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Information Requirements for Model-based Monitoring of Construction via Emerging Big Visual Data and BIM

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Abstract: ***Documenting work-in-progress on construction sites using images captured with smartphones, point-and-shoot cameras, and Unmanned Aerial Vehicles (UAVs) has gained significant popularity among practitioners. The spatial and temporal density of these large-scale site image collections and the availability of 4D Building Information Models (BIM) provide a unique opportunity to develop BIM-driven visual analytics that can quickly and easily detect and visualize construction progress deviations. Building on these emerging sources of information this paper presents a pipeline for model-driven visual analytics of construction progress. It particularly focuses on the following key steps: 1) capturing, transferring, and storing images; 2) BIM-driven analytics to identify performance deviations, and 3) visualizations that enable root-cause assessments on performance deviations. The information requirements, and the challenges and opportunities for improvements in data collection, plan preparations, progress deviation analysis particularly under limited visibility, and transforming identified deviations into performance metrics to enable root-cause assessments are discussed using several real world case studies.***

Keywords: Construction Progress Monitoring, BIM, Photography, Point Clouds, Performance Metrics

I. INTRODUCTION

Detection, analysis, and communication of progress deviations are important onsite project management tasks for achieving smooth flow of production in construction. Accurate and timely delivery of progress monitoring analytics provide opportunities for project management to better understand the state of ongoing construction tasks, facilitate discussions in coordination meetings, and lead to enhanced situational awareness for all project participants.

To achieve instantaneous project controls, research over the past decade has focused on leveraging a wide range of information and communication technologies. Among various modalities of sensing, capturing digital images and videos with smartphones, point-and-shoot cameras, and Unmanned Aerial Vehicles (UAVs) have gained significant popularity. The low cost associated with collecting images and videos and their ease of use has led to the application of such detailed and reliable data in a variety of tasks including monitoring progress, quality, safety, and also productivity. In particular, the spatial and temporal density of these large-scale site image collections and the availability of 4D Building Information Models (BIM) have provided a unique opportunity for BIM-driven visual analytics that can quickly and easily detect, visualize, and communicate construction progress deviations. Han and Golparvar-Fard [1] proposes a BIM-driven visual analytics method for operation-level monitoring of construction progress. The resulting integrated project models which contain 4D BIM (representing expected progress) and images and 3D point clouds (representing actual progress), together with progress analytics have potential to support short-term planning and daily task executions. They can also bridge the information gaps between field reporting and the analytics necessary for managing work commitments and devising look-ahead schedules during weekly work

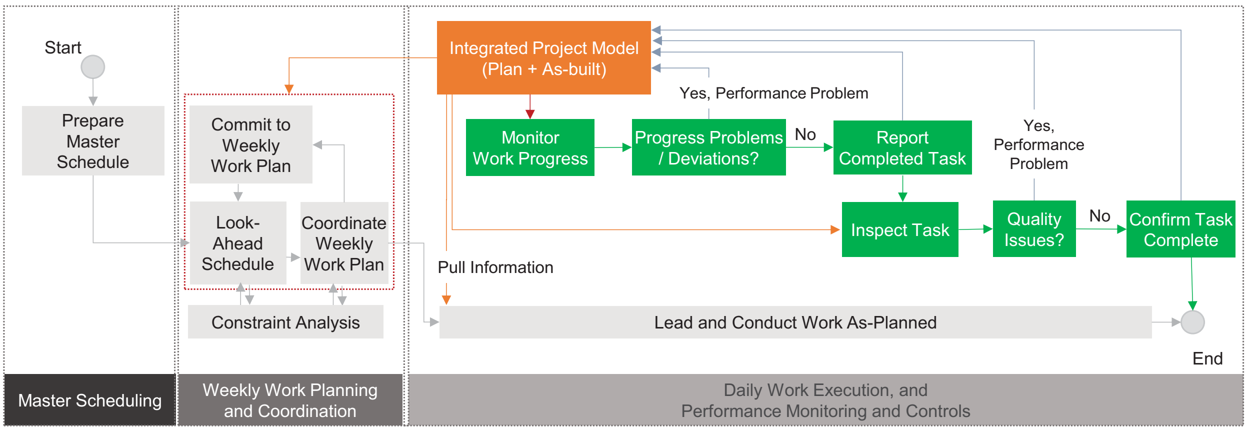

Fig. 1. Integrated project control model support [2].

