Improving Construction Demonstrations by Integrating BIM, UAV, and VR

K. C. Wang[a], R. J. Gao[a], S. H. Tung[a] and Y. H. Chou[a]

[a]Department of Construction Engineering, Chaoyang University of Technology, Taiwan
E-mail: wkc@cyut.edu.tw, a0988554148@gmail.com, s10811614@gm.cyut.edu.tw, a36153615@gmail.com

Abstract –

In recent years, building information modeling (BIM) has been widely used to create animated simulations for engineering demonstrations. On-site engineers often employ animations generated using a BIM system to explain the current project status to their managers, so that the managers can grasp the actual project status. However, the fidelity of the terrain models built using BIM is relatively low, and the modeling process is labor-intensive. These factors negate the advantages of BIM. To overcome these problems, in this study, images of an engineering site are captured using Unmanned Aerial Vehicle and are subsequently used to generate a landscape terrain model of the area surrounding the engineering site by means of image comparison and GPS positioning techniques. The terrain model and the BIM main simulation model are integrated to present the actual site condition. In addition, to further enhance the realism of the integrated model, this study introduces the integrated model into the virtual reality (VR) environment to present the construction site. The manager can check the construction progress of the project easily without having to visit the project site.

To test the feasibility of the proposed method, it is applied to a bridge construction project. The results indicate that the aerial photos captured using Unmanned Aerial Vehicle can be converted into point cloud models and mesh segmentation models. Both types of models can be imported and integrated into BIM software. However, if other renderings (such as Lumion) or VR software (such as Fuzor) are to be used for further animation production, the photos captured using Unmanned Aerial Vehicle can only be converted into mesh segmentation models before importing them for use in subsequent applications.

Keywords –

Building Information Modeling; Unmanned Aerial Vehicle; Virtual Reality, Construction Demonstrations

1 Introduction

Building information models (BIM) have been increasingly adopted to enable construction project presentations through animated simulations. On-site construction projects are usually modeled using BIM with animations to intuitively display the expected final product of a project to managers, allowing managers to understand and manage project progress.

The applications of BIM has also been extended in addition to its common use in animation and four-dimensional simulations[1,2,3]. To achieve satisfactory BIM presentations, using BIM, engineers build a model of the construction site in question and combine it with another model that simulates the surrounding area. However, BIM-simulated terrain models are usually inaccurate, and their construction incurs considerable financial and labor costs, consequently reducing the benefits of BIM displays.

Recently, the rapid advancement of unmanned aerial vehicles (UAV) has enabled the industry and academia in Taiwan to integrate aerial photography with aerial photogrammetry software to create three-dimensional (3D) models[4,5,6]. Numerous studies have proposed route planning suggestions for UAV used in modeling and aerial photography[6]. However, several questions remain unanswered regarding integration between UAV imagery and BIM, including differences between various aerial photogrammetry software programs, UAV 3D modeling procedures, and approaches to integrating UAV 3D models with BIM.

Instead of selecting commercially available UAV photogrammetry software (e.g., Altizure and Contextcapture), this study built models of the project site and its surrounding area simply by using Pix4D and Recap. Subsequently, the constructed terrain model was incorporated into BIM software. The resultant model accurately displayed the actual on-site conditions; different software programs were imported into the model to verify its rendering feasibility.

2   Literature Review

2.1   Display of BIM animation and virtual reality environments

Conventional two dimensional and 3D modeling methods fail to comprehensively display a building. No existing BIM software program can accurately reflect the actual materials or establish a complete 3D scene. Generally, a 3D scene comprises streets, surrounding buildings, cars, pedestrians, trees, and animations. The use of rendering on a virtual scene, which can be realized through a combination of walkthroughs and virtual reality (VR) technologies, creates a realistic scene that offers immersive user experiences [7].

Scholars have incorporated BIM animation into VR in practice; for example, Hu and Wang [8] integrated a tunnel BIM, collision parameters, and remote-control car models with VR to create a third-person VR walkthrough.

2.2   UAV image-based 3D models

UAV photogrammetry 3D models have often been combined with BIM models. Wen et al [4] adopted UAV and augmented reality technologies to construct BIM models. They used a UAV to obtain images of surroundings and established real-time augmented reality markers in a positioning system, after which a BIM model was imported to allow the UAV to instantly combine the BIM with its surrounding area as it flew.

