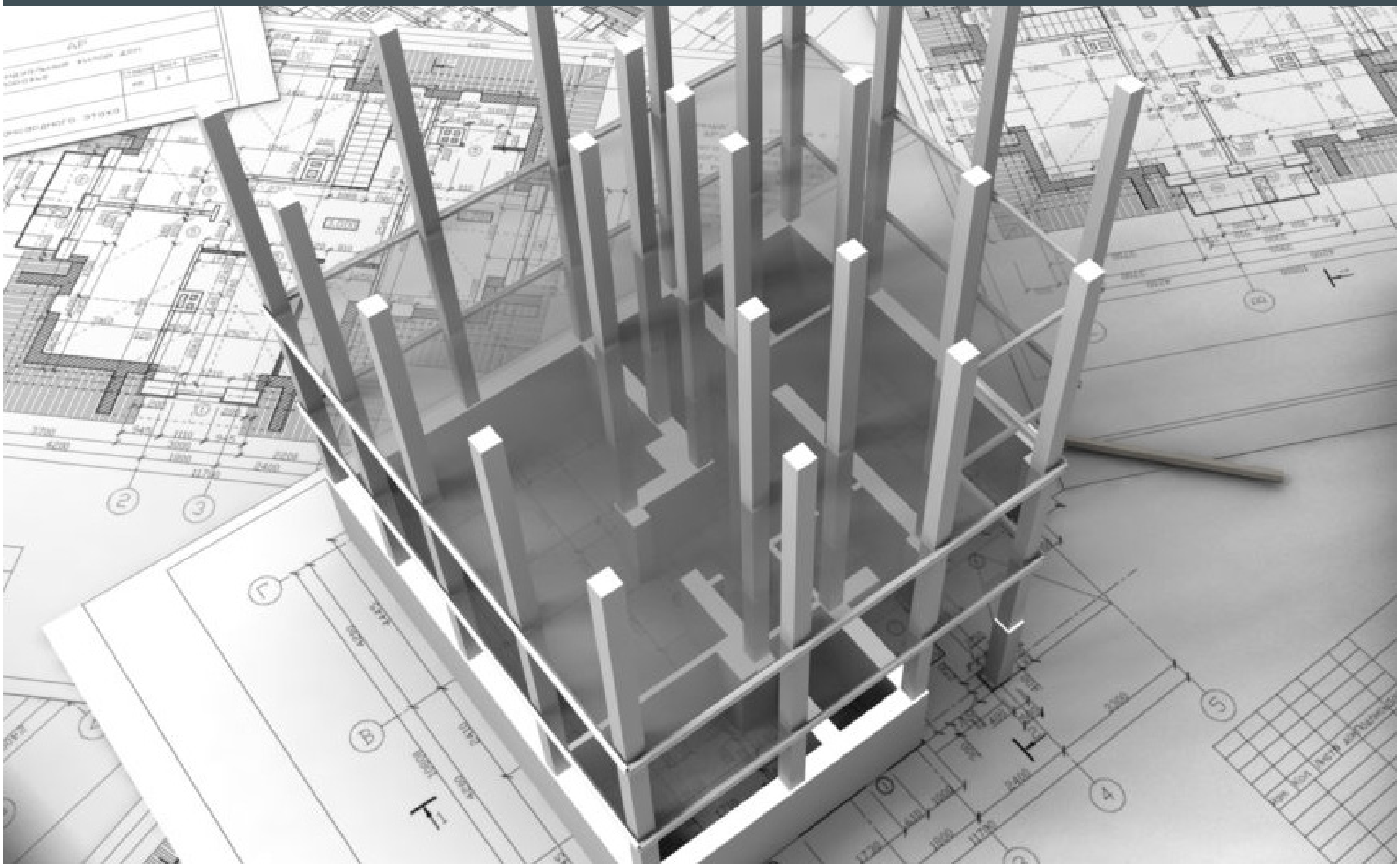
NSW GOVERNMENT

Health and safety management using building information modelling: Phase One Report



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Executive Summary

Background

The construction industry is known as one of the most dangerous industries. Numerous safety incidents, injuries and fatalities could be prevented by improved communication and information flow and analysis in all phases of the asset lifecycle. The use of Building Information Modelling (BIM), a technology enabling the digital representation of physical and functional characteristics of a building or infrastructure project offers the means of improving Work Health and Safety (WHS) outcomes in the construction industry. Yet, its application to WHS management, particularly in Australia, has been varied and inconsistent and the extent to which it can improve WHS outcomes in construction is unclear. The project "Work Health and Safety Management using Building Information Modelling" examines the opportunities to achieve WHS objectives through application of BIM in major construction projects.

This Technical Report presents the outcomes of Phase 1 of four phases and identifies solutions for integrating the WHS aspect in BIM-enabled project planning, design and delivery. Specifically, this includes understanding how and to what extent BIM is used and can be used for WHS management, including different options of implementation and the associated barriers, enablers, limitations and consequences for WHS risk reduction for the industry, the government and the regulator.

The outcomes of Phase 1 provide the theoretical and practical context for Phase 2, which aims to identify preferred procurement models and best practices to evaluate WHS management in BIM-enabled project proposals and develop recommendations for government clients.

Method

Literature review

The literature review aimed to identify BIM use cases focussed on WHS management for the construction industry in both 'grey' and academic literature, and to evaluate Australian and international examples through a comparative analysis. Since the duty to ensure safe practices on the worksite is a shared responsibility, the purpose of this review was also to understand, from both an industry and client perspective, how BIM can support WHS management across all phases of the construction process, inclusive of procurement as a critical point for the specification of WHS standards. The literature review explored five key areas:

- Utilisation of BIM for WHS management
- Solutions for integrating WHS management in BIM-enabled project planning, design and delivery
- Barriers and enablers for BIM adoption
- Comparative analysis of international BIM use cases for WHS management
- Procurement frameworks to initiate WHS management in a BIM-enabled environment

Empirical study

An empirical study was conducted with selected expert key stakeholders associated with Australian and international exemplars to gain more in-depth knowledge of implementation that may not have been published. The purpose was to strengthen findings from the literature review and to confirm the premise that specificity on decision making during the tendering process and subsequent construction phase monitoring would make a valuable contribution to theory and practice. While the interview selection was driven by a strategic sampling approach, further data collection and analysis and future model development are needed in Phase 2 to assure of generalisabiity of findings.

The empirical study involved nine semi-structured interviews with practitioners from the domains of BIM and/or WHS in Australia, Singapore and the United Kingdom. The research participants were asked to reflect on the use of BIM in the construction industry, the use of BIM for WHS management and strategies to promote adoption.

Interview transcripts were then analysed using a four-staged, qualitative technique: first-level thematic coding, second-level categorisation, a third cycle of analysis to map findings against main points of the literature review and a fourth level of analysis to develop narratives.

Discussion

Benefits of BIM for WHS management

Using BIM from the onset of a project supports early identification of WHS risks and enables preventative and elimination strategies to be explored, analysed and implemented in the virtual world, before any physical work commences. While there is increasing evidence of the importance of considering WHS in the preplanning, design and delivery stages, the WHS benefits can extend to all stages of the structure's lifecycle. Benefits of using BIM for WHS management can be summarised in six thematic areas across the design, construction and operational phases: (1) Scenario planning, (2) Requirements briefing, (3) Risk assessment, (4) Education and training, (5) Monitoring, surveillance and reporting and (6) Analysis. Integration of novel information technological systems (such as collaborative robotics, automation, virtual reality, and cloud computing) with BIM is visionary and holds promise. Trends in mobility and technological convergence were described as enablers as these have led to increasingly sophisticated technologies, but interviewees also noted the importance of simple, intuitive technologies and interfaces that could broaden BIM uptake across the supply chain.

Barriers to BIM for WHS management

Empirical findings confirm that key barriers to widespread BIM adoption in Australia are the lack of a nationally consistent approach alongside a culture that is resistant to change and to new technologies. A contractual agreement with a government client appears to be a strategic way to catalyse increased BIM adoption in ways that address or bypass these barriers. Findings also suggest that a government client mandating WHS management at procurement in BIM-enabled projects would address entrenched challenges, including fragmented approaches to WHS management and the failure to plan WHS management initiatives early. Capacity building strategies are critical if this approach to BIM for WHS management is to be implemented on a large scale. Findings suggest that the two most important elements of capacity building are the development of a foundation of integrated information as well as training in the use of information and specific BIM technologies. Future directions include developing tools that will support decisions related to (1) defining WHS management information requirements at tender; (2) evaluating tenders; (3) addressing differences in BIM for WHS outcomes and strategies across difference procurement models and (4) monitoring the main contractor with respect to supply chain performance.

