Development of a Construction-Information System by Measuring, Processing, and Utilizing 3D Data Toward Creating a Digital Twin

Satoshi Kubota[1] and Aika Yamaguchi[1]

[1]Faculty of Environmental and Urban Engineering, Kansai University Graduate School, Japan
skubota@kansai-u.ac.jp

Abstract

Because the scale and conditions of construction sites vary widely and it can be difficult to use a one-size-fits-all method to acquire data, a method for transferring and utilizing three-dimensional (3D) data from one stage to another in construction projects is urgently needed. In this study, we developed a construction-information system based on 3D point cloud data, taking into consideration the characteristics and conditions of construction sites and the definition of information systems in order to efficiently distribute and utilize 3D data. The use cases of the system were applied to the digital twin of a construction site. 3D point cloud data constructed using UAVs and camera-based photogrammetry were used to visualize the progress at the construction site and to understand the transition of earthworks. The results suggested the necessity of changing the measurement and processing methods according to the conditions of the construction site and the intended use of the data, as well as devising ways to reduce the impact on the current workflow.

Keywords –

digital twin, three-dimensional point cloud data, information system, construction practice

1 Introduction

The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan is promoting “i-Construction,” in which information and communication technology (ICT) is fully introduced in construction projects. However, construction sites are diverse and it can be difficult to use a one-size-fits-all method for acquiring three-dimensional (3D) data and 3D point cloud data to understand the site conditions. In urban spaces, digital twins are being promoted to collect data related to civil infrastructure and urban activities and visualize them in a three-dimensional space. An evolution has been transition from using each digital tools to the more integrated framework of digital twins [1][2]. However, in the construction field, there have been few initiatives to collect and manage information on construction sites with the aim of creating digital twins that reproduce information from construction sites in a virtual space, and it remains unclear which types of data can be acquired on construction sites. It is expected that the collection and visualization of data will advance i-Construction; eliminate interference with electric power, gas, and sewage systems in underground buried structures; and assist the engineer’s decision-making process in inspection and diagnosis. However, no methods for transferring data between the planning, surveying, design, construction, inspection, maintenance, and renewal stages of civil infrastructure have been established.

In this study, a construction-information system is proposed in which 3D data and 3D point cloud data are distributed and utilized at small and medium-sized construction sites. The construction information that can be obtained at construction sites is considered and defined, a construction-site digital twin based on 3D point cloud data is considered, and use cases for utilizing construction information are discussed. Furthermore, the issues related to the acquisition, processing, management, and utilization of construction information at each stage of the use case are clarified.

2 Issues of Construction Information

2.1 Current Status and Issues Related to Construction Information

MLIT has published a public survey manual and management guidelines, which include surveying standards for 3D data at construction sites, but detailed information on shooting conditions, survey methods, and survey equipment for different site characteristics are not provided, making it difficult to measure and maintain data in a uniform manner at all sites.

Small and medium-sized construction companies face the problem that the use of 3D data and i-Construction equipment has not progressed. Suzuki et al. proposed a measurement method with the aim of addressing coverage and cost issues [3]. However, a simple 3D data–surveying method and a 3D data–construction method involving inexpensive unmanned aerial vehicles (UAVs) and cameras are necessary to enable small and medium-sized construction companies to introduce ICT and carry out construction projects efficiently. Tanaka et al. [4] and Takahashi et al. [5] proposed and validated a measurement method involving a UAV-mounted camera or laser scanner. However, when determining the target structure and performing measurements, it is necessary to follow a survey method that is appropriate to the scale of the site and the surrounding conditions.

Kanzaki demonstrated how to utilize 3D models in the planning, construction, and maintenance stages and discussed the effects of their introduction but did not describe the data transfer from planning to construction and from construction to maintenance, nor the effects of this [6]. Fujita et al. proposed a method for assigning attributes to point cloud data but did not consider the data volume and format of point cloud data in consideration of operation [7]. Therefore, it is necessary to demonstrate how data can be transferred from the construction stage to the maintenance management stage as well as how data can be utilized between stages.

