Applying BIM and visualization techniques to support construction quality management for soil and water conservation construction projects

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Abstract –

Constructing soil and water conservation (SWC) facilities is crucial to protect soil and water resources, maintain natural ecology and landscape, and prevent erosion, landslide, debris flow, and other disasters. Due to the existence of mountainous terrain in Taiwan and the frequent prevalence of extreme climate changes, thousands of SWC construction projects are built or renovated all over the island in each year. The responsible central governmental entity (home bureau) in Taiwan continuously seek for solutions to improve their current database management system which collects only numbers, texts, and two-dimensional photos to monitor the construction progresses of these projects. This study applies the building information model (BIM), augmented reality (AR) and virtual reality (VR) to develop a new construction management system that can visualize each construction project on a three-dimensional model and access the project information promptly in a cloud environment to support both home bureau and local bureau (the actual project owner). The proposed system is applied to a case project to demonstrate its benefits in supporting construction quality management. The application results suggest that the governmental bureau should provide sufficient incentives to encourage those middle- or small-size designers and contractors to apply the proposed system to the SWC construction projects.

Keywords –

Soil and water conservation construction projects; building information model; augmented reality; virtual reality; construction quality management

1 Introduction

Soil and water conservation (SWC) facilities are used to protect soil and water resources, maintain natural ecology and landscape, and prevent erosion, landslide, debris flow, and other disasters [1]. Due to the existence of mountainous terrain in Taiwan and the frequent prevalence of extreme climate changes, thousands of SWC construction projects are continuously built all over the island in each year.

From the government's viewpoint, the management of each SWC construction project can be classified into two parts, including the one from the branch bureau and the other from the home bureau (that is, the Soil and Water Conservation Bureau, Council of Agriculture, Taiwan). While the branch bureau is the project client in managing the construction project, the home bureau is responsible for monitoring the progresses of all construction projects in an integrated manner.

Currently, both branch and home bureau uses a database management system to collect project data that are in a form of texts, numbers, and a few jobsite photos (and even without drawings) to describe the construction progress and site conditions of each project. That is, the current system has a weakness in helping engineers to visualize a project. Consequently, the governmental engineers must frequently visit the jobsites (with eyes) to get familiar with the projects so that they can manage them accurately on quality, safety and schedule control. Without in-depth understanding about those projects, the bureau engineers would have little sense of the project conditions (in terms of construction quality and safety, for example) and may pay wrong attention to the projects with high vulnerability to an in-coming disaster (e.g., typhoon).

Moreover, these SWC construction projects are often located in mountains or at the places where

transportation is not convenient. Hence, engineers would need to carry heavy hardcopies of design drawings and specifications to find project data to support their quality and safety inspections in the construction jobsite.

Enhancing the visualization ability on the SWC construction projects and improving the efficiency in retrieving project data have been identified by both home- and local-bureau engineers as a solution to reduce extensive engineer's laborious work and improve the management of these construction projects. This study proposes to apply the building information model (BIM), augmented reality (AR) and virtual reality (VR) to develop a new construction management system that can visualize each construction project on a three-dimensional (3D) model and access the project information promptly in a cloud environment.

2 Literature review

2.1 Soil and water conservation construction projects

A soil and water conservation (SWC) construction project is related to civil engineering, hydraulic engineering, agronomic/planting engineering; and, it usually exists in slope areas. Additionally, the treatment work of torrent, river, and landslide is the main work scope of SWC construction project [2].

According to the SWC design handbook [3], the major SWC facilities include: sediment storage dam (check dam), slit dam (comb dam), groundsill works, and revetment. Their usages are described as follows:

1. Sediment storage dam (check dam): A check dam helps reduce channel velocity, prevent erosion, and trap small amounts of sediment by intercepting flow along a channel. See Figure 1 for example.
2. Slit dam (comb dam): Depending partly on the spacing of the posts, the slit dam can keep larger clasts (cobbles and boulders) behind the dam, thus preventing damage downstream [4]. See Figure 2 for example.
3. Groundsill works: A groundsill work is constructed across the waterway to prevent riverbed degradation. See Figure 3 for example.
4. Revetment: Revetment are sloping structures placed on the banks of a river in such a way as to absorb the energy of incoming water. See Figure 4 for example.

