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UAV-based Photogrammetry data transformation as a building inspection tool: Applicability in Mid-High-Rise Building

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Abstract: The photogrammetric concept is used as a practical implementation of this study. Data management is proposed as an active contribution in the process of data integration and data in-operability to develop solutions based on UAV-based Photogrammetry as part of building inspection activities. Point Cloud adjusts the main role as data to initialize objects whose information can be represented in 2D / 3D / 4D rich-data format. Decision making on each management framework is planned with the DJI Go and Pix4D Capture Application which is controlled by a smartphone that has been pre-configured for the plan UAV flights. The flight plan quality control, flight mission supervision, and data acquisition results are important factors in the management and related information framework. The Point Cloud created by the SfM (Structure from Motion) application is then imported by Autodesk Recap and reconstructed in Revit BIM. The 3D Point Cloud is lastly enhanced with some practically detailed information to contribute to the data management experiment. The collaboration model of this study is presented using AR / VR (Augmented Reality / Virtual Reality) to enable mobile monitoring as a research objective and substantial examination. The essence of this study is to develop UAV-based Photogrammetry / BIM / AR-VR as a method to reduce the risk of data mismatches, monitor communications, and increase the impact of practical instructions on decision making on building inspection activities. The results of each verified workflow show that the methodology applied produces informational and visual data products that allow user mobility within the scope of building inspection and monitoring. Furthermore, device limitations do not affect the data acquisition process to provide user safety and efficiency.

Keywords: BIM; AR/VR, integration and interoperability, Building Inspection, Construction management.

Abstrak: Konsep fotogrametri digunakan sebagai implementasi praktikal dalam studi ini. Manajemen data diusulkan sebagai kontribusi aktif dalam proses integrasi data dan in-teroperabilitas data untuk mengembangkan solusi berdasarkan Fotogrametri berbasis UAV sebagai bagian dari kegiatan inspeksi bangunan. Point Cloud menyesuaikan peran utama sebagai data untuk menginisialisasi objek yang informasinya dapat direpresentasikan dalam 2D / 3D / 4D rich-data format.Pengambilan keputusan pada setiap manajemen kerangka kerja direncanakan dengan Aplikasi DJI Go dan Pix4D Capture yang dikendalikan oleh smartphone yang telah dikonfigurasi sebelumnya untuk rencana penerbangan UAV. Kontrol kualitas rencana terbang, pengawasan misi terbang, dan hasil akuisisi data menjadi salah satu faktor penting dalam kerangka manajemen dan informasi yang terkait. Point Cloud yang dibuat oleh aplikasi SfM (Structure from Motion) kemudian diimpor Autodesk Recap dan direkonstruksi di Revit BIM. 3D Point Cloud terakhir ditingkatkan dengan beberapa informasi rinci secara praktis untuk berkontribusi dalam eksperimen manajemen data. Model kolaborasi dari studi ini disajikan menggunakan AR / VR (Augmented Reality / Virtual Reality) untuk memungkinkan mobile monitoring sebagai tujuan penelitian dan pemeriksaan substansial. Inti dari studi ini adalah untuk mengembangkan UAV-based Photogrammetry/BIM/AR-VR sebagai salah satu metode untuk mengurangi risiko ketidaksesuaian data, memantau komunikasi, dan meningkatkan dampak instruksi praktis terhadap pengambilan keputusan pada kegiatan inspeksi gedung. Hasil dari setiap alur kerja yang diverifikasi menunjukkan bahwa metodologi yang diterapkan menghasilkan produk data informasi dan visual yang memungkinkan mobilitas pengguna dalam lingkup inspeksi dan monitoring bangunan. Lebih jauh lagi, batasan-batasan alat tidak mempengaruhi proses akuisisi data untuk memberikan keamanan dan efisiensi pengguna.

Kata kunci: BIM; AR/VR, Integrasi dan interoperabilitas, Inspeksi Bangunan, Manajemen Konstruksi.

INTRODUCTION

In general, building inspection activities require special handling including strategy, tool management, resource management, and data analysis. This activity is quite challenging when faced with inspection procedures in certain conditions and situations. According to (Rakha & Gorodetsky, 2018) and (Knoth et al., 2018) in their study of building inspection and monitoring using UAV-based Photogrammetry, there are several notes that become important issues based on data collaboration and continuous validation of documentation of inspection and monitoring activities. In general, the scale of the building which becomes the object of inspection and monitoring has its own characteristics considering the size, height and environmental conditions around it. The supervisory function using additional tools is one of the means to solve problems in existing buildings. The challenges which proceed to arise are data integration and data operational mobility (Hassan, 2017).

