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Potential of big visual data and building information modeling for construction performance analytics: An exploratory study

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ABSTRACT

The ever increasing volume of visual data due to recent advances in smart devices and camera-equipped platforms provides an unprecedented opportunity to visually capture actual status of construction sites at a fraction of cost compared to other alternatives methods. Most efforts on documenting as-built status, however, stay at collecting visual data and updating BIM. Hundreds of images and videos are captured but most of them soon become useless without properly being localized with plan document and time. To take full advantage of visual data for construction performance analytics, three aspects (reliability, relevance, and speed) of capturing, analyzing, and reporting visual data are critical. This paper 1) investigates current strategies for leveraging emerging big visual data and BIM in construction performance monitoring from these three aspects, 2) characterizes gaps in knowledge via case studies and structures a road map for research in visual sensing and analytics.

1. Introduction

Various applications of camera networks on construction sites have received increasing attention in recent years. Some of the applications include progress tracking, safety monitoring, site security, and as-built documentation. Other recent developments are the diffusion of consumer commodity devices with built-in cameras, such as smart phones, tablets, wearables, and camera-equipped unmanned ground/aerial vehicles (denoted as UGV and UAV). These camera-equipped platforms have led to an exponential growth in the volume of images and videos that are being recorded on construction sites on a daily basis. To streamline the process of collecting images and videos, professional photography has also received significant attention. According to one of the popular construction documentation service providers, about 325,000 images are taken by professional photographers, 95,400 images by webcams, and 2000 images by construction project team members at a typical commercial building project (∼750,000 sf) [1]. These are more than 400,000 images in total. The number can be much higher with the use of UGV and UAV for capturing images. The ever increasing volume of digital images provides an unprecedented opportunity to visually capture actual status of construction sites at a fraction of cost compared to other alternatives such as laser scanning.

In the meantime, *n*th -dimensional (nD) Building Information Modeling (BIM) (i.e. 3D models enriched with performance information such as time, cost, safety, and productivity) has received a certain level of maturity. As BIM has advanced, enhanced 3D visualization with semantic building information at jobsites improved communication and coordination. The applications include design development, construction coordination, and planning and the value-added by BIM are well documented. For example, Lu et al. [2] report 6.92% cost saving by using BIM even after accounting for the added efforts during the design phase. Similarly, Staub-French and Khanzode [3] report 25–30 % productivity improvement through BIM-driven coordination and constructability reviews that identified most design conflicts prior to construction.

Most efforts on documenting as-built status stay at collecting visual data and updating BIM. Hundreds of images and videos are captured during construction but most of them soon become useless without properly being localized with plan document and time. There is a need for a mechanism that would localize a vast amount of visual data with respect to BIM so they can provide useful as-built status with accurate location. There is a need for a visual sensing mechanism that would automate information flow at a high frequency for capturing changes continuously, which requires more

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visual data to “infill” the gaps/disconnection among images and videos.

With the problems discussed above, what the AEC industry needs to solve using big visual data are: 1) data collection and analytics — visual data captured at a high rate of frequency and its analytics that provide insights on project controls; 2) reporting — effectively capturing and reporting issues found on construction sites; and 3) communication — efficient and effective flow of information within a construction site and site-to-office.

In principal, as-built documentation (images and videos) and nD BIM provide good opportunities for sensing, analysis, and communication of construction performance among project teams [4]. As-planned (e.g., nD BIM) and as-built (e.g., images, videos, and 3D point clouds) documents/models combined can support daily work execution and short-term planning (see Fig. 1). The workflow shown in Fig. 1 has an ongoing loop between the short-term planning and daily project controls. What have not been fully investigated by researchers are 1) dealing with images and videos that are not localized with respect to BIM automatically or with minimal input from a user (see Fig. 2) and 2) dealing with a large amount of visual data that accumulates over time. This paper aims to tackle these challenges and provide a roadmap for using big visual data that is well-suited for construction performance monitoring applications.

The main challenges associated with localization of images with respect to BIM include 1) directly aligning images to BIM, 2) aligning via reconstructing a 3D point cloud from image collections, and 3) enhancing alignment using BIM as a constraint to improve 3D reconstruction. This paper also investigates the potential of using the resulting integrated information model to visually identify location and orientation of a user in 3D and provide information query and content authoring capabilities (see Fig. 1). Finally, techniques for comparison of the images and/or the produced point clouds vs. BIM are investigated. Using a large pool of case studies and datasets collected, the underlying technical problems and perceived opportunities in the three areas above are thoroughly explored. In each case, the capturing, analyzing, and reporting the visual performance data are investigated from the following three perspectives:

1. Reliability — accuracy and completeness of the collected data. *2. Relevance* — usefulness to short-term planning (e.g. three-week lookahead plans). *3. Speed* — collecting, analyzing, and reporting at a pace that enables decision making in coordination meetings.