Karachaliou et al [5] preserved cultural heritage buildings by integrating UAV technologies with BIM. Specifically, they obtained indoor data of the target building by integrating a UAV-generated external model with laser scanning and photogrammetry. Next, a BIM was constructed using Autodesk Revit. Through this approach, Karachaliou et al. [5] effectively recorded cultural heritage buildings with complex scales or forms in a museum.

Comparing a conventional model with a UAV imagery-constructed model, Liu [6] discovered that the construction of a conventional environment model involved complex measurement procedures; by contrast, measurements and geographic data can be simultaneously obtained, with the flight route determined, as UAV images were captured. Additionally, UAV can capture images of hazardous regions where human cannot approach and accurately reveal the surrounding terrain.

Researchers of most UAV studies have recognized that UAV-constructed 3D models more accurately present an environment than conventional models do. However, researchers have rarely discussed the overall process of combining UAV imagery with BIM and the subsequent application of rendering software for animation production.

3   Method of integrating BIM, UAV, and VR

This study integrated BIM with UAV and VR technologies to facilitate the presentation and simulation of construction projects; the procedures are presented in Figure 1. UAV images were used to construct 3D models through the separate application of two UAV photogrammetry software programs (i.e., Recap and Pix4D). Subsequently, CloudCompare was used to crop and export a point cloud model with triangle meshes. The exported model was merged with a BIM model, after which Lumion and VR software were run to perform rendering and make animations.

This process is detailed in six subsections, namely "BIM model," "Aerial 3D model construction using Pix4D," "Aerial 3D model construction using Recap," "Point cloud models cropping," "Integration of aerial 3D models with the BIM," and "Rendering and animation production."

3.1   BIM construction

The BIM of a bridge was constructed before being combined with UAV images. This bridge model encompasses basic components including piers, roads, pylons, and steel cables. However, numerous parts of the bridge cannot be established using basic components separately such as pillars, beams, boards, or walls. Therefore, these parts were constructed using grouped components and later integrated into the project.
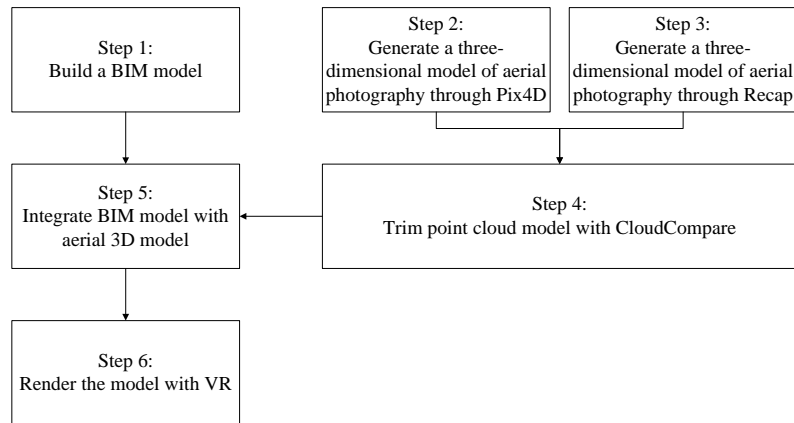
Figure 1. Architecture of integrating of BIM and 3D model

3.2 Aerial 3D model construction using Pix4D

As an aerial photogrammetry software suite, Pix4D can locate UAV-captured images on a coordinate system. After images were imported, this study set the imaging parameters to produce a point cloud model and 3D model.

3.3 Aerial 3D model construction using Recap

Recap is another point cloud processing software program. UAV-captured images were first imported into the software program before a point cloud model was generated using the built-in global positioning system. Furthermore, because Recap is developed by Autodesk, it is more compatible with BIM software than Pix4D is.

3.4 Point cloud model cropping

This study used CloudCompare to crop the 3D models established using Pix4D and Recap. When empty areas are present in the background, CloudCompare allows users to select a few point clouds of the surrounding terrain and fill in these areas through stitching. The software program also hides the area that requires no cropping, making the cropping process easier.

3.5 Integration of aerial 3D models with the BIM

Aerial 3D models must be accurately merged with the BIM model, during which time a point cloud model should be imported into Revit. Currently, only Recap-produced point clouds are compatible with Revit. Because manually aligning the point clouds with the host model does not provide sufficient accuracy, this study redefined the host model position in the Revit project by setting the project base points. This study also relocated the Recap origin to the target position where the point cloud was to be combined the BIM.