Figure 1. Concrete gravity dam

Figure 2. Slit dam

Figure 3. Groundsill works

Figure 4. Revetment

2.2 BIM applications in Civil Engineering

BIM has been mostly used in building projects. Only very few BIM applications are in Civil Engineering. For example, considering that BIM remains a relatively underutilized tool in horizontal construction, Fanning, et al. [5] implemented BIM on bridge construction projects. In their study, BIM may have provided approximately 5–9% cost savings during construction by contributing to reduced change orders and rework. Additional and potentially significantly greater benefits may be realized through future BIM-enabled operation and maintenance of such infrastructure.

2.3 Augmented reality (AR) and BIM

Augmented reality (AR) and Virtual reality (VR) and are two categories of visualization techniques. AR preserves the user's awareness of the real environment by integrating the real world and the virtual contents in a mixed 3D space, while VR replaces the user's physical world with a totally synthetic environment and isolates the user's sensory receptors from the real physical world [6].

There are two types of simple augmented reality: marker-based which uses cameras and visual cues, and marker less which use positional data such as a mobile's GPS and compass [7].

Wang et al. [8] provided examples how BIM and AR can be integrated and used on site. In general, AR can visualize as-planned BIM facility information right in real-world jobsite to enable project participants to review the as-built progress against as-planned.

2.4 Virtual reality (VR) and BIM

Visualization can improve a user's cognition and help communication in discussing an abstract concept or physical object to real-world situations. Virtual reality (VR) is an immersive multimedia technology that uses VR headsets to create realistic images, sounds and other sensations to simulate a user's physical presence in a virtual environment and interact with digital objects in real time.

As indicated by Du et al. [9], most VR applications in design and construction problems must start with an established design deliverable in a form of CAD or BIM. Considering that there is a lack of automated data transfer approach between BIM and VR, Du et al. [9] proposed a BIM-VR real-time synchronization system to update BIM model changes in VR headsets automatically and simultaneously.

3 Proposed system

The proposed system aims to integrate BIM, AR and VR to provide 3D visualization and information accessibility to facilitate the branch- and home-bureau engineers in managing SWC construction projects. Additionally, the proposed system is operated in a mobile device and cloud environment.

Figure 5 presents the framework of the proposed system which consists of four parts: (1) developing SWC facility BIM model and terrain BIM model, (2) integrating BIM and AR, (3) integrating BIM and VR, and (4) developing construction management modules (including quality and safety management modules).

3.1 Developing SWC facility BIM model and terrain BIM model

Executing a SWC construction project consists of the construction of main SWC facilities (such as check dams, slit dams and ground sills) and other appurtenant construction work (such as drainage facilities) which are all located in the jobsite. Thus, a complete BIM model for SWC construction project preferably integrates both SWC facility BIM model and terrain BIM model. This study applies the Autodesk Revit software package to build the BIM model for the SWC facilities (such as slit dams and ground sills). The level of development (LOD) of this BIM model is LOD 300 [10]. That is, each BIM model element (such as slit dam, groundsill work, and revetment) of SWC facility is graphically represented in terms of quantity, size, shape, location, and orientation. Additionally, non-graphic information (such as specifications and unit prices) can be also attached to each element.

In developing a terrain BIM model is comparatively complex. This study uses the digital surface model (DSM) (representing the earth's surface in which the construction project is located) to build a terrain BIM model. To do so, this study write a series of matlab equations to support the transfer of the DSM data (representing the coordinates and elevation for each location point) which are in ASCII format to the data which are in comma separated values (CSV) format. Such a CSV format file can then be read by Revit for producing a terrain BIM model [11].

3.2 Integrating BIM and AR

This study uses a AR model to interconnect to corresponding segmented BIM model and associated information (e.g., design dimensions, quality specifications, etc) of each part (e.g., could be the part of comb dam, groundsill work, etc) of the SWC construction project. Then, the jobsite engineers can scan the AR makers (related to particular AR models) by mobile devices to visualize the 3D design objects and retrieve required information.