Client leadership

Australia has lagged in adopting BIM for WHS management in comparison to countries like the United States (US) and the United Kingdom (UK). While numerous studies have examined the adoption of BIM in the US and UK, and related barriers and drivers, there is a dearth of studies addressing the WHS management in a BIM environment in the Australian context. Although there are numerous Australian BIM guidelines that assist adoption, one also questions how well they are utilised. There are three potential reasons for this lack of attention. First, although there are numerous state-based guidelines, there is a lack of a BIM-enabled WHS strategy, guideline and attendant standards that are nationally harmonised. Second, is the lack of adoption by major clients in both the private and public sectors, and third is the maturity and viability of the construction industry as a whole to adopt a BIM enabled environment. Underpinning the three is a lack of awareness, understanding and perceived awareness of the value of the benefits of a BIM-enabled environment for WHS management. The value of BIM is a contestable concept as anecdotal evidence suggests that the majority of adopters assume there are business benefits or have conducted internal organisational analysis that evidence benefits. Empirical findings confirm the literature, with data pointing to the lack of a strong nationally consistent approach alongside a culture that is resistant to technological change as key barriers to BIM adoption. Empirical findings also confirm that more attention should be paid to the tendering phase in terms of criteria, evaluation, expectations and monitoring the supply chain. The government client could play a catalytic role in stimulating the resistant culture and developing rigour in policy mandates, ensuring WHS management in BIM is considered during design, implemented and monitored during construction, and used for asset management upon completion. It is important to note that there are varying levels of adoption still and that it is beyond the scope of this study to pursue an industry wide approach to the adoption of BIM for WHS management. Instead, the focus of this study is to develop targeted recommendations across the following criteria: project type (civil, commercial, residential, etc.), client type (public vs. private) and tendering approach (traditional design-and-construct, PPP, etc.).

Holistic integration

Both the literature and empirical findings confirm that BIM aids WHS compliance by holistically integrating WHS management in the construction model itself, in contrast to the WHS management system being a standalone strategy for separate workplace integration. Inclusion of WHS in the BIM environment also enables more complete, fair and transparent tendering and more systematic monitoring and reporting. Capacity building strategies are critical if WHS management in BIM is to be implemented on a large scale. Findings suggest that there are two important elements of capacity building. One is the development of a foundation of integrated information. A second is training in the use of information and in the use of specific BIM technologies. Since there is increasing evidence of WHS integration into BIM being crucial to the preplanning and design phases, the integration into procurement strategies and consultant appointment, design and tendering phases is critical.

Key recommendations for Phase 2

Both the literature review and empirical findings have laid a robust foundation for the next phase of the project:

- Phase 2: Evaluation of WHS management in BIM-enabled project proposals, as part of a procurement process

  Identify preferred procurement models and best practices to evaluate WHS management in BIM-enabled project proposals and recommend best way for government agencies to evaluate the quality of WHS management in BIM-enabled project proposals.

The main deliverable for Phase 2 is a Decision Making Framework that will support information management leading to more effective decision-making and to a more clearly-articulated strategy for BIM for WHS management.

It is not the aim of Phase 1 to define specifics of the Phase 2 Decision Making Framework contents. Past research on BIM adoption frameworks indicates that contents can be very flexible and can encompass a broad swathe of tools: roadmaps, checklists, assessment tools, flowcharts (London et al., 2010). The specifics of the proposed Framework can only be determined through further empirical work in Phase 2 and analysis and critique of existing frameworks. There are Australian guidelines for BIM, however, they do not include WHS. The UK PAS (Publicly Available Specifications) and EIR (Employer's Information Requirements) are useful as they present well-developed existing integrations of BIM and WHS. An analysis on their potential for adaptation for the NSW context will therefore be explored. Through interviews in Phase 2, we will also critique other decision frameworks currently in use.

Based on Phase 1 findings, the proposal is that the Framework will explore the following propositions with respect to adaptation of existing exemplars:

Best practice

- Identifying exemplars in Australian major public and private sector client-led projects
- Identifying key decision areas in exemplars with respect to Project Information Integration Requirements

Client leadership

- Establishing WHS management requirements prior to tendering as a priority, based on best practice
- Developing clear alignment to six knowledge domains of WHS management: scenario planning, requirement briefing, risk assessment, education and training, monitoring/surveillance and reporting, and analysis.
- Ensuring client expectations on BIM for WHS management are clearly developed prior to tendering to enable client leadership

- Developing Client Information Expectations/Requirements and Responsibility Matrices for BIM for WHS management

Tendering proficiency

- Ensuring tender criteria and evaluation are transparent and authentic with respect to BIM for WHS management, to ensure clear communication and expectation-setting
- Framing BIM for WHS management outcomes and strategies across different procurement strategies
- Analysing and assuring supply chain capacity to deliver as well as appropriate supply chain monitoring during other project phases

Supply chain monitoring

- Identifying key areas of capacity building across all levels of stakeholders for implementing BIM for WHS management in Australia
- Monitoring the main contractor to ensure that the supply chain is delivering to the original expectations, a function critical to implementation

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List of Abbreviations

ABAB	The Australasian BIM Advisory Board
ACIF	Australian Construction Industry Forum
APCC	Australasian Procurement and Construction Council
BEP	BIM Execution Plan
BIM	Business Information Modelling
BLE	Bluetooth Low Energy
BSI	British Standards Institution
CIC	Construction Industry Council
COBie	Construction Operations Building Information Exchange
COBIM	Common BIM Requirement
CoBot	Collaborative Robots
CRC	Cooperative Research Centre
DB	Design and Build
DBB	Digital Built Britain
DE	Digital Engineering framework

EIR	Employer Information Requirements
EU	European Union
GIS	Geographic Information Systems
HSE	Health and Safety Executive
IFC	Industry Foundation Class
ILO	International Labor Organisation
IoT	Internet of Things
IPD	Integrated Project Delivery
ISO	International Organisation for Standardization
LOD	Level of Development
MapSafe	Safety Information Management System
NATSPEC	National Building Specification
NBS	National BIM Specification
OHS	Occupational Health and Safety
OSHA	Occupational Safety and Health Administration
PAS	Publicly Available Specifications
PTI	Project Team Integration
RACI	Responsible, Accountable, Consulted and Informed
RFID	Radio-Frequency Identification tags
SHP	Segment Handling Plant
TfNSW	Transport for New South Wales
UK	United Kingdom
US	United States
VDAS	Victorian Digital Asset Strategy
WHS	Work Health and Safety
WHS Act	NSW Work Health and Safety Act 2011
WHS Regulation	NSW Work Health and Safety Regulation 2017

Introduction

This Technical Report summarises outcomes and recommendations from Phase 1 of the project "Work Health and Safety Management using Building Information Modelling". The aim of the project is to examine opportunities to achieve WHS objectives through application of BIM in major construction projects.

The project has four phases:

- Phase 1: Development of solutions for integration of WHS in BIM-enabled project planning, design and delivery

  Understand how and to what extent BIM is used and can be used for WHS management, including identifying the different options of implementation and associated barriers, enablers, limitations, and consequences for WHS risk reduction for the industry, the government and the regulator.

- Phase 2: Evaluation of WHS aspects in BIM-enabled project proposals, as part of a procurement process
- Phase 3: Evaluation of the proposed approach for BIM adoption
- Phase 4: Knowledge transfer and information dissemination

To address the objective of Phase 1, two main activities were completed: a literature review and an empirical study.

The literature review explored 'grey' and academic literature in five key areas:

- Utilisation of BIM for WHS management
- Solutions for integrating WHS management in BIM-enabled project planning, design and delivery
- Barriers and enablers for BIM adoption
- Comparative analysis of international BIM use cases for WHS management
- Procurement frameworks to initiate WHS management in a BIM-enabled environment

This provided Australian and international BIM use cases focussed on WHS management to evaluate and compare. It also generated greater understanding, from both and industry and client perspective, of how WHS management across the construction process can be integrated in a BIM environment, inclusive of procurement as a critical point for the specification of BIM and WHS standards.

The literature review was complemented by an empirical study with key stakeholders associated with Australian and international exemplars. This provided a deeper understanding of contemporary implementation of BIM for WHS management, enablers and barriers of adoption, and use cases not otherwise accessible through the published literature.

Method

Literature review

Literature to inform the review was sought in relation to five key areas:

- Utilisation of BIM for WHS management
- Solutions for integrating WHS management in BIM-enabled project planning, design and delivery
- Barriers and enablers for BIM adoption
- Comparative analysis of international BIM use cases for WHS management
- Procurement frameworks to initiate WHS management in a BIM-enabled environment

The search for literature was aimed at identifying the most influential and exemplary use cases, studies and, government and industry documents exploring the areas of interest. Some attention was given to 'grey' Australian publications and to capture the most recent developments in the field.

