Construction Progress Evaluation Using 3-D Model Based on Point Cloud

Korb Srinavin, Supanan Rattanapongwanich, Wuttipong Kusonkhum, and Narong Leungbootnak
Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen, Thailand.
Email: korbsri@kku.ac.th, ssupanan.rt@gmail.com, w.kusonkhum@gmail.com, Narongl.fec@gmail.com

Phatsaphan Charnwasununth
Faculty of Architecture, Chulalongkorn University, Bangkok, Thailand.
Email: Phatsaphan.C@chula.ac.th

***Abstract*— Construction progress evaluation is considered an important process in construction project management. Conventional progress evaluation is time and cost consuming. In recent years, new technologies such as photogrammetry and artificial intelligence have been playing an important role in many industries including the construction industry. This study attempts to use such technologies to evaluate construction progress. The actual progress was captured by photo taking, then a 3-D model was generated by means of the point cloud. The 3-D model of the construction (actual progress) was compared to the plan, which is planned using 4-D modeling. The results showed that the 3-D point cloud based model of the actual construction progress developed can be used to evaluate the construction progress compared to the plan with less than 0.1% error. This technique may be used to reduce some arguments between owner and constructor on construction progress.**

***Index Terms*— construction progress, photogrammetry technology, point cloud, 3-D model, 4-D model, project schedule.**

I. Introduction

The Project Management Body of Knowledge [1] explains that monitoring and controlling a construction project consists of processes required to track, review, and orchestrate the progress and performance of a project, identify any areas in which changes to the plan are required, and initiating the corresponding changes. These processes involve the progress measurement through inspections, and the comparison with the project plan to validate the predicted performance. Progress monitoring is considered a critical success factor for projects to be delivered on time and within budget [2]. Conventional progress evaluation is time and cost consuming, as one of the most difficult tasks due to the complexity and interdependency of activities. Hence, it is one of the greatest challenges for a project manager to encounter. Accurate information of the progress is a necessity for project control that will convince cost and time efficiency of the project. Hence, an efficient on-site data collection, data analysis, and communication of the results in haste fashion is a major concern for construction companies [3].

The repeated inspection allows managers to identify defects early on, preventing potential upcoming delays by making timely decisions for corrective actions. As a result, the feasibility of unpredicted costs from delays re-works, disputes, and claims are mitigated [4, 5]. On the other hand, poor management and low-quality control can cause delays, cost increase and have severe impacts on productivity. [6, 7]. The time to identify the discrepancies between the as-planned and as-built model is proportional to the cost and difficulty in corrective measures [8]. To measure the construction progress consists of measuring the actual construction progress then comparing with the planned progress.

In recent year, new technologies are helpful for monitoring and controlling the construction to save cost and time of construction project. Some of these technologies are photogrammetry and artificial intelligence (AI), which have been playing an important role in many industries including the construction industry.

II. Background

There are many technologies to collect as-built data such as laser scanning method, photogrammetry, etc. All of these datas are collected in a database on the point cloud. The 3D as-built point cloud model is successful with satisfactory accuracy by photogrammetry techniques and by synchronizing the common points between the two-point cloud models, using the constructed 3D point cloud model [9]. For project monitoring, there is an automated project monitoring that affects construction project control. One of the interesting automation applications in the construction industry is the adoption of Building Information Modelling (BIM) [10].

Abeid et al. using a real-time system to monitor construction works suggested installation of multiple cameras on the construction site and Leung et al. agree with the suggestion that fixed cameras provide limited views, obstructions and weather conditions affect to project monitoring. [11, 12].

Manuscript received May 1, 2020; revised November 21, 2020.
Corresponding author: Korb Srinavin

doi: 10.18178/ijscer.9.4.278-282

Recently, 4D BIM is used in the construction industry for the updating of the project schedule. Turkan et al. presented a system for construction progress measurement and schedule updating using data from a 3D laser scanner and a 4D BIM. The as-built model is constructed via the object detection method [13]. The as-built data that has been collected from point clouds have to be compared with the as-planned data to evaluate the current status of construction progress for using in project decision and take corrective actions.

