should be necessary and important to the general contractor. Until recently, on-site progress data collection has been mainly paper-based. This method has been reported as one of the major problems that causes project delays and cost overruns (Davidson and Skibniewski, 1995). Manual methods, which are impractically slow and do not always achieve the desired result, require a great deal of time and energy. (Navon 2007; Trupp et al., 2004; Hegazy and Abdel-Monem, 2012). Consequently, collection of as-built schedules from project participants is ineffective, thus reducing efficiency and resulting in a lack of as-built schedule information. This process ultimately results in confusion. With the advent of Internet technology, web-based as-built schedule information management solutions have facilitated information distribution and sharing among project participants. Utilization of web technology enhances the sharing of as-built schedule information in construction projects and has recently become increasingly important due to the ease with which information can be shared through web solutions.

In Taiwan, there currently are practice problems regarding updating an as-built schedule at the jobsite in Taiwan (such as no as-built updating schedule). One of those problems is hard to understand an accurate position or location from text-based illustrations of a traditional schedule. Building information modeling (BIM) is a new industry term referring to parametric 3D computer-aided design (CAD) technologies and processes in the AEC industry (Taylor and Bernstein, 2009). During the construction phase, effectively tracking and managing as-built schedule information integrated with BIM-assisted illustration in construction reduces mistakes. Effective BIM-assisted as-built schedule information sharing allows project engineers to identify a current as-built schedule and make accurate decisions in the visual environment. Despite many studies and discussions in academic and practical literature regarding the simulation of 4D approaches (3D computer model + time), few studies on the practical updating of as-built schedules, integrated with the BIM approach during the construction phase, have emerged.

It is vitally important for project managers and onsite engineers to obtain knowledge about construction and to solve any problems that may arise. To enhance the knowledge management, onsite engineers can learn from the experience of other onsite engineers. Construction experience transfer involves using knowledge gained during the completion of previous projects to maximize the achievement of current project objectives (Reuss and Tatum, 1993). In order to share knowledge between similar projects, construction professionals have traditionally used techniques ranging from annual meetings to face-to-face interviews (Reuss and Tatum, 1993). In addition to experts' memory, construction experience can be recorded in various media, such as documents, databases, and intranets.

Knowledge management is the collection of processes controlling the creation, storage, reuse, evaluation, and use of experience-based knowledge in a particular situation or problem-solving context. In construction, knowledge management focuses on the acquisition and management of important experience-based knowledge provided by job engineers.

Regardless of whether a project executed by an architectural firm is successful, valuable knowledge can be gained, and should be documented so that onsite engineers can identify what worked and what did not. From the perspective of knowledge management in construction, these experiences and the knowledge gained from them are valuable, as they are accumulated through large investments in manpower, time, and money. Most onsite engineers agree that knowledge management in construction projects is a vital tool construction management. The sharing of knowledge and feedback provided by onsite engineers help to prevent mistakes that have been made in previous projects. Drawing on knowledge and experience thus eliminates the need to solve many problems from scratch.

1.2 Problem Statement

There have been many problems encountered with this as-built schedule during the construction phase. The one of facing problems is that it is difficult to clearly explain a project without a visual representation while the schedule is being processed. Although there is a great deal of previous researches focusing on the simulation of the 4D approach (3D and time simulations), there are few studies on updating an as-built schedule using the BIM approach. Furthermore, most recent construction projects in Taiwan have applied knowledge management systems to improve construction management during the construction phase. In construction projects, knowledge management may involve many important relationships between the presentation and retrieval of knowledge and CAD. However, most of the shared information during the construction phase is in the form of text-based information. Text-based knowledge management is hard to illustrate acquired knowledge from construction project (no relationship with objects or components of buildings). Furthermore, when knowledge is available for sharing, it is not easy for engineers to understand it directly without 2D or 3D CAD illustrations. Therefore, it is a challenge to provide for the general contractor and onsite engineers models and solutions to enhance the as-built schedule management and knowledge management in this work.

1.3 Research Objectives and Scope

The main characteristics of BIM including illustrating 3D CAD-based presentations, keeping information in digital format, and facilitating the easy updating and transfer of information in a 3D environment. The objectives of this study are to: (1) propose as-built schedule management approach integrated with BIM models for schedule information sharing and tracking visually; (2) provide visual knowledge management approach integrated with BIM models for knowledge sharing and reuse. The scope of research is to manage knowledge and as-built schedule for general contractor during the construction phase. Furthermore, Figure 1 shows the research flowchart of the study.

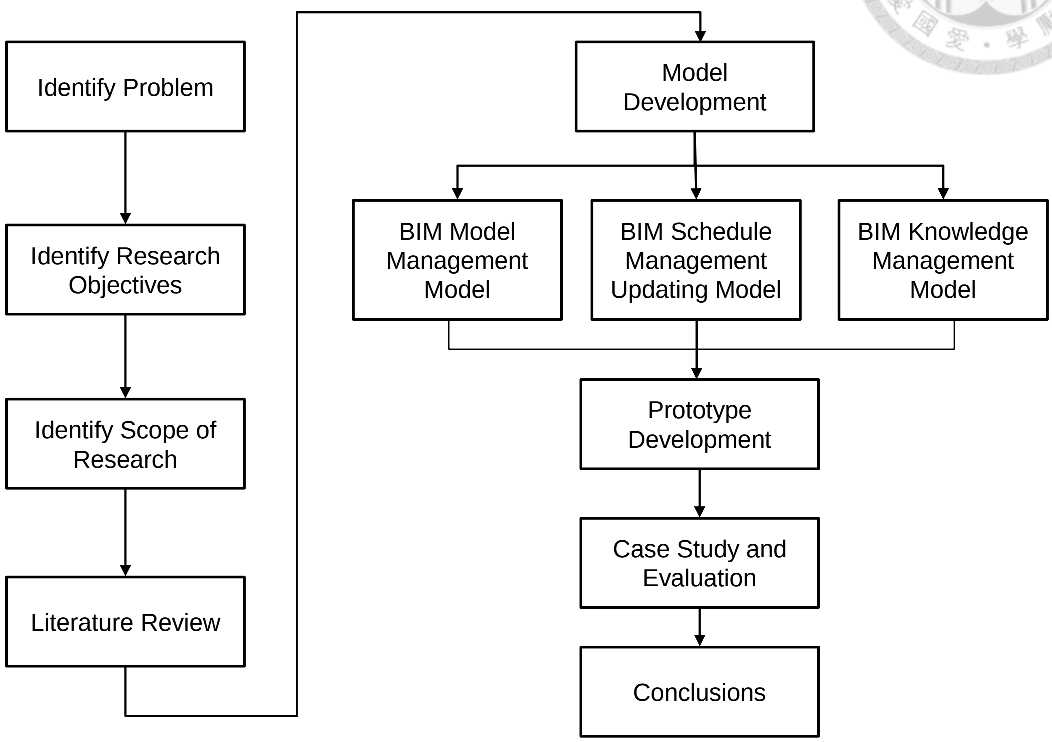

Figure 1. The research flowchart of the study

2. Literature Review

This chapter provides a literature review of topics related to the basic inquiry of the research. Section 2.1 presents an overview of building information modeling (BIM), introducing its main concepts, properties and applications in practice. It also discusses how the literature describes BIM support for interdisciplinary collaboration and interoperability. Section 2.2 discusses literature related to related BIM applications in Practice. Section 2.3 discusses literature related to schedule management in construction. Section 2.4 discusses literature related to knowledge management in construction.

2.1 Building Information Modeling

In the last decade, BIM was introduced as an information technology to improve efficiency and coordination. BIM is defined as the process of generating, storing, managing, exchanging, and sharing building information in an interoperable and reusable way (Vanlande et al., 2008). BIM digitally contains precise geometry and relevant data needed to support the design, procurement, fabrication, and construction activities used to build 3D object-oriented CAD (Eastman et al., 2011). BIM is the process of generating and managing data during the building life cycle (Epstein, 2012). BIM technology has the potential to enable fundamental changes in project delivery that will support a more integrated, efficient process (Teicholz, 2013). BIM is to offer solutions to many of the inefficiencies and systemic failures in the construction industry (Eastman et al., 2011). BIM is a new industry term that refers to 3D illustration technology that incorporates parameters and processes related to the AEC industry (Taylor and Bernstein, 2009). Almost ten years ago, BIM was introduced as an environment in which any information on 3D entity models could be stored and retrieved throughout a project's life cycle (Tse et al., 2005). A BIM model is a digital visual representation of all of a building's physical characteristics and relevant information on its life cycle (Manning and Messner, 2008). In prior research, many different definitions of BIM have been proposed. BIM contains precise digital geometric measurements and data to support a project's design, procurement, fabrication, and construction activities to describe CAD (Eastman et al., 2011). BIM's main feature is that the complete model, with all of its parts, is saved in a single file. Moreover, any changes made to the model automatically affect any related data and drawings accordingly. BIM modeling allows users to create and update project-related documents automatically, and data on the building are attached to the model's elements (Eastman et al., 2011). BIM helps construction planners to make important decisions by providing a visual of the details of the project in the future (Chau et al., 2004). BIM is a tool that allows for efficient delineation of the management and execution of construction projects. Recently, there are many design firms, construction contractors, engineer companies and owner to apply BIM technologies for their business and services. Figure 2 shows main benefits of the use of BIM during the construction phase.

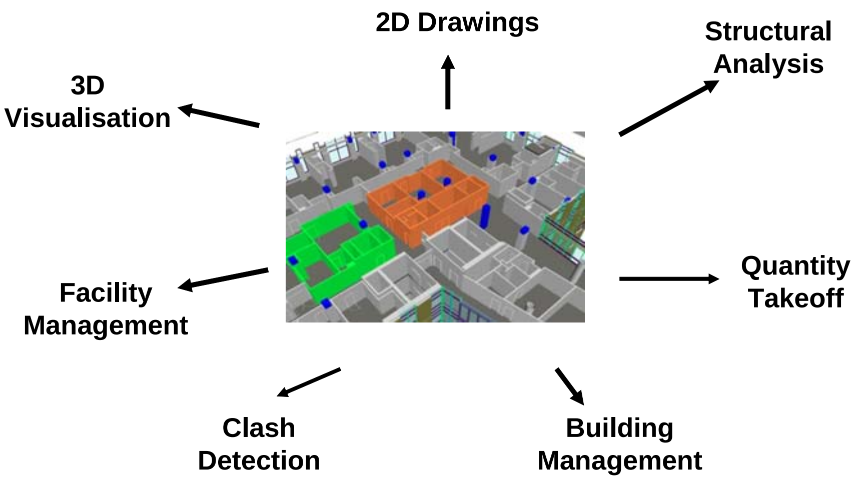

Figure 2. Main benefits of the BIM applications during the construction phase

The applications of BIM technologies have been gaining acceptance in the construction life cycles (Leite et al., 2011). Figure 3 shows the different applications of BIM from conceptual design phase to operation and maintenance phase (Buildipedia, 2013).

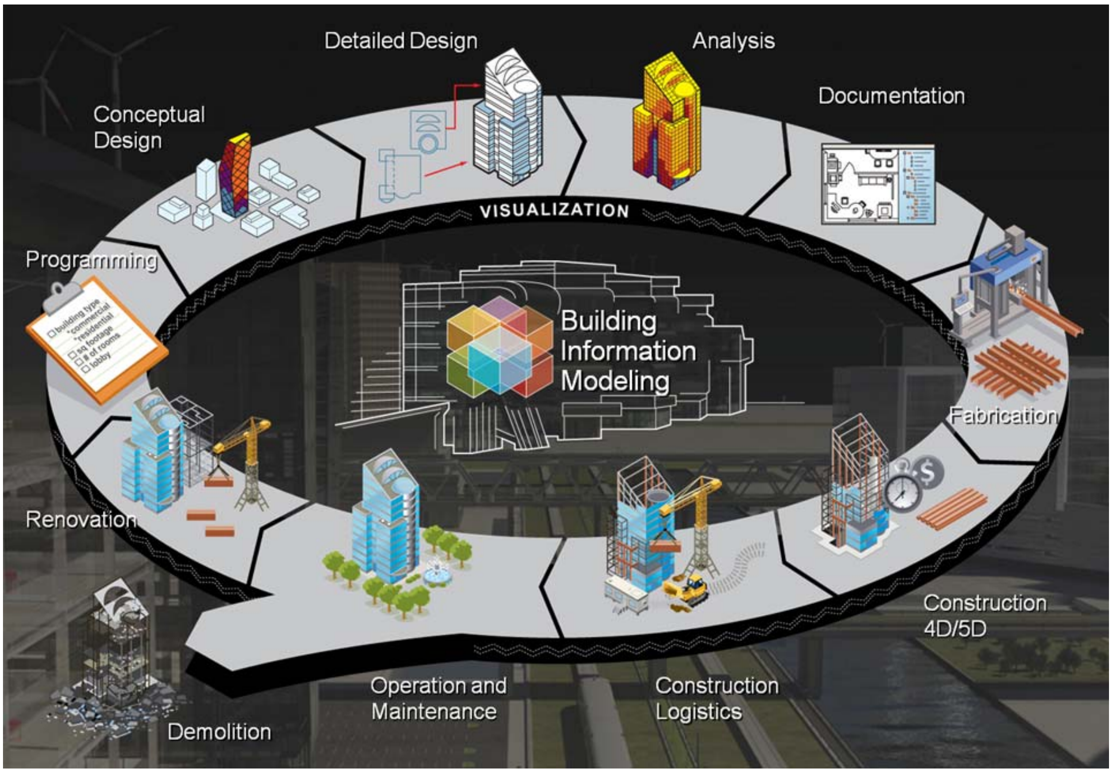

Figure 3. Concept of the use of BIM in construction lifecycle (Buildipedia 2013)

In the BIM model development, the Level of Development (LOD) plays an important role during the process of BIM application. Level of Development (LOD) describes, through five categories, the completeness of elements in a Building Information Model. Completeness will range from geometric detail to element information (BIMForum, 2013). Based on new LOD Specification by BIMForum and

American Institute of Architects (BIMForum, 2013), Level of Development Specification Definitions show as following:

- LOD 100 - The model element may be graphically represented in the model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200. Information related to the model element (i.e., cost per square foot, tonnage of HVAC, etc.) can be derived from other model elements.
- LOD 200 - The model element is graphically represented within the model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Nongraphic information may also be attached to the model element.
- LOD 300 - The model element is graphically represented within the model as a specific system, object, or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the model element.
- LOD 350 - The model element is graphically represented within the model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Nongraphic information may also be attached to the model element.
- LOD 400 - The model element is graphically represented within the model as a specific system, object, or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Nongraphic information may also be attached to the model element.
- LOD 500 - The model element is a field-verified representation in terms of size, shape, location, quantity, and orientation. Nongraphic information may also be attached to the model element.

The LOD of the BIM model will influence the result of BIM application directly. Therefore, it is necessary to consider the LOD of the BIM model in the initial plan and the BIM implantation.

2.2 Current Research of BIM

There are a lot of research and development regarding to BIM to have been conducted in order to further enhance the capabilities of BIM during the construction life cycle. There are many core adoption, advantages, barriers, limitations, and frameworks for the use of BIM in supporting decisions and improving processes throughout the life cycle of a project (Succar, 2009; Shen and Issa, 2010; Manning and Messner, 2008; Becerik-Gerber and Rice, 2010; Underwood and Isikdag, 2010; Gu and London, 2010; Wong et al., 2010; Eastman et al., 2011; Arayici et al., 2011; Jung and Joo, 2011; Barlish and Sullivan, 2012; Porwal and Hewage, 2013; Succar, 2013; Bryde et al., 2013). The characteristics that are beneficial to the construction phase include a reduction in necessary rework, increased customer satisfaction as a result of the visual model, more productive phasing and scheduling, more efficient and timely construction management with a swift form of communication, accurate estimation of cost, and a clearer visual for safety testing (Hardin, 2009; Matta and Kam, 2010; Dossick and Neff, 2010; Eastman et al., 2011; Elbeltagi and Dawood, 2011; Azhar, 2011; Zhou et al., 2013; Hartmann et al., 2012). Bynum et al. (2012) investigated the perceptions of the use of BIM for sustainable design and construction among designers and constructors.