The above integration is carried out by the following three steps: Step 1 transfers the BIM model in .fbx format so that Autodesk 3Ds Max software can read and render. Step 2 builds the AR model by Unity 3D software and developing the relationships between the AR makers the corresponding segmented BIM model. Step 3 uses Unity 3D to attach information to the AR model and save in .apk file format so that a mobile device can read the AR model.

For reading AR model from mobile device, the camera lenses of the mobile device will catch the AR markers' 2D image, and then interpret the marker detection to create the AR model.
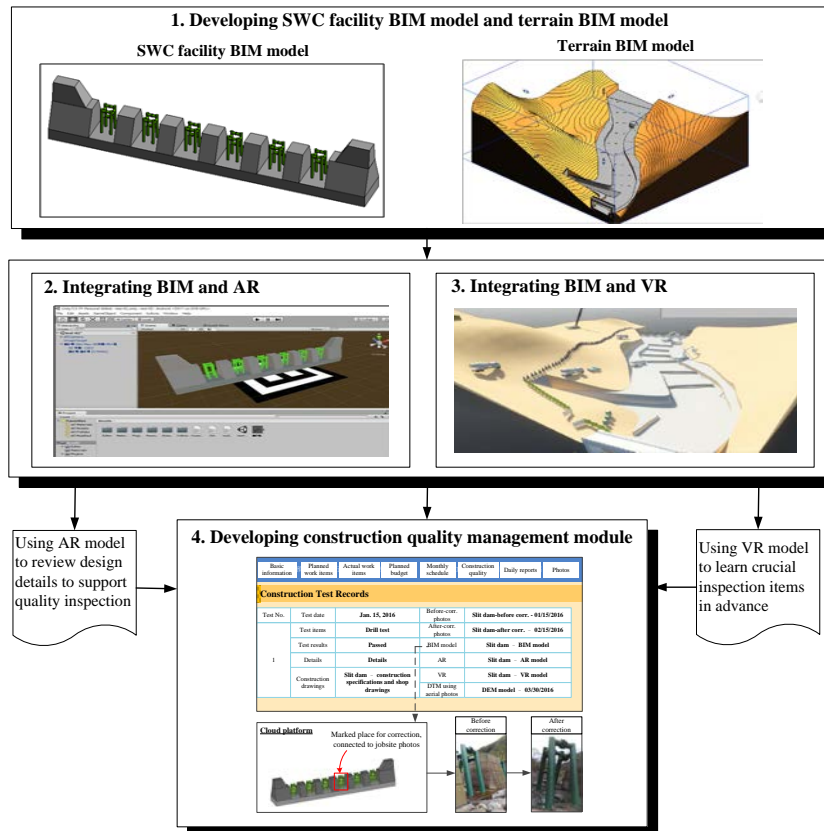
Figure 5. Framework of the proposed system

3.3 Integrating BIM and VR

The proposed system applies a 3D rendering engine called "Enscape" which can be plugged in Revit. Integrating BIM and VR is conducted by the following three steps: Step 1 is to open Revit which has possessed the Enscape functions. Step 2 activates Revit's Enscape function to transfer the BIM model into VR model. Step 3 is to view the VR model from computer screen or VR glasses.

3.4 Quality management module

The current system collects the quality management data of the "sampling inspection records" (including data of inspection date, sampling items, and results) and "quality audit records" (including data of audit date, performance score, A/E defects, and contractor defects).

All these data are numbers and texts.

By integrating the current database system with the AR, VR and BIM, the proposed quality management module provides the following five functions (Q1~Q5) in supporting construction quality management: (1) using BIM model to review the quality correction results, (2) accessing information readily, (3) using AR to review design details to support quality inspection, and (4) using VR to learn crucial inspection items in advance.

4 Case study

The proposed system is applied to a case project located in Northern Taiwan. This project consists of the following main SWC facilities: a set of steel-pipe-type slit dam, six sets of arc-shape drop structure, 1,100

meter of revetments, and 1,385 square meters of masonry boulders. The contractual duration and price of the project are 300 calendar days and around US $1,248,000 US dollars (37,450,000 NT dollars), respectively. Figure 6 displays the bird view of the jobsite and Fig. 7 shows the steel-pipe-type slit dam of this project.