Building information modeling was used from the design process to the construction process as research for displaying various information in 3D space and using it for decision-making. Methods for utilizing 4D models by linking 3D models with scheduling information and for developing a 4D integrated construction-site planning system have been proposed [8][9]. A digital twin used in a bridge inspection has also been discussed [10].

2.2 Problem solving in this research

To address the issue of surveying according to the scale and conditions of the site, this study considers methods that are appropriate to the characteristics of the site, where construction equipment and people are present and data-feature points are few, when measuring the construction site with a terrestrial laser scanner (TLS) or camera. To construct 3D data using inexpensive equipment, we propose the acquisition of 3D point cloud data using cameras shooting from high locations in addition to UAVs, so that the data can be used even at construction sites where there are limitations on the equipment used. A construction-information system is conceived to solve the problem of passing data from the construction stage to maintenance management stage. The points to be considered in the measurement, processing, management, and utilization of data at each stage of pre-construction, construction, post-construction and maintenance are clarified.

3 Concept of a Construction-Information System Using 3D Data

3.1 Construction-Site Digital Twin

In this study, a digital twin is the visualization of a construction site in a digital space that is created by processing data collected at the construction site. The digital twin collects and accumulates daily progress and construction records as data from the start to the completion of construction. It is also assumed that a 3D construction site based on 3D point cloud data will be constructed, and the daily accumulated data will be displayed and used for construction planning and other purposes. Here, the digital twin has three roles: to provide “past records” as a data storage base that can be referred to when data are needed in later processes, by accumulating work records and changes in site data up to the present; “understanding the present” by reproducing the three-dimensional construction space digitally and reflecting the situation in the real world; and “predicting construction progress from the data accumulated thus far.”

In order to use ICT technology to advance construction management and realize a digital twin, it is important to save the data generated at the construction site as a log from the day-to-day construction. However, there is no research on the construction of a digital twin by accumulating data acquired at the construction site from the planning stage to the completion of construction. The 3D data related to the social infrastructure of the digital twin has issues such as surveying methods and 3D data construction according to the site conditions, and verification of accuracy due to differences in objects and surveying methods. Images related to urban activities, the action history of workers and logs of construction equipment are important information that should be acquired and retained at construction sites for use in safety management and health management. However, it is difficult to introduce these systems to all construction sites due to the need to store large amounts of data, the lack of data standardization to accumulate and utilize the data generated on a daily basis, and the high costs involved.

There are no current government initiatives to realize a digital twin of construction sites, where the data acquired from the planning stage to the completion of construction are accumulated. The reasons for this are as follows: the type of data to be acquired and stored at construction sites has not be specified; the work of artificially acquiring data without automatically obtaining logs from i-Construction equipment and wearable devices places a burden on workers; and the use cases for storing data are not clear. The use case for