Over the past few years, the focus of many research efforts has been the use of information technology (IT) to enhance automation aided by the BIM approach. Redmond et al. (2012) utilized cloud computing as a platform on which to integrate the

BIM applications known as "Cloud BIM." This integration enhanced the BIM user's experience in making important decisions regarding design in various disciplines. Ren et al. (2012) proposed a framework in which BIM could be used to integrate applications for cost estimation and quantity takeoff with e-commerce solutions for procurement of materials and evaluation of supplier performance. Li et al. (2012) integrated virtual prototyping and four-dimensional simulation to assist construction planners in testing the sequence of construction activities when mobile cranes are involved. Shen et al. (2012) proposed UASEM system to facilitate the designer-user communications and assist the pre-occupancy evaluation using BIM technology. To manage construction defects, Park et al. (2013) presented a conceptual system framework in which BIM was integrated with ontology and augmented reality (AR). Davies and Harty (2013) developed tools based on BIM to enable site workers to access information on the design, record work quality, and update records of progress on-site on their personal tablets or computers. Wang et al. (2013) developed a framework of how FM can be considered in design stage using BIM technology. Martins and Monteiro (2013) created a BIM-based system to automatically check procedure codes for water distribution systems. Irizarry et al. (2013) integrated the BIM approach with geographic information systems (GIS) to track the status of a supply chain and to provide warning signals that would result in successful delivery of materials. Zhang et al. (2013) integrated BIM with an automated safety-check platform to forewarn construction engineers and managers of potential accidents related to falls before the start of any actual construction. Zhang et al. (2014) proposed and verified Industrial Foundation Classes-based graphic information model as the foundation of data sharing in virtual construction systems and in other AEC/FM applications. Kim and Teizer (2014) developed a rule-based system that automatically plans scaffolding systems for pro-active management using BIM technology. Gurevich and Sacks (2014) developed KanBIM production control system to work in a sequence that was pulled according to the maturity of work packages, thus avoiding rework and stabilizing production rates.

2.3 Schedule Management in Construction

Since the early 1990's, an increasing amount of attention has been paid to the idea of four-dimensional computer-aided design (4D CAD) for planning construction projects (Liston et el., 1998; Wang et el., 2004). Commercially available 4D CAD applications are becoming more widespread and easily accessible, and this technology enables the construction planner to produce more detailed, concise, and rigorous schedules. These commercially available packages typically focus on the use of 4D CAD simulations for the purpose of visualization (Heesom and Mahdjoubi, 2004). A great deal of previous research has concentrated on applying 4D CAD to the use of construction schedules. Ma et al. (2005) developed a 4D Integrated Site Planning System (4D-ISPS) which integrates schedules, 3D models, resources and site spaces together with 4D CAD technology to provide 4D graphical visualization capability for construction site planning. Goedert and Meadati (2008) created a 3D as-built model, a four-dimensional as-built model, and attach the construction process information to the model for the owner to use after construction. Russell et el. (2009) were able to visualize strategies for construction of a high-rise building through the use of linear scheduling and 4D CAD. Tsai et al. (2010) proposed a three-stage consulting framework of system evaluation, usability study, and management plan (SUM) to effectively identify major problems for the use of 4D management tools in the large design–build projects. Kim et al. (2011) presented a case study analyzing construction of a cable-stayed bridge, as well as modelling this process with a 4D graphic simulation. Zhang and Hu (2011) used a 4D structural information model to resolve conflicts and alleviate safety issues throughout construction. Hu and Zhang (2011) developed a BIM-assisted 4D-based system for the same purpose. Li et al. (2012) utilized a 4D simulation and virtual prototyping to help construction planners to examine the feasibility of mobile cranes in the construction process. Chavada et al. (2012) integrated critical path method and BIM to provide real-time management and rehearsal of activity execution workspaces. Zhou et al. (2013) used 4D visualization technology to manage safety throughout the metro's construction. Chen, Y.H. et al. (2013) developed effective and affordable tools for selecting and evaluating color schemes in 4D models. Kim, C., Son, H., and Kim, C. (2013) developed an accurate, essentially fully automated method for construction progress measurement using a 4D BIM in concert with 3D data obtained by remote-sensing technology. Kang et al. (2013) developed a simulation system for visualizing risk information integrated with a four-dimensional (4D) CAD system. Kim, C., Kim, B., and Kim, H. (2013) proposed an image processing-based methodology for the automatic updating of a 4D CAD model. The schedule information was then automatically integrated with an existing 3D CAD model in batch-processing modes to produce the updated 4D CAD model. Moon, H.S., Dawood, N., and Kang, L.S. (2014) proposed a methodology that generates workspaces using a bounding box model and an algorithm in order to identify schedule and workspace conflict within a 4D simulator.

All of the aforementioned research has focused on simulating the 4D approach (3D digital model + time) (see Fig. 4). However, the idea of a 4D approach is hardly new. The 4D simulation approach is different from the BIM-based as-built schedule updating system, for which there have only been a few studies.

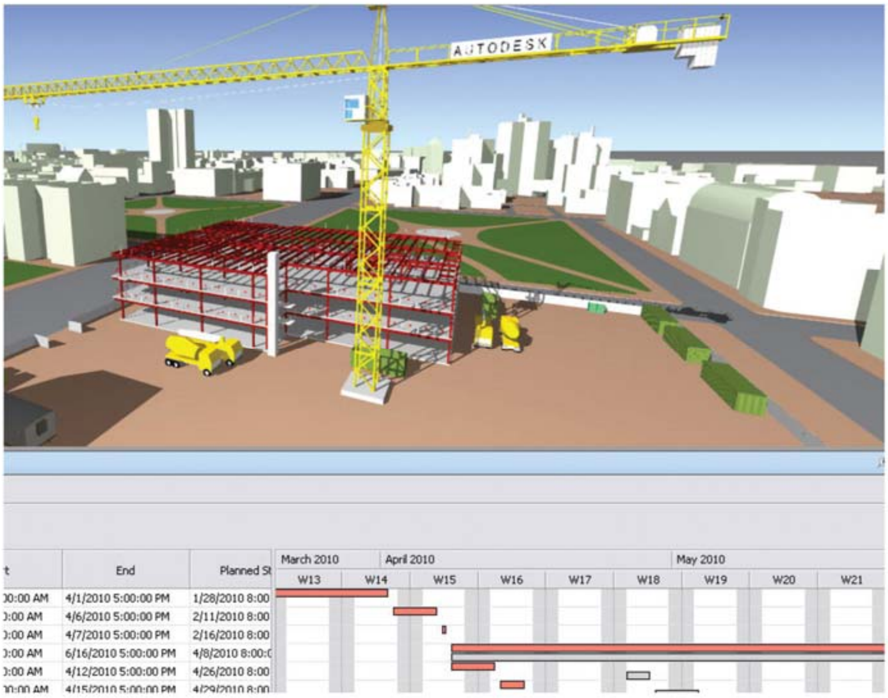

Figure 4. 4D schedule simulation

Numerous research efforts have focused on applications of BIM-reeled schedule management in construction. Shen et al. (2013) proposed a BIM-based user activity simulation and evaluation method to facilitate the designer-user communications especially in terms of spatial properties of the layout. Kim, H., Anderson, K., Lee, S.H., and Hildreth, J. (2013) established a framework for automating the generation of construction schedules by using data stored in BIM and proposed system in this research creates construction tasks, computes activity durations using available activity production rates, applies sequencing rules, and finally outputs a schedule. Chen, S.M. et al. (2013) proposed a BIM-based framework with the function of developing the near-optimum schedule plan according to develop n-dimensional project scheduling and management system for project scheduling and management. Wang et al. (2014) developed an interface system integrated with BIM for quantity takeoffs of required materials to support site-level operations simulation for project scheduling support. Moon, H.S., Kim, H.S., Kim, C.H., and Kang, L.S. (2014) realized an active simulation system based on BIM after constructing a genetic algorithm (GA) process for an alternative schedule management system equipped with decision-making functions of workspace analysis.

In Taiwan, there have been many problems encountered with this system of scheduling during the construction phase. One such problem is that it is difficult to clearly explain a project without a visual representation while the schedule is being processed. In recent studies, there have been attempts to update 4D CAD models with various technologies, such as Radio Frequency Identification (RFID) (Azimi et al., 2011; Lu et al., 2011), Ultra Wide Band (UWB) (Shahi et al., 2013), 3D laser scanning (El-Omari and Moselhi, 2008; El-Omari and Moselhi, 2009; Bosche et al., 2006; Bosche et al., 2008; Tang et al., 2010; Turkan et al., 2012; Kim, C., Son, H., et al., 2013; Xiong et al., 2013), and digital image processing (Kim, C., Kim, B., et al., 2013). These approaches still have a multitude of limitations, such as a high cost, that need to be addressed before the methods can be put into practice. Therefore, in this work it was a challenge to provide for the general contractor and onsite engineers a platform with which they could track and manage the BIM-assisted information on the as-built schedule.

2.4 Knowledge Management in Construction

Usually, construction knowledge management plays an important role in construction management. Knowledge management deals with collecting, modeling, storing, reusing, evaluating and maintaining knowledge (Davenport and Prusak, 1998; Bergmann, 2002; Davenport and Probst, 2002). Numerous research efforts have focused on applications of knowledge management in construction. El-Diraby and Kashif (2005) presented a distributed ontology architectural design developed by rigorous knowledge acquisition and ontology development techniques for knowledge management in the highway construction industry. Hartmann and Fischer (2007) described how project teams can use 3D/4D models efficiently to support the communication of knowledge during the constructability review on construction projects. Ribeiro (2009) analyzed knowledge management effort based on case studies and provided recommendations and insights for enhancing knowledge management in construction firms. Chen and Mohamed (2010) provided empirical evidence for the stronger strategic role of tacit knowledge management in comparison to explicit knowledge management. Kivrak et al. (2008) used a survey to find out how tacit and explicit knowledge are captured, stored, shared, and used in forthcoming projects, as well as to identify major drivers and barriers in knowledge management. Chen et al. (2012) presented a knowledge-sharing model to determine whether risk mitigation based on the use of derivatives would be beneficial to the companies. Forcada et al. (2013) presented a survey of perceptions of knowledge management implementation in the Spanish construction sector and compares the results obtained from design and construction firms. Motawa and Almarshad (2013) utilized the functions of information modelling techniques and knowledge systems to facilitate full retrieval of information and knowledge for maintenance work.

Although numerous information management systems have been developed for the application of construction knowledge management, such systems typically exist for knowledge sharing using only text-based illustrations. To enhance construction-related knowledge sharing using a BIM-based environment, this study proposes a novel BIM-assisted schedule management and knowledge management approach and system for project managers and onsite engineers.

3. Model Development

To enhance visualization of the updated as-built schedule and knowledge management for the general contractor, there are three models developed in the study. They are BIM model management model, BIM schedule management model, and BIM knowledge management model. After the application of BIM model management, the proposed schedule management model and knowledge management model may be executed successfully.

During the process of BIM application during the construction phase, it is necessary to consider the process management regarding the BIM models. In order to improve the performance of BIM management, the study proposes the four phases for BIM models management lifecycle. To enhance visualization of the updated as-built schedule management for the general contractor, this study proposes BIM schedule management model for the general contractor is to enhance visual as-built schedule management effectively at construction site. Finally, the study develops knowledge management model to effectively acquire, manage, and reuse knowledge gained from other onsite engineers integrated with BIM technology.

Figure 5 shows the research conceptual framework for the study. There are three models developed in the study. They are BIM model management model, BIM schedule management model, and BIM knowledge management model. After the application of BIM model management, the proposed schedule management model and knowledge management model may be executed successfully. The main content of three models will focus on the management process and management mechanism. The detailed information will be discussed as following sections.

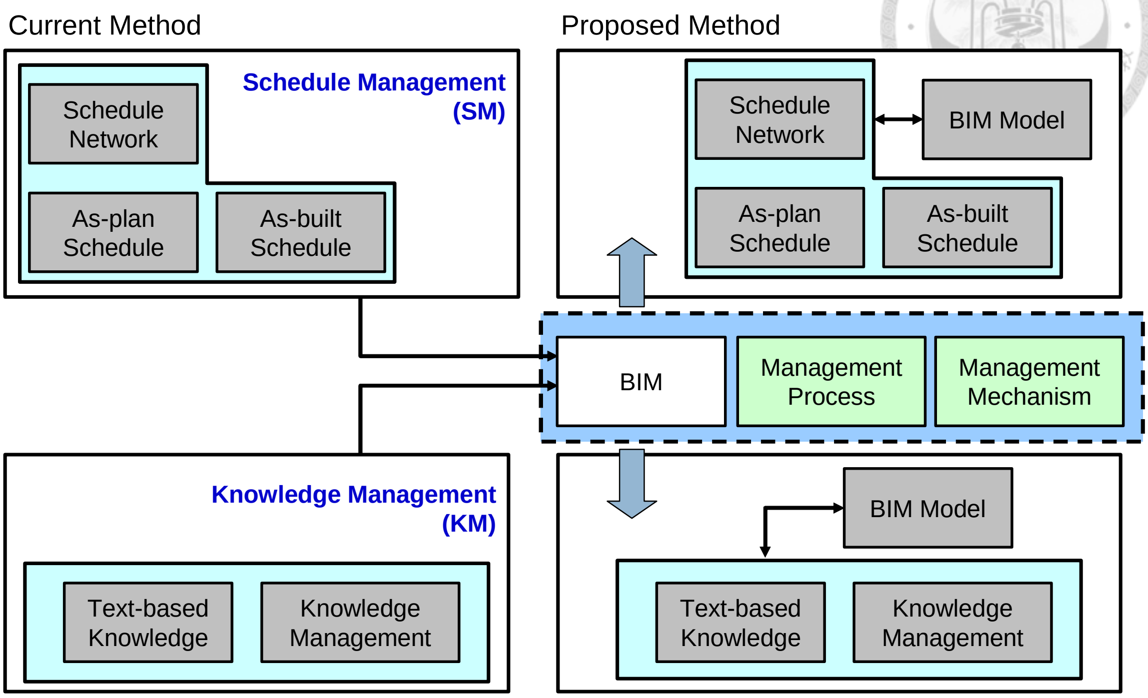

Figure 5.　Research Conceptual Framework

3.1 BIM Model Management Model

It is very important for BIM management during the BIM work. During the process of BIM application during the construction phase, it is necessary to consider the process management regarding the BIM models. In order to improve the performance of BIM management, the study proposes the four phases for BIM models management lifecycle. The four phases are developed and proposed based on the interview of BIM experts in Taiwan. They are creating BIM model, approving BIM model, publishing BIM model, and modifying BIM model. Table 1 shows the description for each phase. Furthermore, the study proposes the flowchart of BIM models management based on the interviews with BIM experts in Taiwan (see Fig. 6). Most of BIM work during the construction phase can be executed based on the proposed flowchart of BIM models management. Before the applications of BIM models, all new BIM model or updated BIM models must be reviewed and approved. Only the approved BIM models can be published and deliver to related participants to apply BIM model. In order to manage the BIM model effectively, the study also proposes the flowchart of BIM model quality management (see Fig.7) and the flowchart of BIM model revised management (see Fig.8).

Table 1. The description of each phase for BIM model management

Phase	Description
Creating BIM model	Handles the initial and developing work of BIM model.
Approving BIM model	Confirms the accuracy of BIM model before the completed BIM model.
Publishing BIM model	BIM model is confirmed and published to project engineers.
Modifying BIM model	Requesting BIM modification and BIM updating processes if the BIM needs changes or updates.