The integrated model can be exported to various formats according to different needs. An advantage of combining point cloud data with a host BIM on Revit is that existing BIM software programs can directly import the integrated model into rendering software by using Revit plug-ins. Moreover, these software programs enable simultaneous model revision and rendering as well as the production of animation or a VR display.

3.6 Rendering and animation production

If the integrated model is displayed in a walkthrough on Revit, the fidelity to the terrains and on-site conditions may is inadequate. To improve the fidelity of the terrain model and host BIM, this study displayed the models using Fuzor.

4 Case study

This case study was of a bridge construction project in central Taiwan. In the following subsections, this study describe the construction of a terrain model based on UAV images and its integration with a host model. This study discuss the process by which the fidelity of the integrated model was improved by using rendering software.
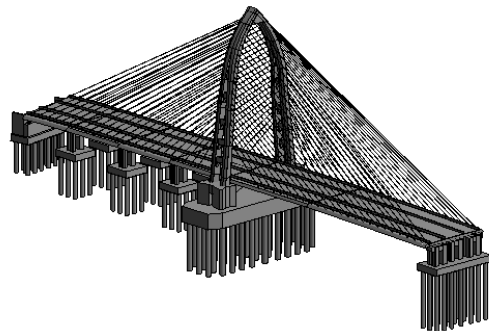

Figure 2. BIM model of case study

4.1 BIM of the bridge

The BIM of a cable-stayed bridge was established. As mentioned, bridges cannot be drawn with basic components used in drawing housing structures, which are composed of pillars, beams, boards, and walls. Therefore, this study divided the bridge into piers, roads, pylons, and cables and built each family components respectively.

4.2 Aerial 3D modeling on Pix4D

On-site images taken by the UAV were imported into Pix4D for 3D modeling in the following four steps:

1. Image importing: The UAV captured on-site orthophotos, oblique photos, and panoramic photos. These photos were then imported into a Pix4D project.
2. Image parameter settings: Image parameters were set after importing was conducted. Because the UAV simultaneously took pictures and recorded their coordinates, the coordinates were already stored in Pix4D in the image importing process. Accordingly, the World Geodetic System 84 (WGS84) was selected in the coordinate system; the coordinate unit was set to m, and the edited coordinate data were directly exported (Figure 3).

Figure 3. Image parameter settings

3. Point cloud modeling: After 3D modeling was completed, the photography methods were set to orthophotography and oblique photography. A point cloud model was then generated, after which two options were available, namely "export the point cloud" and "export the triangle mesh" (Figure 4).
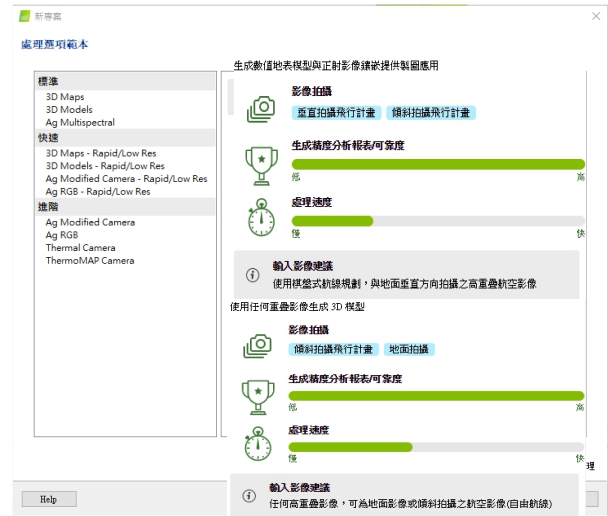

Figure 4. Modeling method settings

4. Exporting the point cloud to CloudCompare: When the terrain in question is vast, the resulted point cloud can be susceptible to the Earth's curvature and becomes imprecise. To avoid such a problem, repeat Step 3 several times to generate a point cloud and cropped and stitched it using CloudCompare to better reflect the actual terrain.