Empirical study

The empirical study involved qualitative techniques aimed at validating and nuancing the key topics identified in the literature review. Based on the literature review, a number of specific sub-topics were specifically selected as pathways for further empirical inquiry because of their direct impact on addressing the study's main objective. These sub-topics are shown in Table 1.

Table 1: Directions identified for further empirical analysis

Recurring sub-topics	Directions for empirical analysis
Legislation/ policy/ standards for BIM Key areas of application Level of adoption of BIM	Further empirical analysis of experiences of BIM adoption and understanding of the context
Examples of application of BIM for WHS Benefits of BIM for WHS Barriers and enablers of BIM for WHS Procurement as an instrument for BIM for WHS	Further empirical analysis of experiences of BIM adoption for WHS management
Stakeholders perspective Future development BIM for WHS movement Government role Client and other stakeholders	Further empirical analysis of capacity building, stakeholder roles, etc.

Empirical research involves "the application of observation and experience to a research question rather than being grounded in theory alone" (Gaskell 2000, p. 349). This type of research can be undertaken using a range of research designs. To conduct an empirical analysis of organisational life, for example, five research designs can be considered: experimental research, survey research, qualitative research, case study research or action research (Bryman 1989, pp. 28- 30). To explore the sub-topics identified in Table 1, qualitative research techniques were used.

Data was gathered through semi-structured interviews with nine participants. The participants were selected to ensure a broad mix of experiences. This included sectors (government vs. non-government), areas of specialisation (BIM, WHS or both) and location (Australian or international). Participant descriptions are summarised in Table 2. Strategic selection based on different project types was not attempted as this is a matter that will be considered as part of Phase 2 of the project.

The interviews covered the following three broad topics, aligned to the empirical areas for further enquiry as outlined in Table 1:

- T1: General application and adoption of BIM in construction
- T2: BIM adoption in relation to WHS management
- T3: Strategies for capacity building to support BIM for WHS

Interviews lasted 45 minutes to one hour. The three broad topics were used to initiate discussions and participants were given the opportunity to share rich, detailed narratives. Interviews were conducted via online using a range of commonly available conferencing software (determined by participant preference). Interviews were recorded using the online conferencing software and were fully transcribed. A total of 223 pages of text were analysed.

Table 2: Description of interview participants in Phase 1.

Interviewee	Australia	International	Government	Private	BIM Specialist	WHS Specialist
Interviewee #1: General contractor, WHS specialist, Australia	X			X		X
Interviewee #2: Government and private, BIM specialist, UK		X	X	X	X	
Interviewee #3: General contractor, BIM specialist, Australia	X			X	X	
Interviewee #4: General contractor, BIM specialist, Australia	X			X	X	
Interviewee #5: Government, specialist in BIM and WHS, UK		X	X		X	X

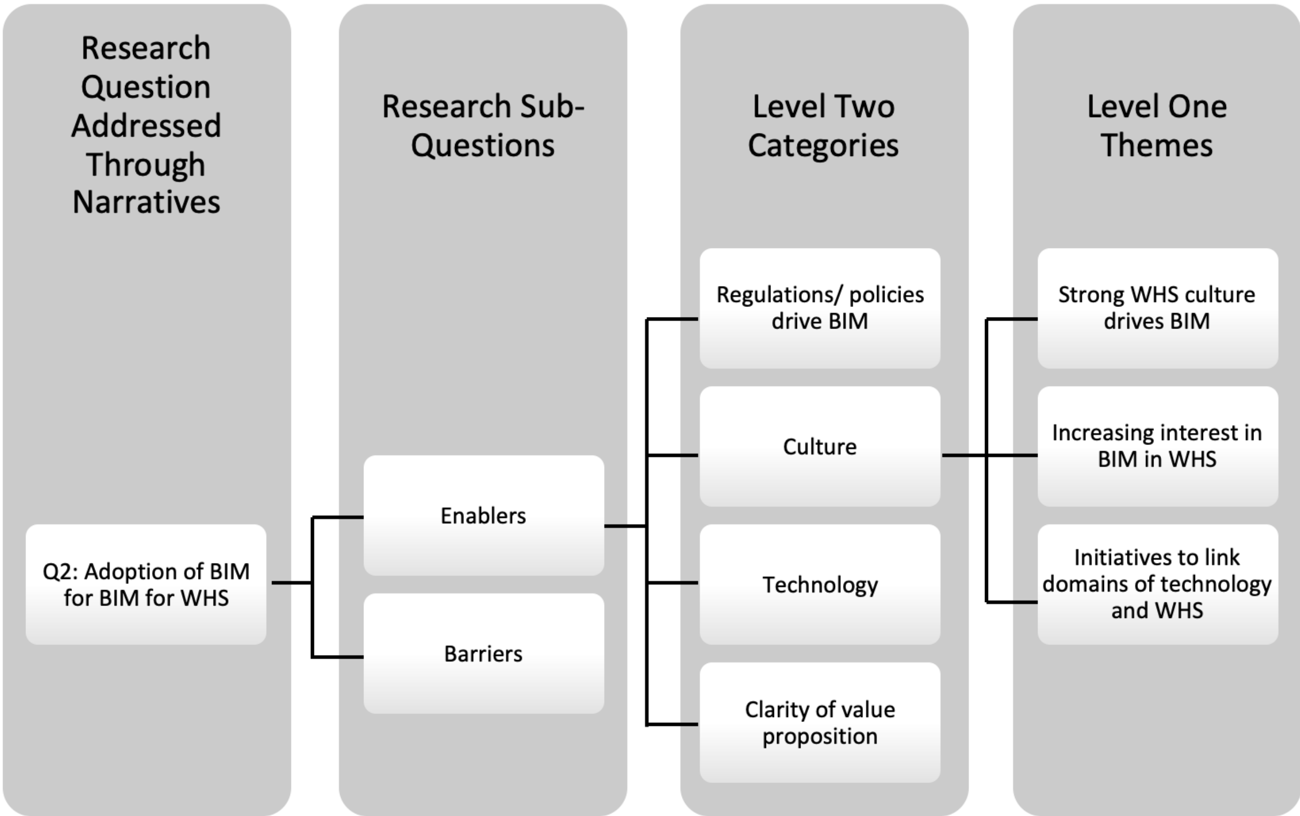
Interviewee #6: General contractor, specialist in BIM and WHS, Singapore		X		X	X	X
Interviewee #7: General contractor, BIM specialist, Australia	X			X	X	
Interviewee #8: Government, BIM specialist, Australia	X		X		X	
Interviewee #9: Subcontractor, General Manager, BIM Specialist, Australia	X			X	X	

Themes were not predetermined at the start of analysis; in the earliest stages of the interview period, the three main interview topics were the primary guides for organising the data. As interviews progressed, themes were identified and a list of themes was built incrementally by moving iteratively between the data and the growing list of codes. For Phase 1, four levels of analysis have been conducted, based on a model by Gioia, Corley and Hamilton (2012):

- First level analysis: Quotes are used to develop participant-driven themes. When the nine interviews were completed, a total of 295 themes were identified.
- Second level analysis: Themes are grouped into researcher-driven categories and mapped to the three topics.
- Third level analysis: Overall findings are examined in relation to the literature.
- Fourth level analysis: Themes and categories are woven together into a coherent picture to bring out lessons learned and transferable principles.

The data analysis approach was rigorous. The purpose of beginning with participant-driven themes instead of researcher-driven themes helps ensure that researchers engage with the full qualitative database. Imposing researcher-selected themes at early stages increases the risk of overlooking nuances in participant narratives and of eliminating ideas too early simply because they do not conform to the researchers' analytical categories. Thus, researcher-driven themes are intentionally mobilised only in the second stage (Gioia et al. 2012). The movement from interview data, to participant-driven themes, to researcher categories is illustrated in Figure 1 below. Figure 1 is provided to reflect the process, but does not capture the list of themes exhaustively. To appreciate the breadth of qualitative data, a sample matrix showing quotes, themes and categories, is provided in Table 3, demonstrating how enablers of using BIM for WHS management were analysed. The complete set of quotes, themes and categories for BIM for WHS enablers is provided as a sample in Appendix 1. Matrices for T1, T3 and other aspects of T2, specifically examples of BIM use and barriers for using BIM to manage WHS, were also developed in the course of analysis. Collectively these matrices make up the large qualitative database that underpin the empirical phase of this project.