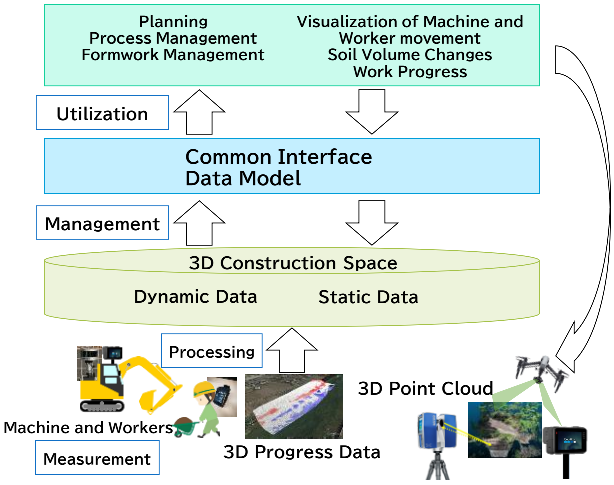

Figure 1. Concept of construction information system

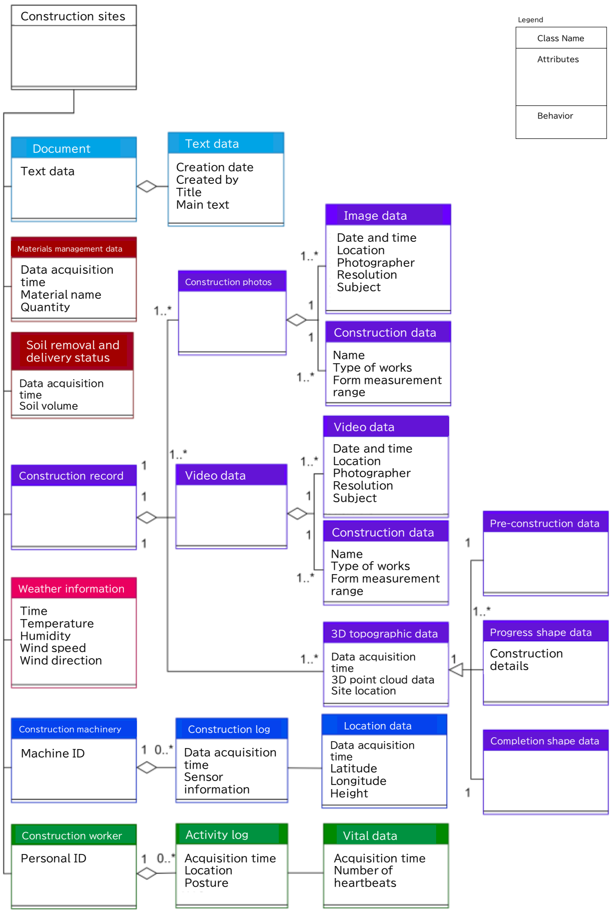

Figure 2. Class diagram of data acquiring at the construction site

storing data is not clear.

The construction site digital twin collects and accumulates data in accordance with data definitions based on the idea of digital threads that accumulate data transitions. The digital thread is a concept that accumulates data attributes and their transitions, analyses useful data from the accumulated data, and uses the results to realize construction sophistication through data utilization. An image of the construction site digital twin is shown in Figure 1. In the construction site digital twin, daily progress and construction records are collected and stored as data during the entire construction period of a civil engineering structure, from the start of construction to construction and completion. The accumulated data is used to construct a three-dimensional construction site based on 3D point cloud data, and as feedback to the site, the daily accumulated camera images and action logs are displayed and used for construction planning.

3.2 Use Cases

The use cases of the construction-site digital twin are process management, quality management, and safety management. In process management, 3D point cloud data of the site topography are acquired on a daily basis by measuring equipment such as TLS and UAVs and then superimposed on past data, enabling each day's progress to be monitored. Because daily records are accumulated, they can be checked regularly and corrected at the construction stage before construction defects are discovered after completion. In quality control, when a construction defect or deficiency occurs, the data collected on the digital twin can be used to reconstruct the situation at the time and identify the cause of the construction error. Furthermore, information from the construction site is aggregated in the digital twin, enabling a remote presence in the digital space. In safety management, the physical condition of workers is managed by quantitatively evaluating changes in their physical condition based on vital data acquired using smart devices. For this purpose, movement history and changes in heart rate are recorded using Global Navigation Satellite System (GNSS) information. The location information of construction machinery and workers is used to analyze situations where contact accidents are likely to occur.

3.3 Proposal for a Construction-Information System

In this section, a digital twin-oriented construction-information system (Figure 1) is proposed to manage data generated at construction sites. It was utilized in the use cases described above. At the construction site, the shape and changes of the structure are acquired by TLS and UAVs, and by cameras and wearable terminals to reduce the workload of artificially acquiring the behavior of

