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Real time progress management: Re-engineering processes for cloud-based BIM in construction

Jane Matthews [a], Peter E.D. Love [b,*], Sam Heinemann [a], Robert Chandler [c], Chris Rumsey [c], Oluwole Olatunj [a]

[a] Department of Construction Management, Curtin University, GPO Box U1985, Perth, WA 6845, Australia
[b] Department of Civil Engineering, Curtin University, GPO Box U1985, Perth, WA 6845, Australia
[c] Aquenta Consulting, 8/197 St Georges Terrace, Perth, WA 6000, Australia

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ABSTRACT

Having timely access to information on the performance of a construction project enables the design team and contractor to improve their decision-making so as to ensure project deliverables are met. This paper examines the effectiveness of cloud-based BIM for real-time delivery of information to support progress monitoring and management of the construction of a reinforced concrete (RC) structure using action based research. To undertake this task, existing paper-based processes were re-engineered to accommodate the use of cloud-based BIM during construction. The design and implementation of a real-time object oriented bi-directional system, allowed information (e.g., the status of the 'As-Built' schedule) to be captured on-site and synchronized with a federated BIM. As a result of adopting cloud-based technology during construction, a new object oriented workflow and processes for progress management are proposed.

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1. Introduction

Construction projects are information intensive. Having access to accurate information at the correct time and in the precise place is pivotal for decision-making and ensuring a project is delivered in accordance with pre-defined parameters that have been established at its onset [26]. The ability to provide a contractor with the information needed to enable construction to be carried out as required, efficiently and without hindrance is a fundamental trait of good quality documentation. Rarely, however, is design and engineering documentation (i.e. two-dimensional (2D) drawings and specifications) produced with all the necessary information required for construction. Thus, there is a proclivity for contractors to be supplied with incomplete, conflicting and erroneous documents [48]. The provision of inadequate information during construction has been consistently identified as a factor that has contributed to poor productivity and rework, which in turn contributes to schedule and cost overruns being incurred, and disputes (e.g., [1,2,8,29,33,48]).

In addressing the inherent problems associated with traditional 2D drawings, building information modeling (BIM) has emerged as a process to ameliorate the generation, and management of information during the design process. Definitions of BIM are abounding, but it is essentially "a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition" (US National BIM Standard [54]). A BIM enables design information to be made explicit, so that its intent and program can be instantly understood and evaluated [40]. As a shared knowledge resource, BIM can reduce the need for re-gathering or re-formatting information [19]. This can result in an increase in the speed and accuracy of transmitted information, reduction of costs associated with a lack of interoperability, automation of checking and analysis, and the support of operation and maintenance activities [19]. However, a BIM developed to detailed design is often not up-dated once construction commences. Primarily, this is due to contractors and their subcontractors being reluctant to change their paper workflows to accommodate the necessary updates to produce an 'As Built' BIM [4,49].

Updating a BIM as construction progresses can enable the design team and contractor to monitor actual against planned performance in real-time [49]. As a result strategies can be developed to improve workflows and mitigate rework and delays. In addressing this issue, the effectiveness of cloud-based BIM for real-time progress management for a reinforced concrete (RC) structure is examined using a case study. To undertake this task, existing paper-based processes were re-engineered to accommodate the use of cloud-based BIM during construction. The design and implementation of a real-time object oriented bi-directional system, allowed information (e.g., the status of the 'As-Built' schedule) to be captured on-site and synchronized with a federated BIM. As a result of adopting cloud-based technology during

* Corresponding author.
E-mail address: plove@iinet.net.au (P.E.D. Love).

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construction, a new object oriented workflow and processes for progress management are proposed.

2. Real-time progress monitoring

A number of studies have suggested that the introduction of mobile technology such as tablet personal computers (PCs), smart phones and personal digital assistants (PDAs) can improve the ability to capture real time information on-site [6,7] [12,13,24,39]. Evidence of this can be seen with the use of smart phone applications, such as ‘Construction Progress Control’ (CPC), which have been developed to monitor a project's construction program [17]. The CPC application imports a construction schedule *via* a Microsoft® Excel spreadsheet. Site personnel can then add a percentage complete status for each task in the construction program, using a smart phone, so as to enable an ‘As-Built’ schedule update. Similarly, Tserng et al. [49] developed a system called Construction BIM-assisted Schedule Management (ConBIM-SM) which enhanced the visualization of an updated ‘As-Built’ schedule in real-time, although this was PC-based, and used on site *via* a notebook PC. Tserng et al. [49] made no attempt to re-design workflows to accommodate the use of ConBIM-SM, which may have contributed to eschewing the technology's acceptance by end-users, with it being perceived to be cumbersome to use, with more time spent using ConBIM-SM than on the traditional system. It is imperative that existing processes are not simply automated when technology is introduced to construction projects otherwise performance improvements will be marginal or even negligible [27,30].

