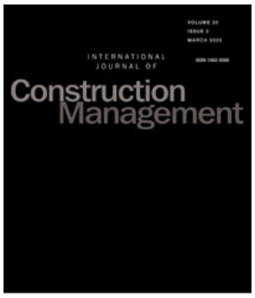

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Exploring the status, benefits, barriers and opportunities of using BIM for advancing prefabrication practice

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ABSTRACT
Building information modelling (BIM) has significantly influenced the construction industry. However, the existing BIM tools and frameworks within prefabricated buildings are minimal. This research study aims to identify the opportunities and barriers of integrating BIM in the Australian prefabrication industry. The research was carried out using a mixed method of literature review and questionnaire survey with 30 indudstry professionals. The literature review identified the key challenges associated with prefabricated buildings including construction discipline-specific, fabrication-specific issues and communication-specific issues. The survey results proved that the most significant BIM opportunities are minimizing design errors and discrepancy of final product model between designers and manufacturers and increasing mass customization. The study revealed that seamless and timely information exchange among key project stakeholders *via* a BIM system was identified as the most critical success factor to adopt BIM in the prefabrication industry. This research provides practical insights into how to utilize BIM effectively for prefabrication in the housing sector. The survey results document the opportunities and barriers to BIM integration and provide professional insights on how BIM can benefit the prefabrication. The study contributes to the body of knowledge on enhancing the productivity/practice of prefabrication through BIM integration within the Australian housing context.

KEYWORDS
BIM; prefabrication; housing; Australian construction industry; construction technology

Introduction

Prefabrication is a growing new technology in the architecture, engineering and construction industry (AEC) (WEF 2016). According to McGraw Hill Construction report (2011), the practice of prefabrication has increased by more than 50% from 2006 to 2011. According to Schesinger (2014), prefabrication has a share of 3% of the overall construction industry in Australia at AUD 150 billion. The categories of prefabrication buildings can be divided into two major categories: two-dimensional (2D) or non-volumetric pre-assemblies (panel system), and three-dimensional (3D) volumetric pre-assemblies or modular systems (Blismas and Wakefield 2009; Mostafa et al. 2016). The panelized systems are assemblies that are often used as cladding wall (e.g. SIP), roof or floor building components, whereas 3D modular systems are volumetric assemblies which enclosed usable spaces and are fully factory finished units (e.g. bathroom pods and shower room) (Ramaji and Memari 2013).

These prefabrication categories have been adopted in delivering building projects in Australia. An example for prefabricated building projects in Australia is the Little Hero apartments building in Melbourne. The nine-story building (consisting of ground-level in-situ retail and eight levels of modular apartments) consists of 63 apartments. The building was designed and fabricated using Hickory's UB System which includes precast core and prefabricated apartment modules (each apartment was broken into of seven modules). The building was completed in an accelerated timeframe of nine months using synchronized on-site off-site construction program, which is about twice as fast as could be achieved with conventional construction methods. The Concorde South development is another successful project using prefabricated building technology in the residential

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building sector in Western Australia. The building with 108 modules were complexed to offer 77 modern architecturally designed apartments across the six stories for the building. The modules were 100% Australian designed and fabricated for completion within the factory and delivered to the site via a mix of road and sea transportation. The building was constructed on the site in just eight and a half days during May 2014 (Hickory 2017). These projects offer best practice for the actual implementation of prefabricated building systems for residential and commercial projects due to the need for high-quality production available in a controlled factory environment and reduced construction cost and schedule as well as reduced needs for skilled labour on the construction site.

The actual implementation of prefabrication renders 10% reduction of installation labour costs due to reduced congestion at the construction site and enhanced efficiency in assembly building components (Sullivan and Dye 2015). Researchers emphasized that prefabrication is capable of enhancing the overall project performance by coping with a compressed project schedule, unorganized site conditions and a shortage of skilled labour (Tam et al. 2007, 2006; Tam and Hao 2014). Furthermore, prefabrication has become a global scale strategy to minimize construction costs and maximize the return on investment (ROI) by improving design and construction processes in a construction project (Gil et al. 2005; Eastman and Sacks 2008). Consequently, prefabrication has been introduced to the Australian construction industry, as a general term, off-site manufacturing (OSM) to achieve better quality with fewer costs of a construction project (Manley et al. 2009; Mostafa et al. 2016; Tam et al. 2018).