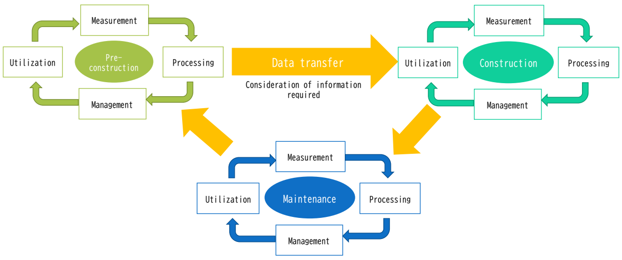

Figure 3. The information-systems cycle in construction projects

construction equipment and workers. The data to be acquired and accumulated at the construction site are classified with reference to the data hierarchy in the local dynamic map [9] in automatic operation, based on the characteristics of the construction site where the situation is constantly changing. In other words, the data are classified as "dynamic information" or "static information" according to the speed of change in the acquired data, while the acquisition frequency is defined so that the data acquired at the construction site are always the latest. The data to be managed were examined based on the MLIT guidelines, as shown in the class diagram in Figure 2. Figure 2 was described using UML (Unified Modeling Language). Construction photographs and 3D point cloud data are classified as "construction records." The 3D point cloud data for the ground survey, which are acquired before construction, and the 3D point cloud data used for the formwork inspection at the time of completion are each acquired once. In contrast, the topographic data acquired to record the daily progress during construction are managed on a daily basis together with the details of the construction work, thereby serving as a construction record. By classifying these data, it becomes easier for the user to distinguish the data by purpose. In addition, the metadata that summarize the measurement and processing methods of the data are also managed together, providing a reference when proceeding to the next step in the process.

As shown in Figure 3, the construction-information system implements the process of collecting information by measuring the construction site or structure, processing the collected data, communicating by managing the data and utilizing the data at each stage of pre-construction, construction, and post-construction as well as maintenance management. This cycle is repeated for each stage of construction and maintenance management, and information is accumulated accordingly. When the pre-construction, construction, post-construction, and maintenance management processes are completed and the next stage is reached, the necessary information is reviewed and the data are passed on. The data acquired in the maintenance management stage are used as part of the completion drawings and

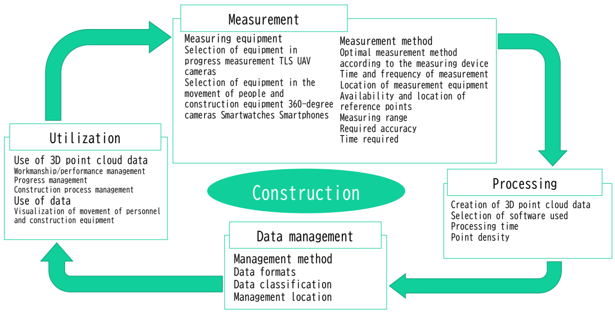

Figure 4. Collection, processing, communication, and use of information during and after construction

construction plans before repair work is carried out.

Figure 4 shows the items to be considered at each stage of measurement, processing, management, and utilization of information in the construction-information system during and after construction. In the "collection of information" stage, the measurement range and equipment locations are set according to the measurement target, the existence and location of reference points, and the timing and number of measurements in order to meet the required accuracy, specified in the workmanship management guidelines, workmanship management supervision and inspection guidelines, and the work piece calculation guidelines. In the case of 3D point cloud data, the TLS point cloud data measured at multiple locations are combined and 3D point cloud data are constructed based on videos and photographs. Software is selected that is appropriate for the equipment used, and the density of the 3D point cloud data is taken into account. In the "information transfer" stage, data are passed from the construction stage to maintenance management stage in accordance with the data specification (Figure 2). In the "use of information" section, the constructed 3D point cloud data and visualized soil volume data are used for daily progress management, construction-process management, and formwork management. It is also possible to visualize changes in soil volume from two 3D point cloud data measured at different times and to visualize the movements of people and construction equipment from 3D point cloud data and GNSS information. In the maintenance management stage, the 3D point cloud data of structures captured when construction was completed can be used to visualize damage as well as for periodic inspections.