Particularly, UAV (Unmanned Air Vehicle) flight patterns and point cloud are part of essential issues to be explored related to accuracy during a mission due to data management purpose. This issue is essentially based on data collaboration and continuous validation for project documentation. Realization of the method sometimes demands mandatory and technical problem which defines the validity of information, especially on the project information life-cycle. Updated information originally involves flexible method, integrated tools, and interoperability of data format in the context of data management (Knoth et al., 2018).

To overcome critical issue UAV integration with other environments on data management, collected data from UAV usually processed and compiled using SfM Software.
In a formed concept, a known software which uses the technique of SfM (Structure from Motion) adapt procedures by input series of images with overlapping camera perspectives and proceed to be estimated as 3D positioned scene whilst geometry points are reconstructed automatically by matching on each specific image component related to accuracy improvement (Szeliski, 2006). The step of UAV-based Photogrammetry open access of Point cloud to data management study based on DTM (Digital Terrain Modelling), DEM (Digital Elevation Model) and Orthophoto created by SfM software.

By using a generated Point Cloud, data transformation is considerable to explore which has many roles in the field of data management in engineering. The fundamental characteristics of Point cloud can be explained as a set of data points to represent position and object in a rendered and projected coordinate system (Lemmens, 2014). The dataset of Point cloud also considered as basis format for input in CAD, BIM, and other software for planners, designers, inspectors, and other users. The functionality of point cloud involves transformation to the other application environment without ignoring the main information (Lemmens, 2014). This ability positively decreases geometric error due to point cloud reconstruction which predisposes the 3D model and measurements. Initial studies of UAV-based Photogrammetry are considered to be reconstructed as 2D/3D/4D model, existing data insertion, and primarily towards mobile data visualization in AR/VR.

The hypothesis of this research by combining UAV-based Photogrammetry with BIM and visualized in AR/VR enables the integration and interoperability of data to improve the understanding and ease of use in the real-life project coordination. This model is not only a feasible presentation but also a technology gap which can well-establish the design from real-world to the virtual world. In order to deal with the issues that often arise regarding the potential of data management, the development of data integration applications and data interoperability, this study then adopts several methodologies to develop the boundaries of inspection and monitoring of buildings in operational status within the scope of construction management and computer science.

RESEARCH METHODOLOGY AND EXPERIMENTAL CONCEPT

This research is a constructive finding on optimization of the existing standard capabilities and capacity of UAV data integration towards BIM-AR/VR on its function as a tool due to building inspection management workflow. Each phase of the study is explained as the procedure of data integration and data interoperability. Their purpose, background and elements will be presented in Sections A–C. As stated earlier, the conclusion designed from the research framework in four steps can be shown in **Figure 1**. The methodology applied in this study is an experimental method sequentially to test the concept of data integration and data interoperability in several virtual environments, however, the parameter of the results of this study is that there are technological limitations that require a standard framework when used for management purposes, especially in the field of inspection and building monitoring.

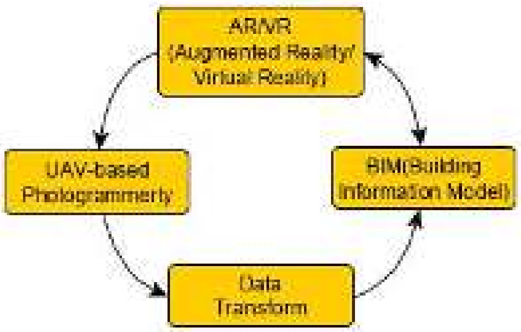


Figure 1. Data management integration and interoperability workflow

A. DATA ACQUISITION AND 3D POINT CLOUD PROCESSING

This study utilized the concept of UAV-based Photogrammetry to produce 3D model Point cloud in terms of data simulation and compilation. For the purposes of this study a low-cost UAV (DJI Phantom 3 Std) was used as an inspection tool allowing the user to make initial contact. In the process, several stages and preconditions will be applied as the basis for carrying out a safe and controlled mission without compromising the main objective of this study. A low-cost UAV was selected to collect images of study object by following specific flying pattern both autonomously and manually. Manual survey on coverage area and the study object were planned to enhance images quality and avoid risk during UAV mission (Nex and Remondino, 2014). Technically, it is stated that a photogrammetric knowledge is an initial step to enter the data collection process, therefore the main definition and purpose of the mission is implanted to deal with potential mission risks which may arise, survey costs, survey scale and various scenarios related to resources and the environment (Figure 2).