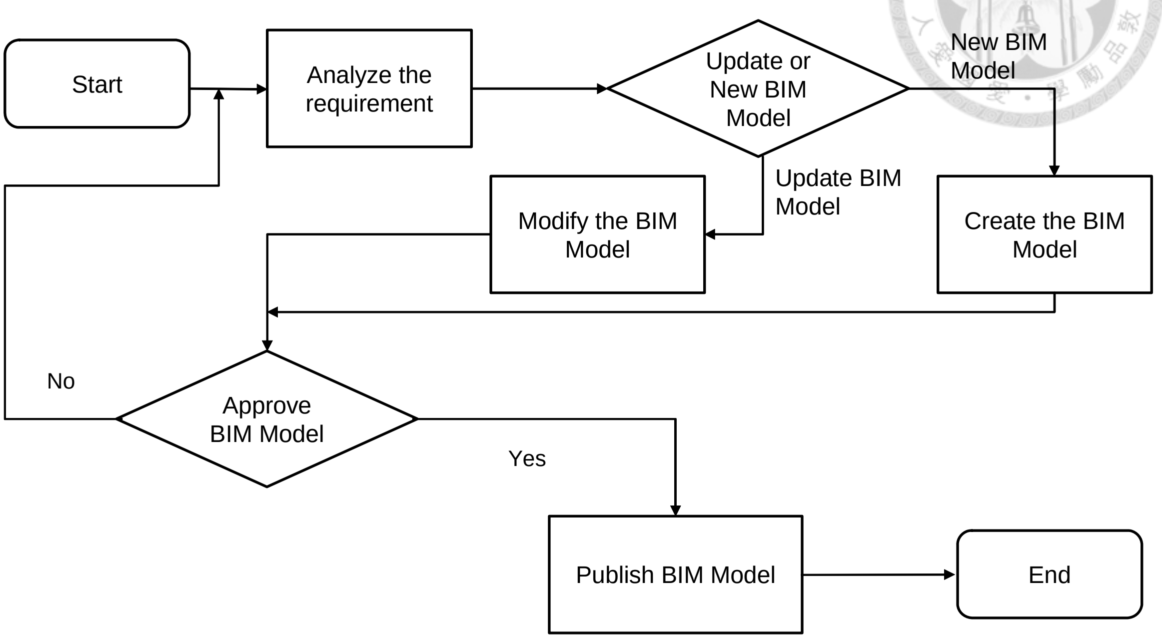

Figure 6. The flowchart of BIM model management

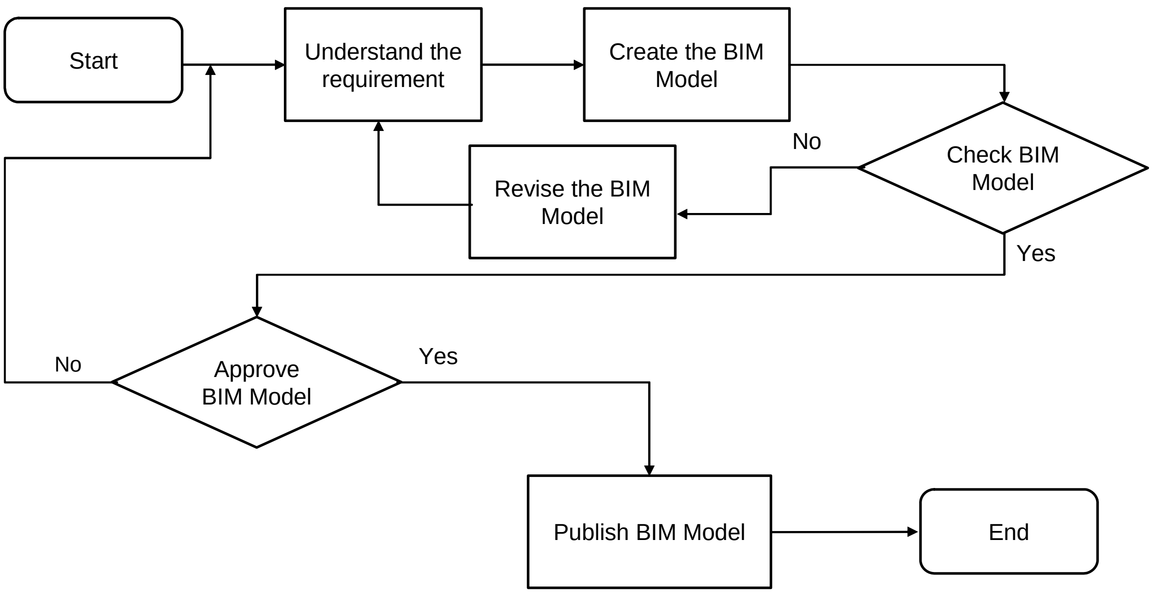

Figure 7. The flowchart of BIM model quality management

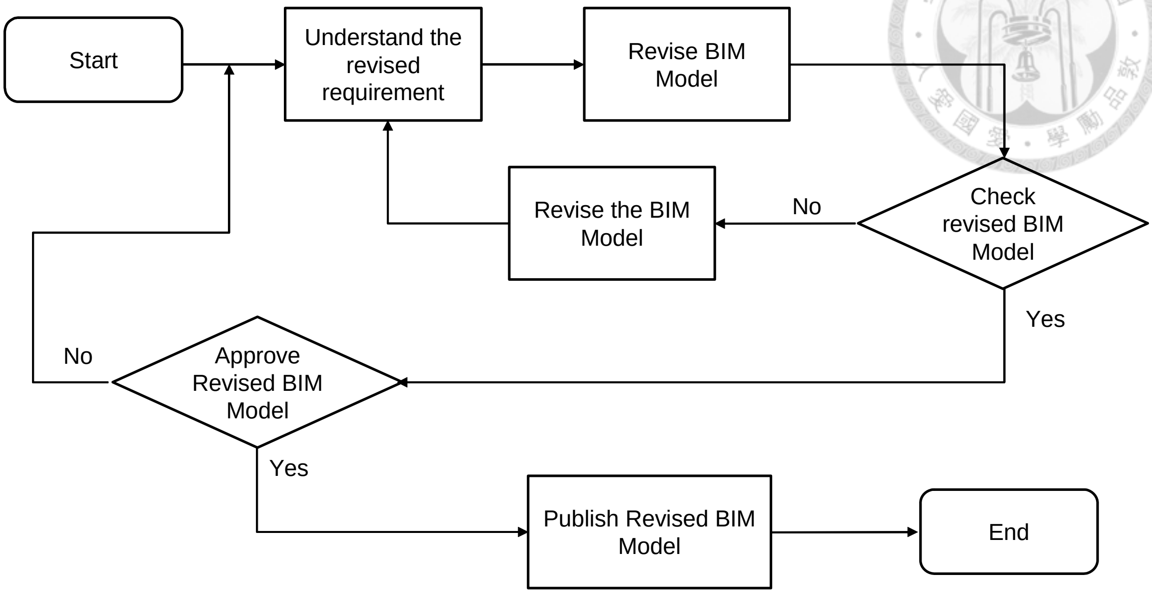

Figure 8. The flowchart of BIM model revised management

3.2 BIM Schedule Management Model

Visual representations aid communication amongst project staff and facilitate decision making, and, when implemented well, they can provide the project team with clear and fast feedback. Currently, there is much commercial BIM software to provide the 4D simulation for construction management. Tekla, for example, provides BIM value beyond design to virtual construction and project time simulation. Autodesk Navisworks functions to simulate construction schedules and logistics in 4D to visually communicate and analyze project activities. Vico software provides 3D model elements connected to tasks for 4D simulation. However, this software mainly provides users with the 4D simulation functionality. If the general contractor wants to utilize the commerce BIM software for the application of as-built schedule management, most 4D simulation functionality is incapable of meeting the requirement of updating the as-built schedule management in practice.

Fig. 9 shows the concept of the traditional as-built schedule network. Usually, schedule network is utilized currently for as-built schedule management. Furthermore, onsite engineer need to update the as-built schedule at the jobsite during the construction phase (see Fig. 10).

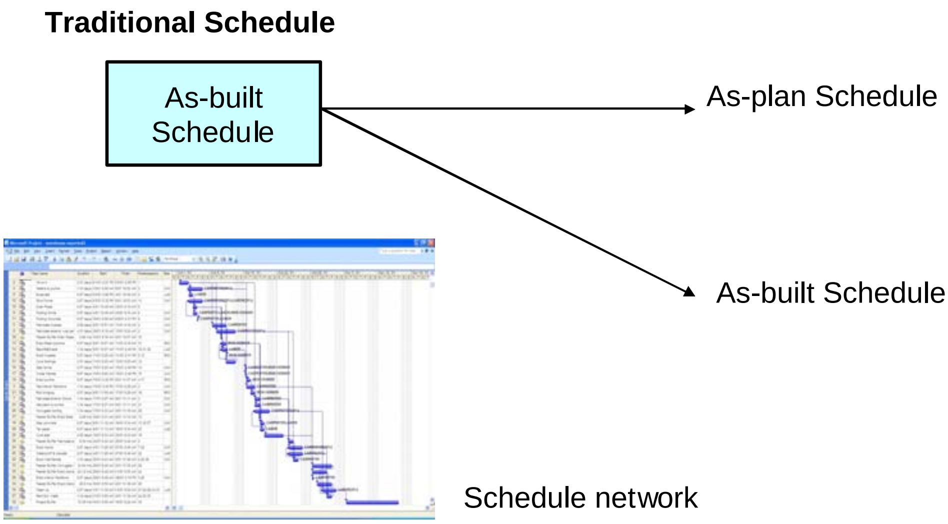

Figure 9. Concept of the traditional as-built schedule network

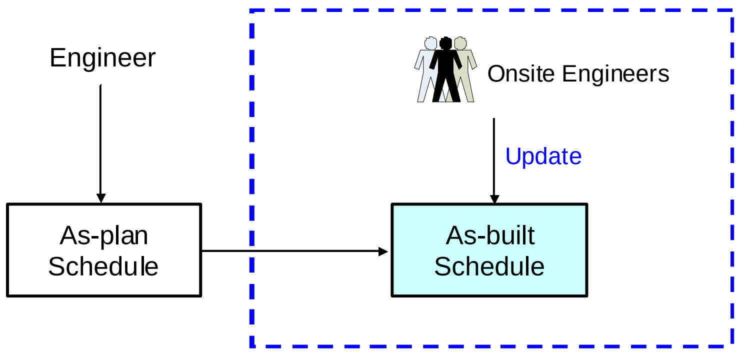

Figure 10. Concept diagram of the traditional as-planned and as-built schedule

The primary advantages of the BIM-based as-built schedule are as follows: (1) it provides a BIM-assisted illustration for sharing the updated as-built schedule in the web environment; (2) it provides project managers and engineers with the ability to track color-assisted statuses of all virtual as-built schedule processes during the construction phase of a project; and (3) it gives project engineers the ability to respond to the updated or feedback content using the BIM approach in practice.

The proposed schedule management model with BIM-assisted visualization allows all project engineers to access the most recent visual as-built schedule using the BIM model. Furthermore, the updated as-built schedule can also be shared with marked information related to changes (see Fig. 11).

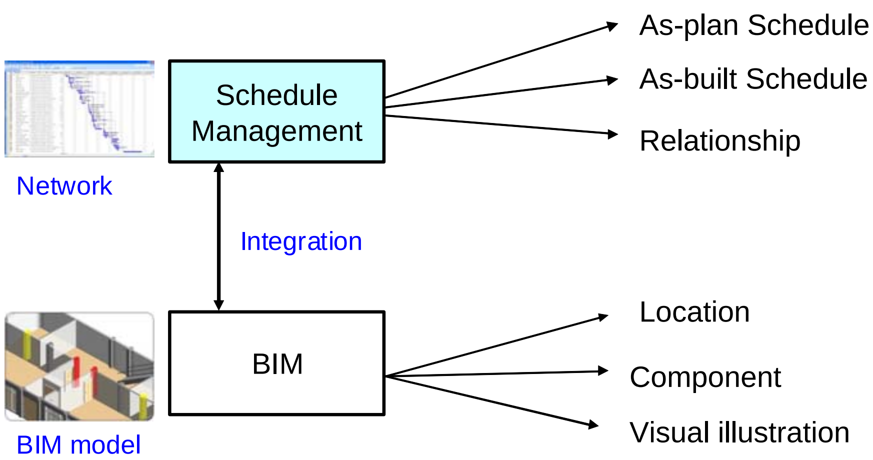

Figure 11. The concept of the schedule management using BIM model

The main contribution of the study is to explore the experience of tracking and managing BIM-assisted as-built scheduling during the construction phase (see Fig. 12). In the beginning, new as-built schedule is identified and updated for approving by onsite engineers. After the updated as-built schedule is approved, approved as-built can be published and tracked for future use.

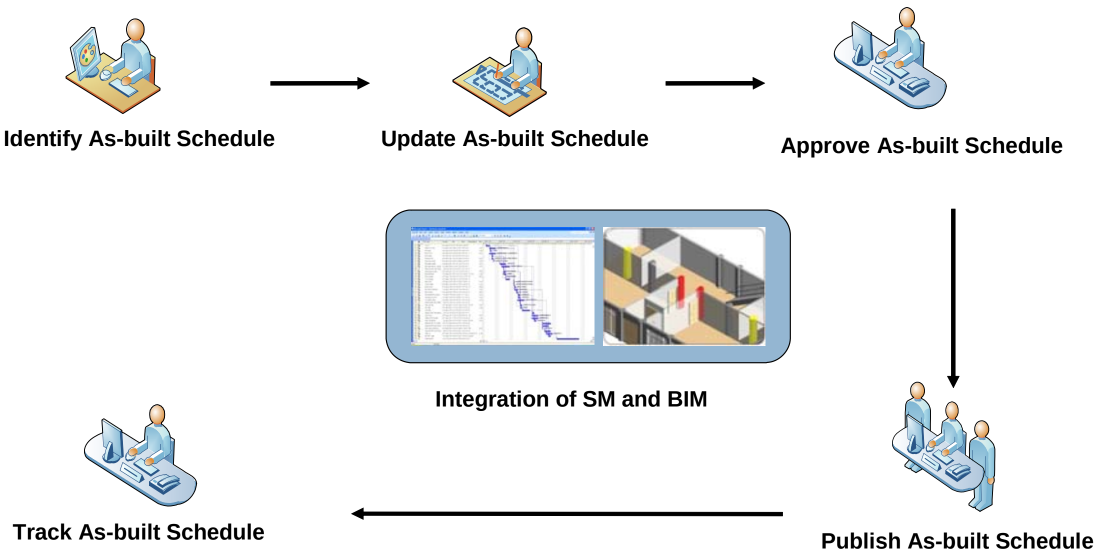

Figure 12. The concept of schedule management integrated with BIM model

The study proposes a new innovative multi-field updated approach to the as-built schedule to enhance its management, which in turn allows engineers to update multiple as-built records of each activity or task in the field at various times (see Fig. 13). The main purpose is for engineers to build upon the previous updated content for each activity or task. This multi-field updated as-built schedule approach allows engineers to track past and present progress of the as-built schedule content. When onsite engineers also select a traditional single field for as-built updates, they need not use a multi-field progress update system.

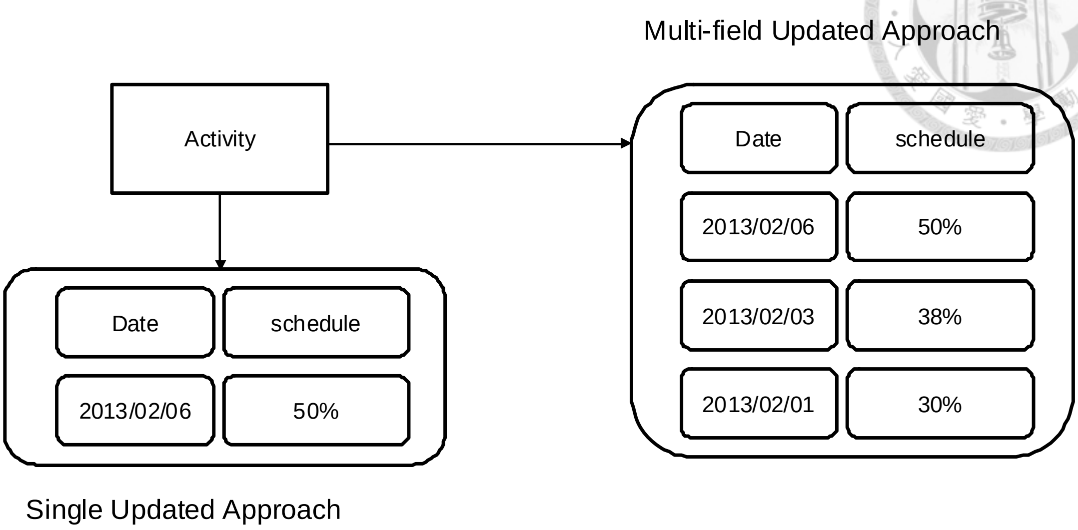

Figure 13. The multi-field updated approach for the as-built schedule management

The 3D markup-enabled schedule models can be defined as a 3D CAD graphic representation of as-built schedule activities linking relationships between CAD objects and attributes of schedule models. The BIM approach retains as-built schedule information in a digital format, facilitating easy updating and transfer of activities in the 3D CAD environment. The as-built schedule information with 3D BIM approach can be identified, tracked, and managed virtually during construction projects. The most recent as-built schedule status and comments can be acquired from onsite engineers and then shared and illustrated by way of the 3D BIM model for better understanding and communication.

The 3D markup-enabled schedule models, which are defined in multiple objects, are constructed from variables that can be decomposed into CAD component units and cam store the status of the as-built activity schedule. The 3D markup-enabled schedule models allow users to access information from the as-built schedule stored in layers based on the attributes and type of the as-built schedule. As-built schedule information stored in components of the 3D markup-enabled schedule model includes both the status of the as-built schedule and comments. As-built activity schedule status includes the as-built schedule, comments of the as-built schedule, descriptions of problems regarding the as-built schedule, or related attachments (e.g., documents, reports, drawings, and photos). Additionally, the 3D markup-enabled schedule models allow users to review the as-built schedule with the BIM model to enhance effectiveness of visual communication. The 3D markup-enabled schedule model is associated with the as-built schedule, locations, and comments on activities.