Figure 1: Illustration of the multi-level thematic analysis process



The use of detailed narratives to present findings was a methodological decision made for two reasons. First, rich narratives have the capacity to draw out concepts and lessons from cases, contexts and situations that are not yet well-explored. BIM for WHS management is one of them. A second reason was raised by the interviewees themselves: there is a need to build up compelling case studies and to frame successful experiences as vivid stories of how BIM can be used to manage WHS. For this reason, and also because it is consistent with the ideals of good qualitative research (Gioia et al, 2012), detailed narratives are presented here. The narratives also draw heavily on quotes to allow readers opportunities to engage the data directly where key points are made.

Table 3: Partial matrix (quotes, themes, categories) for enablers for BIM for WHS management

Category	Themes	Quote	Interviewee
CULTURE	CULTURE VALUES WHS/ WHS AS A WAY OF LIFE	I think there's, there's a lot of good movement in the last five years towards safety first culture.	Interviewee 7
CULTURE	STRATEGIES TO LINK SEPARATE WHS AND TECHNOLOGY DOMAINS	Some of it is going to come through standardisation, to be honest, because people talk about risk. It's a very confusing language, sometimes, the way people talk about risk and how to manage health and safety problems, and there is an ontology. In academic terms, there's an ontology issue about understanding the language so you can talk to designers.	Interviewee 5
VALUE PROPOSITION	BECOMES CLEAR WHEN STAKEHOLDERS EXPERIENCE ITS BENEFITS OVER TIME	And there are those that are converted because they've experienced it on a project and they've seen what they can learn from, you know, having those aerial views from a drone on a regular basis. And, you know, the kind of problems we solve when we have a well-coordinated design, so that we're not, you know, we're minimising the amount of time on site because we're doing the work one time only and getting it right. All of these things have OH&S benefits, but until you experience it firsthand, you can remain sceptical. And so we still have that transformational process to take within our own business, as well as across the industry. You know, I think it's pretty endemic.	Interviewee 6
VALUE PROPOSITION	INCREASES PRODUCTIVITY AND SAFETY	we're seeing directly from that is we're seeing increases in our productivity that we finish a project and we're seeing a safer result at the end of it, without a doubt, yes.	Interviewee 9
CLIENT ROLE	CLIENT IS EDUCATED AS HANDHELD THROUGH CONTINUED BIM USE	From a security perspective, you can check visibility lines, for example. So, you know, you just have it up there and then you start to talk to it, and it starts to become accepted that, okay, we can do that. So it starts to educate our client. ...where we did all of our safety workshops with the model. I make sure the model was open and then we'd check, you know, how are we going to get this piece of equipment in and out of that room, for example.	Interviewee 4
CLIENT ROLE	WHS REQUIREMENTS OUTLINED BY GOVERNMENT CLIENT CONTRACT	We have a number of obviously WHS requirements that are outlined within our [client's] contract schedules, our scopes of work, which are all [given] to subcontractors during that procurement phase.	Interviewee 1

Category	Themes	Quote	Interviewee
SYSTEMS/ PROCESS/ HOLISTIC INTEGRATION	EARLY INVOLVEMENT IS BETTER	So the earlier, we can get involved in that, the better it is, because then we can then inform the builder and tell them where they need to be doing their work in order to support the future work that we've got to do.	Interviewee 9
SYSTEMS/ PROCESS/ HOLISTIC INTEGRATION	EARLY INVOLVEMENT IS BETTER	This idea of the integration between pre-construction and construction is part of the key. So getting designers early contractor involvement, getting those conversations happening earlier, even between the end users of a building, people are going to maintain the property and the designers is so, so important.	Interviewee 5
DATA	STRUCTURED DATA	So that goes back to the element matrix and also the LOI as well, which is what metadata is supposed to be delivering and that can go from CoBIE, it can go from, you know, your classification which uni class, 2015, are they putting that right information in because, again, it's quite important. And this will come back to Work Health and Safety as well. If everyone's using the right structured data that's all talking to each other as well effectively.	Interviewee 3
DATA	COMMON CODING BREAKS DOWN SILOS	I know there's many other datasets we manage on a project, requirements management, risk management, especially for managing hazards and safety assessment and documenting many others. And the key takeaway is that they all use siloed software, but more than that, they have siloed business practices. So each different business party – or so a project party, uses their own descriptors, their own breakdown to describe the same projects.	Interviewee 8
TECHNOLOGY	TECHNOLOGY/ MOBILE	And if anything. I think one of the big things is BIM is becoming more on the site, that you know if you went back 10 years ago, it was something that sat on a screen on a designer's or an architect's there. But now, I think it's fair to say that with site mobility, we're seeing it much more now, you know on the job site on mobile devices within there as well.	Interviewee 2
POLICY/ REGULATORY	OTHER REGULATIONS WITH CONGRUENT GOALS	But ISO 19650 has introduced a concept of a project information requirement. So it has four – it has the organisational information requirement, which is what the client, the originating company has as its organisational values and core requirements, and then it has an asset information model or set of requirements, and from these is supposed to be derived the project information requirements.	Interviewee 5

Results from Literature Review

Construction is known as one of the most dangerous industries in which to work and many safety incidents, injuries and fatalities could be prevented through improved design, planning, practice and communication. BIM, an enabler technology that involves digital generation and management of WHS in construction, facilitates the separation of people and hazards by the use of technology and data. The purpose of this literature review is to better understand the application of BIM to support WHS management in construction and, specifically, the role the client can play in enhancing its application. Under this overarching aim, this review will explore the use and adoption of BIM for WHS management, examine the barriers and enablers for BIM adoption, identify solutions for integrating WHS management in BIM-enabled project planning, design and delivery, and explore procurement frameworks and the client's role in using BIM for WHS management. The literature review contains five sections. This section outlines the need to examine the status of WHS in the construction industry and provides a brief overview of the WHS legislative environment across various countries, including Australia.

Significance

The construction industry is well known for its hazardous working conditions and association with a concerning number of injuries and fatalities. The issue of WHS is international, with the construction industry responsible for the highest proportion of the 2.3 million work-related fatalities that occur around the world each year (International Labour Organisation, 2020). According to the Bureau of Labor Statistics (2019) of the US, construction worker fatalities are increasing (from 965 in 2017 to 1003 in 2018). Similarly, construction workers in the UK constituted the highest proportion of occupational fatalities in 2017 and 2018 (Garner-Purkis, 2018).

In Australia, the construction industry employs 9% of the workforce (1.16 million people; Safe Work Australia, 2017) and has the second highest work-related injury and disease incidence rate among all industries. Numerous statistics support the seriousness of the issue. For example, between 2003 and 2013, 401 workers died on construction (Safe Work Australia, 2017). This is an average of 40.1 workers per year. Over the five years from 2013 to 2017, a total of 153 work-related fatalities were reported in the construction industry, equalling an average of 31 fatalities per year (Safe Work Australia, 2017). While the rates are decreasing, the construction industry remains one of the most dangerous and has been listed as a priority industry for improvement in the Australian WHS Strategy 2012–2022 (Safe Work Australia, 2020).

Work-related injuries and fatalities have wide-ranging implications. In addition to direct impacts to victims, work-related injury and disease impose significant losses to victims' families, employers and society (Feng et al., 2015). For example, damage caused to productivity, property, equipment and morale can have a detrimental effect on a construction company's profit and loss statement

Effective investment to improve WHS could therefore bring significant returns, both human and economic (Feng, 2013).

Government initiatives

To reduce workplace incidents and injuries many countries have enacted legislation and established statutory oversight bodies to ensure best practices are identified and implemented for WHS management in the workplace, including construction. At the international level, the International Labour Organisation (ILO) provides and operates standards on Occupational Health and Safety (OHS). They provide necessary tools for employers and workers to establish good OHS prevention, reporting and inspection practices. In Europe, the European Agency for Safety and Health at Work operates at the European Union (EU) and national levels, while the Directorate-General for Employment, Social Affairs and Inclusion is responsible for regulation at the EU level. In the UK, it is the Health and Safety Executive (HSE) that is responsible for standards enforcement, while in the US, the Occupational Safety and Health Administration (OSHA) has the primary responsibility of enforcing OHS regulations. The OSHA Act provides workplace standards as well as assuring OSHA the power to create its own standards, subject to certain restrictions.