During flight missions the UAV relies on a location, position and coordinate guidance system based on the GNSS system which is connected to a pre-configured application via remote control and smartphone. For the X, Y, Z positions, the UAV is equipped with a 3-axis gimbal as part of the camera support in assigned autonomous missions. The autonomous mission, which is carried out through the DJI Go platform, was previously set to determine the flight pattern and flight direction with the Pix4D application and then became a waypoint controlled by the operator within a maximum distance of 1 km. The flight plan setup process is made regular with a circular pattern with an elevation interval of ± 5m down. In general, the camera's point of view is directed at an angle of 45˚ and follows the flight pattern at the perimeter of ± 85mX85m and a maximum altitude of ± 110 m to get maximum results. There are 4 GCPs (Ground Control Points) that are placed around the survey object area with conditions visible to the UAV camera as a reference as part of the next image stitching process. The interior was not included in the data collection process because this experiment was only limited to exterior supervision.

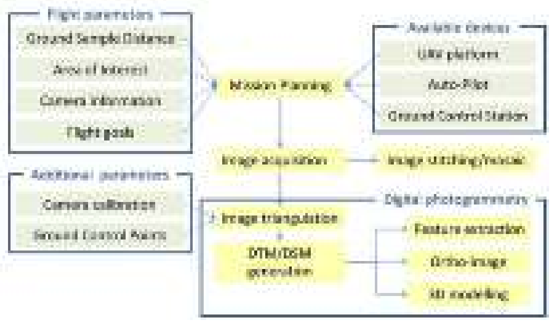


Figure 2. UAV Acquisition Workflow

Completed images were compiled using Agisoft PhotoScan as a Photogrammetry software to create 3D Point Cloud. Compiled images produced by Agisoft PhotoScan were generated to be DTM (Digital Terrain Modelling), DEM (Digital Elevation Model) and Orthophoto (Boland et al., 2004). In the UAV-based photogrammetry process, the procedure will lead to data extraction needs, which are the standards in the initial application of the mission to the flight mission supervision which will determine the initial results which become one of the factors in the data process. This variable is a condition that needs to be considered if it is related to the needs and scale of the mission that has been determined.

B. DATA MANAGEMENT AND DATA INTEROPERABILITY

As a means of enabling the process of analyzing data that has been obtained using UAV, data information management and data interoperability are used as advanced methods after data acquisition. By using REVIT BIM, this study was consisted of exporting the Point Cloud produced from SfM software to be reconstructed and by given assisted information, modeling and data application can be deployed in AR/VR for further interoperability.

This research administered a multi-step iterative methodology which performed simulations of data integration and interoperability as shown on Figure 3. The underlying concepts for data management can be formalized based on the data format and the interoperability between software applications. UAV-based Photogrammetry acknowledged several data formats to fully automate the mechanism of data interoperability from Point Clouds. This process was demonstrated using AUTODESK Recap as a bridge to handle Point Cloud to establish proper data format for reconstruction in REVIT BIM. Relationship between AUTODESK Recap and REVIT BIM contributes formalized representation due to autonomous Point Cloud translation using a link add-ins. This scenario works in visual-based reconstruction and by given existing elements, REVIT BIM automatically provide relevant information to enrich the study object.

Based on the Thesis by S. Hassan (2017) about 3D model, there is general information that should be understood through both object visualization and writing which can then be translated into important information as part of integration and interoperability (Hassan, 2017). Interaction among platform was used to enhance the data Interoperability. Rich data such as: 2D drawings (.CAD files, .PDF files, .RVT file) and .IFC files created from REVIT BIM were imported to Dalux BIM Viewer as data integration platform. 2D drawings were used to set-up the levels and to provide reference for the visual path in Dalux BIM Viewer. By using 2D drawings, relation to the 3D model is possibly achieved by matching two position in order to combine information and simulation. Several important settings were also performed as a setup due to integrated platform in mobile application using Dalux BIM Viewer.