In order to explain the flowchart for the as-built schedule with BIM model, the study proposes the flowchart of the procedure of the as-built schedule with BIM model (see Fig. 14). Table 2 illustrates the description of use of color for BIM models for as-built schedule. The use of color for BIM models for as-built schedule is summarized and proposed based on the interview and discussion of BIM experts and onsite engineers. Furthermore, the use of color will be changed and applied based on different purposes and situations. In order to enhance as-built schedule alarm purpose, another color model is proposed for the as-built schedule alarm (see Table 3).

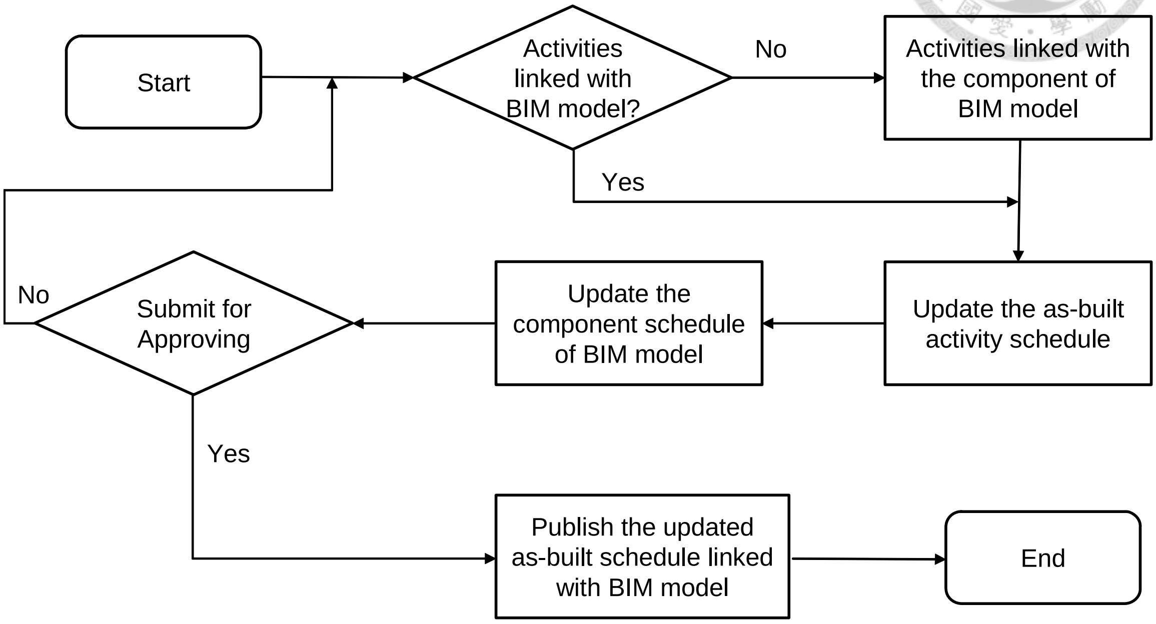

Figure 14. A flowchart of the as-built schedule management with BIM model

Table 2. The description of color use for BIM models for as-built schedule

Color of Status Usage	Description
Pink Color	To index schedule regarding to no start status
Yellow Color	To index schedule regarding to under construction status
Blue Color	To index schedule regarding to completion status

Table 3. The description of color use for BIM models for as-built schedule alarm

Color of Status Usage	Description
Red Color	To index schedule regarding to delay status

The above two types of color use will be different and applied based on different purposes and situations.

The example of grille installation activity uses three colors to illustrate different schedule statuses (no start status, under construction status, and completion status) (see Figure 15). Furthermore, another example regarding the whole project schedule uses three colors to illustrate no start, under construction, and completion schedule statuses (see Figure 16).

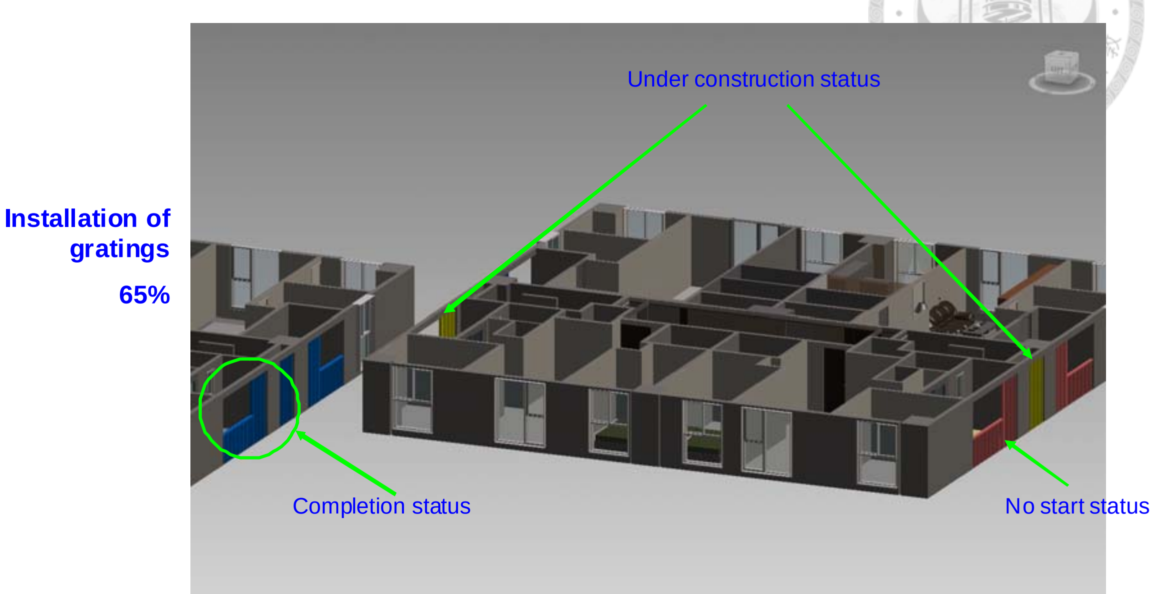

Figure 15. The sample illustration of as-built updating schedule integrated with BIM model (1/2)

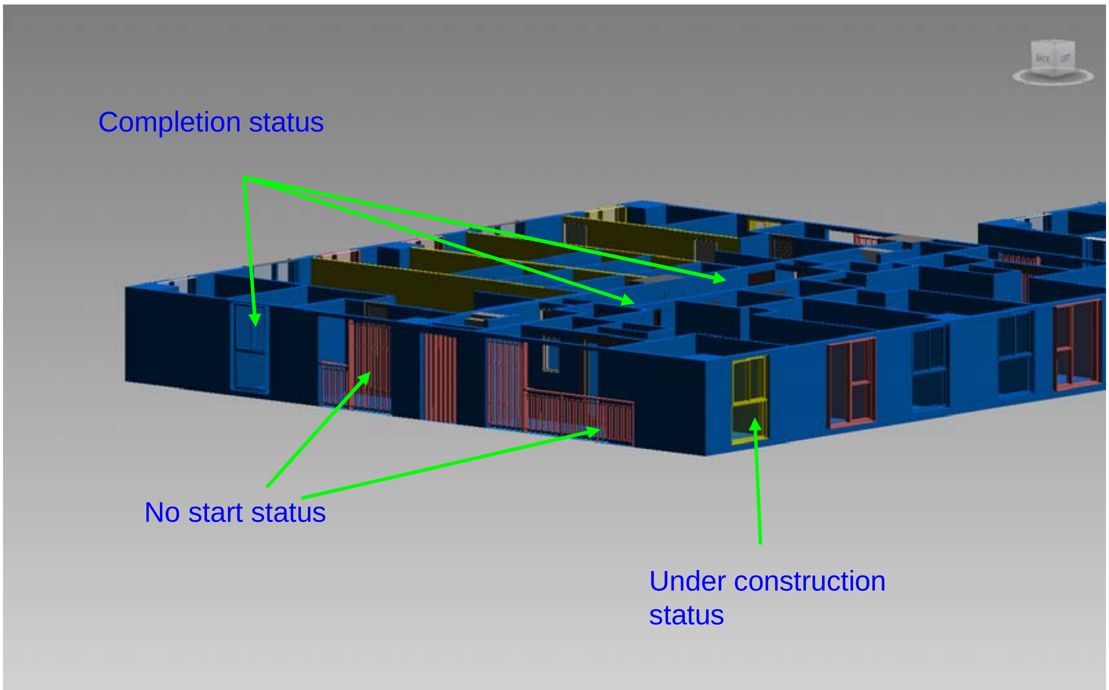

Figure 16. The sample illustration of as-built updating schedule integrated with BIM model (2/2)

Figure 17 illustrate the sample of as-built updating schedule integrated with BIM for alarm use. Furthermore, another alarm example regarding the whole project schedule uses red color to illustrate delay status (see Figure 18).

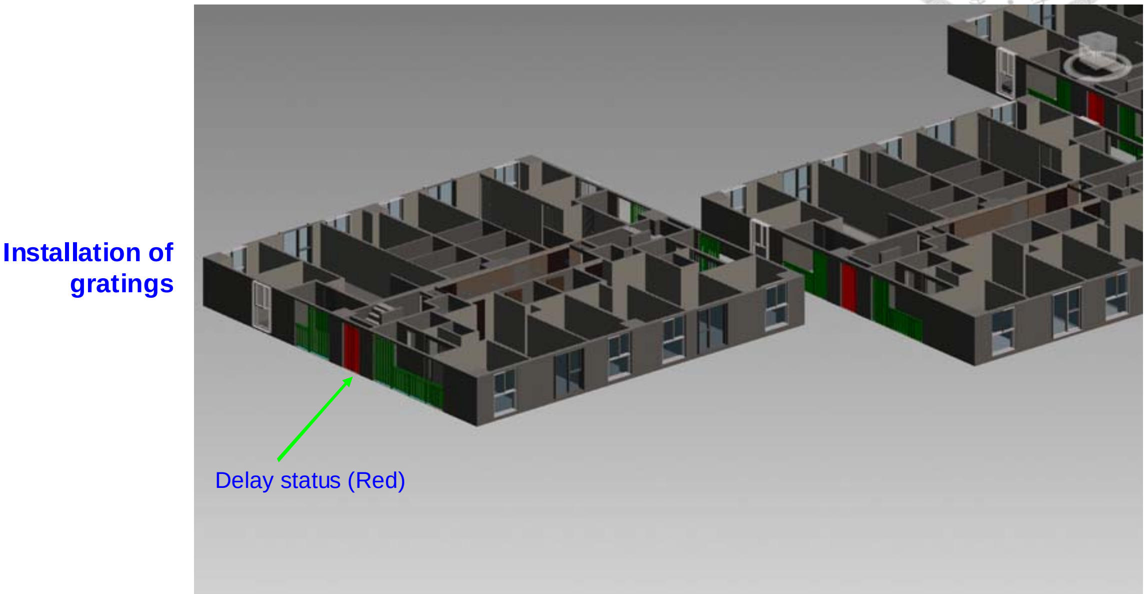

Figure 17. The alarm sample illustration of as-built updating schedule integrated with BIM model (1/2)

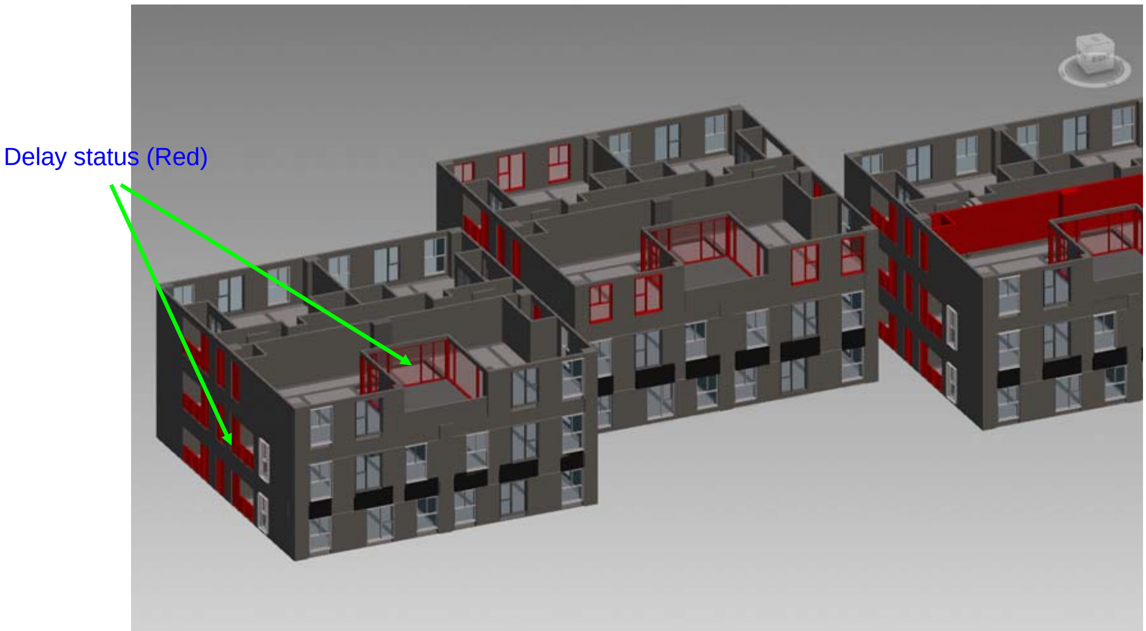

Figure 18. The alarm sample illustration of as-built updating schedule integrated with BIM model (2/2)

3.3 BIM Knowledge Management Model

Usually, most knowledge can be classified as either tacit or explicit knowledge in knowledge management (Tiwana, 2000). Tacit knowledge is personal, context-specific knowledge that is difficult to formalize, record or articulate. This type of knowledge is stored in the heads of people (Hart, 1992). Tacit knowledge or experience is primarily developed through a process of trial and error in practice. Tacit knowledge that can be communicated directly and effectively is personal knowledge embedded in individual experience and shared and exchanged through direct, face-to-face contact (Tiwana, 2000). In contrast, the acquisition of explicit knowledge is indirect: it must be decoded and re-coded into one’s mental models, and is then internalized as tacit knowledge. Explicit knowledge can be codified and transmitted in a systematic and formal language. Explicit knowledge can be found in the documents of organizations, including reports, articles, manuals, patents, pictures, images, video, audio, software, and other forms. In this study, "tacit knowledge" refers to "hard" information that is visibly or invisibly related to part of an area of knowledge, including experience and know-how; explicit knowledge is "soft" information that enables or facilitates the execution of specific information, including contracting, drawing, solving problems, or approving proposals. Figure 19 shows construction tacit and explicit knowledge management. Furthermore, Figure 20 shows traditional knowledge management approach.

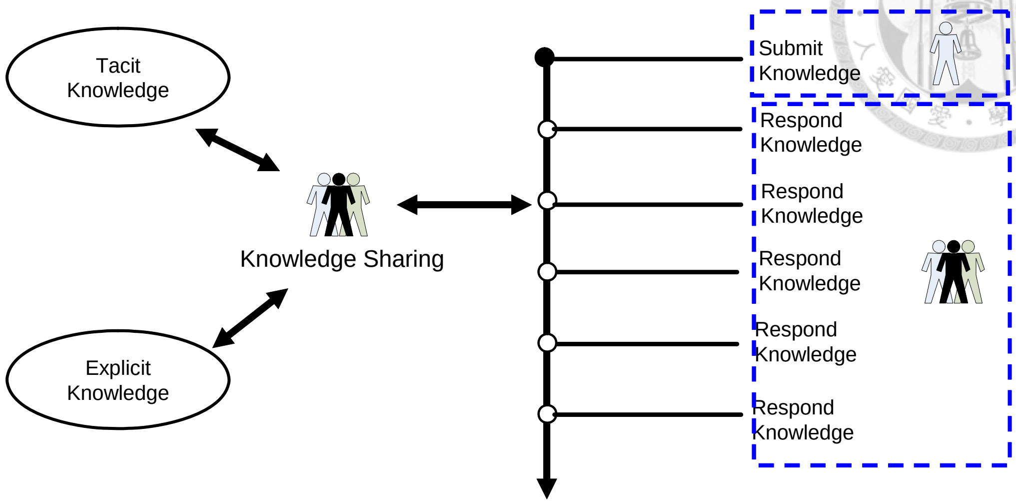

Figure 19. Construction tacit and explicit knowledge management

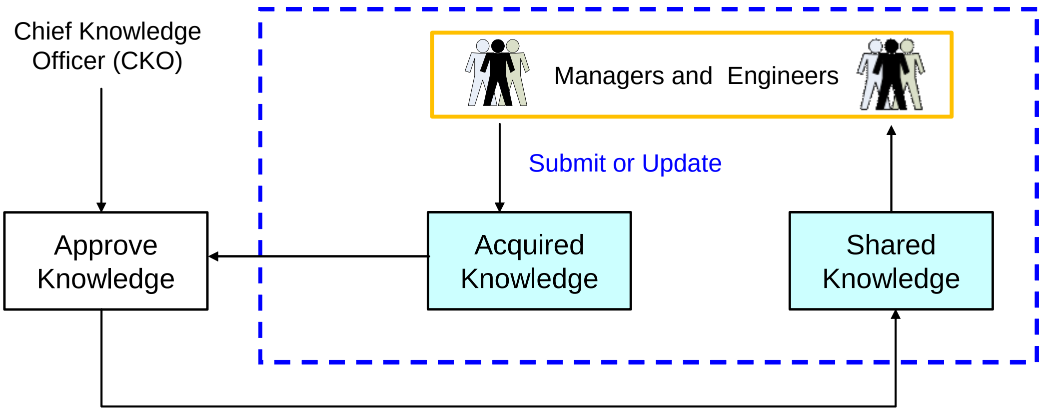

Figure 20. Traditional knowledge management approach

All onsite engineers are responsible for sharing knowledge pertaining to their own domain. Any BIM model that’s integrated information/knowledge sharing requirements have been noted will be classified as explicit in order to allow relevant experiences and processes to be recorded. Therefore, the shared information associated with objects of BIM model can be referred to and reused in other projects.