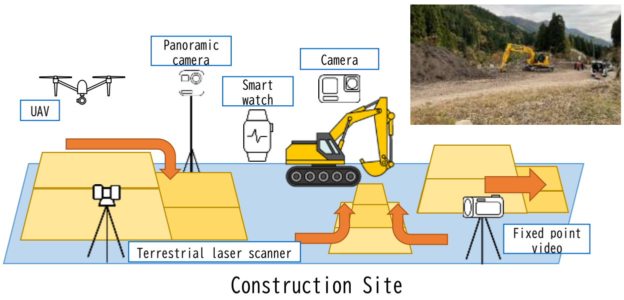

Figure 5. Experiment site

(a) Panoramic view of heavy equipment with camera attached

(b)An image acquired from the heavy equipment camera

Figure 6. Experimental

4 Implementation of Construction Information Systems

4.1 Experimental Overview

In this section, the cycle of measurement, processing, management, and utilization of the construction-information system is verified at the construction site, and the points to be considered in each process toward the construction of a digital twin are clarified. Figure 5 and 6 show the experiment. Assuming a small to medium-sized construction site, measurements were taken before and after construction with different embankment shapes. An Inspire2 UAV (DJI) was used when human access was restricted, and an action camera mounted on a monopod was used for photogrammetry from a height in areas where UAV flight was restricted or where the area was too narrow. From these, 3D point cloud data were generated using structure from motion/multi-view stereo processing. In aerial photogrammetry, the measurement time, 3D point cloud data construction time, and TLS 3D point cloud data are compared with the accuracy of the data as the most accurate values by changing the measurement equipment and altitude.

4.2 Experiment

4.2.1 Measurement of Construction Sites

To verify the accuracy of photogrammetry and visualize progress using the UAV-mounted camera and a camera mounted on a monopod, four black-and-white markers were used as feature points on the photographs: two wooden stakes were used as marking points and two wooden stakes as verification points. The positions of the fixed points and verification points were not changed before and after the construction, and the same values were used: the UAV flew one round-trip at 30 m and two round-trips at 20 m, depending on the angle of view of the camera. Photogrammetry by UAV and camera was carried out twice, once before and once after construction, in order to visualize the construction progress, using 3D point cloud data.

4.2.2 Data Processing

The data measured by the camera were given the absolute coordinate values of the six fixed points, so that the actual dimensions of the site could be measured. The accuracy and quality of the data during processing were considered to be the highest. In the public survey manual, the standard is 80% overlap and 60% sidelap, but in this study, the number of photographs was reduced by changing the shooting altitude, considering that the measurement and processing time for constructing the 3D point cloud data from camera images is proportional to the number of photographs used, given that the construction progress is the subject of this study. In the constructed 3D point cloud data, the UAV photogrammetry was carried out in the vertical direction, so depending on the flight route and altitude, the vegetation became a barrier and data on the ground surface were lost. When constructing the 3D point cloud

Table 1 Accuracy assessment by comparison of photogrammetric results with TLS point cloud data.

	Percentage of points within the required accuracy of ±200 mm (%)			Measurement Time	Processing Time	Data (GB)
	Land 1	Land 2	Land 3			
UAV (Height 20 m)	92.9	95.9	99.9	3 m19 s	24 m	2.45
UAV (Height 30 m)	93.9	96.2	99.9	4 m58 s	8 m	0.89
Camera (Height 3 m)	99.8	96.8	99.9	5 m58 s	8 h30 m	10.81
Camera (Height 8 m)	98.5	95.7	99.8	3 m43 s	1 h50 m	2.86

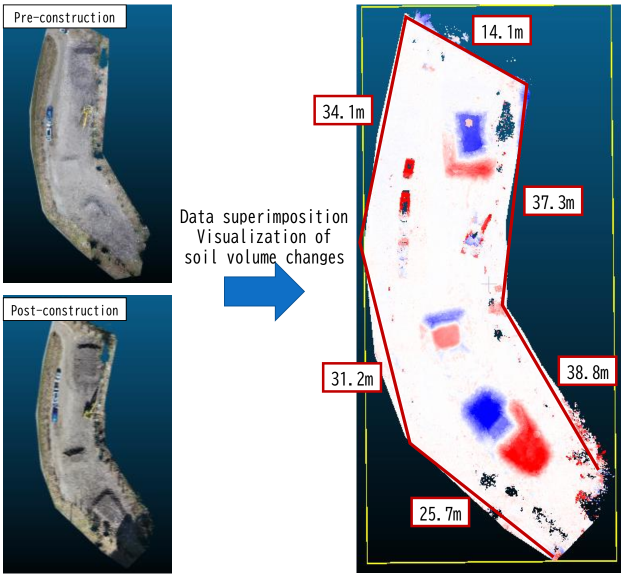

Figure 7. Visualization of construction progress with color display

data, any people, vehicles, and building materials reflected in the data were manually clipped out, thereby reducing noise.