Ordinarily, a BIM model that included the schedule of tasks called a 4D BIM model is used as as-planned model and superimposed over the 4D BIM. The registration process has been performed manually that requires human interaction for registering the as-built and the as-planned model to assign data such as time and location [14].

For as-built modeling, Bosché [15] presented a 3D CAD model with actual data using a laser scanner in object recognition method, The 3D CAD model is exported in STL format then converted to a point cloud. In Bosché's algorithms, aligning the coordinate system using a semi-automated process. A given model recognized a 3D CAD component and an as-built model, the study report that 83% of completed as-built components were recognized as being completed if the number of actual 3D data covering the component surface is larger than some threshold.

In addition, C. Kim et al. [16] presented a method of object recognition for as-built modeling using a 3D CAD model with the 3D stereo vision data (contain position and color). The structural components have detection based on using a color thresholding. Then the coordinate system for the 3D data has been aligned with 3D CAD model and a given recognized CAD component by counting the number of 3D data points. The study reports this method correctly recognized the status of 88% of component that was completed.

A. 3-D Model Based on Point Cloud Generation.

The 3-D model was generated from object images that were captured with a camera which used the photogrammetric calibration with digital chessboard capturing (Fig. 1) to calibrate the camera. The specifications of the camera are shown in Table I.

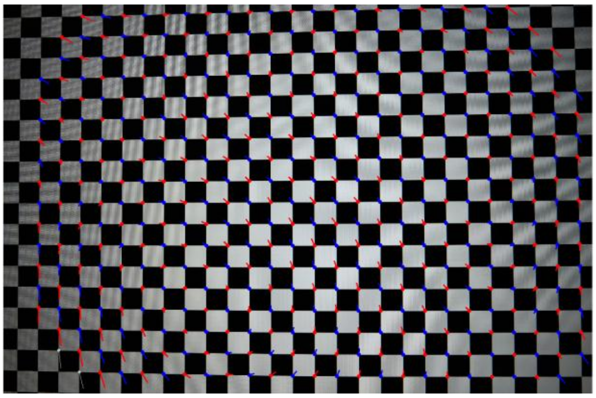


Figure 1. Images captured chessboard for lens calibration.

TABLE I. CAMERA SPECIFICATIONS

TYPE	SPECIFICATION
MODEL NAME	FUJIFILM X-E2
SENSOR	(APS-C) X-TRANS CMOS II
LENS	XF18-55MMF2.8-4 R LM OIS
EFFECTIVE PIXELS	16.7 MILLION PIXELS
WIRELESS TRANSMITTER	STANDARD IEEE 802.11B / G / N (STANDARD WIRELESS PROTOCOL) ACCESS MODE INFRASTRUCTURE
PHOTO FORMAT	JPEG (EXIF VER 2.3), RAW (RAF FORMAT), RAW+JPEG (DESIGN RULE FOR CAMERA FILE SYSTEM COMPLIANT / DPOF-COMPATIBLE)

The images have captured in different positions on circular paths with different angles around the object (Fig.2). Then generated the images by image-matching algorithm in software to build the point cloud model with a simplified box shape (Fig. 3).

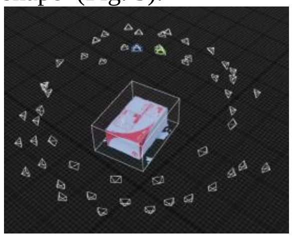


Figure 2. Position of the cameras around the object.

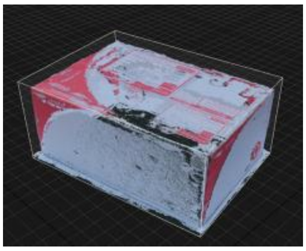


Figure 3. Point cloud simulation

After model cluttering, we will get a clear model then export a generated model into Autodesk Revit to measure the model in terms of width, length and height. Then we must compare two models between a real post box that was measured with manual equipment and a generated 3-D model that was measured with manual software measuring. Tolerances are considered acceptable (Table II).

TABLE II. 3D POINT CLOUD MODEL OF SAMPLE BOX.