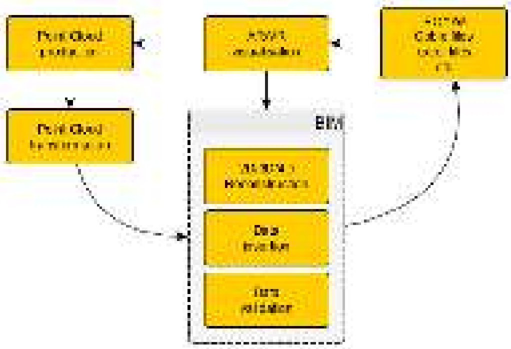


Figure 3. Simulations of data integration and interoperability

Free mobile application named Dalux Viewer, downloaded from Apple App Store, adopted to assess embedded information added to review the model, sections, levels, 2D drawings, and measurements. The device was utilized to synchronize and exchange data from computer to mobile device. Data management was performed using Dalux Viewer. Measurements, database reporting, and visual reference matchmaking were taken to develop model and information for further purpose.

C. DIGITIZATION AND CONSTRUCTIVE MANAGEMENT

Generation of data integration and data interoperability is complex and sensitive considering the challenge during representing data model and establishing transformed information which relatively suffer from unreliable technique (Hossain & Yeoh, 2018). UAV-based Photogrammetry was used as a starter application to achieve 3D representation to help monitoring, building inspection and conduct a reconstruction of a building using images. This potent method was also recognized as a solution towards digitization of building inspection towards automation and collaboration in constructive management. Documentation and management of building inspection presents different challenges and advantages: historical documents, data access point, inspection scheduling and maintenance, and team-in-charge related to each maintenance elements are often queried with different tools (Zhan et al., 2019). This uncertain condition is available to be reviewed in BIM in terms of data validation since planning phase, design phase, pre-construction phase, post-construction phase, and maintenance phase to reduce information degradation. By using collaborative platform, building inspection management is affordable to keep information quality and improve safety environment for the workers.

AR/VR application in terms of virtual simulation can be realized as an application in response of technical process to avoid miscalculation, disinformation, and to trace back information to provide reliable data derived from BIM. Furthermore, constructive management in building inspection can be obtained by implementing collaborative communication from different field but not restricted to simulation. As a result, documentation and management can be standardized as an information library and linked as interoperability of data format (Eastman et al., 2011).

APPLICATIONS

The framework that is compiled and implemented in a flowchart is designed as a setup that involves operators, supervisors and management at the experimental level. This research aims to explore methods in the use of data integration and data interoperability through the basic concepts of UAV-based Photogrammetry in the data acquisition process. Several virtual environments represent processes for life-cycle management data to formulate solutions in building inspection management activities at the National Yunlin University of Science and Technology, Taiwan (**Figure 4**).

A. UAV-based Photogrammetry

In this section, the case study was carried out to present a previous research by (Han & Golparvar-fard, 2017) which compose integrated and collaborated management on the inspection subject. The object was consisting of 14 floors building, located in Taiwan. The building has exactly 14 floors associated with exposed red brick to define the exterior (Pan et al., 2020). A further orientation aimed on this subject is that the existing parts of the building are difficult to conduct maintenance activity since the position was not accessible by manual inspection (Figure 4). Moreover, weather impact contributes the biggest considerable variable in implementing this research in order to promote building inspection.

Figure 4. Yuntech Tower

This study basically proposed as an alternative in the contribution of inspection management and project controlling in the multi-stage process. There are several steps which transformed into data acquisition through UAVs to obtain 3D Point Cloud. There are identification variables can be recorded as additional information and then used as constraints to make decisions in planning flight missions on January 10, 2019, namely: location survey (VLOS / BVLOS), environmental conditions within the flight perimeter, weather and supporting light factors. For data acquisition, the UAV used is a light commercial type weighing less than 25kg (1216 g - Weight (Battery & Propellers Included)) from the DJI Phantom 3 Standard Edition. There is a standard setting on the monitor screen as a manual flight function complete with camera angle settings. This type of UAV is capable of flying with a maximum control condition of ± 1 km and it is advisable to setup a waypoint to avoid lost control RTH (Return to Home) before carrying out a mission. The camera installed in this type has a 12 MP sensor and is equipped with a video 2.7K resolution, FHD: 1920x1080p, and HD: 1280x720p. With FOV 94˚ 20 mm (35 mm format equivalent) in this type then embed with f / 2.8 apertures are enough to target a wide area to support missions. In this type of frame, there are rubber pads specifically designed to reduce motor and propeller vibrations to camera conditions. DJI Phantom 3 Standard also embedded with LiPo 4S battery with max fly time ± 25 minutes on 0˚C-40˚C (32° to 104°F) of operating temperature range.

