Integrating mobile Building Information Modelling and Augmented Reality systems: An experimental study

Michael Chu[a], Jane Matthews[a], Peter E.D. Love[b],*

[a] VDC Cooperative, Department of Construction Management, Curtin University, GPO Box U1987, Perth, Western Australia 6845, Australia
[b] Department of Civil Engineering, Curtin University, GPO Box U1987, Perth, Western Australia 6845, Australia

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ABSTRACT

The benefits of Building Information Modelling (BIM) have typically been tied to its capability to support information structuring and exchange through the centralization of information. Its increasing adoption and the associated ease of data acquisition has created information intensive work environments, which can result in information overload and thus negatively impact workers task efficiency during construction. Augmented Reality (AR) has been proposed as a mechanism to enhance the process of information extraction from building information models to improve the efficiency and effectiveness of workers' tasks. Yet, there is limited research that has evaluated the effectiveness and usability of AR in this domain. This research aims to address this gap and evaluate the effectiveness of BIM and AR system integration to enhance task efficiency through improving the information retrieval process during construction. To achieve this, a design science research approach was adopted that enabled the development and performance of a mobile BIM AR system (artefact) with cloud-based storage capabilities to be tested and evaluated using a portable desktop experiment. A total of 20 participants compared existing manual information retrieval methods (control group), with information retrieval through the artefact (non-control group). The results revealed that the participants using the artefact were approximately 50% faster in completing their experiment tasks, and committed less errors, when compared to the control group. This research demonstrates that a minor modification to existing information formats (2D plans) with the inclusion of Quick Response markers can significantly improve the information retrieval process and that BIM and AR integration has the potential to enhance task efficiency.

1. Introduction

Low levels of task efficiency have been and remain a pervasive problem for the Australian construction industry. Instead of focusing on people, increasing emphasis has been placed on the use and development of technical-based solutions associated with information and communication technology (ICT), specifically Building Information Modelling (BIM) to deliver 'value' in construction (e.g., [1,2]). However, there is limited empirical evidence to substantiate claims that the use of BIM leads to increases in task efficiency; though, it should be acknowledged that pockets of research have demonstrated workflow improvements for precast and modular construction, scaffolding erection and safety within a BIM environment (e.g., [3,4]). If BIM is to deliver 'value' then structures and processes need to be re-engineered to accommodate new workflows that are engendered by implementing BIM [5–7]. For asset owners who are dependent on the use of a building information model for operations and maintenance their 'value proposition' will need to be amended to adapt to the changes that will be required to their intra and inter-organizational business processes [5,6].

While technology enabled systems such as BIM have their merits, the pace at which they are evolving and their capability to capture significant quantities of data, raises concerns as workers are confronted with too many information systems [8]. This can result in information overload, and negatively impact on task efficiency, with workers spending increasing amounts of time managing data on complex systems, rather than gaining the benefits [9,10]. Consequently, for systems such as BIM, that are dependent on the transfer of information through models, utilization is affected, as workers perceive less value in the system due to the increased effort required to retrieve information [11].

To improve the access and utilization of information, Augmented Reality (AR) has been identified as a technology that can be used to enhance the process of information extraction from building information models [12,13]. AR is an enhanced version of reality created by the use of technology to overlay digital information of an artefact when viewed through a device such as tablet or smartphone camera [14]. However, research demonstrating AR effectiveness or usability from a

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scientific perspective remains scant [14,15]. In addition, there is a distinct lack of developments that demonstrate 'proof-of-benefit' to construction tasks [13,15]. This is further compounded by difficulties associated with developing AR systems, as they tend to exist on non-standardized hardware and software, which has hindered their adoption by the construction industry [15]. According to Wang et al. [15] AR and BIM are complementary technologies, but their integration has tended to be examined and evaluated from a technical standpoint rather than examining their potential to enhance the performance of work tasks.

Researchers and practitioners within the construction industry rarely possess the knowledge base required to solve the prevailing issues that exist to effectively utilize AR technologies (e.g. software and hardware development). Consequently, Meža et al. [13] has suggested AR applications from disciplines such as gaming, media and marketing should be used as a source of innovation for construction. Against this contextual backdrop, the research presented in this paper utilizes a design science research approach to evaluate the effectiveness of BIM and AR system integration that is designed and developed to enhance efficiency through improving the information retrieval process during construction. By adapting existing AR development kits/tools that would typically be used for non-construction purposes, this research demonstrates the appropriateness of using pre-existing functionalities from commercially available AR software and hardware. In addition, the benefits for future researchers of leveraging performance capabilities from existing defined software applications are identified.