Despite the identified benefits, the use of prefabrication is not widely practised in the Australian construction industry due to a lack of skilled personnel, a low level of technical knowledge and perceived value of prefabricated buildings (Manley et al. 2009; Azman et al. 2010). It could also be due to the difficulty of constructing and engineering multi stories prefabricated buildings with a high number of combining parts with site built components such as shear walls. The key challenges associated with multi-story modular buildings include: (a) construction discipline-specific issues such as complex structural design and mechanical/electrical/plumbing (MEP) system for the modules and the building; (b) fabrication-specific issues such as limitation and preferences at design phase; (c) product-specific issues including multifaceted interactions among modules, supporting structures, and façade components; (d) complicated site and logistics management; and (e) communication-specific issues such as the low collaboration level between multiple stakeholders through all stages of project, and lack of information exchange/integration basis and software tools to address these issues (McGraw Hill Construction 2011).

Research works have been conducted for investigating the potentials in overcoming these challenges by transferring and fitting successful technologies and processes that extensively adopted in other construction sectors. Blismas and Wakefield (2009) emphasized that effective and collective efforts to integrate information regarding design and construction should be coordinated and integrated from the outset of prefabrication for increasing its practical adoption. Johnsson and Meiling (2009) and Zavichi et al. (2010) highlighted the importance of timing to correct design errors and a defect-proofing process by asserting the needs of efficient information management process or an information management tool. Goulding et al. (2012) and Lu et al. (2012) suggested BIM as a computational technological advanced platform for exchanging and integrating building information across different stages of a prefabricated project. Recent research supports the arguments that BIM can be a solution for minimizing design and coordination errors, and a methodology for enhancing prefabrication processes (Dalton et al. 2013; Wynn et al. 2013; Arashpour et al. 2015; Ramji and Memari 2013). BIM can support the communication of information related to the prefabricated building product and its production related, and the overall project phases. Although the potentials and benefits of BIM adoption in the prefabrication industry are recognized, it is still slow in adopting BIM as approximately 50% of project stakeholders including architects, engineers and contractors are not using BIM in conjunction with prefabrication (McGraw Hill 2011). Furthermore, only 30% of construction professionals acknowledge that BIM has potentials to improve efficiency in the prefabrication industry. While research indicated that BIM is recognized either relevant or irrelevant for improving efficiency in the prefabrication industry, the fundamental reasons contributing the slow adoption and low perception of BIM in the prefabrication industry have not been fully identified. Therefore, this research is conducted to address these shortcomings by identifying the practical opportunities and barriers in BIM integration (as a process and technology capability) for improving productivity in the prefabrication industry within the Australian housing sector.

The implication of BIM in the prefabrication industry

In response to the current barriers in the prefabrication industry, BIM has been introduced as one of the alternatives for productivity improvement. In particular, BIM has been recognized as a potential solution to achieve efficient information integration between construction and manufacturing work locations. The reason is that BIM is an information management system that integrates and manages various construction information throughout the entire construction project and product life-cycle based on a 3D parametric design for facilitating effective communication among project stakeholders (Kim 2014). Indeed, BIM has been recognized as a methodology and technology to facilitate process improvement in the prefabrication/modular construction sector. It can enhance construction personnel's understanding of the design intent and provide additional accurate dimensional information and specifications of building material/components based on instant and timely feedback loop among stakeholders (Nawari 2012; Zhong and Huang 2015; Wu 2017). Researchers have identified that the integration of a BIM tool and prefabrication can render an improved visualization of building components, effective clash detection and additional accurate shop drawings at the early design stage of a construction project (Lu and Korman 2010; Nawari 2012). According to a case study of integrating BIM in a prefabrication project (total cost $44 million), a total cost saving of 1% ($220,000) was achieved by minimizing design and mechanical, electrical and plumbing (MEP) coordination errors at the early design stage (Lu and Korman 2010).