4.2.3 Data Management

The processed data were classified according to the class diagram: the 3D point cloud data were classified as 3D topographic data in the construction record. The 3D point cloud data before construction were classified as pre-construction topographic data and the post-construction data as progress topographic data, and the acquisition time, measurement location, and construction implementation details of each data point were recorded.

4.2.4 Utilization of Data

To quantitatively monitor the daily progress at the construction site, the accuracy for this study was set according to the MLIT's Draft Guideline for the Calculation of Earthworks Completion Using Stereo Photogrammetry (Ground Moving Object) and Draft Guideline for the Calculation of Earthworks Completion Using Ground Photogrammetry (Moving Image Type), using 3D point cloud data captured by the TLS as the most accurate value. The horizontal and elevation range were within ±200 mm.

As a verification method, the difference between the 3D point cloud data captured by the TLS and the 3D point cloud data captured by aerial photogrammetry was calculated using the 3D point cloud data-processing software CloudCompare. The accuracy evaluation results are shown in Table 1. UAV aerial photogrammetry and high-altitude camera photogrammetry surveys conducted in this study, more than 92% of the 3D point cloud data points satisfied the required accuracy of ±200 mm. This indicates that the overlap and sidelap in the photogrammetric surveys were adequate. Noise and deficiencies due to vegetation and photogrammetric errors resulted in some points failing to meet the required accuracy, so it is necessary to cut out unnecessary data and change the number and location of the fixed points.

The distance between the points of the 3D point cloud data before and after construction is calculated as the construction progress at the site, and the change in soil volume is visualized by a color display. As shown in Figure 7, red indicates a positive change in height after construction compared with before construction, blue indicates a negative change, and white indicates no change. The color becomes darker if the change in soil volume is large, and lighter if it is small. If 3D measurements are taken at each stage of the construction progress, they can also be used for construction-progress management.

The third use case is to understand the construction status by tracing back the time period from the data recorded throughout the construction. The camera images were positioned and oriented on top of the 3D point cloud data, which are topographic data. In addition to the data acquired before and after the construction, the topographic data visualizing the progress of the slide shown earlier are also displayed, and the acquisition time (shooting time) for each data point was set. As shown in Figure 8, by moving the time axis, the site conditions and the data acquired at that time can be displayed.