2. Digitization in construction

The last decade has seen significant improvements in the digitization (i.e. process of converting information into a digital format) of information in construction. The increased capabilities of new ICT systems to capture and manage information in projects, have, over time, created information intensive work environments. This has enabled construction personnel to gain near on-demand access to project data, plans, drawings, schedules and budgets [16]. Increased mobility due to technologies such as laptops, tablets and smart-phones, provides access to relevant and up-to-date digital building data whenever and wherever needed. As a result of BIM and the emergence of smart technologies, the construction industry is at the cusp of a transformative change [17]. To leverage the benefits of technology, such as BIM and AR however, an improved understanding of the information required by workers to carry out construction-related tasks is needed.

A BIM environment is supported by an array of interrelated databases in a central location, which can accrue and store data over time [18]. This centralized resource encourages collaboration between stakeholders, allowing them to exchange information, query, simulate and estimate activities throughout a project's life-cycle [19]. More often than not, however, BIM is simply perceived as a tool for visualizing design and coordinating construction activities on-site [20]. It has been suggested that the integration of BIM with on-site construction processes can provide an array of benefits such as: [8] improved co-ordination; [9] clarity in task requirements; and [10] a reduction in misunderstanding of project requirements [20,21]. This in turn translates to eliminating waste, minimizing transaction costs, as well as enhancing the transfer of shared knowledge and expertise among all parties in a project [22,23].

Taking advantage of the recent growth in cloud-computing capabilities, the construction industry has begun to shift toward the adoption of cloud-based BIM solutions such as Autodesk's BIM 360™ Glue® and Viewpoint™. The resulting ability to access information 'on-demand' has provided a platform for the digitization of information during the construction process. While there are many positive aspects to using cloud-based solutions, there is also concern that workers are being provided with by too many systems to effectively communicate and collaborate [8]. While many non-value adding activities can be automated, resulting in improved workflow performance [10], BIM enabled systems can complicate and overload processes with non-critical project information. This can have a negative impact on worker's performance and productivity, requiring them to spend more time manipulating or managing the data on complex systems, rather than reaping its potential benefits ([9,10]). Consequently, this can lead to a 'productivity paradox' being experienced [5,24].

For investments in BIM to be justified, optimal productivity of workers engaging with the technology must be attained with systems that are utilized by all stakeholders [10,25]. Existing barriers to collaboration and interoperability, need to be overcome, with an emphasis being placed on improving the ability to extract information effectively and efficiently from a building information model [26–28].

2.1. BIM utilization

The benefits of BIM have typically been tied to its capability to support object oriented information structuring and exchange through the centralization of information [18]. It has also been acknowledged that BIM has the potential to deliver benefits for facility and asset managers, who have traditionally been left with incomplete or obsolete documentation to support their activities, during operations and maintenance (e.g., [6,21]). Research has demonstrated that changes made during construction are rarely federated into a building information model for use later by construction and operations teams [11]. This results in a series of sub-models which do not represent what has actually been constructed, which stymies an asset manager's ability to effectively use them during operations and maintenance.

To develop an accurate federated model for handover to the operations team there needs to be collaboration between disciplines. Yet, Fazli et al. [26] revealed that organizational difficulties exist when justifying the initial cost and time requirements for training staff to work efficiently with BIM throughout a project's life-cycle. This has contributed to designers tending to perceive less value (i.e. gain/return on time and costs spent) in generating fully interoperable, federated models. This has been reinforced by Kerosuo et al. [11], who found that designers tended not to regard fully integrated models useful for their activities and often avoided the collaborative co-designing features of software. This has typically restricted the use of BIM to the design stages [20]. Even when models are transferred from the design to construction stage, site teams have tended to not to find them useful, instead preferring to use traditional 2D paper plans [11].

A shift from conventional standalone frameworks to cloud-based BIM systems to support full collaboration between stakeholders has been initiated [7]. While cloud-based BIM systems have paved the way for future offerings to support mobile workers access to a centralized database, they still tend be archival in nature and have yet to fully address issues associated with visualization [29]. To improve the effectiveness of BIM across an asset's life-cycle, integration with AR is required to enhance the extraction of building and product data that has been captured [13]. This creates a world whereby an AR user can interact with real-time augmentations of virtual information in their current environment that is contextual in nature and therefore enable improved decision-making [30,31].

2.2. Augmented reality

Information-intensive activities that rely on paper mediums for information retrieval such as those undertaken during construction are well suited to AR [32]. The contextual awareness of AR systems enhances the process of information retrieval by providing a mechanism to filter data, information and services, thereby removing redundant data and allowing the user to see only relevant information [16]. The feasibility of AR in augmenting construction related-tasks can be assessed using the following cognitive principles ([32]; p.316): [8] information searching and accessing; [9] attention allocation [10]