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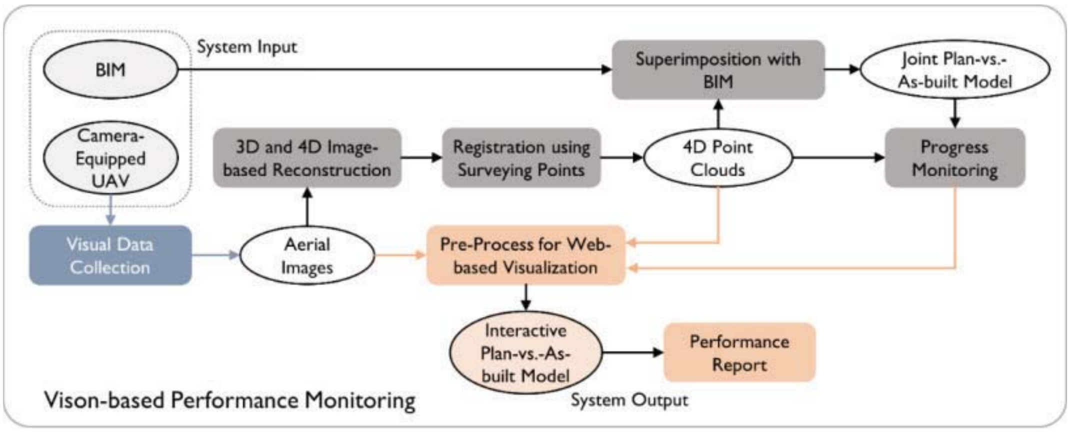

Fig. 2. Model-driven progress monitoring system [2].

planning and coordination meetings. Figure 1 illustrates an example work flow from Han et al. [2] on how the resulting integrated project control models via BIM-driven visual analytics can support weekly work planning and coordination, task execution, monitoring work-in-progress, quality inspection, and documentation of task completion. Figure 2 illustrates Han and Golparvar-Fard [1]'s work procedure for model-driven construction progress monitoring. Here, camera-equipped UAVs are used as an example of how visual data can be collected.

By frequently capturing project status information, translating them into visual as-built models, and contrasting them with 4D BIM, these integrated project models serve a rich basis for instantaneous project controls. To better leverage their potential, the following presents discussions on the information requirements on each aspect of 1) capturing, transferring, and storing images; 2) BIM-driven analytics to identify performance deviations, and 3) visualizations that enable root-cause assessments on performance deviations. Particularly the challenges and opportunities for improvements in data collection, plan preparations, progress deviation analysis, and transforming identified deviations into performance metrics to enable root-cause assessments are also discussed using several real world case studies.

II. Types of Information Required

A. *Visual Data and 4D BIM*

To access progress deviations both expected and actual progress models are needed. 4D BIM — if coordinated and updated on a weekly basis — can serve as the expected progress model. For documenting and modeling as-built progress, any visual data that generates as-built 3D point clouds can be used. Close-range images captured via point-and-shoot and smartphone cameras and also images taken via camera-equipped UAVs can be used as input to image-based 3D reconstruction methods to produce 3D and 4D as-built point cloud models. To do so, images should have sufficient visual and spatial overlaps to completely capture the onsite construction operations. These image however do not necessarily need to be in form of an ordered set. Figure 3 shows snapshots of three point clouds that were generated using overlapping images taken via a camera-equipped UAV. It also shows an integrated project model that is formed via superimposing point cloud with BIM. To streamline the data collection process, the UAVs flew autonomously using GPS through a pre-determined path.

B. *Site Information for Model Registration*

A 3D point cloud generated using images is up-to-scale. It needs to be scaled and registered with a BIM to be transformed into the real world coordinate system. For registering the point cloud, at least three corresponding points should be selected to perform similarity