Shared information from all onsite engineers is divided and saved as “activity,” “object,” or “issue” for collection and management. The main advantage of BIM-based knowledge management is the ease with which information and knowledge can be understood and reapplied. Knowledge saved in the "issue" category includes both tacit and explicit knowledge. With respect to explicit knowledge, BIM-related information normally includes original comments, reports, drawings, documents, and comments submitted by onsite engineers. In contrast, tacit knowledge may include process records, problems faced, problems solved, expert suggestions, know-how, innovations and notes on experience. Such information is better saved in issue-based components to facilitate classification and searching by users. Information that relates to the whole project that cannot be easily classified into issue components is saved under the “project” category.

A BIM-based knowledge model can be defined as a graphic representation of experiences linking relationships between objects of the BIM model and aspects of experience-based knowledge. The BIM technology retains knowledge in a digital format, facilitating easy updating and transfer of knowledge into the BIM environment. A BIM-based knowledge model is designed to be easily integrated with information and components of the BIM model. Information in the BIM-based knowledge models can be identified, tracked, and managed, and problems encountered during construction projects can be solved. The most up-to-date knowledge and solutions can be acquired from participating engineers and then shared and saved as objects of the BIM model for future reference. The model is constructed from variables that can be decomposed into objects of a BIM model and can then store the identified knowledge. Information stored in the objects of BIM models includes both facing problems and solutions. Facing problems may be knowledge issues, knowledge attributes, descriptions of problems, or knowledge attachments (e.g., documents, reports, drawings, and photographs). Fig. 21 illustrates the concept and framework of knowledge management using BIM models. With the assistance of BIM model, the knowledge can be enhanced illustrated and focused on updated knowledge the location or components of building. Because of BIM model characteristic, the application of ConBIM-SKM prototype for knowledge management will be illustrated different colors and status based on knowledge management using BIM model.

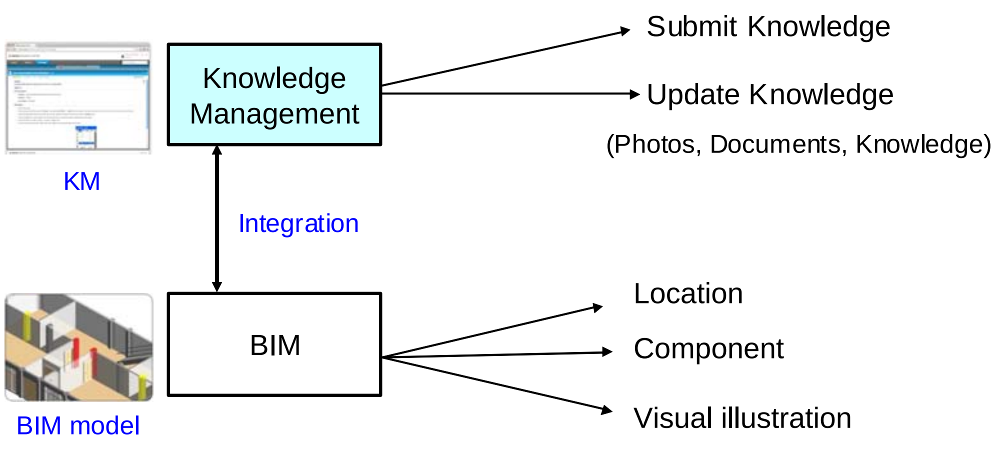

Figure 21. The concept of knowledge management using BIM model

Figure 22 shows the conceptual of knowledge management integrated with BIM models. After engineers acquire the knowledge, engineers can submit the collected knowledge for approving. Finally, the knowledge can be published and shared with other related participants after the knowledge is approved.

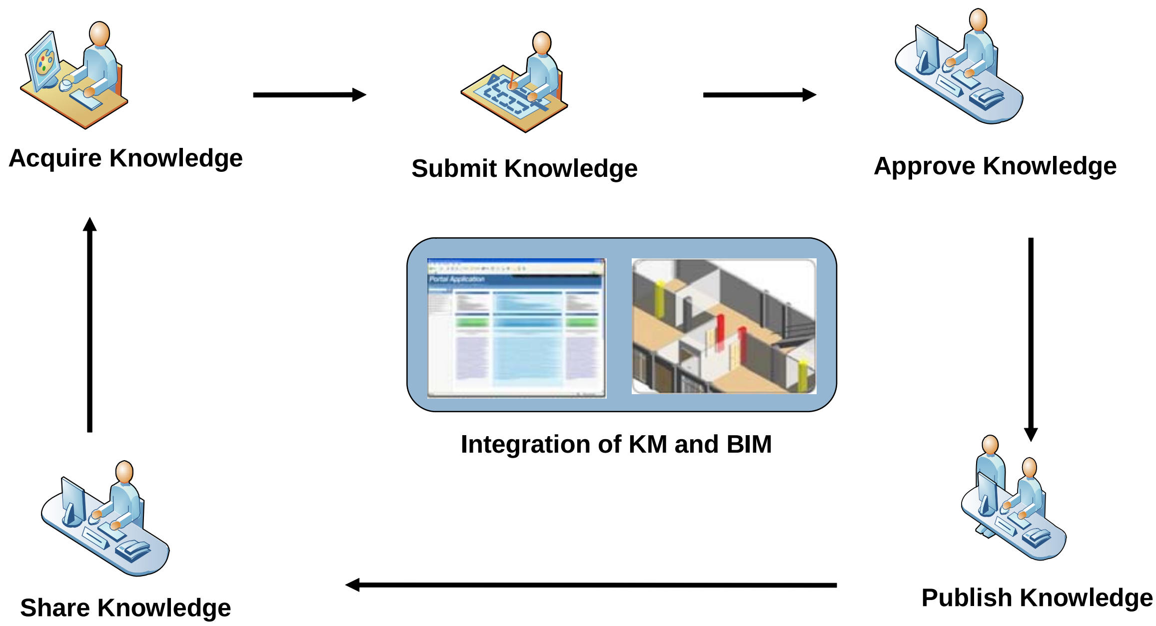

Figure 22. The conceptual of knowledge management integrated with BIM model

The procedures for using BIM-based knowledge models are based on a knowledge management framework. Figure 23 presents a flowchart of the knowledge management integrated with BIM. After the engineer identify the knowledge for knowledge sharing, the engineer can select the component of BIM model based on knowledge topic. Furthermore, the engineer can select the existing knowledge topic or create new topic of KM. Finally, the engineer may edit the knowledge linked with the component of BIM model and submit for approving.

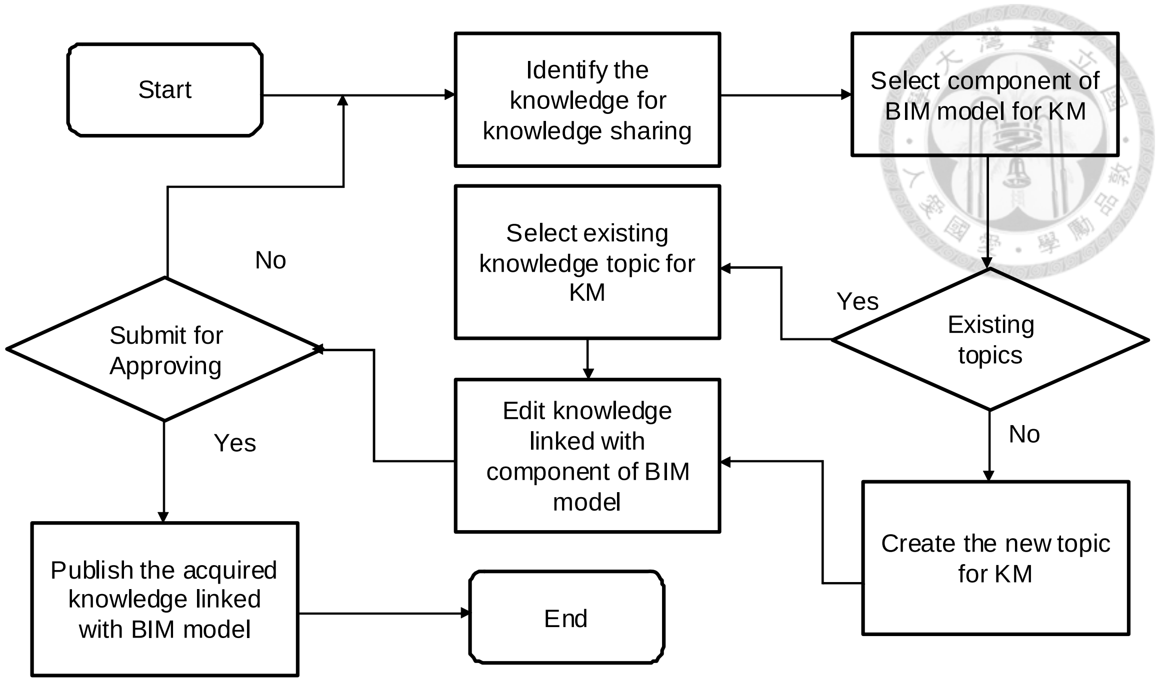

Figure 23. A flowchart of the knowledge management integrated with BIM model

In order to let the engineers understand where the knowledge is available for sharing in the model, the study proposed the two type of color use for BIM models for knowledge management (see Table 4). One type with blue color indexes available knowledge in the component of BIM model. Another type with orange color indexes new updating knowledge in the component of BIM model. Figure 24 illustrates sample of available knowledge illustration integrated with BIM models. Furthermore, Figure 25 shows sample of available knowledge illustration integrated with BIM models.

Table 4. The description of use of color for BIM knowledge management

Color of Status Usage	Description
Blue Color	To index available knowledge in the component of BIM model
Orange Color	To index new updating knowledge in the component of BIM model

Figure 24. The sample illustration of available knowledge integrated with BIM models

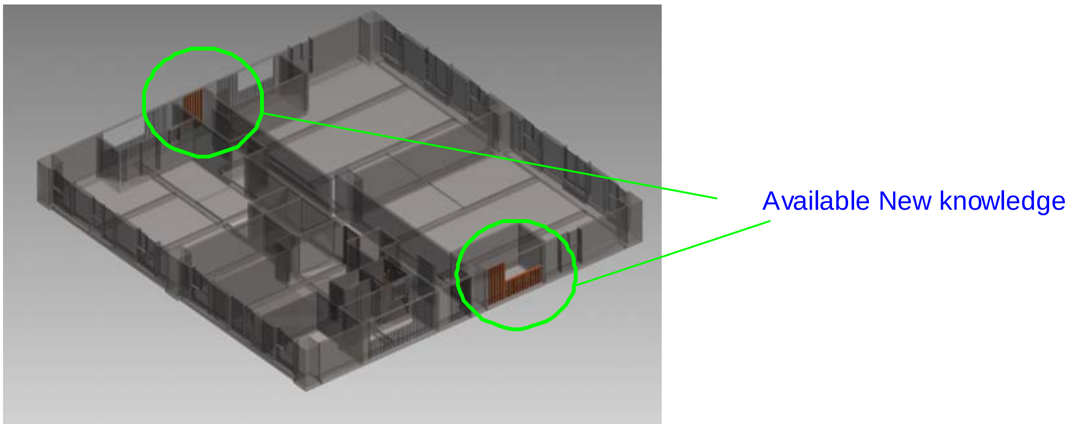

Figure 25. The sample illustration of available new knowledge integrated with BIM models

The study proposed the procedures for using BIM-based knowledge models are based on a knowledge management framework. The procedure consists of three phases: issue creation phase, knowledge sharing phase, and knowledge updating phase.

Issue Creation Phase

The initial engineer may determine which projects, activities, and issues are suitable for knowledge sharing. Furthermore, the issue must be set up by the initial participant (engineer) at the beginning of the phase. Such information under knowledge issues includes determining the type of knowledge, objects of BIM model, activities, and projects that should be assigned in association with the issue.

Knowledge Sharing Phase

After studying the published materials, all qualified and interested engineers are invited to edit and submit any knowledgeable comments they may have on the issue. All explicit knowledge prepared by engineers needs to be digitized by them or by assistants before it can be submitted to the ConBIM-SKM prototype. All knowledge must also be examined and confirmed before publishing. All interested engineers can discuss problems related to selected issues and objects of the BIM model and seek responses from other engineers and managers through the ConBIM-SKM prototype. Meanwhile, the engineers can direct responses either to individuals or a group. After tacit and explicit knowledge is saved in the system, all knowledge can be referenced and reused. Engineers can gain knowledge from the issues catalogue of the objects and can access this catalogue for use in other similar projects.

Knowledge Updating Phase

After applying tacit and explicit knowledge to similar projects, the engineers can resolve their problems related to those issues. Finally, the engineers can note and submit the new tacit knowledge and record the experiences through which it was gained, and they can associate this information with the original knowledge. Furthermore, the information is updated again because further feedback and updated knowledge is provided regarding the issues. After the approval process has been completed, the updated knowledge set is republished to authorized members.

Most of domain knowledge can be illustrated using BIM-based animation. After knowledge and scenario were identified for approving, the BIM-based PPT and movie file can be created using BIM model on the scenario of domain knowledge (see Figure 26).

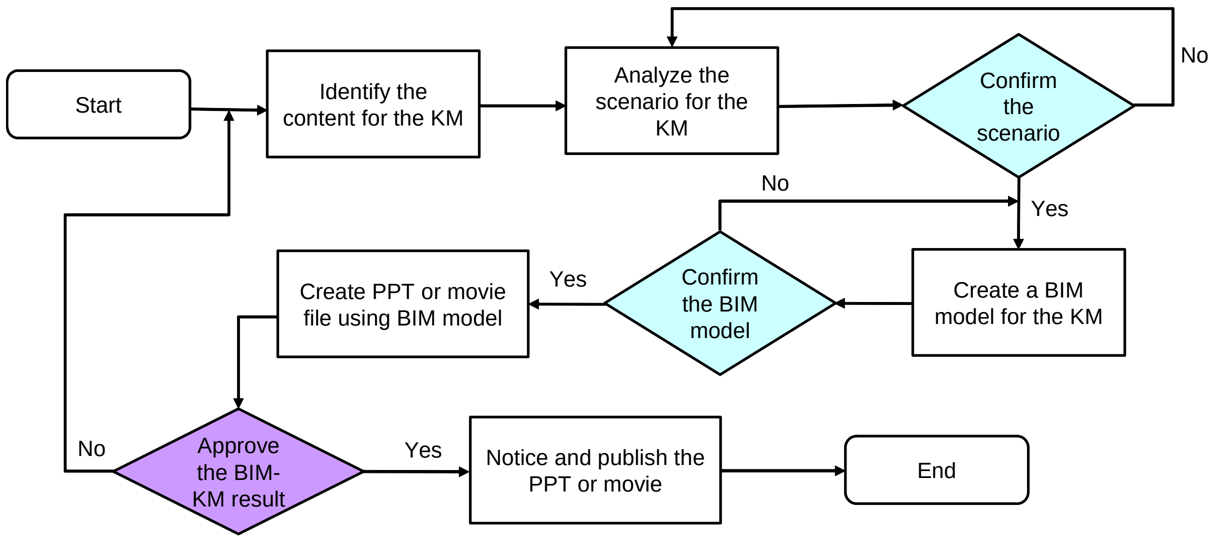

Figure 26. The flowchart of domain knowledge illustration using BIM model

All the BIM-based animation can be developed and enhanced of knowledge sharing and knowledge. Based on the interviews with junior engineers, those BIM-based animations are helpful for them to acquire domain knowledge easily and effectively.