Notably, this case study is the after-the-fact analysis to demonstrate the feasibility of the proposed model.

Figure 6. Bird's view of case project

Figure 7. Steel-pipe-type slit dam of the case project

4.1 Developing SWC facility BIM model and terrain BIM model

4.1.1 Developing SWC facility BIM model

A complete BIM model integrates two BIM models of SWC facilities the terrain. Four steps are conducted to develop the SWC facilities BIM model. The following uses the steel-pipe-type slit dam for example.

1. Step 1: developing slit dam (or comb dam) templates. Drawing a plane section to be a template for representing the cross section of slit dam, as shown in the left of Fig. 8.
2. Step 2: defining parameters to describe slit dam. In the template, parameters, such as the height, the

width on the top, the width on the bottom, the width of anti-sliding tenon, and so on (as displayed in the right of Fig. 8), and used to depict the slit dam. Thus, a user can develop a BIM object of slit dam by simply specifying the scale numbers of those parameters and the length of the slit dam.
3. Step 3: developing BIM objects of the steel pipes. That is, repeating Step 1 and 2 can build the steel-pipe templates and define parameters to depict the steel pipe.
4. Step 4: integrating the slit dam BIM objects and steel pipe BIM objects to generate the steel-pipe-type slit dam, as shown in Fig. 9.
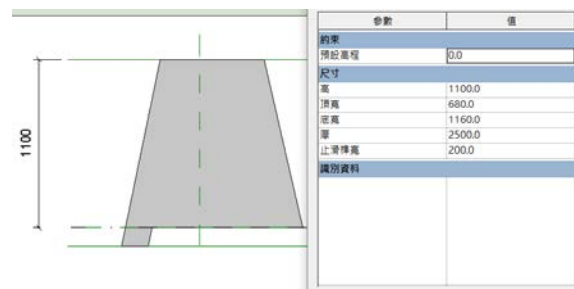

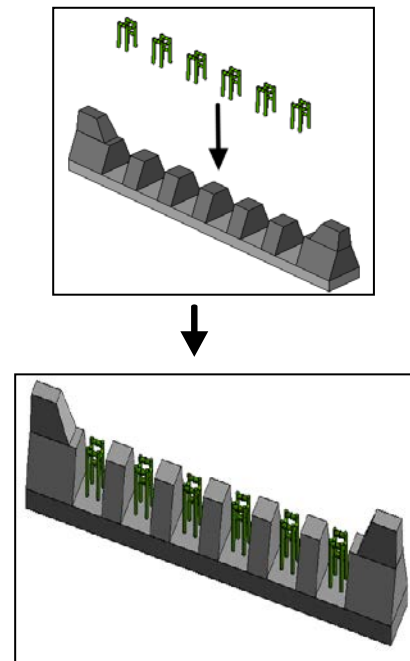Figure 8. Using parameters to define the slit dams

Figure 9. BIM objects of the steel-pipe-type slit dam

4.1.2 Developing terrain BIM model

Then, according to the steps described in Section 3.1, the proposed system generates a BIM model of the terrain in which the case project is located. Figure 10 presents the complete BIM model integrated with SWC

facilities and terrain for the case project.

Notably, while each the SWC facility (such as slit dam and ground sill) can contain its geological information or data (such as design dimensions and construction specifications), the terrain can also carry with relevant information or data (such as the governmental regulations of the terrain, and the information of ecological sensitive areas)
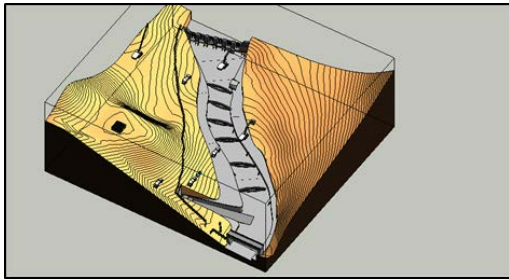