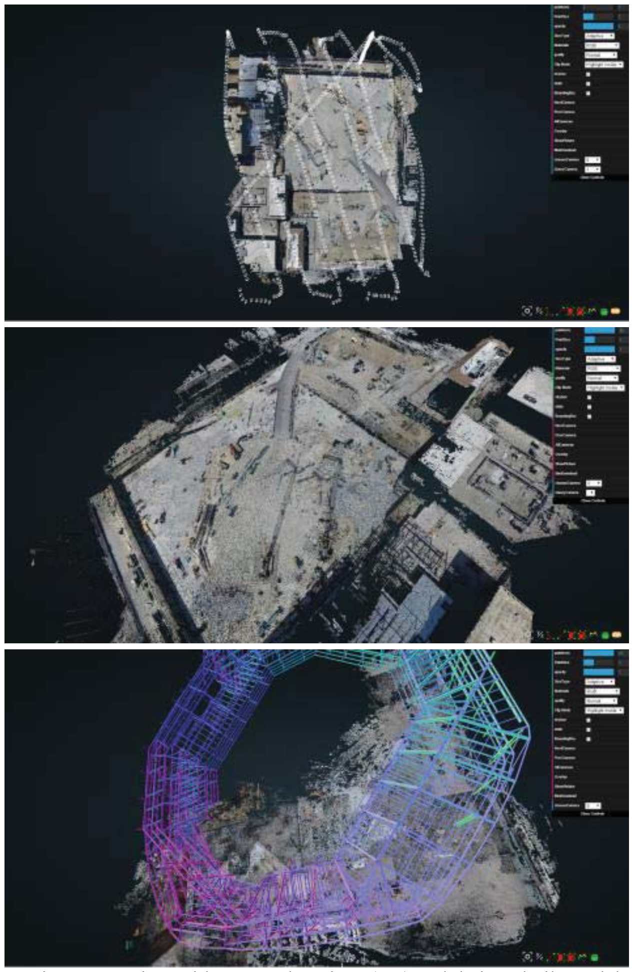

Fig. 3. Top view with camera locations (top) and their as-built model (bottom)

Fig. 4. An image registered with a BIM by BIM-assisted SfM.

transformation on the point cloud. If the BIM is in the site coordinate system, having pre-surveyed geo-targets on site can be utilized. It allows easier and more consistent selection of correspondences for the registration throughout the project and also leaves a possibility to implement automated registration process through automatic detection of those geo-targets from images.

Karsch et al. [3] proposes BIM-assisted SfM that takes advantage of BIM as *a priori* geometric knowledge and allows users' input prior to 3D reconstruction. A user selects correspondences from an image and BIM. These selected points (now in the real world coordinates from the BIM) guides 3D reconstruction (SfM) process. Figure 4 shows an image and BIM registration used as an initial step of BIM-assisted SfM. The blue crosses indicate the correspondences.

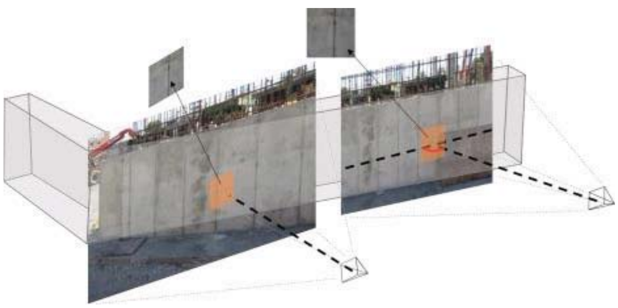

Fig. 5. Illustration of viewpoints normal to the desired plane for the enhanced appearance-based progress monitoring method.

C. *Data Analytics*

To analyze deviations in integrated project models and infer progress information at the operation-level, a method is needed to analyze the appearance of project elements. This can be done via back-projecting BIM elements in geo-registered site images, recognizing construction materials in these back-projections, and inferring the most updated progress status via the observed material.

To achieve reasonable performance, BIM with high level-of-development (LoD) (i.e. LOD>400) and detailed work breakdown schedule depicting daily operations are needed. A large library of construction material images is also needed to support recognition of a wide range of construction materials under different lighting condition, pose, and scales. Here, creating canonical views can enhance appearance-based material classification. This can be done by transforming each image or image patch corresponding to an element in BIM into a frontal view and comparing it against a discriminative classifier that is also trained for canonical views. This can dramatically reduce the amount of labor required for preparing the training data for comprehensive appearance-based recognition methods. Figure 5 illustrates how canonical view can provide the desired plane for the enhanced performance.

C. *Visualization and Information Communication*

To support both onsite and offsite personnel with most updated project information, a ubiquitous visual aid is vital. One possible solution is to use a web-based visual

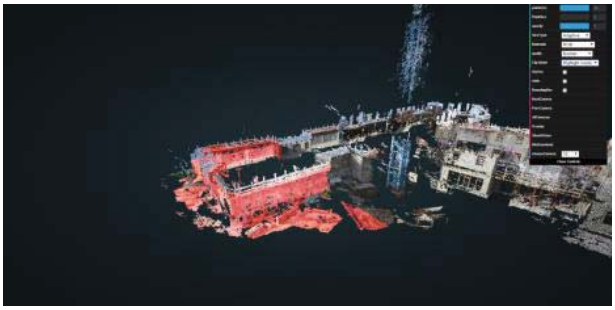

Fig. 6. Color coding an element of as-built model for supporting communication at coordination meetings.

representation that can be accessed via commodity smartphones and tablets. Using these platforms, field personnel can upload images and project information onsite and they also use the same platform to access integrated project models. Figure 3 presents such web-based interface using BIMserver [4], viewing platform by Scheiblauer and Wimmer [5], and WebGL. This web interface is an interactive tool that displays as-built point clouds with 4D BIM and allows quick and easy ways to analyze and communicate about the project information. Figure 6 presents how color coding part of an as-built point cloud that corresponds to an element of a BIM can help communication state of progress on ongoing construction operations. It can be used as a visualization feature that shows the status of work-in-progress element and its relative progress and location compared to other elements, facilitating and allowing effective communication during a coordination meeting.