More importantly, managerial benefits have been recognized when BIM is adopted as a methodology for facilitating effective information exchange and decision making on any changes *via* effective communication among stakeholders (Mohsen et al. 2008; Alwisy et al. 2012). The identified managerial benefits were mainly associated with proactive design change management with reduced delays and reworks. In addition, having additional accurate dimensions of building components can enhance cost estimation and resource planning which, in turn, can minimize unnecessary waste of resources (Wu 2017). Neelamkavil (2009) asserted that BIM has the potential to automate the processes of fabrication and component assembly in the modular construction industry. In the current research of Eastman et al. (2010), BIM is identified as an information exchange platform for implementing automated processes for modular building projects, with further research studies having been conducted to confirm the potential of BIM in the precast concrete manufacturing industry. As a result, the capability of BIM to improve all project processes including design, fabrication and construction has been confirmed.

In alignment with the concept of BIM as an information flow management platform, there have been various efforts in developing BIM system or BIM framework for prefabrication construction to support stakeholders' informed decisions. Basbagill et al. (2013) and Crawley et al. (2008) argued the potential use of BIM as a methodology for improving current practice of housing construction. This is due to the fact that BIM is capable of enhancing collaboration and integration of project information among stakeholders by improving the overall information flow throughout a project life-cycle (Eastman et al. 2010; Wong and Fan 2013). In aligning with the potentials in BIM as a methodology, Kim and Park (2013) conducted a BIM feasibility study for housing refurbishment, and BIM was recognized as a feasible methodology when sufficient BIM datasets are available. Rysanek and Choudhary (2013) asserted that housing projects should utilize Information and Communication Technology (ICT) tools including BIM for supporting informed decision making among various design options, while considering multiple criteria such as the implication of cost and environmental impact.

In relation to this research arguing BIM as a decision making supporting tool, Park and Kim (2014) recognized that BIM is a capable tool to accommodate customers' preference for housing refurbishment regarding refurbishment material and options at the early design stage. A web-based BIM platform using building components' object library in a BIM system has been developed to facilitate stakeholders' timely decision making (Huang and Krawczyk 2007). Similarly, Dave et al. (2013) proposed a BIM object library as appropriate design decisions could be made, and additional accurate design information for prefabrication could be provided. In addition, an automated design process map based on an algorithm system has been proposed for selecting the most suitable designs for prefabrication (Alwisy et al. 2012). In a recent study aimed at integrating prefabrication in a BIM system for housing projects (Zhong and Huang 2015), a BIM platform has been used to facilitate informed decision making at the design phase. Thus, it is evident that BIM can be used as both a useful design management tool and as an information management methodology to integrate diverse construction information in the prefabrication industry.

The significance of BIM for prefabricated house building

Clients need high capital investment for purchasing a house, and the value for money is a vital aspect to be considered from the outset of the investment. Clients have become additionally diversified in their needs from a house, and the current high price of energy demands clients to make additional careful decisions regarding the trade-off between the capital costs and the level of energy efficiency of a house. For construction professionals to provide acceptable and affordable housing that is appealing to potential clients, it is critical to understand and accommodate their preferences from the outset of a construction project. Lomas (2010) emphasized that construction professionals should research and integrate technical and sociotechnical aspects (clients' design plan and preference) for a house to supply affordable homes. According to Burton (2012), clients usually would like to generate a design of a house by combining interior and exterior designs in which they are interested. Researchers assert the importance of potential clients' early involvement at the briefing stage of a housing project for house design decisions (Gupta and Chandiwala 2010). This early involvement would allow construction professionals to make informed decisions by understanding clients' requirements clearly from the outset of a project. Stevenson and Leaman (2010) also supported the early involvement of clients to improve customer satisfaction, and researchers specifically pointed out that the necessity of clients' direct involvement in a project life-cycle. Despite the importance of clients' preference, the current construction industry is limited in accommodating their needs and requirements from the outset of a construction project to improve clients' satisfaction (Gupta and Chandiwala 2010). Indeed, clients are limited in accessing required information to design their own houses, and eventually, a final design is generated by designers without sufficiently incorporating clients' needs into a design. To design a financially affordable and environmentally sustainable house, a sufficient level of information regarding clients' preferences such as design and technical specifications, clients' preferences and construction materials needs to be collated and integrated from the outset of a project. Researchers emphasized the importance of proper decision-making and the necessity of using appropriate ICT tools that support clients and construction professionals considering various alternatives at the early design phase (Crawley et al. 2008; Eastman et al. 2010) .