4.3 Aerial 3D modeling on Recap

On-site images taken by the UAV were imported into Recap for 3D modeling in the following four steps:

1. Photography mode setting: When creating a new project, the user must choose either the "Object" (for general objects) or "Aerial" (for terrains) photography mode for 3D modeling. Because terrain photos were taken by a UAV, "create 3D aerial" was selected to construct a 3D terrain model (Figure 5).
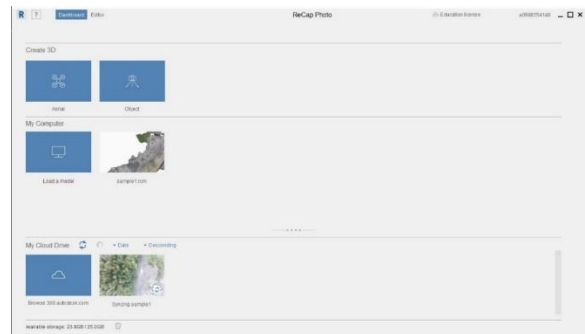

Figure 5. Selecting the Aerial mode

2. Image importing and coordinate settings: To create a 3D terrain model, images were imported (Figure 6);

subsequently, coordinates can be set for the imported images. Notably, our UAV already attached coordinates to images it captured. Consequently, this study only had to choose the coordinate system of the target location (WGS84) when setting coordinates for the project.

3. Point clouds generation: In this step, a point cloud model was constructed. When the model is being exported, .rcp or .rcs formats can be selected to facilitate the subsequent combination with the Revit host model.

4. Point cloud exporting to CloudCompare: Although point cloud clipping and deleting is allowed on Recap, this software focuses on point cloud creation. To obtain an accurate point cloud, this study used CloudCompare to clean up the point cloud, whereby the point cloud model was cropped and modified.

4.4 Point cloud cropping

This study cropped and modified point clouds using CloudCompare to facilitate the subsequent display of an integrated host model. Because the point cloud failed to present vegetation realistically, such parts in the point cloud was cropped out. However, such practice resulted in empty areas in the model (Figure 7); therefore, nearby point clouds were used to perform stitching and fill in these empty areas. When each area is being filled in, at least three base points must be selected, after which the software automatically aligned the clouds with corresponding areas to complete the stitching (Figure 8). The stitching area between the point cloud model and host model was also modified so that other software programs could be used subsequently to more realistically present vegetation.
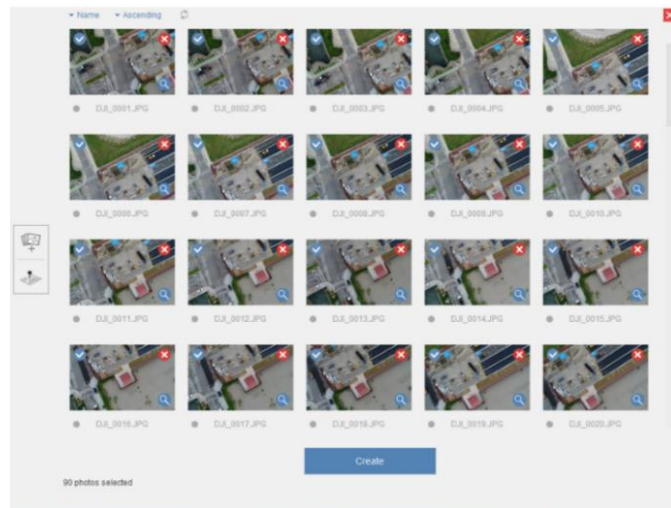

Figure 6. Terrain image importing

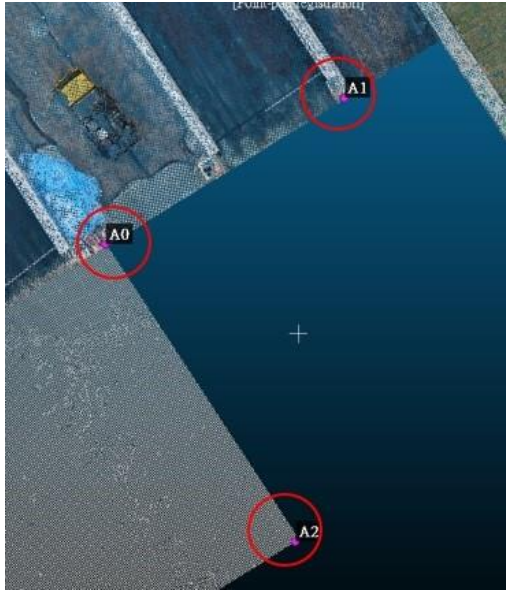Figure 7. Comparison between uncropped and cropped terrain point clouds