In Australia, ensuring WHS is a statutory requirement in each state and territory. In New South Wales (NSW), the NSW Work Health and Safety Act 2011 (WHS Act) and the NSW Work Health and Safety Regulation 2017 (WHS Regulation) define the obligations of Persons Conducting a Business or Undertaking (PCBU), workers, officers and other persons to ensure WHS in the workplace. The WHS Act is supported by local compliance policies and prosecution guidelines, which supplement the National Compliance and Enforcement Policy (Safe Work Australia, 2011). The national model Code of Practice for Construction Work provides further practical guidance to achieve the standards of health, safety and welfare required in relation to construction work (Safe Work Australia, 2020).

In summary, government led initiatives in the form of statutory bodies, Acts of Parliament, regulations, guidelines and policies, across national and state levels provide the foundation for setting WHS standards and compliance regimes in workplaces.

Information technologies to improve Work Health and Safety

Although various guidelines and legislation have been developed to reduce incidents and injuries in the workplace, there is always the imperative to introduce and develop new technologies to increase WHS through improved project planning, building design and communication. More recently, different information technologies (IT) have been used with the aim of providing new ways of enhancing WHS management throughout the lifecycle of the structure. This section briefly summarises four different and innovative IT approaches related to what is commonly referred to as 'digital construction' involving data modelling and management.

Building Information Modelling

BIM is an integrated model-based process, which is used for creating and managing building projects. BIM has been variously defined over the last decade. According to Gu and London (2010):

> *"BIM is an information technology enabled approach that involves applying and maintaining an integral digital representation of all building information for different phases of the project lifecycle in the form of a data repository. The building information involved in the BIM approach can include both geometric data as well as non-geometric data." (Gu & London, 2010).*

According to British Standards Institution (BSI) and International Organisation for Standardization (ISO) 19650, BIM is the:

> *"Use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions." (BSI ISO 19650, 2019).*

BIM facilitates design, visualisation, simulation and collaboration of all information in the integrated model for better decision-making. It allows all stakeholders to access the same information at the same time through a common data environment. As BIM allows the visualisation in advance of its physical realisation, it provides greater cost certainty, facilitates error elimination, and thereby risk reduction.

Existing research indicates that BIM is being increasingly adopted by the architecture, engineering and construction industries (Martínez-Aires, et al., 2018), although adoption levels have varied across countries, sectors and supply chains (London and Singh, 2013). The adoption or uptake of BIM, known as BIM maturity, can be categorised into four levels according to increasing level of collaboration. BIM Level 0 is the lowest level with no cooperation between participants and mainly involves the use of computer-aided design to make 2-dimensional (2D) drawings. BIM level 1 progresses to the generation of a suite of 2D information with sharing of data using a common data environment. BIM level 2 involves collaborative working and the sharing of information between project participants, whereas BIM level 3 aims to achieve full integration of BIM in a cloud-based environment (National Building Specification (NBS), 2020a).

BIM adoption can also differ in the Level of Development (LOD). BIM LOD is an industry standard that details the development stage of different systems in a BIM environment, specifying the design requirements at each stage. It allows professionals to clearly and effectively specify the content of BIM by articulating the expected LOD of an element's geometry and associated information. At LOD 100 (pre-design), the model mainly constitutes the 2D symbols to define an element's existence. By LOD 200 (schematic design), the elements are partially defined by outlining the model's approximate size, shape, quantity and location. At LOD 300 (design development), elements have accurate dimensions and location. The LOD 400 level (construction stage) provides basic information about the construction of various elements including fabrication, assembly and installation. By LOD 500 (as built), the model is field-verified and includes real-life functions of elements in the real building.

Building Information Modelling and the Internet of Things

With more recent innovative developments in technology, BIM is being explored as a natural interface to managing the deployment of the Internet of Things (IoT; Dave et al., 2016). The IoT has been described as the:

> *"...network of physical objects that contain embedded technology to communicate and interact with their internal states or the external environment." (Gartner, 2019).*

The IoT is a novel paradigm that is rapidly gaining ground in the area of modern wireless telecommunications. The basic idea of this concept is the pervasive presence of connected things or objects around us – such as Radio-Frequency Identification tags (RFID), sensors, actuators, and mobile phones – which, through unique addressing schemes, are able to interact with each other and cooperate with their neighbours to reach common goals (Atzori et al., 2010).

One of the most focussed examples of construction WHS management using BIM and the IoT is that of Teizer et al. (2017), who aimed to create a safer job site through real-time recording and visualisation of worker performance, along with environmental and localisation data in an indoor environment. The prototype system consisted of BIM, Bluetooth Low Energy (BLE) beacons, sensor-enhanced personal protective equipment and an IoT platform that enabled the collection and storage of data from the IoT-functional equipment, which was subsequently connected to a BIM system to seamlessly integrate real-time data. The study developed this infrastructure solution for indoor tracking of personnel across three trades and the results revealed the possibility to collect and visualise actual project data in real-time.

Another example demonstrating how the IoT can bring a new dimension to BIM and WHS management is Riaz et al. (2014). Riaz et al. (2014) used BIM and a wireless sensor network to develop a system to monitor the environmental oxygen level and temperature in confined spaces in line with US WHS regulations. The research resulted in the Confined Space Monitoring System, which enables the BIM platform to be used for information enriched visualisation of confined spaces.

A third example is the introduction of spatial digital twins. For example, in February, 2020, the Australian NSW government introduced virtual replicas of physical built assets. These digital twins can integrate information from IoT enabled sensors to provide 3D real-time data. The implementation of digital twins will help planners, data and IT professionals, developers and policy makers make more informed construction decisions (NSW Government, 2020).

Building Information Modelling and robotics

For some years, the area of robotics has been identified as playing a key role in addressing WHS issues in construction. Robotics can have numerous benefits including; reducing injuries and fatalities by saving workers from conducting dangerous tasks; improving productivity of construction tasks (Bock, 2015); optimising construction processes; reducing labour requirements; and increasing flexibility (Haas et al., 1995). Specifically, automated systems such as robotics can mitigate risks and impacts on the WHS of workers. For example, by minimising exposure to health hazards (such as dust, gases, toxic fumes, chemicals, harsh temperatures, levels and intensity of noise exposure, radiation and pressure) and physical hazards (such as works that could cause instantaneous death, or activities that could maim, disfigure or cause fatal incidents). Examples where the use of robotics provides protection include teleoperation of dangerous equipment (Lee et al., 2010) and reducing the need for intensive, physically hard and repetitive tasks, such as bricklaying and concrete reinforcement tasks that otherwise commonly result in back injury and other musculoskeletal disorders (Saidi et al., 2016).

While robotic technologies can play a crucial role in reducing injury and fatality rates and also improving productivity (Keay, 2018), a more interesting and far-reaching challenge is how to integrate robotics within a BIM-enabled environment.

Robots are "autonomous machines that move within their physical environments and manipulate objects" (Keay, 2018), while 'robotics' is defined as "the science of designing, building, and applying robots" (Jackson, 1990). The latter is an interdisciplinary area that includes the fields of mechanical and electrical engineering, computer science, social sciences, design, creative arts and law (Keay, 2018; Jackson, 1990).

Lee et al. (2010) classify robots into two groups:

1. those that conduct repetitive tasks based on a standard program
2. those able to work and co-exist with humans in atypical, unpredictable environments dissimilar to production facilities

Robots can also be classified as industrial or service robots. Industrial robots are used in industrial automation and are automatically controlled, reprogrammable, multipurpose manipulators that are programmable in three or more axes that are fixed or mobile for use in industrial automation applications. Service robots on the other hand, are semi-autonomously or fully autonomously operated for the well-being of humans or equipment.

In terms of construction robotics, Saidi et al. (2016) classified construction robots as either onsite or offsite robots and highlighted the WHS impacts that may result from onsite and offsite prefabrication systems, usage of drones and autonomous vehicles, and exoskeletons. An onsite, for instance, is defined as "*one that executes orders while moving around in a dynamic environment where structures, operators, and equipment are constantly changing*" (Lee et al., 2010). However, there has been slow adoption of these technologies due to high implementation costs to contractors and clients, weak business cases and lack of expertise (Delgado et al., 2019).

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A recent Australian study (London, Feng & Ang, 2018), exploring the potential of collaborative robotics in the housing sector in Australia, identified various strategies for onsite adoption And suggested that the future of robotics is in collaborative robots. In 1996, the name 'CoBot' was coined as a short form for Collaborative Robots (Peshkin & Colgate, 1999), defined as "*a robotic device, which manipulates objects in collaboration with a human operator*" (Peshkin & Colgate, 1999). CoBots are designed to be cognisant, agile and mobile (Rethink Robotics, 2018). They interact, collaborate and work closely with human workers, and are designed with the ability to be aware of and learn from their surroundings using sensors and intelligent systems. Subsequently, the rules embedded in a CoBot's programme that governs its behaviour provide the capacity for the CoBot to avoid collisions with humans and other physical obstructions in their surroundings. This helps to mitigate dangerous situations and addresses some WHS concerns (Rethink Robotics, 2018).