	Actual BOX (cm.)	3D point cloud model (cm.)
Width	30.85	30.83
Length	45.35	45.43
Height	20.00	20.03
The error	Less than ±1%	

III. PROPOSED METHOD

This study attempts to use such technologies to evaluate construction progress. The actual progress was captured by photo taking, then the 3-D model was generated by means of the point cloud. The

3-D model of the construction (actual progress) was compared to the plan, which is planned to use 4-D modeling.

Start with a 3D point cloud model that generated from photos shot in different position around the object then import the model to remove clutter and occlusion repeatedly to obtain an uncomplicated model because the uncomplicated model is easy to draft to 3D BIM model. Next, generate 4D BIM from schedule data fused with 3D BIM model that includes working time, milestone date, planned estimate time, actual working time and 3D BIM model.

A. Draft to 3D BIM Model

Draft the point cloud model with vector lines to build a 3D model that can be exported to Navisworks for the link with the project schedule (Fig. 6).

B. Linking Schedule with 3D BIM Model

Determine main tasks of project with three boxes to construct. Divide each box into five tasks to construct in one box. Assume two status of schedule time, the first is finish ahead from the plan and the second is finish delay from the plan (Fig. 7).

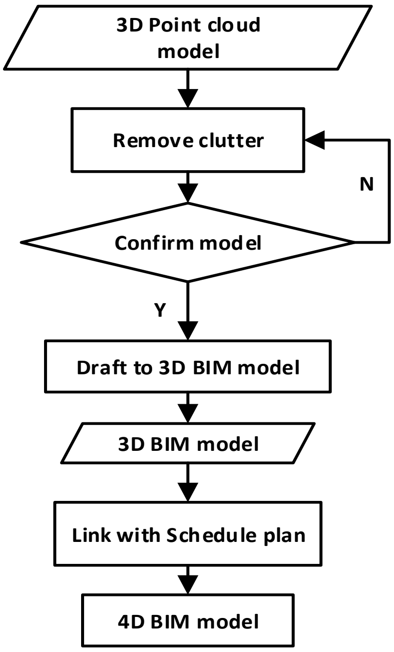
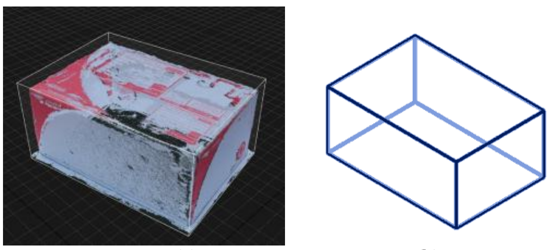


Figure 5. Methodology flowchart



(a) (b)

Figure 6. 3D model of sample box.
(a) 3D model based on point cloud, (b) 3D BIM model

Active	Name	Status	Planned Start	Planned End	Actual Start	Actual End
	BOX1		01-Apr-19	05-Apr-19	01-Apr-19	04-Apr-19
	1		01-Apr-19	01-Apr-19	01-Apr-19	01-Apr-19
	2		02-Apr-19	02-Apr-19	02-Apr-19	02-Apr-19
	3		03-Apr-19	03-Apr-19	03-Apr-19	03-Apr-19
	4		04-Apr-19	04-Apr-19	04-Apr-19	04-Apr-19
	5		05-Apr-19	05-Apr-19	04-Apr-19	04-Apr-19
	BOX2		06-Apr-19	10-Apr-19	05-Apr-19	09-Apr-19
	1		06-Apr-19	06-Apr-19	05-Apr-19	05-Apr-19
	2		07-Apr-19	07-Apr-19	06-Apr-19	06-Apr-19
	3		08-Apr-19	08-Apr-19	07-Apr-19	07-Apr-19
	4		09-Apr-19	09-Apr-19	08-Apr-19	08-Apr-19
	5		10-Apr-19	10-Apr-19	09-Apr-19	09-Apr-19

(a)