Researchers have applied a simulation approach for effective resource planning and scheduling in prefabrication for housing projects (Al-Bazi and Dawood 2012). However, the scope of the research is mainly focused on employee allocation rather than the integration of diverse construction information at the early design stage. Lu et al. (2012) suggested a model that is capable of considering cost and delivery time for the detailed operational processes to produce house components, and BIM has been utilized as a tool to create an information-enriched model that contains all the essential information for planning cost and delivery time. Greenwald (2013) explored further in BIM capability, and assert that BIM can be used as a visual aid tool to visualize and analyze the house design elements at the early design stage by incorporating clients' preferences. This argument is supported by other research that emphasizes the necessity of using visual simulation for effective and efficient management of on-site planning (Dalton et al. 2013; Rohani et al. 2013). Furthermore, Marshall et al. (2013) argued that simulation approach can be used for the coordination of various fabricated house elements including building fabrics, joinery finishing, plumbing fitting and installation of electrical components. All construction processes from foundations through to the provision of walls can be carefully planned and reviewed that is highly aligned with the time-phased clash detection and visualized construction scheduling capability of BIM as known as 4D BIM capability. Through the research, visual simulation is recommended as the essential aspect of enhancing productivity in prefabrication for housing projects, and it is evident that BIM has been recognized as a visual simulation tool and a data repository system for prefabrication. The main advantages of BIM are an effective mean to construct a building twice since building design and components can be built and reviewed digitally before actual construction, and eliminate inconsistency and discrepancy in design and prefabricated products while the design flexibility meets clients' demands. Indeed, simulation is capable of achieving 10% reduction in project completion time by assessing discrepancy in various designs for fabrication plans (Alvanchi et al. 2012). However, the fundamental reasons contributing slow adoption and low perception of BIM in the prefabrication industry have not been fully identified. Therefore, the research aims at shedding light on the fundamental causes of low perception and adoption of BIM in the prefabrication industry. Furthermore, the research reveals the perceived opportunities and benefits of BIM for improving productivity in the prefabrication industry through a questionnaire survey.

Research methodologies

This study aims to examine the opportunities and barriers of integrating BIM within the Australian prefabrication industry. To achieve this aim, the study employed mixed method approach that comprised of literature review and questionnaire survey. The study first undertook a review of related literature on prefabrication and BIM, which was reported in the previous sections. The literature review assists in establishing a stable-base on prefabrication and the implications of BIM in prefabrication. This facilitates the survey design. The questionnaire survey was conducted to obtain specific insights on the status of BIM adoption and BIM capabilities integration within Australian prefabrication industry. The survey questions adopt a 5-point Likert scale since it is the most popular method among researchers and easy to communicate with respondents (Knight and Ruddock 2008). The questionnaires were distributed through PrefabAUS, the professional affiliation of the OSM/prefabrication industry in Australia, for obtaining valid and relevant research findings. This research employs purposive sampling for obtaining individual responses from professionals specifically involved in integrating BIM in OSM practice across Australia.

The survey was circulated to 35 PrefabAUS members employed in a nationwide construction company who attempted to use BIM or get involved in a prefabrication project using BIM. Thirty members responded and completed the questionnaire (approximately 86% response rate). This response rate deemed adequate for data analysis as Akintoye and Fitzgerald (2000) argued that 20–30% response is the norm of the rate in a questionnaire survey of the construction industry. All respondents are in the managerial positions with average 10 years of experience in the prefabrication industry across Australia, and primary roles of respondents were comprised of consultants (60%), BIM managers (20%), managing directors (10%) and project managers (10%). Their participation within the prefabricated building project lifecycle is significant for planning and design, engineering and procurement, construction and building services stages. It was discovered from the respondents' organizations that the primary markets for prefabrication are educational facilities, office, retail and industrial facilities, healthcare facilities and commercial buildings. The questionnaire was comprised of 15 questions designed to explore the following three key aspects: (a) awareness and current uptake of BIM, (b) perceived advantages and barriers to BIM adoption and (c) potential advantages of BIM integration to the prefabrication industry. A pilot questionnaire survey was conducted before the main questionnaire survey to eliminate misleading questions, ambiguity and any difficulty in responding. A statistical analysis tool, IBM SPSS Statistics, was used to conduct a statistical analysis such as standard deviation, correlations and cross-tabulation analysis to render specific insights from the research findings.