Augmenting robotic fabrication processes with sensors can also facilitate human-machine interactions. With the introduction of sensor technologies, dangerous processes may be interrupted by real-time feedback about the material's location and characteristics, the work environment and the location of co-workers (Dubor et al., 2016). Moreover, the human-CoBot collaboration and interaction provides in-depth and precise information about the material, context and user's movements (Dubor et al., 2016). Analyses of this wealth of information could enhance creativity and innovation in this area. With the introduction of lower-cost sensor technologies, CoBots could be adopted more widely, and their applications could be extended to other fields and industries.

The inter-relationship between robotics and BIM is in its infancy and yet the concept is extremely powerful for not only offsite but onsite construction, enabling the digitisation, automation and integration of the construction process at different stages (Oesterreich & Teuteberg, 2016). The UK tunnel project is an example that specifically aimed at integrating BIM with robotics, resulting in efficiencies and cost savings in relation to WHS. This project implemented a custom-built Segment Handling Plant (SHP, Harmill Systems), which used a robotic lifting arm that was fixed to a mobile work unit. All technical problems were identified by the three-dimensional (3D) BIM model and dealt with before the work commenced. The use of the SHP resulted in a safe and efficient changeover process enabling the project to be completed without compromising the WHS of the workforce or the safety of the public, and resulted in 15 % savings in planning, risk assessment, WHS and assurance costs.

Despite the prevalence of robotics in offsite prefabrication, robotics on the construction jobsite is generally rare. The National Robotics Roadmap states that the construction industry is in "*dire need of robotic vision*" and that "*Digital maturity is very low*" (Keay, 2018). While expectations are that even a small improvement to the efficiency of a process can result in substantial cost savings due to the large scale of construction projects, it is speculated that the conceptualisation of robotics in construction for the future requires more than a technological solution. It is a 'people-solution', involving dramatic changes to business processes, workflow, capabilities and mindsets.

The National Robotics Roadmap argues that Australia needs robotics technology "*as a force multiplier, augmenting and extending our world-class, skilled human capability while reducing human exposure to dirty, dull, and dangerous processes*" (Keay, 2018). While WHS, quality and productivity are enhanced with robots in a production system, the Roadmap notes that the productivity for person-robot teams is greater than either person teams or robot teams alone (Keay, 2018). Yet, the Roadmap does not indicate any research in Australia or internationally on the topic that focussed on the adoption of collaborative robotics.

Building Information Modelling and cloud computing

Cloud computing is a computing resource sharing technology (Mell & Grance, 2011) that is a relatively new development in the construction industry. The underlying idea of Cloud computing is to turn computing into services and offer such services as utility, similar to electricity, water and gas, to cloud users on an on-demand basis (Buyya et al., 2009).

As the results of contextual information received from WHS monitoring needs to be communicated simultaneously to workers onsite (Cho et al., 2015), cloud computing can play a crucial role in facilitating information sharing. For example, Fang et al. (2016) integrated RFID sensors, BIM, and cloud communication in an indoor construction WHS management system based on proximity-based location tracking. Similarly, Park et al. (2017) utilised BLE, motion sensors, and BIM to develop a low-cost indoor tracking system for conducting site inspections.

Another example incorporating cloud computing is Zou et al. (2017), who designed and developed a cloud-based Infrastructure Safety Information Management System (MapSafe) as a promising platform to improve the practice of WHS management in infrastructure construction projects (e.g., road construction). The MapSafe system functions include Pre-starting safety meeting recording, Permit to penetrate request and approval, Job safety analysis, and Safety incident reporting. The MapSafe platform has successfully integrated several currently available IT, including cloud computing, Geographical Information Systems and mobile technology, and offers an electronic method for collection and communication of WHS data and information. The MapSafe captured WHS data is stored and processed automatically in the Cloud. The processed WHS data and information can then be visualised on a map instantly, to allow real-time WHS decision making. The project WHS supporting information, such as design drawings in pdf format and BIMs, could also be easily accessed through the MapSafe interface, which is an advantage for data management.

A third example is Mutis and Paramashivam (2019), who proposed location detection utilising BLE technology, BIM-based automated hazard detection, and a cloud-based platform for real-time communication of contextual information collected from a construction site. A Cloud-BIM model provided a central access point for the workers and ensured data consistency (Mutis & Paramashivam, 2019), which is essential for efficient WHS management.

Cross country analysis of Building Information Modelling adoption

Although the concept of BIM has been around for some time, the levels of adoption vary between countries, between disciplines and even between clients. Coupled with the varying levels of adoption, the way in which organisations approach adoption across both technical and non-technical aspects plays a significant role in increasing the use of BIM (Gu & London, 2010).

As the use of BIM has been increasing across countries, governments have developed various BIM standards and policy initiatives to guide both private and public sector adoption. Particularly important standards include:

1. PAS 1192 (UK)
2. The National BIM standards (US)
3. Common BIM Requirement (COBIM) (Finland)
4. Singapore BIM Guide (Singapore)
5. National Building Specification (NATSPEC) National BIM Guide (Australia)
6. Statsbygg BIM Manual (EU)

At the international level, ISO has developed international ISO standards based on the UK BS/PAS 1192 series.

United Kingdom

Up until 2016, the UK Government mandated Level 2 maturity BIM adoption for government funded projects up to a certain project value in line with the British Standards Institution's (BSI), Publicly Available Specifications (PAS). The BSI PAS documents define good practice for products, services and processes, and help establish consistency and integrity through universal approaches across the country. Of particular note for this study is 'PAS 1192-6: Specification for integrated and collaborative sharing and use of WHS information using BIM' (BSI, 2018), which supports the development of structured WHS information for Construction projects using BIM.

However, this mandate has since ceased as the UK has moved to promote BIM Level 2 as part of normal operations and is developing strategies for a fully digitised construction industry (NBS, 2020b).

Since 2018, the BSI PAS 1192 series is progressively being replaced by the International Standards Organisation's (ISO) 19650 series. Three international standards in this series have been published and another two are under development at time of writing:

- BS EN ISO 19650–1: Organization of information about Construction works – Information management using building information modelling – Part 1: Concepts and principles
- BS EN ISO 19650-2: Organization of information about Construction works – Information management using building information modelling – Part 2: Delivery phase of assets.
- BS EN ISO 19650–3 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – information management using building information modelling – PART 3: operational phase of the assets [UNDER DEVELOPMENT]
- BS EN ISO 19650–4 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – information management using building information modelling – PART 4: information exchange [UNDER DEVELOPMENT]
- BS EN ISO 19650–5:2020 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – information management using building information modelling – PART 5: security-minded approach to information management

The three new standards are founded on the UK's standards for information management using BIM; BS/PAS 1192-1 (principles), BS/PAS 1192-2 (delivery phase) and BS/PAS 1192-5 (security).

To support digitisation of the construction industry, two new programs of work were established in 2016-2017. Firstly, the UK BIM Alliance promotes Level 2 BIM as part of normal operations and, secondly, Digital Built Britain (DBB) promotes new initiatives. In 2019, the UK BIM Alliance, BSI and the Centre for DBB announced the launch of the UK BIM Framework. This framework sets out a guided approach to implementing BIM in the UK and managing information provided by the BS EN ISO 19650 series.

Scandinavia

BIM was first used in Finland in 2002 and as early as 2007, it was made mandatory for design software to pass Industry Foundation Class (IFC) certification. IFC is a software file format that can be used across different software applications, allowing teams to share models and collaborate while still working independently. In 2012, Senate Properties migrated the BIM Requirements for Architectural Design into the Finnish National BIM Guidelines (COBIM). Similarly, Norway has been using IFC file formats and BIM in their projects since 2010.

United States

The US was one of the first countries to implement BIM. However, the lack of national standardisation slowed down its progress. It was in 2003, through the Public Building Services, that the General Services Administration established a 3D/4D/BIM program that released limited guidelines for the construction industry. In recent years, the National Institute of Building Sciences has made considerable progress in ensuring the adoption of BIM in the US.

Singapore

Singapore's nationwide BIM implementation roadmap was first laid out in 2011. BIM is increasingly being used in public sector building-projects and since 2015 it is mandatory for all building projects larger than 5,000 m^2 to incorporate BIM. Another important initiative was the Building Information Model Fund administered by the Building and Construction Authority, which aimed to boost the uptake of BIM by construction firms across Singapore by supporting training, consultancy, software and hardware cost for projects

Hong Kong

The Hong Kong Housing Authority piloted BIM around 2006 and the Construction Industry Council (CIC), a government agency, has been promoting BIM adoption across the sector. It has developed CIC BIM standards based on international standards like the PAS 1192 series, and the Singapore BIM guide. Since 2018, all government projects valued over $30 million are required by legislation to include BIM in their design and construction.