4. Prototype Development

The study presents a novel ConBIM-SKM prototype for general contractors to enhance visual as-built schedule management and knowledge management. This study presents the novel ConBIM-SKM prototype to visually update the as-built schedule information for project participants. The proposed ConBIM-SKM prototype improves project control efficiency and cost-effectiveness, enhances construction updating of as-built schedule information among project participants, and increases flexibility in updating the as-built project schedule and response time. The primary advantages of the proposed ConBIM-SKM prototype for schedule management are: (1) to enhance dynamic project schedule tracking and management visually; (2) to enable project participants to access the most up-to-date as-built schedule status using different colors; and (3) to improve project BIM-assisted as-built schedule control and management efficiency for general contractors.

In this study, the proposed ConBIM-SKM prototype facilitates visual knowledge sharing and management using the BIM technology during the construction phase. The BIM technology stores any problems, solutions, and comments, allowing project managers and onsite engineers to access the most up-to-date knowledge. The primary advantages of the proposed ConBIM-SKM prototype for knowledge management are: (1) to effectively link knowledge using BIM-based graphic representations; (2) to promote relationships between areas of expertise via both vertical and horizontal graphic representations; and (3) to provide statuses of acquired knowledge of different situations using different colors.

4.1 Overview of ConBIM-SKM prototype

The following section describes the development of the proposed ConBIM-SKM prototype. The ConBIM-SKM prototype server is based on the Microsoft Windows Server 2008 operating system with an SQL Server 2008 R2 as the database. The ConBIM-SKM prototype is developed using C.NET programming, which is easily incorporated with ADO.NET to transact schedule, knowledge and BIM information with a SQL Server database. The ConBIM-SKM prototype consists of three different user areas, project manager, onsite engineer, and BIM engineer areas. Access to the ConBIM-SKM prototype is password-controlled. All data are stored and classified using the visual schedule management dashboard in the ConBIM-SKM prototype. Furthermore, the ConBIM-SKM prototype is a solution that uses a single, unified database linked to the as-built models' files with different levels of access determined by user roles. Participants can access the BIM model schedule management information entry and updates, based on their responsibilities in the ConBIM-SKM prototype. When information is updated in the ConBIM-SKM prototype, the server automatically sends e-mails to the project manager, and the project engineers associated with the issue. One purpose in this study is to extend BIM to the construction phase and provide as-built schedule updating service for general contractor. The as-built model is applied in the ConBIM-SKM prototype to capture and store as-built model information. The ConBIM-SKM prototype was developed by integrating the BIM schedule management-related information using Autodesk Revit Architecture and Revit MEP software. A program in C.NET was written to integrate acquired data from different system or programs for information delivery.

Industry Foundation Classes (IFCs) are a set of building product model specifications developed by the International Alliance for Interoperability (IAI) for product data representation and exchange in the construction industry (Wix and Liebich, 1998; Hassanain et al., 2001). IFC standard enable interoperability among AEC/FM software applications and this means the end-users in the AEC/FM area can effectively share the model data through IFC files (Fu et al., 2006).

Updating the as-built schedule during the construction phase is generally recognized as the most critical strategy for successful schedule management. This study focuses on the practical implementation of the as-built schedule for the general contractor at a jobsite. In this study, the proposed ConBIM-SKM prototype facilitates different statuses of as-built schedule process during the construction phase. In order for the project manager and project engineers to track the visual BIM-assisted as-built schedule, the study proposes three types of process statuses for updating the as-built schedule in the ConBIM-SKM prototype. The three process statuses include: (1) ahead of schedule status; (2) on schedule status; and (3) behind schedule status. Various statuses have been developed and modified for different purposes in order to meet requirements for the as-built schedule.

The proposed ConBIM-SKM prototype with BIM-assisted visualization allows all project engineers to access the most recent visual as-built schedule using the BIM model. Furthermore, the updated as-built schedule can also be shared with marked information related to changes. The framework of the proposed ConBIM-SKM prototype includes integration of BIM technologies with schedule management. With the assistance of BIM model, the schedule can be enhanced illustrated and focused on updated schedule the location or components of building. Because of BIM model characteristic, the application of ConBIM-SKM prototype for schedule management will be illustrated different colors and status based on as-built schedule using BIM model.

The study utilizes the BIM approach to apply as-built BIM models in the updating of the as-built schedule. The first generation of ConBIM-SKM prototype in the study, Design Web Format (DWF) and Navisworks (NWD) files are the selected format of the BIM file for markup as-built schedule use. Onsite engineers may update the status and corresponding color of the progress using as-built BIM models (BIM DWF file or NWD file), and upload it to the system for updated as-built schedule sharing. Finally, the system will convert as-built updated component units of BIM models under the BIM DWF or NWD file by API programming and upload them to the ConBIM-SKM prototype. In the newest generation of ConBIM-SKM prototype, IFC-based BIM files are the selected format of the BIM file for markup as-built schedule use.

4.2 Prototype Modules for schedule management

This section demonstrates the implementation of the ConBIM-SKM prototype modules.

Authority Management Module

The authority management module is an access control mechanism preventing unauthorized users from entering the system or retrieving sensitive as-built schedule information. The ConBIM-SKM prototype requires all project engineers, project managers, BIM engineers, and system administration to register. To register, users provide a unique User ID and password for authentication. As ConBIM-SKM information and reports required by different project engineers and different BIM models vary, the authority and access rights of project managers and BIM engineers vary from those of others.

BIM Process Monitoring Module

The BIM process monitoring module tracks provide the visual BIM-assisted updating schedule management dashboard environment. Additionally, project engineers and managers can access visual schedule management dashboard regarding the current process or status of the as-built schedule information. The process monitoring module has an easy access option that allows participants to track as-built schedule information with different status color of BIM models illustration. Furthermore, project engineers and project managers can share the most recent updated as-built schedule with related BIM models and access all current responses about schedule problems with an as-built model from onsite project engineers.

Alert Management Module

The Alert Management module helps the project engineers, who set up an alert service to monitor and manage the updating of as-built schedule via e-mail. Dates related to the notification about updates in BIM-assisted schedule information are recorded systematically. Furthermore, this module provides convenient access and a push-based function to help the project manager and project engineers respond to decisions in advance, before an update in the schedule is tracked and others respond.

BIM Schedule Management Module

The BIM schedule management module lets users update the as-built schedule information regarding selection of BIM model components, which are stored with the corresponding as-built models. Authorized records for updating as-built schedule information can be extracted and summarized for the BIM-assisted updating schedule summary. Furthermore, the entire BIM-assisted updating schedule summary can be presented on the web or extracted using commercially available software such as Adobe Acrobat.

<u>**BIM Models Problem Response Module**</u>

The module centralizes storage of all problems of the corresponding components of the as-built schedule in the 3D BIM model in a visual environment. This allows onsite engineers to respond effectively from a central location to problems in the as-built schedule and provide a revised description of corresponding modified as-built models. Usually, the onsite engineer can submit the problem in the as-built schedule information about corresponding components in the 3D BIM model through the module. Furthermore, project participants can communicate problems with the BIM-assisted as-built schedule through the module.

<u>**BIM Schedule Management Report Module**</u>

The module allows users to easily access the brief updates in information about BIM schedule regarding the corresponding components in the 3D BIM model. Authorized records for updating the as-built schedule can be extracted and summarized with the visual BIM model reports. Furthermore, all BIM schedule management reports can be presented on the web or extracted using commercially available software such as Microsoft Word and Acrobat PDF. Figure 27 shows the BIM-based knowledge sharing and management process flowchart in the ConBIM-SKM prototype.

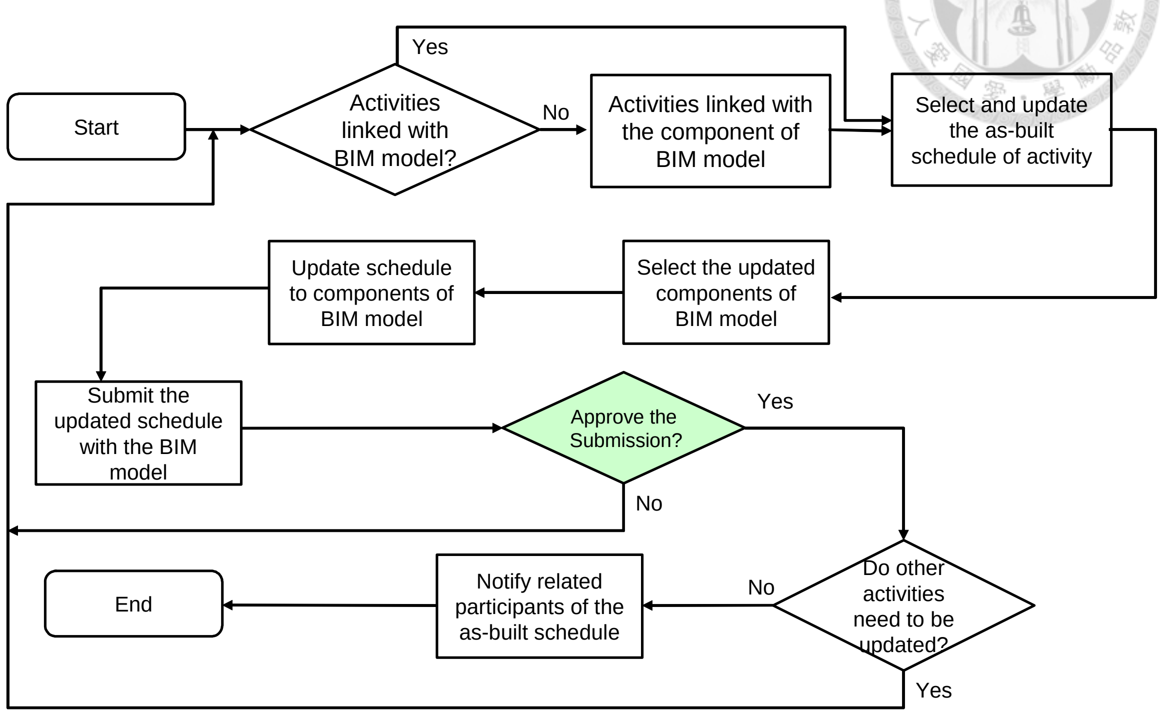

Figure 27. The process flowchart of as-built updating schedule management integrated with BIM

4.3 Prototype Modules for knowledge management

All modules in the system are briefly described below.

Authority Setup Module

The authority setup module is an access control mechanism preventing unauthorized users from entering the system or retrieving sensitive information. The ConBIM-SKM prototype requires all project participants (managers and onsite engineers) to register by providing a unique User ID and password for authentication.

Knowledge Edition Module

Through this module, project participants can edit their relevant contributions to the objects in the BIM model. Generally, participants may create a new issue or contribute to those started by others in order to share their knowledge on various aspects of the project. The edited information will be saved in issues by categories associated with the relevant objects of the BIM model. Also, attached documents and report files must be uploaded in PDF format, the standard file format. The knowledge edition module allows experts and engineers to share issue-based tacit knowledge via a discussion forum.

Alert Setup Module

This module helps project participants set up an alert service for monitoring and managing knowledge via e-mail and RSS. Dates related to any notification of new information are submitted or updated systematically and project participants can determine who is invited to submit knowledge.

Report Module

The report module allows users to easily access the summarized information to identify needs and analyze what has been recorded. The knowledge report can be illustrated with a BIM model, a description, and a summary of the information. Furthermore, all reports can be presented on the web or extracted to PDF format. This process allows users to make and organize knowledge-related reports from a central location. Figure 28 shows flowchart of knowledge management integrated with BIM.

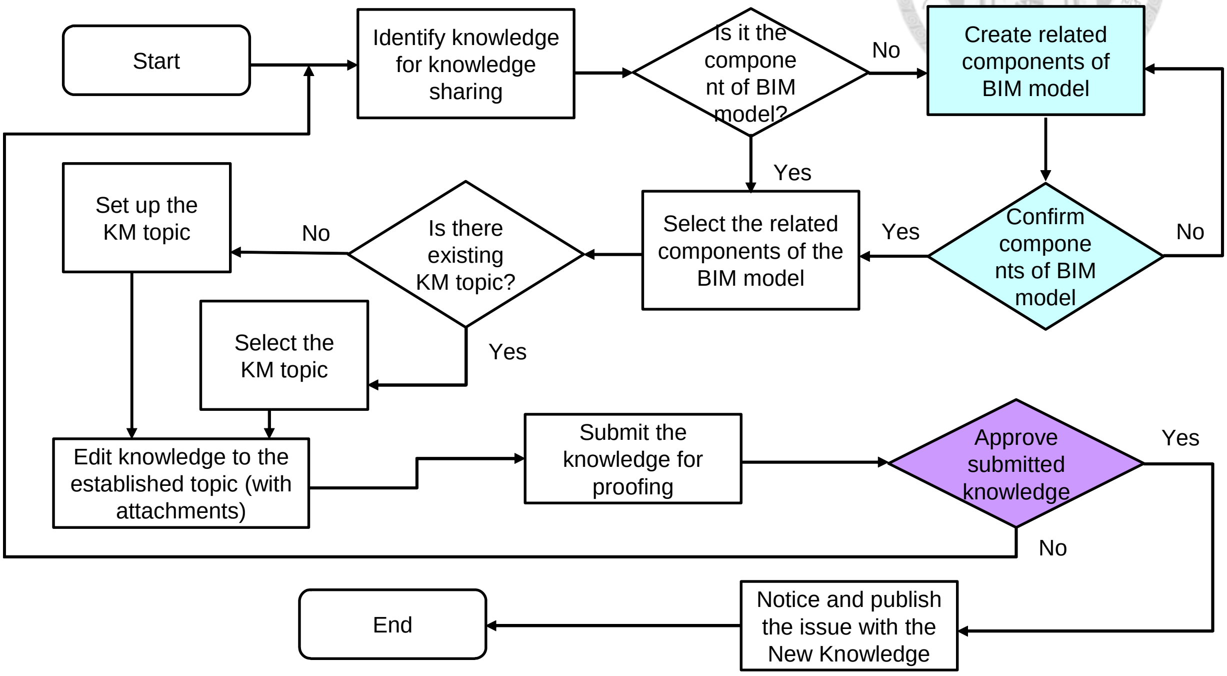

Figure 28. The process of knowledge management illustration integrated with BIM

Figure 29 shows GUI of the ConBIM-SKM prototype for the master IFC-based BIM model. Figure 30 illustrates GUI of the ConBIM-SKM prototype for updating as-built schedule. Figure 31 illustrates GUI of the ConBIM-SKM prototype for schedule management. Figure 32 illustrates GUI of the ConBIM-SKM prototype for updating knowledge.