Findings and discussions

Overview of the prefabrication practice in Australia

This section of the questionnaire aimed to identify information on the prefabrication business in the Australian context. This covers suppliers of prefabrication material or components, the location of prefabrication markets and fabrication facilities, and types of prefabrication components and housing. The respondents were asked to indicate the countries that supplied material to prefabrication industry. The majority of respondents (64.1%) highlighted that they procured their material locally. This is because the material and design of prefabricated buildings must meet the Australian specifications and standards and, in addition, that material must meet the Building Code of Australia (BCA). The second main material supplier was China (20.5%) as some of the prefabrication builders (mainly those who have facilities in Western Australia and the Australian Territories) adopt a hybrid model that involves China (for the supply of material and components) and Australia (for assembly and construction). The prefabrication units are produced in China, but in accordance with the Australian standard. Those builders used sea-based transportation to an Australian port in Western Australia where a factory is ready for inspection of the modules and to operate the mechanical, plumbing and electrical fit-off. The module units are then ready

Table 1. Responses to prefabrication types in Australia.

Prefabrication types	Responses N	Responses (%)	Cases (%)
Kits-of-parts (KOPs)	12	15.8	41.4
Structured insulated panels (SIPs)	16	21.1	55.2
Modules (3D)	24	31.6	82.8
Bathroom pods	15	19.7	51.7
MEP assemblies	6	7.9	20.7
Others	3	3.9	10.3
Total	76	100.0	262.1

to be transported to the construction site for assembly.

The respondents were asked to indicate their organization's prefabrication markets and the location of fabrication facilities across Australia. Most of the respondents (39%) indicated that the central market for their prefabrication building projects was NSW. These projects were to build education facilities (60%), health facilities (40%) and residential buildings (40%). These projects used prefabricated units or elements fabricated in offsite facilities in New South Wales (31%), Victoria (23%) and Queensland (19%). The respondents highlighted the types of prefabrication components used in their projects as detailed in Table 1.

As is evident from Table 1, 31.6% ($n = 24$) of the survey responses indicated they were using modules (3D volumetric units) in their prefabrication business. As also shown in Table 1, 21.1% ($n = 16$) of the survey responses highlighted that prefabrication panels (or panelized systems) were used in their buildings. Furthermore, bathroom pods were another type of prefabrication used (19.7%, $n = 15$). After identifying these types of prefabrication components, respondents were asked to specify the main residential market types as present in Table 2.

As shown in Table 2, twenty-three (34.3%) responses indicated that prefabrication was mainly used in building single-storey detached dwellings. Low-rise (2–3 storey semi-detached) was the second most common type of building in which prefabrication was utilized. The survey respondents were asked to specify the stages of a prefabricated building project from receiving the client order until completion. The respondents agreed on seven stages of prefabricating any building: sales and concept development, design and engineering, procurement, modules/components fabrication, site preparation and development, delivery and logistics and installation and lock-ups. The respondents then identified the importance of each prefabrication stage. They agreed that all OSM processes must happen and that these processes were equally crucial from a prefabrication perspective, delivering an efficient outcome. However, the majority of respondents ($N = 13$) indicated that design and engineering stage is an essential stage of prefabrication building projects. This is because this stage is partnered with other stages such as fabrication, procurement and installation. Another reason was that the clients are involved in the design and engineering stage. There are much design happening to win the job and how much need to be designed for other stages of the project. The design and engineering stage involves various resources including structural engineers, architects, CAD operators, external consultants and project managers.

Table 2. Responses to prefabricated residential building types.