In order to support the UAV system to work autonomously, the system is then connected with DJI Go to lock the initial location and RTH (Return to Home) on the iPad A1489 smartphone platform. The connection that is controlled from the Smartphone was then added by the Pix4D application to plan full operational missions. As a location marker and control point, 4 GCPs (Ground Control Points) are installed with the format and position according to applicable standards.

To support this study in relation to building inspection management, data integration and interoperability process are acknowledged as important strategy to allow evaluation and analysis process through visual and digital composition. Complexity taken in this method also stated in data collection using UAV-based Photogrammetry, data compilation, data modelling and data visualization using digital environment. This workflow sequentially represented in digital transformation as part of the research purpose.

B. 3D Point Cloud and Model Reconstruction

269 images were taken and processed using SfM (Structure from Motion) software. Total time spent to produce final 3D model was about 8 days in average. The most time used in the 3D model compilation process was in the "Build Dense Point Cloud" reconstruction step. 4 CP (Control Points) have been deployed as a reference. The highest value of generated Point Cloud from first mission was 183.861 points. The highest value of generated Point cloud from second mission was 192.135 points. Meanwhile, the visualization of generated Orthophoto were different compared to each other.

(a)Point Cloud in Agisoft Photoscan

(b) Point Cloud Exchange using Autodesk Recap

(c) Point cloud reconstruction using REVIT BIM

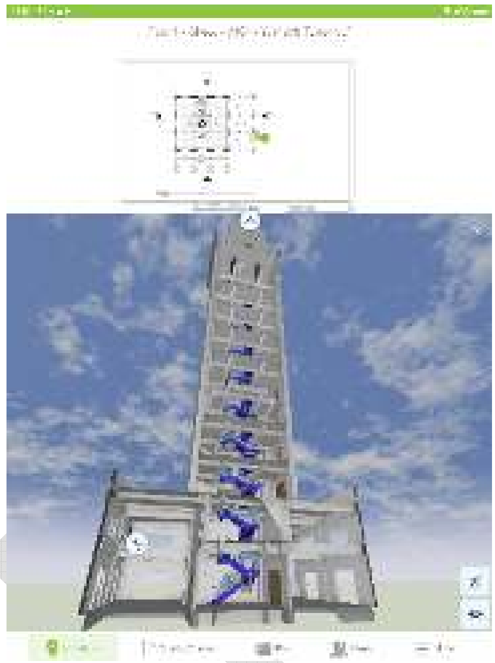
Figure 5. Point Cloud Transform workflow

This study involved a Photogrammetry software application to process the aerial image data to compile a 3D model as visualization. These data were processed by Agisoft Photoscan as SfM (Structure from Motion) with 269 aerial images. Based on the literature review that was explored, there were several workflow designs that were manifested based on need and scale, but the principles that were carried out had in common which then led to processing 3D image data. (Irschara et al., 2010) (Eschmann et al., 2012) (Khaloo & Lattanzi, 2017), and simplified to be following workflow: align photos, build dense cloud, build mesh, build texture, build tiled model, build DEM, and build orthophotomosaic. Total time spent to produce final 3D model was about 8 days in average. The most time used in the 3D model compilation process was in the "Build Dense Point Cloud" reconstruction step. The highest value of generated Point cloud was 192.135 points.