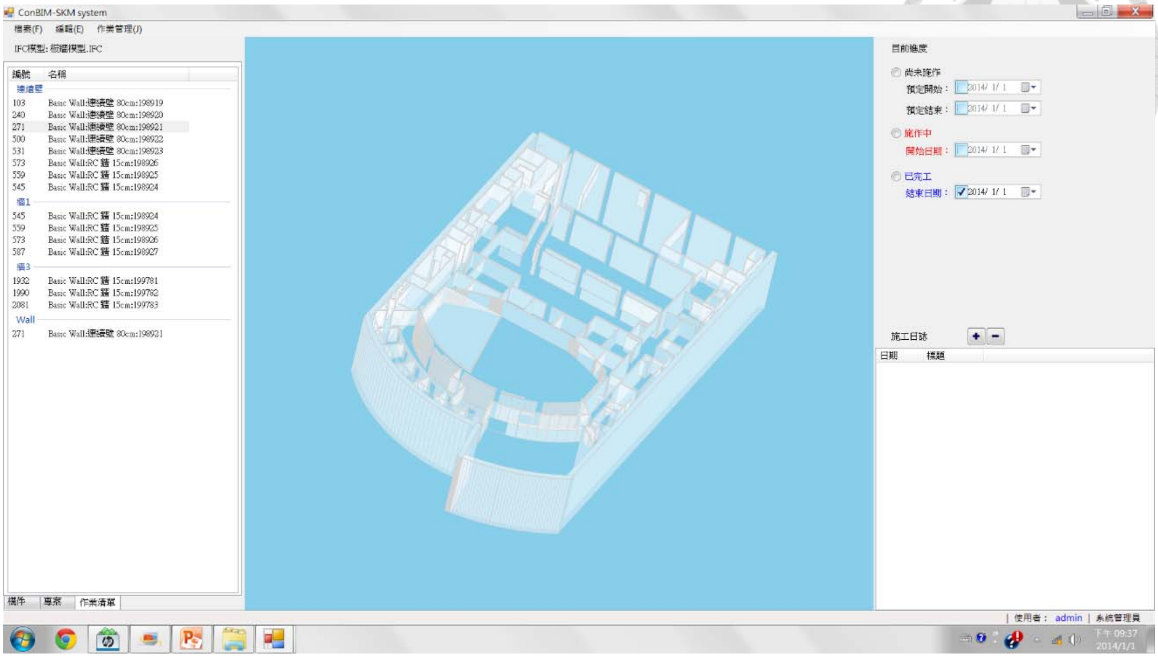

Figure 29. GUI of the ConBIM-SKM prototype for the master IFC-based BIM model

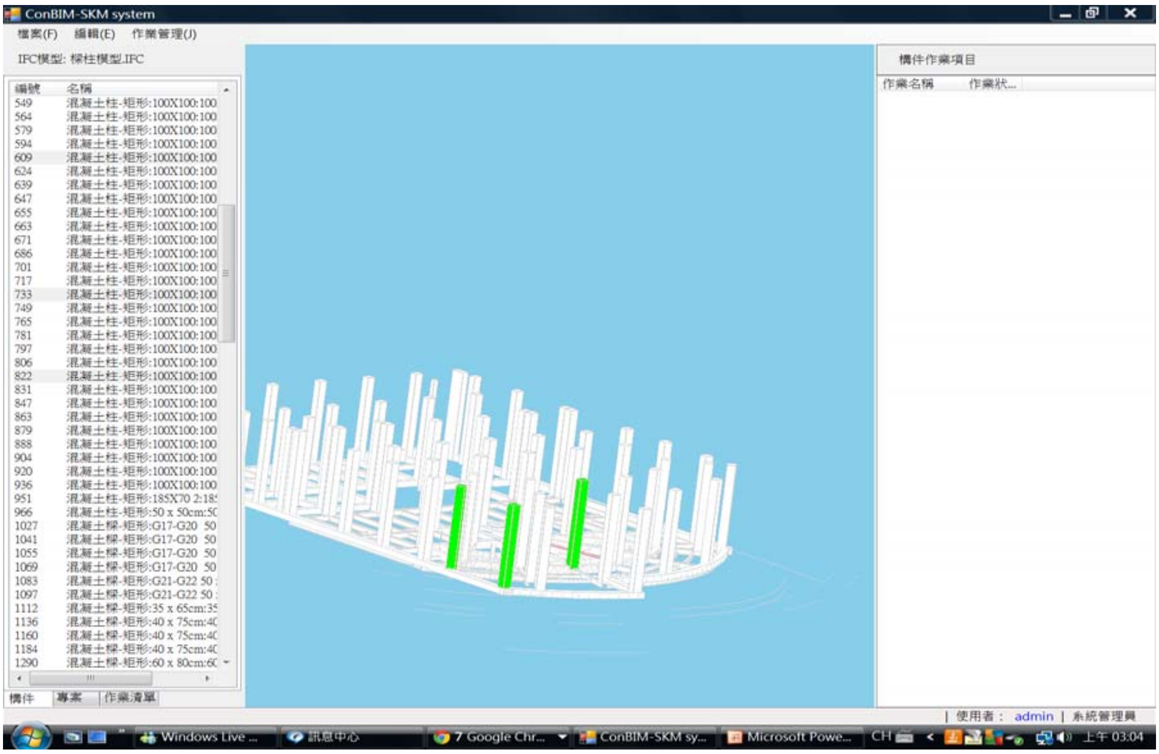

Figure 30. GUI of the ConBIM-SKM prototype for updating as-built schedule

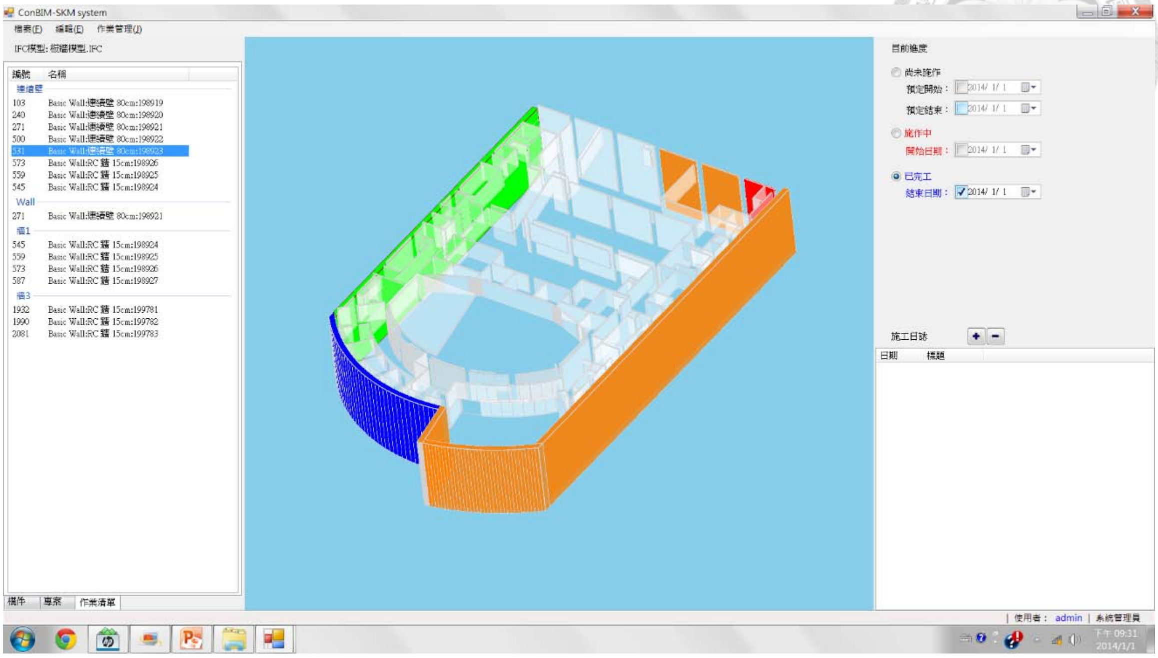

Figure 31. GUI of the ConBIM-SKM prototype for schedule management

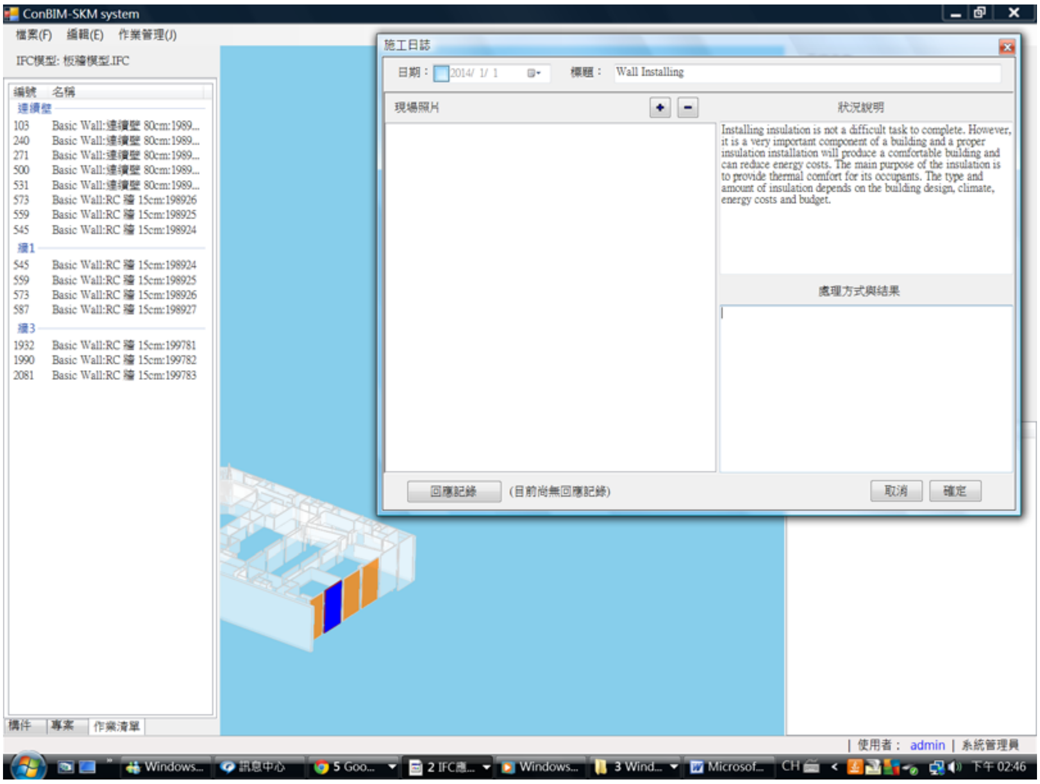

Figure 32. GUI of the ConBIM-SKM prototype for updating knowledge

5. Case Study

5.1 The Description of Case Study

The project of case study was a commercial building consisting of fifteen stories with 164,000 sq. ft. of residence building. The construction work also included all related site, structural, mechanical, plumbing, fire protection, and electrical components. The implementation of case study made around 2-months for schedule management. The case study involves a general contractor with 25 years of experience in constructing office buildings in Taiwan. The construction phase of this office-building project also involves three subcontractors and five suppliers. The general contractor wanted to take full advantage of using the visual approach to enhance onsite construction management (aspects of which include schedule management, visual discussion, and so on). In the general contractor's previous experience, there have been serious problems with onsite as-built schedule updating and tracking. One such problem has been obtaining an accurate position and location from the text-based illustrations of a traditional schedule. Therefore, the general contractor had assigned project engineers, project managers, and BIM engineers to utilize the ConBIM-SKM prototype to solve the problems related to the onsite as-built schedule during the construction phase. The ConBIM-SKM prototype was used in the office-building project to demonstrate its efficacy and that of the visual BIM-assisted updating and management of the as-built schedule. A major aim of selecting this project was to emphasize the general contractor's use of BIM tools to manage construction during the construction phase. All BIM models were created and developed by the general contractor.

5.2 Case Study for Schedule Management

The main benefits of using BIM in construction for general contractor included less rework, better cost estimation, and improved productivity. Therefore, the general contractor decided to reuse these BIM models to enhance the application of visual BIM as-built schedule management. In other words, the BIM models were reused and applied to as-built schedule management. There were two full-time engineers with three years of BIM experience to perform the BIM as-built schedule management in the project. The ConBIM-SKM prototype was installed on the general contractor's main server during the test. A user guide was provided, and three ConBIM-SKM prototype workshops were held to demonstrate the use of the ConBIM-SKM prototype. All invited engineers originally used the MS Project™ software to control the project schedule. During the test period, they used the ConBIM-SKM prototype only for the test project and used MS Project™ to control the schedule and management of the company simultaneously. During the case study, responsible onsite engineers updated their as-built schedule, and updated the status and content of the BIM model in the ConBIM-SKM prototype. The BIM engineers needed to prepare and convert BIM model into IFC-based BIM files in the initial phase. After the BIM models were converted, the onsite engineers linked the as-built activity with the BIM model and uploaded the submission via the ConBIM-SKM prototype. The attached files with selected components of the BIM model included digital documents and photos. The BIM engineers assisted the onsite engineer in the creation and conversion of the BIM models for use in future as-built scheduling. Furthermore, BIM engineers will revise the BIM models based on the as-built situation, if necessary. All onsite engineers were required to update the as-built schedule using the ConBIM-SKM prototype. Onsite engineers updated the status color of the current schedule's components that corresponded with the BIM models, and updated their discussions and comments via the ConBIM-SKM prototype. Finally, all BIM-assisted schedule information was centralized and stored in the central database to prevent the collection of redundant data. The ConBIM-SKM prototype automatically sent a message concerning any updated information to the onsite engineers and project manager after saving the new content.

In the case study, the decoration engineers attempted to utilize the BIM approach for illustrating the as-built updated schedule regarding the installation of windows and doors. The decoration engineers and BIM engineers utilized the as-built BIM models and linked the BIM models to the activity in the ConBIM-SKM prototype. After the as-built BIM models were revised and linked with related activities, the decoration engineers were invited to update their as-built schedules with the BIM approach. All decoration engineers were required to update their own as-built schedules regarding the activities for which they were responsible. The as-built schedule information with the corresponding components of the BIM models included the as-planned schedule, as-built schedule, descriptions and comments, and as-built photos (when they were necessary). When the submitted as-built schedule document set was approved by the project manager, the system illustrated the process automatically. In other words, users could find and read the related as-built schedule directly simply by clicking on activities and referring to the appropriate components of the BIM models. Finally, all submitted as-built schedules whose components corresponded with the BIM models had to have their performance quality approved before the final as-built schedule could be published. All of the validation needed to be executed by the project manager.

The decoration engineer identified and updated the as-built schedule records of selected decorations (such as descriptions, as-built videos, and documentation) provided by the responsible engineers. The decoration engineer continued to update and provide comments on the as-built schedule in the portion of the project assigned to the installation of windows and doors using the multi-field as-built schedule records. Additionally, the decoration engineer provided additional suggestions and feedback pertaining to any delay problems after the work was completed. Subsequently, another decoration engineer updated the new as-built schedule and selected the status of the as-built schedule in the ConBIM-SKM prototype after personally completing the installation of the windows and doors. Furthermore, the engineer uploaded the as-built photos and descriptions of the components corresponding to the BIM models in the ConBIM-SKM prototype. Moreover, the decoration engineer republished the updated as-built schedule from the approval section to the published section of the ConBIM-SKM prototype after the approval process was completed, and a notification was sent to authorized members.

5.3 Case Study for Knowledge Management

As same with the above case, the implementation used as a case study lasted 4 months for knowledge management. The architecture firm hoped to take full advantage of the BIM-based knowledge management system to facilitate knowledge exchange and management during the construction phase and reuse it in other similar projects. Therefore, the architecture firm announced that all jobsite and project managers would be encouraged to use the ConBIM-SKM prototype to apply knowledge management in order to effectively manage acquired information during the construction phase in the BIM environment. The ConBIM-SKM prototype was utilized in the construction project to verify the proposed methodology and demonstrate the effectiveness of sharing previous experience in the construction phase. During the case study, all jobsite and project managers were encouraged to explore and edit their own recorded experiences in the ConBIM-SKM prototype.

As previously mentioned, the case study was implemented in the middle of the construction phase. All BIM models used in the study were created and developed for the purpose of construction management. Finally, the BIM models were reused and applied for knowledge management.

First, the engineers were invited to explain their experiences and provide comments based on the issue and include relevant information and documents. The initial engineer created issues regarding the selected activity and objects of the BIM model in the initial phase. All related documents for this issue were collected and digitized by the senior engineers and knowledge assistants. After the issue was created, the senior engineers were invited to share their knowledge and comments related to the issue using the system. The posted files included digital documents, photos, and films. The knowledge assistants helped the senior engineers to digitize the content, and they then created the BIM objects related to the issue. The other issues were communicated in the same manner. All engineers were required to submit experience-based information and discussions regarding the issue via the ConBIM-SKM prototype. The engineers read previous comments provided by others, learned from these records, and submitted their own comments via the ConBIM-SKM prototype, which then allowed other engineers to discuss their work. The comments provided by the senior engineers included notes, actual problems/solutions, and suggestions. The engineers communicated problems and solutions to the senior engineers, posted their comments in the system and shared their case discussions with others. The engineers were required to submit their knowledge pertaining to the BIM objects of the BIM model via the ConBIM-SKM prototype. The senior engineers reviewed all questions and solutions and posted comments for all interested individuals. Furthermore, all information was stored in the central database to prevent the collection of redundant data. Finally, the information was automatically backed up from the system database to another database. Moreover, the knowledge was updated later because further feedback and another solution to the same problem were provided. The updated knowledge set was republished in the object of BIM model of the ConBIM-SKM prototype after the approval process was completed. A notice message was then transmitted to authorized members.

5.4 Evaluation

During the field test, the three BIM engineers handled all the BIM-related work. The BIM works included the as-built schedule integrated with BIM models creation, modification, and revision. The twelve onsite project engineers and the general contractor handled the entire construction project up to its completion using the as-built schedule. The ConBIM-SKM prototype was installed on the general contractor’s main server during the test. A user guide was given and two ConBIM-SKM prototype workshops were held to show how the ConBIM-SKM prototype could be integrated with the BIM approach. Furthermore, BIM-related software (Autodesk Revit) was selected to create and revise the as-built models. All BIM files were converted into DWF files for review and markup in the ConBIM-SKM prototype.

In this case study, the BIM engineer handled and assisted the production and revision of BIM models for BIM-assisted as-built scheduling. The onsite engineers developed and updated the BIM-assisted as-built schedule. Finally, the project managers and onsite engineers accessed and tracked the updated as-built schedule with the BIM approach in the ConBIM-SKM prototype.