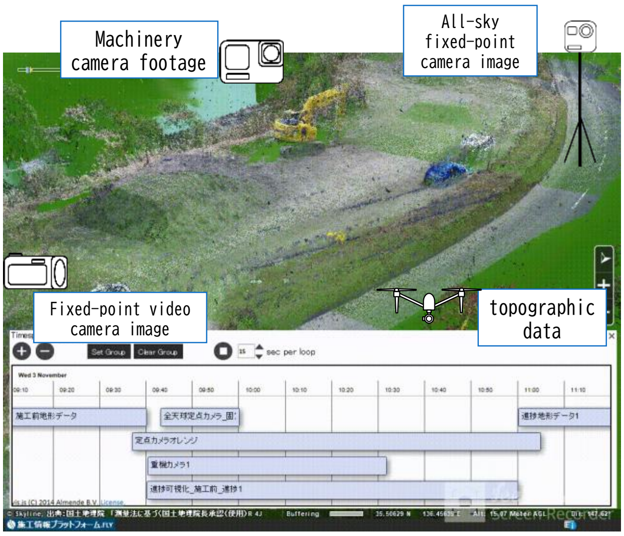

Figure 8. Construction-information system

5 Considerations

5.1 Considerations on the Construction Information System

For photogrammetry using the UAV-mounted camera, the flight altitudes were 20 m and 30 m. In this study, to compare 3D point cloud data at different flight altitudes, two round-trips were made over the site at an altitude of 20 m, where the angle of view is narrower, and one-round trip was made at an altitude of 30 m, with the same lap rate. At an altitude of 30 m, the flight time and the construction time of 3D point cloud data were shorter than at an altitude of 20 m. Increasing the altitude increases the area that can be photographed, reduces the number of images, and shortens the time for photographing and constructing the 3D point cloud data. Although the accuracy of the 3D point cloud data decreases as the altitude increases, the topographic data measured on a daily or weekly basis is not required to have high accuracy for the purpose of understanding the daily progress. In the photogrammetric measurement at an altitude of 3 m using a camera mounted on a monopod, the construction site was photographed in two rounds, with the camera facing forward in the direction of travel in the first round and facing sideways in the second round, in order to reduce the loss of 3D point cloud data. Depending on the site conditions, it is necessary to devise ways to extract feature points, such as setting the walking route and image cropping intervals when taking photographs. By mounting the camera on a monopod, it is possible to take photographs from high altitudes, even in areas where UAVs have flight restrictions or weather conditions are not met.

5.2 Considerations on the Feasibility of Use Cases

In this chapter, use cases of process control, quality control, and safety control are examined to clarify the feasibility and issues. In the process control, 3D point cloud data and workers' vital data were used to determine the quantity of work, work progress, and workload of embankment construction. The results suggest that the UAV can be utilized for workmanship control. Therefore, the front wrap rate of 60% and sidelap rate of 40% set for the measurement using the UAV-mounted camera and the walking route for the measurement using the elevated camera were appropriate. On the other hand, 7.1% of the points did not meet the required accuracy at an altitude of 20 m for the UAV and 4.3% at an altitude of 8 m for the camera. It is necessary to walk around the measurement target multiple times and change the camera angle to avoid blind spots caused by structures and construction equipment. For the soil volume, the coordinates of the cross section were evaluated using the coordinates of the cross section of the 3D point cloud data from the UAV flight altitude of 30 m in the embankment area and the TS coordinates.) In this study, errors were also found at the top and bottom corners of the embankment by TS surveying. This difference may have affected the construction progress, volume and volume.

The volume of soil was calculated because the volume of soil is used to calculate the progress of construction in earthwork. Since each embankment was deformed, the volume of soil did not change significantly, but the volume of soil before and after deformation differed due to the use of heavy machinery to shape and compact the soil. This difference in soil volume can be used to calculate the compaction ratio, which is one of the criteria for earthwork.

In this study, the accuracy is low because 3D point cloud data by SfM/MVS processing was used, but if the measurement accuracy is high, a more accurate evaluation is possible. To visualize the progress of construction, two sets of data, one before and the other after construction, were superimposed and displayed in color to grasp the transition of earthwork. The 3D point cloud data before and after construction were given absolute coordinates, which eliminated the need to superimpose the data. In this study, two sets of data were used for construction progress, but daily progress can be visualized with three or more sets of data. In the experiment, the distance between two selected data points was calculated, so that the worker can select two data points at worker discretion and grasp the daily progress of construction and the progress since the start of construction. In this study, the 3D point cloud data by TLS was used as the most accurate value, but it can be used for visualization of construction progress in the same way as photogrammetric data by camera.

In quality control, time synchronization of the acquired images was performed to reproduce the on-site conditions. This allows us to confirm the site conditions at that time from multiple viewpoints. Video data was replayed on 3D point cloud data using TerraExplorer. We set the shooting position, orientation, and height, and we believe that we were able to reproduce the construction site digitally. However, the data acquired at the construction site must be brought back to the office for processing, and it takes time for the data to be reflected. A system is needed to upload the data acquired at the construction site to the cloud and display detailed information on the site status in real time.

For safety management, 3D point cloud data created based on worker positions and heart rate data were superimposed on the underlying 3D point cloud data. The color of the points changes according to the heart rate value, enabling quantitative judgment of changes in the worker's physical condition. The superimposition of the position of the construction machinery on these data can be used to prevent accidents involving contact between the construction machinery and the worker. Vital data can be visualized as 3D point cloud data, and it is effective to change the display method depending on the application. However, there are issues such as setting threshold values to capture changes in workload and physical condition, and managing the time axis to display the worker's position in real time.