Residential building type	Responses N	Responses %
Single-storey detached dwellings	23	34.3
Low-rise (2–3 storey semi-detached)	21	31.3
Medium-rise (3–6 storey apartments)	10	14.9
High-rise (>6-storey apartments)	9	13.9
Others	4	6
Total	67	100

BIM uptake within a prefabrication project

The previous section discussed the prefabrication stages and highlighted that design and engineering stage is the most significant for any prefabrication project outcome. Therefore, the questionnaire respondents were asked to indicate the utilization level of BIM that match their organization's business. The majority of the respondents (25%) indicated that their company had partial BIM integration in their prefabrication stages, while 75% highlighted that they had no BIM integration in their prefabrication stages. BIM was mainly applied at design and engineering stage of a prefabrication project. The reason was that BIM software capabilities were used to develop architecture, structural and MEP systems of the building. Additionally, BIM models were adequately used for clash detection during the design stage.

The survey participants were asked to specify BIM tools currently used in their organizations, and it has been revealed that 80% of respondents utilized Autodesk Revit Structural and MEP within design and engineering stage. Other respondents (20%) highlighted the usage of the BIM 360 Glue and Integrated Environmental Solution Virtual Environment (IES VE) for structural and architectural building component design. Respondents specifically emphasized the seamless data exchange and integration of design intend at

Table 3. Benefits of integrating BIM in prefabrication.

BIM benefits	*N*	Min	Max	Mean	Std. deviation
Early identification of long completion time	60%	1	4	1.4	1.04
Shortening the procurement schedule	60%	2	4	2.3	0.66
Exploring design constraints for fabricators	60%	1	3	1.1	0.47
Reduce differences between design and manufacturing models	60%	2	3	2.8	0.38
Reduce the fabrication cycle time	60%	1	3	1.2	0.54
Reduce the coordination errors	60%	1	3	1.2	0.51

Cycle time ($r = 0.809,\ p < .1$).

the early design stage for efficiently coping any changes before a design is finalized. Consequently, the BIM 360 Glue is identified as an information management platform, which is highly aligned with the implications of BIM in the prefabrication industry for better work and information management flow. Based on the identified BIM tools, it can be extrapolated that a broad level of knowledge on BIM fundamentals as a CAD software is presented in the prefabrication industry.

Benefits of integrating BIM in prefabrication

This study found some benefits of integrating BIM within prefabrication. The benefits indicated by the survey respondents are present in Table 3.

As shown in Table 3, the most vital benefit is the reduced differences in a final model between designers and manufacturers, and this benefit of BIM integration is highly relevant to overcome the current barriers identified in the literature. It can be regarded that all respondents come to an agreement that the benefit is realistic and achievable based on the small numeric value of standard deviation with 0.38. The second significant benefit is the shortening the procurement schedule as an integrated BIM system can facilitate design collaboration from the outset of a project, and any necessary changes or alterations on a model can be implemented before the actual manufacturing stage without compromising duration and quality of a project and a product. It should be noted that the two most important benefits stemmed from the BIM integration into the prefabrication industry are directly related to the seamless information exchange and practical collaboration based on better communication through a BIM tool or system.

To investigate further regarding the relationship between the benefits of BIM implementation, the Spearman's rho analysis has been used. As shown in Table 4, a very positive strong correlation is found between the early identification of long completion time, shortening procurement schedule ($r = 0.994,\ p < .01$) and reducing fabrication cycle time ($r = 0.847,\ p < .01$). Moreover, a strong correlation is presented among exploring design constraints, and reducing coordination errors ($r = 0.889,\ p < .01$) and reducing fabrication cycle time ($r = 0.809,\ p < .1$).

These results in Table 4 show that the benefits of BIM integration are largely related to reducing the time of prefabrication project through early identification of long completion time, reducing the fabrication cycle time and shortening the procurement schedule. Based on the correlation findings, it can be advised that the BIM integration with prefabrication should not be considered as adopting and using BIM software tools. The benefits are also highly related to the exploring the design constraints and enhancing the coordination among stakeholders involved in a prefabrication building project. Respondents addressed that BIM integration should be considered as improving prefabrication processes and enhancing information flow among stakeholders based on the collaborative industry culture. Thus, the findings are highly aligned with the literature review, and consequently the BIM adoption can be considered an opportunity to improve productivity in the prefabrication industry.