Figure 10. Complete BIM model integrated with SWC facilities and terrain for the case project

4.2 Integrating BIM and AR

After the proposed system develops the BIM model of both SWC facilities and terrain, the system follows the steps described in Section 3.2 to integrate the BIM model and AR for the case project. Figure 11 shows the BIM model that is read by Autodesk 3Ds Max software (Step 1 in Section 3.2). Figure 12 presents the screenshot of the AR model for the jobsite overview of case project.
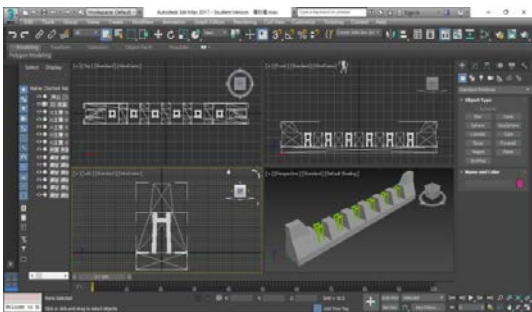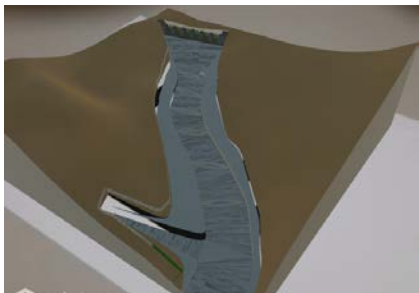

Figure 11. BIM model imported into 3Ds Max

Figure 12. AR screenshot of the jobsite overview

4.3 Integrating BIM and VR

The proposed system applies a 3D rendering engine called "Enscape" which can plug in Revit. That is, the system uses Enscape to transfer the established BIM model to VR model. Figure 13 presents the VR screenshots of the jobsite overview, construction fence, and falsework of the case project, respectively.
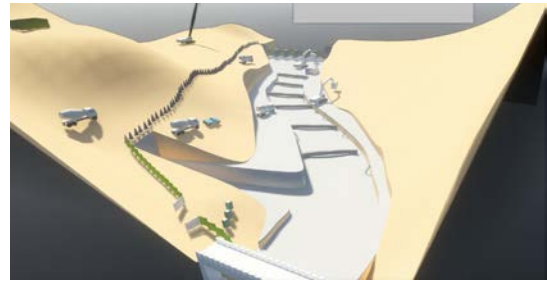

Figure 13. VR screenshot of the jobsite overview

4.4 Construction quality management module

Based on the integrated BIM model, AR model, and VR model, the construction quality management modules can support the following quality control activities:

1. Using the BIM model to support review the quality correction results. This can be carried out by evaluating the quality-correction photos, specifications, quality inspection/testing records which are retrieved from to the BIM model. See Figure 14 for example.

2. Accessing quality information readily. An engineer can visualize the 3D model and view/download project documents in the cloud device or in mobile devices for supporting communications.

3. Using AR model to review design details to support quality inspection: An AR model provide both 3D visualization and design information by scanning an AR maker for comparing the planned and actual conditions for a particular construction object in the jobsite. See Figure 15 for example. An AR model can be applied especially in the suburbs where a SWC construction project is usually located and internet is not available. This is because an AR maker represents a particular AR model which corresponds to a specified portion of BIM model and associated information (see Section 3.2). Hence, a mobile device can activate each AR model by scanning the AR marker without the need of internet.

Using VR model to learn crucial inspection items in advance: Before conducting field quality