In summary, the contributions of this exploratory study are: 1) investigating current strategies for leveraging emerging big visual data and BIM in construction performance monitoring; and 2) characterizing gaps in knowledge via case studies and structuring a road map for research in visual sensing and analytics.

2. Defining big visual data for construction performance monitoring

According to National Consortium for Data Science in 2012, “big data” or massive data collections is historically transforming every sector of the society — business, science, medicine, and government [5]. Big data is a broad term with multiple definitions but there are common characteristics. Most commonly used characteristics that define big data are volume, variety, and velocity or 3 V model [6]. There are other emerging “Vs” that are defined by different data scientists, such as veracity and variability [6–8]. Veracity is not directly applicable to visual data because visual data capture as-is conditions. They capture scenes and objects how they appear to be. They can certain have bad qualities (i.e., blurriness) and misinterpretations but they still present *as-is* conditions. Text and words can have varying meanings and change their meanings as time evolves [8]. These characteristics of variability, however, are not applicable to visual data because the contents (what is captured in pixels) do not change. Again interpretation of an object captured might change but not the values of pixels representing the object. The pixels representing an object form features that are used for visual data analytics. In addition, big visual data have to be characterized differently because the use of database is not directly applicable for detecting meaningful patterns out of visual data. The only way to place visual data in form of tables is to put attributes of exchangeable image file (EXIF) tags or place analyzed data (already processed). There is no existing database solution that can capture and provide meaningful real-time querying of raw visual data at the best of the authors' knowledge.

The 3 V model, however, is still applicable for characterizing big visual data. Volume can characterize visual data for each construction project because of the large volume of visual data accumulated over the duration of construction. Visual data collected during daily execution (see Fig. 1) can be in a scale of terabytes (refer to case studies in the following section). For a company to manage hundreds of their projects, the volume of their visual data can grow to petabytes. Variety also characterizes big visual data because they come in various formats. For instance, there are images and videos with different formats. Different types of camera lens require different processing (i.e., fish lens requiring careful calibration to remove radial distortion). Lastly, velocity can characterize visual data because of continuously accumulated images throughout construction. All project participants – owners, general contractors, and subcontractors – capture visual data every day for multiple purposes.

In addition to the 3 V model, what can characterize big visual data for construction performance monitoring is incremental time instances. To monitor construction performance, a gradual change

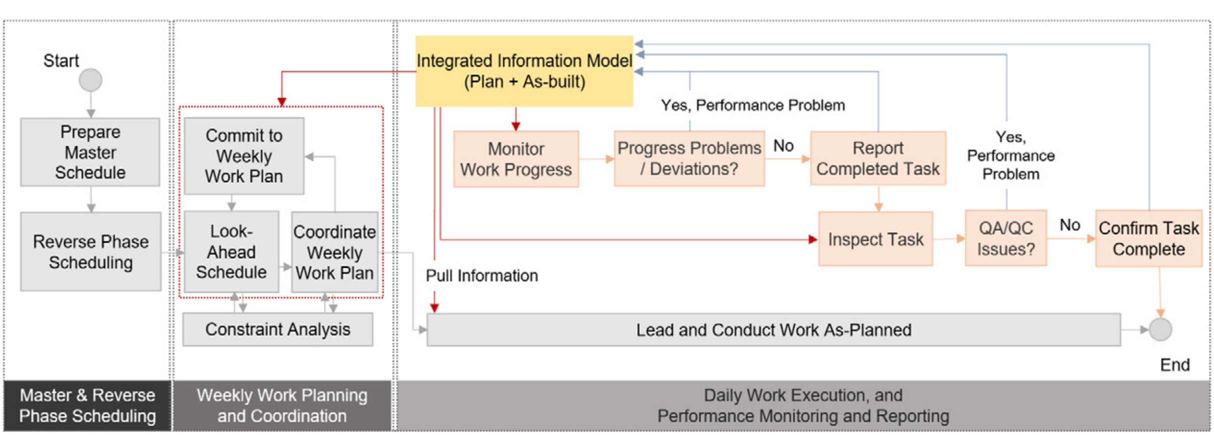

Fig. 1. The Integrated Project Model for supporting short-term planning and daily execution and reporting. Adapted from Ref. [4].