D. Visualization and Information Communication

With integrated project models, an analysis on construction progress using any performance metrics (e.g., earned value analysis (EVA), percentage plan complete (PPC)) and visualization of performance deviations is possible. Moreover, with help of methods for operation-level monitoring of work in progress, task-oriented metrics such as task maturity [6], task anticipated (TA) and task-made-ready (TMR) [7] can be measured and provided as feedback to project participants. Such metrics require frequent observation of the project status and the model-driven progress monitoring can provide such frequency. Hence, integrated project models with detailed progress analytics can communicate performance metrics measured both at project and task levels.

III. Integrate Project Model

The integrated project model that embraces the abovementioned components (visual data collection, visual analysis, visualization of progress through up-to-date as-built model + as-planned BIM, and progress analysis) can serve as a project planning and control tool that supports the entire project team – from downstream to the project management.

As seen in Figure 1, the workflow of the integrated project model is as follows: 1) the entire project team, especially field personnel and project engineers, take hundreds of photos at a construction site. Together with aerial images are uploaded to the cloud; 2) as-built models (3D point clouds from 3D reconstruction) are generated. There models are superimposed with 4D BIMs; 3) vision-based analytics such as the appearance-based method of Han and Golparvar-Fard [1] detects the state of progress; 4) this monitored progress is constantly updated and visualized as the integrated project model that further presents analyzed progress to support short-term planning and coordination meetings.

Since this is a web-based project model, it can also support field reporting and pulling information and tasks such as field inspection to be performed. This model is frequently updated. It can facilitate information flow and allows work tracking of operation-level tasks, enhancing situational awareness, supporting identification and removal of constraints before work assignments, and finally allowing continuous flow of production.

V. Conclusion

This paper presented a BIM-driven method for tracking construction progress. Several key steps of 1) capturing, transferring, and storing images; 2) BIM-driven analytics to identify performance deviations, and 3) visualizations that enable root-cause assessments on performance deviations were presented. The application of the resulting integrated project models for supporting short-term planning, daily field reporting, and enhanced situational awareness for all project participated were discussed as well. The future work will focus on enhancing each step of the method and also validating them in the context of real world case studies.

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References

[1] K. Han and M. Golparvar-Fard, “Appearance-based Material Classification for Monitoring of Operation-Level Construction Progress Using 4D BIM and Site Photologs,” *Autom. Constr.*, vol. 53, no. 0, pp. 44–57, 2015.

[2] K. Han, J. Lin, and M. Golparvar- Fard, “A Formalism for Utilization of Autonomous Vision-Based Systems and Integrated Project Models for Construction Progress Monitoring,” in *Proceedings of the 2015 Conference on Autonomous and Robotic Construction of Infrastructure*, 2015.

[3] K. Karsch, M. Golparvar-Fard, and D. Forsyth, “ConstructAide: analyzing and visualizing construction sites through photographs and building models,” *ACM Trans. Graph.*, vol. 33, no. 6, p. 176, 2014.

[4] J. Beetz, L. van Berlo, R. de Laat, and P. van den Helm, “bimserver. org–An Open Source IFC Model Server,” in *bimserver. org–An Open Source IFC Model Server*, 2010.

[5] C. Scheiblauer, N. Zimmermann, and M. Wimmer, “Workflow for Creating and Rendering Huge Point Models,” in *Fundamentals of Virtual Archaeology: Theory and Practice*, A K Peters/CRC Press, 2015.

[6] R. Sacks, R. Barak, B. Belaciano, U. Gurevich, and E. Pikas, “Kanbim workflow management system: Prototype implementation and field testing,” *Lean Constr. J.*, vol. 9, no. 1, pp. 19–34, 2013.

[7] F. R. Hamzeh, I. Saab, I. D. Tommelein, and G. Ballard, “Understanding the role of ‘tasks anticipated’ in lookahead planning through simulation,” *Autom. Constr.*, vol. 49, Part A, no. 0, pp. 18–26, 2015.