inspections, a VR model with 3D and information can be walked through freely in the office to get acquainted with the construction project and learn the crucial inspection items in advance. Such a walk though with marked notes can also be recorded in a file for educating young engineers. A recorded VR file can be viewed from a mobile device in the jobsite. Figure 16 displays the snapshot using VR for the case project.
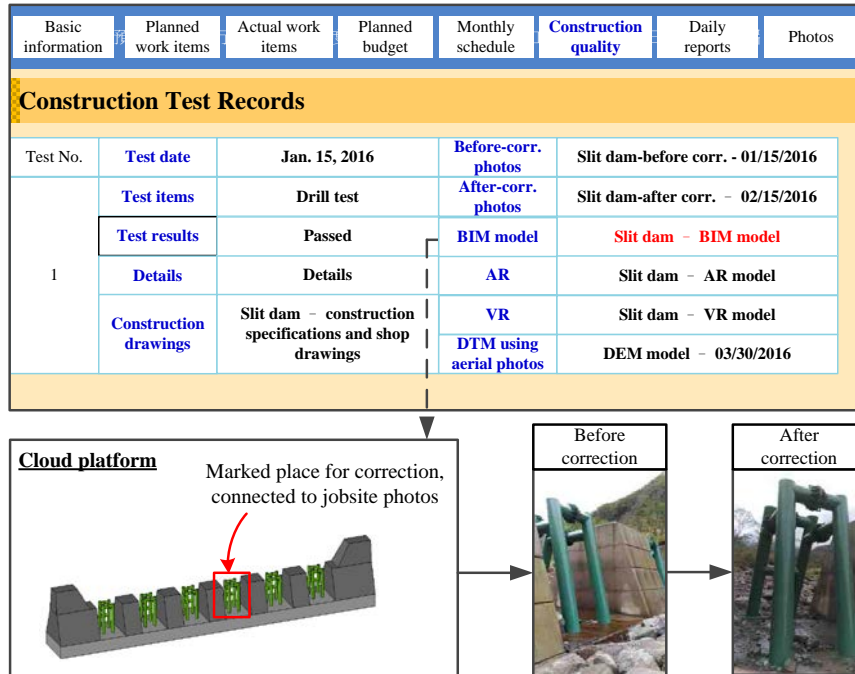

Figure 14. Using BIM model to support review the quality correction results
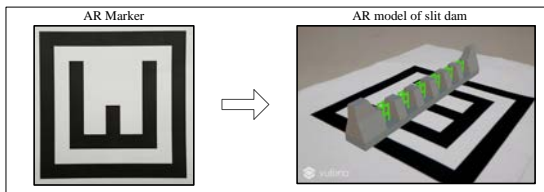

Figure 15. Using AR to review design details to support quality inspection in the field

Figure 16. Using VR to learn crucial inspection items in advance

5   Discussions

During the course of this study, several governmental engineers are appreciated of the proposed system's benefits in providing 3D visualization and easy information accessibility to support construction quality and safety management of the SWC construction projects. However, several difficulties of future implementation of the system are also raised. Their feedback can be summarized as follows:

First of all, insufficient budget available to perform new technologies for each contractor and designer is an obstacle to implement the proposed system. According to 839 SWC projects performed during 2014 and 2016 in Taiwan, the average contractual cost of each project is only about US$200,000, which is relatively small comparing with building projects. Assuming that 0.5% of averaged construction costs is budgeted for adopting these new technologies mentioned here, only US$1,000 (=200,000×0.5%) is available, which is mission impossible. Hence, additional budgets must be provided to support contractors and designers.

Secondly, insufficient capability to conduct new

technologies is another obstacle herein. As can be found, most designers and contractors involving in these small-scale projects are often from small- or middle-size firms and are unacquainted with BIM, AR and VR. Thus, training those designers and contractors for using these new technologies is needed. Listing the capabilities of using these new technologies as one pre-qualification for bidding could be a solution for overcome the obstacle here.

6 Conclusion

This study applies BIM, AR and VR to develop a new construction management system to support the government bureaus in managing numerous SWC construction projects. The proposed system built in a cloud environment provides 3D visualization model and access project information from mobile devices.

The case-study results are appealing. However, additional budgets and training must be provided to encourage those middle- or small-size designers and contractors for adopting the proposed model.

Besides the future research directions discussed in Section 5, additional future research may include applying the proposed system to the maintenance/ operation project phase. Although this study focuses on the applications of construction phase, the proposed model should have greater benefits in the maintenance/ operation project phase. For instance, Moreover, the graphic and non-graphic information provided by the proposed model (integrating BIM, AR, and VR) may be useful for government officers in evaluating the conditions of SWC facilities after the occurrence of natural disasters (such as earthquakes or floods).

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