Australia

Australia has gradually adopted BIM, with the most significant growth occurring between 2010 and 2020. During that time a number of key organisations including the Australasian Procurement and Construction Council (APCC), Australian Construction Industry Forum (ACIF) and the Australasian BIM Advisory Board (ABAB) were established to promote the use of BIM in the construction industry.

As early as 2003, the Collaborative Research Centre for Construction Innovation led many early BIM initiatives in Australia. One of the first initiatives in the policy area was the creation of the National BIM Working Party, which reported to the Built Environment Industry Innovation Council in 2010. In 2015, the APCC, in partnership with the ACIF, launched the 'BIM Knowledge and Skills Framework' and in 2017, established the ABAB, together with the key standard-setting bodies NATSPEC, buildingSMART and Standards Australia.

The ABAB consists of stakeholders from government, industry and academia who partner to provide expertise and leadership on the adoption of BIM and Project Team Integration (PTI). PTI is an approach that facilitates collaboration among participants at the earliest stages of the project for better efficiency. It supports best practice through advocating a consistent approach to BIM practices, standards and requirements, as well as a holistic approach to the national adoption of BIM in Construction. It is through the' Australian Strategic BIM Framework' that all state and territory governments commit to improving procurement methods to allow for the adoption of BIM. As exemplars, they commit to adopt a nationally-consistent approach to BIM in the procurement of government-initiated building construction, infrastructure and management projects.

The Australian Strategic BIM Framework was launched in March 2017 to incorporate the various guideline developed since 2010. Included were the NATSPEC 'National BIM Guide and BIM Management Plan Template', which clarify BIM requirements to all project stakeholders, inclusive of clients and consultants, in a nationally consistent manner. Also, in 2017, the buildingSMART National BIM Initiative launched BIMcreds, which provides BIM practitioners with a framework for demonstrating their competence. BIMcreds is designed to be used in conjunction with the APCC/ACIF BIM Knowledge and Skills Framework.

In 2014, Sustainable Built Environment National Research Council developed a 'Towards a National Strategy' that continues to guide the development of an Australian national strategy for BIM adoption. It also developed the 'BIM Value Tool', with NATSPEC, to support practitioners who want to implement BIM and understand how BIM will be useful for them.

As a result of joint efforts by the ACIF and the APCC, the ABAB has more recently developed the 'Framework for the Adoption of Project Team Integration and Building Information Modelling' and 'Building and Construction Procurement Guide' with a predominant focus on BIM and PTI. The APCC and ACIF see their role as mediators between industry interests and government requirements, with a focus on legal, procurement, collaboration and process-related topics (ABAB, 2020).

The array of BIM documents and guidelines available provide guidance for Australian public and private sector clients and construction industry professionals on BIM implementation, however, the nature of the material is, generic to the construction process and lacks specific guidance in relation to WHS management. Given the critical importance of improving WHS in Construction, both nationally and internationally, and the increasing global uptake of BIM it appears the integration of WHS in BIM is an area that should be further explored to facilitate better WHS outcomes.

Models of Building Information Modelling adoption

There are various approaches to understanding, analysing and improving BIM adoption presented in the research literature. Since 2010, the literature has grown exponentially. The following is a summary of some of the more prominent approaches to provide context to drivers for adoption of procurement models and recommendations that will eventually be proposed as part of this project.

As early as 2009, Succar proposed a tri-axial framework of domains for BIM knowledge that outlines a multi-dimensional relationship between three main axes: BIM fields, BIM stages and BIM lenses. BIM fields identify domain players, their requirements and deliverables, BIM stages outline minimum capability benchmarks, whereas BIM lenses provide the breadth and depth of information required to access BIM fields and BIM stages. As this framework has a comprehensive coverage of BIM domains of knowledge, it was a "scene setting" framework that provided a research and delivery foundation for many industry stakeholders early on.

In the following year, Gu and London (2010) analysed industry readiness to BIM with respect to the product, processes and people. They proposed four key parts within the Collaborative BIM decision framework:

1. Defining scope, purpose, roles, relationships and project phases
2. Developing work process roadmaps
3. Identifying technical requirements of BIM and customisation of the framework
4. Evaluating skill

The framework was developed in close partnership with industry through the Cooperative Research Centre (CRC) Construction Innovation program and extended by London with further Victorian state-funded studies that developed implementation detail from a large infrastructure construction contractor perspective. The framework had 11 elements. While there is no customised tool available, a Fact Sheet that explains the purpose, context and operation of the Element has been developed for each Element. Gu and London (2010) moved the academic decision framework, partially developed in the CRC Construction Innovation, through empirical investigation to an implementable decision framework of adoption for companies. The research approach was specifically designed to enable impact and knowledge transfer by following innovative action research methodologies.

More recently, specifically to the use of BIM for WHS management, Olugboyega and Windapo (2019) developed a BIM-enabled safety culture model based on research articles as a dataset. Construction safety culture may be defined as "*a set of beliefs and values that influence safety-related behaviours and perceptions of construction workers, and associated parties*" (Fang & Wu, 2013). Olugboyega and Windapo's (2019) model comprised of the following core dimensions; (1) safety management system, (2) safety behaviour, and (3) safety climate. Safety climate reveals the safety culture as it relates to safety behaviours that are a result of an effective WHS management system in any workplace. Their stage-based model revealed that BIM-enabled construction safety culture is improved through visualisation, simulation, animation, digital fabrication, and virtual reality. With all stages being important, it was revealed that the most critical dimension was 'safety behaviour', as a central aspect of ensuring construction safety culture.

Barriers to adoption

Despite the numerous benefits, BIM adoption has its own set of challenges. It is useful to understand the significant body of research that has been conducted on the adoption of BIM technologies in construction and the barriers to industry and government uptake when seeking to introduce a BIM-enabled environment for WHS management. Research studies have categorised barriers according to common characteristics, for example, people, process and product barriers (Lindblad, 2013) or technical, social context, process-related, and work practice issues (Gu and London, 2010). More recent research has added categories such as contractual and legal barriers.

More specific examples of these barriers are; the lack of expertise in BIM within organisations (Zahrizan et al., 2013, Chan, 2014; Tan et al., 2019; Wang et al., 2015); the fragmented nature of the construction industry (Gu and London, 2010); the lack of standardisation (Zahrizan et al., 2013; Chan, 2014; Tans et al., 2019; Wang et al., 2015; high costs (Azhar, 2011; Coates et al., 2010; Yan & Damien 2008); the lack of collaboration among stakeholders (Tan et al., 2019; Wang et al., 2015); legal and contractual issues around ownership and intellectual property (Christensen et al., 2007; Furneaux, & Kivvits, 2008; Oluwole, 2011); the lack of client demand (Wang et al., 2015, Zubrizan et al., 2014); resistance to change (Abubakar et al., 2014, Watson, 2010; Yan & Demian, 2008), and the lack of training and learning (Abubakar et al., 2014; Azhar, & Bahringer, 2013; Chan; 2014).

Barriers to the adoption of BIM for WHS management are interlinked with the drivers for its adoption and understanding both, along with developing appropriate responses to encourage uptake, will facilitate future higher levels of BIM adoption. This paves the way for unified action by policy makers, industry and stakeholders alike to achieve the common goal of better WHS management in the construction environment.

Drivers for adoption

Understanding the drivers of BIM adoption is important to influence the intention and decision by stakeholders to adopt BIM (Ahmed & Kassem, 2018). Research has identified several examples of drivers, such as the increasing client interest in BIM (Eadie et al., 2013; Hamma-adama & Kouider, 2019), cost savings (Eadie et al., 2013; Hamma-adama & Kouider, 2019), government mandates (Eadie et al., 2013; Hamma-adama & Kouider, 2019), guidance by professional bodies (Oladapo, 2007), and the availability of trained professionals (Badrinath et al. 2016; Macdonald, 2012).

Research indicates that pressure from a variety of sources; government, market competition and clients; are important factors in driving BIM adoption. This demonstrates the importance of government strategies in promoting BIM-adoption and implementation, as evidenced in the Australian Strategic BIM Framework. BIM adoption is also influenced by many operational drivers; clients and major contractors tend to adopt BIM due to the time and cost savings that can be achieved, as well as clash detection and improved design quality (Eadie, et al., 2013). Over time, each driver has contributed to the uptake and adoption of BIM in the construction industry. These drivers provide important insights for policy makers and construction stakeholders, to make informed decisions and policy recommendations that are capable of positively influencing increased BIM adoption by the construction industry.