Potential outcomes of integrating BIM into the prefabrication design and construction

There was a high level of agreement from the survey respondents that reducing the project duration and increasing mass customization were the top two potential outcomes benefiting from BIM integration within the design and construction stages of a prefabrication building project. Table 5 presents the cross-tabulation between the BIM benefits and outcomes based on the survey responses.

The reduction in project duration is due to the main four benefits shown in Table 5. Whereas, the mass customization is highly resulted from the first three BIM benefits listed in Table 4. This means that BIM uptake within the prefabrication industry in Australia would result in positive outcomes for the client (mass customization) as well as for the builders (reducing the project duration and schedule risks). The respondents were asked to specify the types of buildings projects and prefab components that are

Table 4. BIM benefits interrelationship within prefabrication.

		Early identification of long completion time	Shortening the procurement schedule	Exploring design constraints for fabricators	Reduce differences between design and manufacturing models	Reduce the fabrication cycle time	Reduce the coordination errors
Early identification of long completion time	*r*	1	0.994[a]	0.373	−0.687[a]	0.847[a]	0.293
	Sig.		0.00	0.128	0.002	0.00	0.02
Shortening the procurement schedule	*r*		1	0.269	−0.726[a]	0.784[a]	0.199
	Sig.			0.28	0.001	0.00	0.42
Exploring design constraints for fabricators	*r*			1	0.108	0.809[a]	0.889[a]
	Sig.				0.6	0.00	0.00
Reduce differences between design and manufacturing models	*r*				1	−0.373	−0.149
	Sig.					0.12	0.5
Reduce the fabrication cycle time	*r*					1	0.695[a]
	Sig.						0.001
Reduce the coordination errors	*r*						1
	Sig.						

[a]Correlation is significant at the 0.01 level (2-tailed).

most likely to integrate and benefit from BIM. The respondents agreed that the projects of high-rise multi-residential buildings, health and education facilities would be most likely to integrate BIM in the design and construction stages. This is because of the complexity of the designing and constructing multi stories prefabricated buildings with a high number of combining parts and collaboration amongst multiple stakeholders at two working locations (construction site and offsite fabrication facility). In addition, the

Table 5. Potential outcomes of integrating BIM with prefabrication[a].

			BIM outcomes[b]					
			Reduce planning and scheduling duration with prefabrication	Reduce project duration from model approval to completion	Higher quality fabrication	Reduce scheduling risks with BIM based planning	Mass customization	Total
BIM benefits[b]	Early identification of long completion time	Count	3	6	2	3	6	20
		% within BIM benefit	15.0%	30.0%	10.0%	15.0%	30.0%	–
		% within $BIM outcome	25.0%	24.0%	20.0%	27.3%	26.1%	–
		% of total	3.7%	7.4%	2.5%	3.7%	7.4%	24.7%
	Exploring design constraints	Count	3	7	3	3	6	22
		% within BIM benefit	13.6%	31.8%	13.6%	13.6%	27.3%	–
		% within $BIM outcome	25.0%	28.0%	30.0%	27.3%	26.1%	–
		% of total	3.7%	8.6%	3.7%	3.7%	7.4%	27.2%
	Reduce fabrication cycle time	Count	3	6	2	3	6	20
		% within BIM benefit	15.0%	30.0%	10.0%	15.0%	30.0%	–
		% within $BIM outcome	25.0%	24.0%	20.0%	27.3%	26.1%	–
		% of total	3.7%	7.4%	2.5%	3.7%	7.4%	24.7%
	Reduce coordination errors	Count	3	6	3	2	5	19
		% within BIM benefit	15.8%	31.6%	15.8%	10.5%	26.3%	
		% within $BIM outcome	25.0%	24.0%	30.0%	18.2%	21.7%	
		% of total	3.7%	7.4%	3.7%	2.5%	6.2%	23.5%
Total		Count	12	25	10	11	23	81
		% of total	14.8%	30.9%	12.3%	13.6%	28.4%	100.0%

Percentages and totals are based on responses.
[a]There are not enough (less than 2) multiple response groups for pairing. Percentages are based on responses, but no pairing is performed.
[b]Dichotomy group tabulated at value 1.

Table 6. Challenges of BIM integration within prefabrication construction.