Many studies akin to Tserng et al. [49] have suggested that BIM can be effectively used for on-site reporting and progress monitoring (e.g., [12,15,16,18,22,50,53]). Davis and Harty [12] revealed that a contractor openly embraced a system called ‘Site BIM’ through the use of tablet PCs, which were used to access “design information and to capture work quality and progress data on-site” (p.15). Davis and Harty [12] observed that the system was judged to be successful though no formalized plan was put in place for its adoption. Instead ‘Site BIM’ was delivered and developed through an emergent development process of informal prototyping whereby skills were adopted into the construction project through personal relationships and arrangements rather than formal processes [12]. Consequently, ‘Site BIM’ was viewed as being simply “a tool to support and partly automate existing processes and practices, rather than transforming them by, say, making site investigations less necessary” [12]. This observation remains an on-going leitmotiv of technology adoption during construction, particularly in the case of tracking technologies such as Radio Frequency Identification (RFID) and barcoding.

Technologies such as RFID/Laser Tagging [14,44], Time Lapse Camera's [18] and Augmented Reality (AR) [50] have been integrated with BIM, though with limited effectiveness and efficiency gains demonstrated. Noteworthy, RFID, Laser Tagging and bar coding have been extensively utilized in the field to track the delivery of plant and equipment for progress and quality purposes [21,34]. For the purposes of inventory management, technologies such as RFID and barcoding have significant benefits. However, in terms of real-time monitoring and integration with a BIM, the benefits are limited to identifying an object or piece of equipment that has been installed or brought on-site using hand-held scanners, which can then be used to update the BIM [14]. Yet such objects and equipment still need to be inspected to ensure that they conform to their desired specification and require assurances that they have been installed correctly.

There has been limited empirical based research that has been able to adequately quantify the espoused productivity benefits of RFID and barcoding technologies for construction. As noted above, the issue here is not that technologies are unable to provide productivity improvements, but for contractors to re-engineer their processes to accommodate them within existing methods of project delivery. A contractor's ability to proffer alternative or innovative process and technological solutions is often constrained by the delivery strategy that is adopted (i.e. lack of involvement during the design process). Furthermore, cost, schedule, quality constraints are invariably imposed upon them prior to their involvement within a project (Love et al. [55]). Contrastingly, when collaborative forms of project delivery strategy (e.g., Design and Construct (D&C) with early contractor involvement) are used, contractors are better positioned strategically to embrace process and technological innovation during design and construction [25,28,32].

Time lapse photography and videos in relation to BIM have been used to superimpose an as-planned BIM 4D model onto the ‘As-Built’ image (e.g., [18]). According to Golparvar-Ford et al. [18] deviations from the planned and actual schedule can be identified relatively easily as the BIM is subsequently fused into the reconstructed scene by a control based registration-step and is traversed and labeled for expected progress visibility. A machine learning scheme based upon a Bayesian model can be used to automatically detect physical components that are occluded and thus demonstrate that component-based tracking at schedule activity level can be fully automated. The resulting 4D Augmented Reality (4DAR) model enables the ‘As-Planned’ and ‘As-Built’ models to be jointly explored with an interactive, image-based 3D viewer where deviations are automatically color-coded within the BIM. The 4D AR model challenges the traditional progress monitoring practice and enables practitioners to conduct various decision-enabling tasks in a virtual environment rather than the real world where it is time consuming and costly.

The research undertaken by Golparvar-Ford et al. [18] has provided a fundamental platform for examining how AR can be used on-site, but the proposed system does not have any real time attributes. Moreover the system is dependent upon ‘static’ photographs and overly reliant on the use of Earned Value Analysis (EVA) as its form of cost reporting mechanism. Essentially, EVA is a methodology to measure and communicate the real physical progress of a project and to integrate scope, time and cost management. While the advantages of using EVA have been widely espoused (e.g., [3]), its application to construction remains limited, as this methodology assumes that “one earned hour is as good as another, and the correlative supposition is that the productivity of each type of work activity is independent of the performance of other work activities, even when they are in a predecessors-successor network” ([23]:p.2).

The potential for BIM-based AR to monitor the process of construction was investigated by Meza et al. [37]. The development of their mobile BIM-based AR system required a considerable amount of coding, and the integration of time (e.g., to monitor schedule) with the 3D geometry was identified by Meza et al. [37] as an arduous and time-consuming task as every single element in the model had to be associated with exactly one operation in the schedule. In addition, problems associated with the transfer of information between platforms, particularly when considered in the iterative context of a construction project, currently limit the benefits of such a system. Despite such limitations, the research of Meza et al. [37] has provided a pathway to explore how processes can be better designed to improve the flow of information and enable the management of time (4D) and cost (5D) through BIM in real-time.

2.1. Cloud-based BIM/collaboration

Cloud-based computing provides ubiquitous, on-demand access to a shared pool of configurable computing resources (e.g. networks, servers, applications, devices and data) that can be quickly accessed and discharged with minimal management or service provider interaction [35]. Thus, cloud-based computing has enabled real-time collaboration and provided project teams with the ability to extend BIM from design to construction [42,43]. Several theoretical frameworks and deployment models have been promulgated and have provided the basis for exploring how cloud-based BIM could be implemented

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