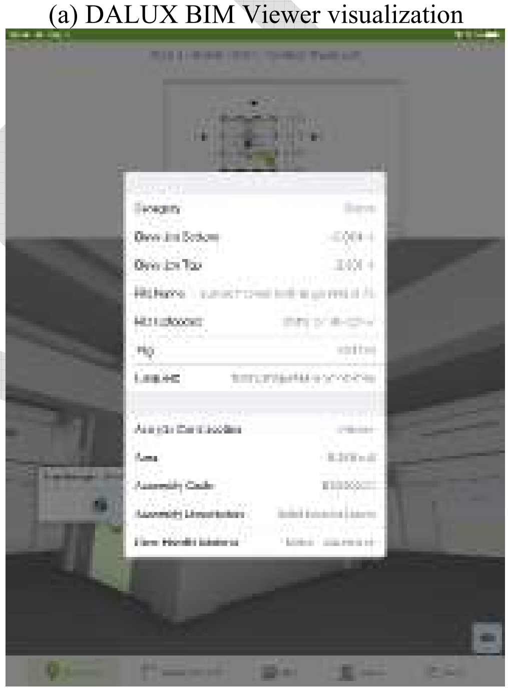
A continues engineering process on the generated Point Cloud was applied to Autodesk Recap to synchronize Point Cloud data to be acknowledged in REVIT BIM. This exchange provided similar elements and forms to support information transfer and facilitate the reference obtained from UAV survey for further representation (Zhou et al., 2018)(Irizarry et al., 2012)(Han & Golparvar-fard, 2017). Several adjustments were done as a mechanism of underlying reference in different environment.

In relation to the insertion of data flow, Point Cloud from Autodesk Recap proceed to be exported to REVIT BIM. The methodology was to acknowledge reconstructed 3D modelling from Point Cloud and determine embedded information in the presence of data interoperability. As a result, technical drawing reconstruction become an integral part to geometry technical information. This process also facilitated insertion of component information and provide description for individual elements in BIM for data management purpose.

Finally, further process was performed on the data integration from REVIT BIM to DALUX BIM Viewer (**Figure 5**). By using .IFC file, exported data were used to setup the final representation of data integration and data interoperability. In this regard, detailed information was visualized in interactive 3D model integrated with 2D drawing and geometric elements information were listed to confirm the components obtained from BIM.



(a) DALUX BIM Viewer visualization



(b) DALUX BIM Viewer mobile report

Figure 5. DALUX BIM Mobile application

DISCUSSIONS

Various application of UAV has been developed to view possibility of integration and interoperability in the scope of construction management. Most of the use of UAV aims to collaboration and support data management which effectively possible to manage project documentation and inspection process. At the same time, technology presents many features which allow user to shift in solving problems for data management in construction management sector. Interestingly, BIM also provide extension to connect UAV-based Photogrammetry product with specific sub-application. By deploying this feature, Point Cloud reconstruction process is no longer time consuming if proceed to BIM environment. Information workflow from UAV were used as a reference and geometrically reconstructed again to host environment in BIM without ignoring the position. Existing data insertion can be processed to enrich the model. As a result, 2D/3D/4D BIM were generated as a rich model which can be used in further application environment. In order to enhance the visualization and mobility inspection, collaboration, integration, and data interoperability using AR/VR were considered as the main key to reduce the deviation of data management process. Geometry and information presented using AR/VR can be considered as a way which leads to perform building inspection management.

CONCLUSIONS

This research confirmed that data integration and data interoperability applied to UAV-BIM-AR/VR can significantly contribute to the understanding of project documentation and project controlling in multi-stage process. The contribution also defines development of data creation through automated data transform from different application environment, thus following techniques acknowledged as a digital bridge during monitoring for construction management. Some interesting visualization reconstructions were done manually in BIM to compare between automated images compilation using SfM software to the real-world object. Information insertion process also become part of preliminary techniques to improve understanding and ease of use of the integration. Combination among hardware and software were concluded as following techniques: (1) UAV-based Photogrammetry, (2) Point Cloud sync in Autodesk Recap, (3) BIM 2D/3D/4D reconstruction, (4) BIM information insertion, and (5) IFC to AR/VR. Data management essentially visualized by comparing among workflow validation which defined by: (1) object visual perception, (2) data insertion and manipulation during integration, and (3) project documentation in monitoring process. In this context, information is delivered in 3D model with a list of related information on each element. Interactive visual movements also enhance the inspection process by implement 2D/3D drawing and model. Interactive report and documentation can be generated and synchronized digitally from mobile device as well as the web server. Reverse engineering is considered as data validation and data management. This paper has given an account of implementing innovative workflow of data integration and data interoperability from UAV-based Photogrammetry, transformed and determined in BIM, and visualized in AR/VR. This study is the first step towards enhancing our understanding of potential integration and interoperability using various tools and situation of building inspection in scope of construction management.

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