In Japan, local governments have released 3D point cloud data on the Web. However, these data are available only at the operational stage or after construction, and there are no examples of releasing 3D point cloud data during construction. If the data measured in this study during construction and 3D point cloud data, along with metadata, are made publicly available on the Web, it is expected to promote the use of 3D data and new applications at many construction sites. Therefore, it is necessary to consider how to manage and store the enormous amount of data acquired at construction sites.

6 Conclusion

In this study, a construction-information system was proposed with the aim of distributing and utilizing 3D data and 3D point cloud data at small and medium-sized construction sites where ICT-assisted construction may be challenging. The system enables the construction of a digital twin and specifies the data to be acquired. In verifying the use case, the measurement method and required accuracy of the UAV-mounted camera and an elevation camera to monitor the construction progress were clarified. In addition, soil volume changes were visualized by data superimposition and measuring differences in distance, using 3D point cloud data.

In the future, the usefulness of the construction-information system will be evaluated through practical application at several sites. Furthermore, to manage the enormous amount of data acquired daily at construction sites, a system for sharing weekly 3D point cloud data and images extracted from videos among construction workers as well as a method for visualizing the site situation by using mesh data generated from 3D point cloud data will be studied.

References

[1] Albalkhy, W., Kamaoui, D., Ducoulombier, L., Lafhaj, Z. and Linner, T. Digital twins in the built environment definition, applications, and challenges. *Automation in Construction*, 162, 2024.

[2] Soman, R. K., Farghaly, K., Mills, G. and Whyte J. Digital twin construction with a focus on human twin interfaces. *Automation in Construction*, 170, 2025.

[3] Suzuki, R. Maehara, H., and Taira, K. Mobile Camera Localization Utilizing Automatic Tracking Total Station. *Journal of the Japan Society of Photogrammetry, and remote sensing*, 58(6):322-327, 2019.

[4] Tanaka, S., Kubota, S., Imai, R., Nakamura, K., Yamamoto, Y., Tsukada, Y., Taniguchi, H., and Nakahara, M. Accuracy evaluation of measurement with laser scanner equipped UAV for earthworks construction management. *Journal of Japan Society of Civil Engineers, Ser. F3 (Civil Engineering informatics)*, 74(2):II_125-II_135, 2018.

[5] Takahashi, G., Tsunogai, R., Miyamoto, S., Matsuura, Y., Takiguchi, Y., Ogawa, M., Miyahira, E., and Hayashi, T. Consideration to topography survey of river bed using UAV, *Journal of Japan Society of Civil Engineers, Ser. G (Environmental Research)*, 75(5):I_313-I_322, 2019.

[6] Kanzaki, K. Utilization of the three-dimensional model to a construction production system, *Journal of Japan Society of Civil Engineers, Ser.F4 (Construction management)*, 73(4):I_55-I_63, 2017.

[7] Fujita, Y. Ogata, S. Wo, C. and Kobayashi, I.: Attribute assigned road point cloud for using in construction life cycle, *Journal of Japan Society of Civil Engineers, Ser.F3 (Civil Engineering informatics)*, 70(2):I_144-I_151, 2014.

[8] Wang, H. J., Zhang, J. P., Chau, K. W. and Anson, M.: 4D dynamic management for construction planning and resource utilization, *Automation in Construction*, 13(5):575-589, 2004.

[9] Ma, Z., Shen, Q. and Zhang, J. : Application of 4D for dynamic site layout and management of construction project, *Automation in Construction*, 14(3):369-381, 2005.

[10] Ye, C., Butler, L., Calka, B., Iangurazov, M., Lu, Q.,

Gregory, A., Girolami, M., Middleton, C.: A Digital Twin of Bridges for Structural Health Monitoring, *Proceedings of the 12th International Workshop on Structural Health Monitoring*, 2019.

[11] ETSI TR 102 863 V1.1.1：*Intelligent Transport Systems(ITS)；Vehicular Communications；Basic Set of Applications；Local Dynamic Map(LDM)；Rationale for and guidance on standardization*, 2011.