Figure 8. Filling up the empty areas

4.5 Integration of the aerial 3D models with the BIM

In this study, the host model of the bridge was built using Autodesk Revit. The aforementioned point cloud 3D model was imported into Revit to merge it with the host model. However, the point cloud exported using Pix4D was incompatible with Revit. Therefore, this study

used the origin-updating command in Recap to relocate the origin in the stitching area (Figure 9). By updating the project base points, this study moved the bridge model origin in the stitching area to align the point cloud model origin with the host model origin. When the cloud point was being imported, the option "Origin to Origin" was selected to facilitate the precise combination of the two models, as illustrated in Figure 10.
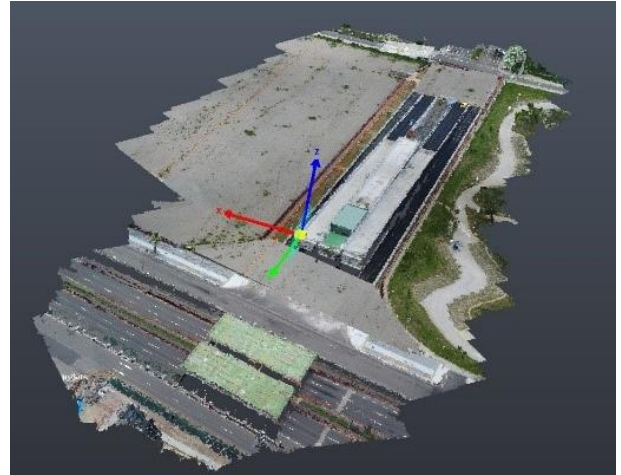

Figure 9. Updating the origin of the point cloud model

Figure 10. Integration of the point cloud model with the host model

4.6 Rendering and animation production

To further enhance the fidelity of the terrain model and BIM, this study displayed the model using a VR software program termed Fuzor. After the terrain model was merged with the BIM, a plug-in was employed to convert the integrated model for use on Fuzor, whereby

the model can be instantly modified and synchronized with Fuzor models. Fuzor were then used to add elements such as trees, cars, and pedestrians in the model. Finally, rendering was implemented and landscape elements were added to create a complete and realistic scene. Subsequently, walkthrough animations or VR environments, which provides immersive experiences,

may be created using Fuzor, allowing users to better understand the project status.

5 Conclusion

This study was of a bridge construction project in central Taiwan. In the following subsections, this study describe the construction of a terrain model based on UAV images and its integration with a host model. This study discuss the process by which the fidelity of the integrated model was improved by using rendering software.

5.1 Comparison of terrain modeling procedures

According to the comparison between terrain modeling procedures in Pix4D and those in Recap, the following advantages and drawbacks were determined.
1. Pix4D terrain modeling
   (1) The triangle mesh is delicate: After generating the point cloud on Pix4D, the user can reduce the size of each triangle by adjusting related parameters. Therefore, the exported triangle mesh is more delicate, contributing to a better visual effect during animation display.
   (2) The point cloud is complete: After the UAV-captured terrain images are imported, the point cloud generated by Pix4D is not affected by overlap rate, allowing researchers to create a point cloud model. By contrast, in Recap, a point cloud model cannot be generated if the overlap rate is low.
2. Recap terrain modeling
   (1) Higher compatibility with BIM software programs: Because Recap was developed by Autodesk, the Recap-derived point cloud is compatible with other Autodesk-developed BIM software programs. By contrast, the Pix4D-constructed point cloud must be converted into a compatible format using Recap before being integrated with a Revit model.
   (2) Ability to redefinition the origin: After creating a point cloud model, Recap can update its origin, allowing the model to be accurately merged with a host BIM. By contrast, Pix4D does not have this origin-updating feature.

5.2 Rendering and animation production

After the terrain model and host BIM are integrated, Lumion and Fuzor may be more suitable options for model rendering and animation display compared with Enscape, which fails to display a terrain model when the model is imported. To use the coordinate alignment function on Lumion, the host BIM and point cloud must be exported to the .fbx format and a triangle mesh, respectively. By contrast, Fuzor can simultaneously display terrain models without changing the file format.

After the fidelity of the terrain and host BIM is improved, the models are ready for animation production and VR environment import. The use of VR technology to present the construction site can provide an immersive experience, enabling users to clearly preview the expected final product and monitor construction progress. The strengths of Fuzor are further demonstrated through its functions of five-dimensional display of construction simulation, conflict detection, and animation production.

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