	N	Min	Max	Mean	Std. deviation
Business change practices to support BIM	18	1	4	2.7	0.46
Replacing CAD technologies with BIM	18	1	4	2.3	0.74
Investment required in software, training and hardware	18	1	4	1.8	0.80
Legal concerns with fabrication and multiple designs	15	1	3	1.6	0.84
Challenges with collaborating and sharing information among project team members	14	1	2	1.2	0.94

buildings clients/owners and architects are looking for additional sustainable designs for improved environmental impact. Therefore, BIM is an efficient working platform information exchange/integration among stakeholders through all stages of a prefabricated building project.

Challenges in integrating BIM in prefabrication

According to Schesinger (2014), the use of prefabrication accounts for 3% of the construction work undertaken in the Australian construction. The practice of prefabrication is expecting to grow to at least 10% especially in multi-trade modular construction projects. BIM technology plays a significant role to make this possible. However, there are challenges for future BIM uptake within the prefabrication construction. Table 6 lists the three main challenges indicated by the survey respondents.

As shown in Table 6, the most significant challenge is the changes in the business practices to adopt BIM process, regardless of the software capabilities. More planning for the use of prefabricated assemblies on the project is taking place in the design phase. BIM requires using the integrated project delivery (IPD) and various forms of design-build for effective coordination and collaboration at early stages of the project. The other two challenges are replacing CAD technologies with BIM and investment required in BIM software, training and hardware. BIM requires extensive resources and in-depth knowledge of construction methods and process. Most small and medium-size organizations could not afford employing BIM specialists for developing, maintaining and operating BIM models for each prefabrication project. The usage of dual CAD-BIM system functioning in the same project is still an issue for most organizations. This requires educating major contractors, material suppliers and some architects for integrating only BIM system into their work platform. Other than the above barriers, the project team has experienced legal and collaborative issues. The use of BIM promotes multi-disciplinary collaboration, which contrasts to defining responsibility to each party and then assigning liability issues among the parties. In addition, using BIM models instead of traditional contract document raises questions on insurance coverage and the model of intellectual property rights.

These challenges could overcome with the Australian Government support. The National BIM initiative report recommended that Australian Government should mandate full collaborative BIM based on open standards for information exchange [open BIM] (buildingSMART Australasia 2012). The report further recommends that the Australian Government encourage the State and Territory Governments, through the Council of Australian Governments, to commit to a similar timeframe for full collaborative BIM based on open standards to be required for procurement of their buildings. International experience indicates that when governments have required BIM for their procurements, other public bodies and the private property industry have been motivated to follow suit.

Conclusions

This research identified the benefits and potential outcomes of, and the barriers to, adopting BIM within the prefabrication industry. The research findings designate the potential to achieve improved productivity by integrating prefabrication with a BIM system to coordinate the design plan and to communicate effectively. In addition, the findings recognize reduction in the differences in a final model between the designer and the manufacturer. Shortening of the procurement schedule is the most significant benefits of BIM integration in the Australian prefabrication industry. It was also identified that seamless and timely data exchange via a BIM system is essential in the prefabrication industry. As soon as reliable building components are constructed within a BIM system, these components can be built digitally and physically, and the information about them can be disseminated and shared over the project life-cycle. Therefore, critical project stakeholders can make informed decisions on design changes and the fabrication of building components. The synergy of integrating BIM and prefabrication minimizes unnecessary and costly reworks and conserves resources. BIM enables the early involvement of project stakeholders, thus improving the design and prefabrication processes and identifying design errors earlier compared to the traditional workflow. Hence, the low perceived value of prefabricated buildings will be improved, and an open and a collaborative project team culture could be established. This research contributes to the identification of potential outcomes of BIM integration within the Australian prefabrication context. For a full realization of the benefits of BIM and the outcomes for Australia's prefabrication industry, future research studies could be developed to further categorize these benefits and outcomes from the perspectives of clients and builders. Moreover, these benefits and outcomes should be studied about the types of prefabricated projects (e.g. commercial buildings and healthcare facilities). The identified outcomes could lead to the future development of prefabrication practice in Australia. Some limitations are acknowledged as the study reports on these findings from the Australian context. Future studies could employ case studies and be conducted in other countries for enhancing the generalization of this research findings.

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