During the field test, the verification test was carried out through the assessment of whether the ConBIM-SKM prototype performed tasks as specified in its design. During the validation test, selected case participants were asked to use the system; project teams then provided feedback via a questionnaire. The case participants consisted of three BIM engineers of general contractor with three years' experience, six onsite engineers with five years' experience, two senior subcontractor engineers with ten years' experience, and two general contractor project engineers with ten years' experience. Questionnaires were distributed to evaluate system function and user satisfaction with system capabilities. System users were asked to grade the system's usage, functionality, and capability separately, based on a comparison with the previous meeting approach on a five-point Likert scale, ranging from 1 for "not useful" to 5 for "very useful." Questionnaire results indicated that enhancing the management of the visual as-built updated schedule with graph visualization using the BIM approach was significantly improved through the use of the proposed system. Comments regarding possible improvements to the ConBIM-SKM prototype were also obtained from project participants. The ConBIM-SKM prototype was demonstrated to the respondents, who were asked to express their opinions towards the system by completing the questionnaire. Table 5 shows the results of the testing of the system. Based on the questionnaire result, respondents thought BIM should be a helpful tool in construction schedule management. Obviously, most of the respondents agreed the use of BIM to support as-built schedule illustration and improve updating as-built schedule sharing visually.

Table 5. System Evaluation Result for schedule management Using BIM

System Evaluation Item	Mean Score
Enhance visual as-built schedule illustration	4.5
Applicability to Construction Industry	4.8
Reduces Mistakes in As-built schedule	4.2
Enhances Virtual As-built Schedule Sharing	4.3
Enhances Tracking As-built Schedule Status Virtually	4.2
Improves Updating As-built Schedule Sharing	4.5
Enhances BIM-assisted Schedule Communication	4.4
Enhances Updated Parts of As-built Schedule	4.1
Enhances Managing As-built Schedule Virtually	4.3

Note: the mean score is calculated from respondents' feedback on a five -scale questionnaire: 1(Strongly Disagree), 2, 3, 4 and 5 (Strongly Agree)

The principal advantages of the ConBIM-SKM prototype, based on questionnaire results, The principal advantages of the ConBIM-SKM prototype, based on questionnaire results, are as follows: (1) The ConBIM-SKM prototype allowed project engineers and managers to track and manage the visual BIM-assistant as-built schedule information during construction (92% agreed). (2) The ConBIM-SKM prototype allowed onsite engineers to provide as-built schedule feedback with color-coded statuses through the ConBIM-SKM prototype (89% agreed). (3) The ConBIM-SKM prototype enabled the project engineers to track and view the updated contents of the as-built schedule when using it with the BIM approach (88% agreed). (4) The ConBIM-SKM prototype enhanced visual management of the as-built schedule effectively in the visual environment (92% agreed).

The following recommendations are based on user feedback. (1) Successful ConBIM-SKM adoption should be supported by the individuals of highest authority in a firm and on a jobsite. (2) Policy and strategy must be considered to encourage use of the ConBIM-SKM prototype at the jobsite during the construction phase. (3) Further efforts and additional approaches are required to overcome unwillingness to adopt BIM software (such as Autodesk Design Review) at a construction jobsite. (4) Initial case study results should be used to educate users about adoption of BIM software, and additional staff training is needed. (5) Further training and workshops on the ConBIM-SKM prototype and BIM software are necessary for all users.

Regarding to knowledge management section, Questionnaire results from the case study evaluation reveal that the ConBIM-SKM prototype effectively shares knowledge for construction projects. A verification test was performed by checking whether the ConBIM-SKM prototype could perform tasks as specified in the system analysis and design. The validation test was undertaken by requesting selected case project practitioners to use the system, and the provide feedback by answering a questionnaire. There were 18 respondents; two project managers with ten years of experience; six onsite engineers with ten years of experience; seven onsite engineers with five years of experience; two assistants with three years of experience, and one CKO with ten years of experience. The ConBIM-SKM prototype was demonstrated to the respondents, who were requested to give their opinions on it by completing the questionnaire. Table 6 shows the results of the system evaluation. Based on the questionnaire result, respondents thought BIM should be a helpful tool in construction knowledge management. Obviously, most of the respondents agreed the use of BIM to support knowledge illustration and improve knowledge sharing visually.

Table 6. System Evaluation Result for knowledge management Using BIM

System Evaluation Item	Mean Score
Enhances visual knowledge illustration	4.5
Applicability to construction knowledge management	4.8
Reduces rework percentage	4.2
Reduces percentage of mistakes occurring	4.3
Improves the knowledge collection	4.2
Enhances knowledge communication	4.4
Improves knowledge sharing	4.7
Enhances learning performance	4.3

Note: the mean score is calculated from respondents' feedback on a five -scale questionnaire: 1(Strongly Disagree), 2, 3, 4 and 5 (Strongly Agree)

Overall, the onsite engineers' feedback for the case study was positive. Most engineers and project managers agreed that the ConBIM-SKM prototype helps them to view all collected knowledge and experience in the BIM environment. Questionnaire results indicate that the primary advantages of using the ConBIM-SKM prototype are as follows: (1) it provides 3D visual illustration of knowledge regarding to project-based knowledge (86% agreed); (2) it provides BIM-assisted animation easily and effectively (89% agreed); and (3) it clearly identifies available knowledge and different status of different knowledge in the BIM environment (90% agreed).

Questionnaire results indicate that the primary advantages of the application of BIM in BIM-based knowledge models are as follows: (1) it provides clear 3D representations, thus identifying knowledge and experience feedback relevant to an object or activity (92% agreed); (2) one can generate a visual object of BIM model illustrations of knowledge, thus identifying acquired knowledge and experience feedback relevant to tasks and projects (90% agreed); (3) it allows one to view knowledge and information provided by onsite engineers easily and effectively (90% agreed); and (4) it enables engineers to trace and manage any acquired BIM-based knowledge feedback (88% agreed).

5.5 Barriers and Limitations

User feedback indicated that the primary barriers to using the ConBIM-SKM prototype for schedule management were as follows: (1) Most onsite engineers were unsatisfied with the slow Internet speed at the jobsite; (2) Substantial amounts of time and assistance were needed for engineers and managers to update the as-built schedule with the BIM approach; (3) A few onsite engineers were unwilling to update as-built schedule information; and (4) Two senior project engineers had difficulty becoming familiar with utilizing BIM model.

User feedback indicated that the primary barriers to using the ConBIM-SKM prototype for knowledge management were as follows: (1) insufficient updated information related to different types of knowledge; (2) substantial amounts of time and assistance needed for onsite engineers and managers to use the ConBIM-SKM prototype to edit and update knowledge feedback; (3) further effort is required to update information related to various objects of a BIM model or the activities in a project; (4) the senior and onsite engineers require substantial time and assistance to edit knowledge feedback; and (5) few engineers don’t accept BIM applications in the construction sites.

The findings of this case study revealed several limitations of the ConBIM-SKM prototype. The following are inherent problems recognized during the case study.

- An initial plan or discussion to integrate the BIM models in BIM-assisted schedule management is necessary at the project's onset to avoid ensuing problems with the as-built schedule updated with the BIM approach.
- Generally, BIM at different LOD will affect the results of the visual updates to the as-built schedule. For example, a BIM model with LOD400 makes it easier to update the as-built schedule than one with LOD100. The corresponding components of a BIM model with LOD100 will require more detail for schedule updating than a BIM model with LOD400.
- In the case study, project engineers who were unfamiliar with the use of 3D BIM models initially required additional time to apply the corresponding BIM-assisted as-built schedule in the ConBIM-SKM prototype. Therefore, more time was used with this system than the current approach. After the users became more skilled and familiar with the BIM models, the amount of time necessary for the current approach was almost identical to the time necessary for the proposed system in utilizing BIM models.
- Onsite project engineers who experienced a pressing work schedule often lacked sufficient time and assistance to update the as-built schedule. Additionally, the attitudes of the project engineers involved in the use of the ConBIM-SKM prototype to update the as-built schedule were found to vary greatly. The development of systems that satisfies all the needs of the various project engineers depends on their contrasting viewpoints and attitudes.

- Support of the upper management helps to assure the implementation of the updated as-built schedule, especially at the jobsite. In the case study, overcoming resistance to using the 3D BIM models and ConBIM-SKM prototype by onsite engineers during their work was an important factor, as well as one of the major prerequisites for the successful implementation of the ConBIM-SKM prototype. Upper management, therefore, gave project participants an incentive/bonus reward for using the ConBIM-SKM prototype more consistently during the case study. Future research must address how an updated BIM model can be implemented onsite effectively and directly (including BIM model creation, modification, updating) in practice.
- The ConBIM-SKM prototype can only be used at the jobsite directly. The findings of the case study indicate that most onsite engineers updated their as-built schedule when they were at the jobsite. The case study revealed that most onsite engineers considered updating their as-built schedule at the jobsite using a smart phone or notebook in a Wi-Fi or 3G environments to be inconvenient. Therefore, onsite engineers began using tablet computers (such as iPads) which, according to case observations, improved their willingness to apply the ConBIM-SKM prototype and update their as-built schedule directly at the jobsite.
- In this case study, many onsite engineers chose to use the proposed multi-field as-built schedule's progress records to facilitate tracking the updated as-built schedule with the BIM approach in the ConBIM-SKM prototype. According to the questionnaire's results, most of the engineers thought the use of multi-field as-built schedule records was very helpful for updating progress and tracking management, although the BIM-assisted as-built schedule could be very time-consuming.

- Regarding to the use of various colors in the BIM model for updating and tracking purposes, it is recommended to limit the amount of different colors used, so as to reduce confusion for the user. Additionally, the next steps in the system's development are providing users with the 2D illustration map for updating the condition of the schedule, identifying the 2D location, and reviewing the 3D visual BIM model in the future.

6. Conclusion and Future Research

6.1 Conclusion

Various visual representations of a project management and associated information combined with visual representations of the project in progress, i.e. BIM, can assist with these tasks of identifying effective construction strategies for managing a project's knowledge and schedule. The application of BIM integrated with knowledge management and the as-built schedule management for building projects during the construction phase is discussed in this work. To assist the general contractor in effectively and efficiently managing knowledge and schedule, this study proposes BIM model management model, BIM schedule management updating model, and BIM knowledge management model. Furthermore, this study presents novel prototype called the Construction BIM-assisted Schedule and Knowledge Management (ConBIM-SKM) prototype for general contractors in Taiwan. Finally, the ConBIM-SKM prototype is applied to a case study of a commerce building project in Taiwan to verify its efficacy and demonstrate its effectiveness during the construction phase.

Although there is a great deal of previous researches focusing on the simulation of the 4D approach (3D and time simulations), there are few studies on updating an as-built schedule using the BIM approach. Notably, the proposed approach retains information about changes and conditions to the as-built schedule in a digital format and facilitates easy and effective visual updating of as-built schedule information in the BIM-based environment. Furthermore, project participants can access and utilize the most recently updated as-built schedule integrated with BIM model in practice during the construction phase. All as-built schedules can be updated, and changes and problems are made known to each project engineer via the markup-enabled BIM models. Finally, the proposed ConBIM-SKM prototype is applied to a case study of a building project in Taiwan to verify its efficacy and demonstrate its ConBIM-SKM prototype's effectiveness. The case study results show that the ConBIM-SKM prototype provides users with centralized storage of all updates to the contents and status of the as-built schedule during the construction phase of a project, such that the project managers and project engineers can track and manage the visual newest schedule status effectively. The case study also highlights the need to improve as-built schedule management work during the construction phase. Integration of web-based technologies and the BIM approach is promising for the alleviation of problems in updating an as-built schedule during the construction phase. Overall, field test results indicate that the proposed ConBIM-SKM prototype is an effective and user-friendly platform for the general contractor to handle as-built schedule management integrated with BIM model.

This study presented the ConBIM-SKM prototype to construction project participants so that they could update and share any information about their as-built schedule in an enhanced visual way. The ConBIM-SKM prototype improves efficiency in tracking the as-built schedule information collected visually from onsite engineers, and provides monitoring services for project participants. This study shows that the ConBIM-SKM prototype significantly enhances control of the visual aspect of a construction project's as-built schedule. In the view of construction management, the proposed prototype assist the visual illustration of real-time as-built information from all project participants and visually monitor and control the construction project's as-built scheduling process by using statuses of various colors. Furthermore, project participants and managers can access the ConBIM-SKM prototype to track the BIM-assisted as-built schedule anytime and anywhere, based on what they are permitted to do by their authorities.

Regarding to BIM-based knowledge management, this work presented and developed the ConBIM-SKM prototype as a visual platform to improve construction knowledge sharing in building projects. The ConBIM-SKM prototype illustrates knowledge with problem descriptions and solutions in the BIM environment. BIM is a highly promising means of enhancing knowledge management during the construction phase of a project. Collecting problem descriptions and solutions using the BIM technology allows project managers and onsite engineers to contribute and share the most up-to-date knowledge and experience regarding problems and solutions in construction. The BIM technology generates 3D drawings, thus identifying valued experience-based knowledge relevant to issues and activities. Additionally, BIM provides objects and illustrations when knowledge is available. The ConBIM-SKM prototype collects specific problem solutions, and supports all information across projects. Overall, field test results indicate that the ConBIM-SKM prototype is an effective and simple platform for construction knowledge management. The case study results demonstrate the effectiveness of a ConBIM-SKM-like system for KM during the construction phase.

The concept of a BIM-based knowledge management system was presented to be utilized as a knowledge-sharing platform in construction projects. The application of BIM-based knowledge management system mainly allows project participants to access the knowledge easily and effectively. Although effort is required to update information on various problems and solutions, the proposed system benefits knowledge management by (1) developing web-based BIM-assisted knowledge management system for construction knowledge sharing, (2) providing an effective and efficient method to assist and manage visual knowledge management work, (3) enabling users to learn knowledge through BIM-based knowledge animation.

In sum, the engineers were able to increase their understanding of previous captured knowledge and experience from all participants working on different projects. Notably, BIM integrates the objects comprising knowledge management work by incorporating external factors, such as problem and solution descriptions, comments, and suggestions, into a single source for all construction BIM-based knowledge management information. Effectively utilizing knowledge management integrated with BIM during the construction phase allows project participants to identify, monitor, coordinate and access information for future A/E/C projects.

6.2 Contributions

As the application of BIM becomes more common, construction management integrated with the BIM approach becomes essential to enhance visual construction management implementation for the general contractor during the construction phase. To enhance visualization of the updated as-built schedule and knowledge management for the general contractor, there are three models developed in the study. They are BIM model management model, BIM schedule management model, and BIM knowledge management model. After the application of BIM model management, the proposed schedule management model and knowledge management model may be executed successfully. The study develops the BIM model management model for BIM models management lifecycle. There are four phases in the BIM model management model. They are creating BIM model, approving BIM model, publishing BIM model, and modifying BIM model. Furthermore, the study proposes the flowchart of BIM models management based on the interviews with BIM experts in Taiwan. Most of BIM work during the construction phase can be executed based on the proposed flowchart of BIM models management.

With assistance of the BIM schedule management updating model, the advantages of the ConBIM-SKM prototype lie in improved as-built schedule tracking and management efficiency for general contractors to access the most current as-built schedule information through Internet. The case study results show that the ConBIM-SKM prototype is an effective visual as-built schedule management platform integrated with the BIM approach for general contractors during the construction phase.

With assistance of the BIM knowledge management model, construction knowledge can be communicated and reused among project managers and onsite engineers to alleviate problems on a construction jobsite and reduce the time and cost of solving problems related to constructability. The main characteristics of BIM include illustrating 3D CAD-based presentations and keeping information in a digital format, and facilitation of easy updating and transfer of information in the 3D environment. Integrated with the BIM knowledge management model, project managers and engineers can gain knowledge related to BIM and obtain feedback provided by onsite engineers for future reference.

Finally, this study presents novel prototype called the Construction BIM-assisted Schedule and Knowledge Management (ConBIM-SKM) prototype for general contractors in Taiwan. Finally, the ConBIM-SKM prototype is applied to a case study of a commerce building project in Taiwan to verify its efficacy and demonstrate its effectiveness during the construction phase. The results demonstrate that the ConBIM-SKM prototype can be used as a visual BIM-based schedule management and knowledge management platform by utilizing the BIM technology.

6.3 Future Research

There are still many important applications of nD modeling special for construction management. In the future, nD modelling will be considered for practical use and research on a jobsite. Over the past few years, there has been a great deal of studies on the application of nD modelling. However, most of these ideas have not actually been put to use on a jobsite. Usually, there are extra consideration and approaches when the application of nD modeling at the jobsite. Future research of the ConBIM-SKM prototype will explore interface design and develop extra system functions if ConBIM-SKM prototype is to be utilized on a jobsite. These advances aim to ultimately lead to the system's more comprehensive practical use in A/E/C applications. Accordingly, the development and implementation of ConBIM-SKM prototype for the whole project in schedule and knowledge management will come to next development in the ConBIM-SKM prototype if it is customized for the characteristics of different construction activities.

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