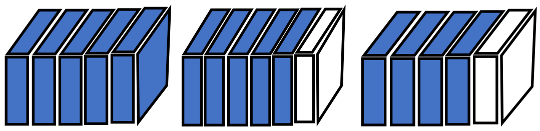
Active	Name	Status	Planned Start	Planned End	Actual Start	Actual End
	BOX1		01-Apr-19	04-Apr-19	01-Apr-19	05-Apr-19
	1		01-Apr-19	01-Apr-19	01-Apr-19	01-Apr-19
	2		02-Apr-19	02-Apr-19	02-Apr-19	02-Apr-19
	3		03-Apr-19	03-Apr-19	03-Apr-19	03-Apr-19
	4		04-Apr-19	04-Apr-19	04-Apr-19	04-Apr-19
	5		04-Apr-19	04-Apr-19	05-Apr-19	05-Apr-19
	BOX2		05-Apr-19	09-Apr-19	06-Apr-19	10-Apr-19
	1		05-Apr-19	05-Apr-19	06-Apr-19	06-Apr-19
	2		06-Apr-19	06-Apr-19	07-Apr-19	07-Apr-19
	3		07-Apr-19	07-Apr-19	08-Apr-19	08-Apr-19
	4		08-Apr-19	08-Apr-19	09-Apr-19	09-Apr-19
	5		09-Apr-19	09-Apr-19	10-Apr-19	10-Apr-19

(b)

Figure 7. Assume status of working schedule.

(a) Assumed box for finish ahead from the planed status, (b) Assumed box for finish delay from the planed status

Monitoring at dayX assumes plan is the first box to have to finished. The finish early from the planed status represent the actual that can construct more than one small box. For the finish delay from planned status the actual that can construct less than one small box from the planned (Fig. 8).



(a) (b) (c)

Figure 8. Model assumed status of the working schedule.
(a) Planned status at dayX,
(b) Assumed box for finish ahead from the planed status,
(c) Assumed box for finish delay from the planed status

IV. RESULT

A. Ahead from the Schedule

Assume the tradition measurement is correct. Compared with software measurement the results of error are shown in Table III.

TABLE III. ERROR IN CASE OF AHEAD FROM THE SCHEDULE.

Ahead schedule	Software measurement	Traditional measurement	Error (%)
Planned	39.98	40.00	-0.05
Actual	49.99	50.00	-0.02

B. *Behind from the Schedule*

Assume the tradition measurement is corrected. Compared with software measurement the results of error are shown in Table IV.

TABLE IV. ERROR IN CASE OF BEHIND FROM THE SCHEDULE.

Ahead schedule	Software measurement	Traditional measurement	Error (%)
Planned	39.98	40.00	-0.05
Actual	49.99	50.00	-0.02

The results showed that the 3-D point cloud model of the actual construction progress developed can be used to evaluate the construction progress compared to the plan with less than 0.1% error.

V. CONCLUSION AND RECOMMENDATION

Finally, the study show that we could be applying photogrammetry technique to improve checking progress om construction sites. The errors of experiments object that we study have less than 0.1 %. This technique may be used to reduce some arguments between owners and constructors on construction progress.

CONFICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Rattanapongwanich S. conducted the research; Kusonkhum W. and Charnwasununth P. analyzed the data; Srinavin K. and Leungbootnak N. supervised the research; all author had approved the final version.

ACKNOWLEDGMENTS

We would like to thanks to Khon Kaen University for funding this study.

REFERENCES

[1] O. Turner, *A Guide to the PROJECT MANAGEMENT BODY OF KNOWLEDGE (PMBOK ® GUIDE) Library* of Congress Cataloging-in-Publication Data. 2017.

[2] K. C. Iyer and K. N. Jha, "Factors affecting cost performance: evidence from Indian construction projects," *Int. J. Proj. Manag.*, vol. 23, no. 4, pp. 283–295, May 2005.

[3] K. S. Saidi, A. M. Lytle, and W. C. Stone, "Report of the NIST Workshop on Data Exchange Standards at the Construction Job Site | NIST," *Autom. Robot. Constr.*, 2009.

[4] R. Maalek and F. Sadeghpour, "Reliability assessment of Ultra-Wide Band for indoor tracking of static resources on construction sites," *CSCE, Edmont.*, 2012.

[5] J. K. Yates and A. Epstein, "Avoiding and minimizing construction delay claim disputes in relational contracting," *J. Prof. Issues Eng. Educ. Pract.*, vol. 132, no. 2, pp. 168–179, 2006.

[6] E. K. Zavadskas, T. Vilutienė, Z. Turskis, and J. Šaparauskas, "Multi-criteria analysis of Projects' performance in construction," *Arch. Civ. Mech. Eng.*, vol. 14, no. 1, pp. 114–121, Jan. 2014.

[7] S. Alizadehsalehi and I. Yitmen, "The Impact of Field Data Capturing Technologies on Automated Construction Project Progress Monitoring," *Procedia Eng.*, vol. 161, pp. 97–103, 2016.

[8] R. Navon, "Automated project performance control of construction projects," in *Automation in Construction*, 2005, vol. 14, no. 4, pp. 467–476.

[9] S. El-Omari and O. Moselhi, "Integrating 3D laser scanning and photogrammetry for progress measurement of construction work," *Autom. Constr.*, vol. 18, no. 1, pp. 1–9, 2008.

[10] M. Kopsida, I. Brilakis, and P. A. Vela, "A review of automated construction progress monitoring and inspection methods," in *Proc. of the 32nd CIB W78 Conference 2015*, 2015, pp. 421–431.

[11] S. Leung, S. Mak, and B. L. P. Lee, "Using a real-time integrated communication system to monitor the progress and quality of construction works," *Autom. Constr.*, vol. 17, no. 6, pp. 749–757, 2008.

[12] J. Abeid, E. Allouche, D. Arditi, and M. Hayman, *PHOTO-NET II: A computer-based monitoring system applied to project management*, vol. 12. 2003.

[13] Y. Turkan, F. Bosche, C. T. Haas, and R. Haas, "Automated progress tracking using 4D schedule and 3D sensing technologies," *Autom. Constr.*, vol. 22, pp. 414–421, 2012.

[14] Z. A. Memon, M. Z. A. Majid, and M. Mustaffar, "An Automatic Project Progress Monitoring Model by Integrating Auto CAD and Digital Photos," in *Computing in Civil Engineering (2005)*, 2005, pp. 1–13.

[15] F. Bosché, "Automated recognition of 3D CAD model objects in laser scans and calculation of as-built dimensions for dimensional compliance control in construction," *Adv. Eng. Informatics*, vol. 24, no. 1, pp. 107–118, 2010.

[16] C. Kim, C. Kim, and H. Son, "Automated construction progress measurement using a 4D building information model and 3D data," *Autom. Constr.*, vol. 31, pp. 75–82, 2013.

Korb Srinavin is an Associate Professor in Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, Thailand. He obtained his B.Eng. in Agricultural and Civil Engineering and M.Eng. in Structural Engineering and construction from Asian Institute Technology. He gained his PhD in Construction Engineering and Management from Griffith University Australia. His research interests involve project management and construction industry development.

Supanan Rattanapongwanich is a master degree student in Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, Thailand. She obtained her B.Eng. in Environmental Engineering from Khon Kaen University. Her research interests involve project management and construction industry development.

Wuttipong Kusonkhum is a Doctoral degree student in Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, Thailand. He obtained his B.Eng. in Civil Engineering from Mahasarakham University and his M.Eng. in Civil Engineering from Khon Kaen University. His research interests involve project management and construction industry development.

Narong Leungbootnak is an Associate Professor in Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, Thailand. He obtained his B.Eng. in Civil Engineering and his M.Eng. in Structural Engineering from Khon Kaen University. He gained his PhD in Construction Engineering and Management from Asian Institute Technology. His research interests involve project management and construction industry development.

Phatsaphan Charnwasununth is a lecturer in Department of Civil Engineering, Faculty of Architecture, Chulalongkorn University, Bangkok, Thailand. He obtained his B.Eng. and M.Eng. in Civil Engineering from Chulalongkorn University. He gained his PhD in Construction Engineering and Management from Chulalongkorn University. His research interests involve project management and construction industry development.