Application of BIM to improve Work Health and Safety

Table 4 below outlines some interesting exemplars in countries that are at the forefront of research in construction WHS management using BIM. The US has been a significant contributor in this field and its collaborative links with the UK, Australia, South Korea, Germany and Spain have also influenced research efforts in this area (Akram et al., 2019). A review of the literature indicates the research focus combining BIM and WHS has been predominantly within the planning and design phases of the project lifecycle (Akram et al., 2019). Table 4 provides a limited summary of relevant studies of BIM and construction WHS from these countries. This is not an exhaustive list of research studies in this area. Rather, the table depicts how different researchers and industry practitioners have utilised BIM to ensure better WHS on construction sites.

Table 4: Summary of the use cases on application of Building Information Modelling (BIM) to enhance Work Health and Safety (WHS) performance in various countries.

Countries	Phase	Focus Area	Approach	Authors (year)	Summary
Finland	Construction	Fall prevention	Visualisation	Sulankivi et al. (2010)	4D-BIM for construction safety planning
	Design	Fall prevention	Rule Algorithm/ Case study	Zhang et al. (2013)	Automatic safety checking through construction models and schedules
Hong Kong	Design	Risk detection	Risk recognition mechanism/ Case study	Li et al. (2018)	An automated safety risk recognition mechanism for underground construction at the pre-construction stage based on BIM
United States	Design	Fall prevention	Rule checking/ Case study	Melzner et al. (2013)	Automated safety compliance checking to assist fall protection design and planning in building information models
	Design	Safety hazards	Algorithm/Case study	Kim et al. (2016)	Integrating work sequences and temporary structures into safety planning: Automated scaffolding-related safety hazard identification and prevention in BIM
	Design and Construction	Risk Detection	Visualisation/algorithm /Case study	Shen and Marks (2016)	Near-Miss Information Visualisation Tool for BIM
Australia	Design	Risk Detection	Prevention through Design Prototype	Kamardeen (2010)	The system architecture of an 8D modelling tool for BIM-based Prevention through Design.
	Design and Construction	Fall prevention	Algorithm/Case study	Shou et al. (2015)	BIM-based dynamic scaffolding design and safety prevention.
United Kingdom	Design and Construction	Risk detection	Case study	Health and Safety Executive, (2018)	Improving Health and Safety Outcomes in Construction decision making/ value propositions of BIM

Countries	Phase	Focus Area	Approach	Authors (year)	Summary
Spain	Design	Safety hazards	Visualisation/ Methodology	Cortes-Perez et al. (2020)	BIM-integrated management of occupational hazards in building construction and maintenance

Finland

As noted previously, Finland has been at the forefront of BIM adoption internationally and is considered a leader of the BIM movement. In Finland, significant progress was made when the Technical Research Centre of Finland (Sulankivi et al., 2010) introduced a manual procedure to support the use of BIM technology for WHS risk management. A specific example was developed whereby the Technical Research Centre visualised BIM-based 4D safety railings for fall prevention in Tekla Structures. This involved preparing a building model and establishing connections between the model objects and the schedule. By applying rules, safety hazards were identified.

In another example from 2013, Zhang et al. developed a framework of automated safety rule-checking algorithms for BIM proposing four major stages to rule checking:

1. Rule translation stage, which involves interpretation of rules and logical structuring of rule
2. Model preparation stage, which involves the necessary information required for rule checking
3. Rule execution stage, which involves rule checking against the defined models
4. Reporting stage, which involves the production of graphical reports

This rule-checking algorithm was then tested in two case studies (Zhang et al., 2015). In the first case study using a model of an office, a comparison of manual vs. automated safety modelling of fall protective systems was presented. The second case study provided results of applying the framework to the project schedule of a residential building in Finland. This second case study used simulated fall-4D design to formulate an automated safety rule checking system. This system helped identify risky locations in 3D-space and provided solutions to interactively overcome the identified hazards.

Hong Kong

Anecdotal evidence indicates that Hong Kong researchers and government have been involved in application of BIM for WHS management for more than a decade. One such example is that of site safety management as part of the BIM specification for the Hong Kong Airport project. The contractors aimed to achieve Level 2 BIM maturity. This specification included WHS managements using a 4D-model as a visual tool to assess conditions, and identify hazards and risky areas that might not otherwise be realised until the work begins.

Further, Li et al. (2018) proposed an automated WHS risk recognition process based on BIM for collection and sharing of risks for underground construction. This was composed of three parts. The first part was to build the risk knowledge database from available safety risk knowledge sources. The second part was to study the relationship between engineering information (retrieved from BIM) and safety risks. The safety risks were categorised into three types: (1) technical risks, (2) geological risks and (3) environmental risks and engineering information was categorised into four types: (1) project characteristics information, (2) construction and technique information, (3) geology and hydrological information, and (4) construction environment information. Engineering information and safety risks were then linked. Finally, through automated safety-risk-recognition mechanisms, the risk level was identified based on the confidence values. In this, the confidence levels act as a bridge to link project information and risk knowledge.

United States

Using both German and US standards, Melzner et al. (2013) analysed fall protection rule-checking systems regarding holes in slabs and leading edges on high-rise building models. They applied two rules: Rule 1 was related to protecting workers from falling into holes. Rule 2 was related to protection on slab edges. An algorithm was developed for fall protection and structured in the following way. First, the attribute type 'slab' or 'hole' will detect all objects that have such names. Then, the rule-checker was able to check the geometrical attributes related to them. If there is a hole detected, the algorithm will apply the first rule. If an unprotected edge is identified, Rule 2 will be applied. After the application of the rules, the results can be visualised in the virtual building model. The automated safety rule checking system will then show all the identified hazards and automatically apply protective equipment to holes and leading edges. The reports generated can depict where, when, what, and how much equipment is required for fall protection for any project or organisation.

Simulation and visualisation have also been important developments in BIM-enabled WHS management research. Kim et al. (2016) created a WHS planning platform to simulate and visualise spatial movements of work crews using scaffolding. In this case study, the development of algorithms within this platform enabled the identification of WHS hazards that were not normally noticed by workers participating in the study. The results were visualised in the developed safety planning platform to communicate early WHS instructions.

A framework for near-miss data collection and visualisation within a BIM environment has also been developed in the US (Shen and Marks, 2016). A near miss may be defined as "*an incident where no property was damaged and no personal injury sustained, but where, given a slight shift in time or position, damage and/or injury easily could have occurred*" (Occupational Safety and Health Administration, 2002). The database in BIM was created where construction-site personnel reported near misses. Algorithms were created to enable filtering for visualisation based on user input properties. This near-miss visualisation user interface allowed construction personnel to view near misses throughout the construction phase to locate hazardous areas and the frequency of near misses.

Australia

A study by Kamardeen (2010), applied the concept of Prevention through Design by using an eight-dimensional (8D) modelling BIM tool. The 8D BIM model included 3D information combined with time, cost, facilities management, and WHS management. Kamardeen's (2010) particular tool aimed to perform hazard audits on BIM models and then exhibit hazard profiles for elements that could be rated as one of three levels of severity; critical, moderate or low. This prototype tool also made suggestions for design revision, resulting in elimination of hazards.

Shou et al. (2015) demonstrated a commercially available BIM-system by integrating the BIM scaffolding design with algorithms that align with local state WHS regulations, producing a scaffolding design for fall-prevention purposes. The first step was to identify and generalise the potential risks from the existing WHS Codes of Practice. Then, they applied the LEC hazard assessment method (Dai et al., 2006) to rank identified risks associated with different scaffolding activities. The LEC method specifies that the level of danger (D) is the product of the likelihood (L), the frequency of personnel exposure to risk (E), and the consequence of the risk materialising (C; i.e., $D=L\times E\times C$). This approach enhanced worksite WHS by implementing an automated rule-checking process of erecting scaffolds and providing a smarter scaffolding erection plan.

United Kingdom

One example of the use of BIM for WHS management in the UK is the Thames Estuary Asset Management 2100 (TEAM2100) project. In this project, a Common Data Environment was used to capture information about flood defence assets and WHS. All information was stored in the common Construction Operations Building Information Exchange (COBie) format, enabling all stakeholders to access the information for the duration of the project. COBie is a non-proprietary data format focussed on providing asset data that is different from geometric information. During field inspection, all data recorded on iPads was uploaded for editing in a GIS-based information system. This allowed it to be linked to COBie where it could then be retrieved and reused for hazard and risk information over time, and thereby facilitate safer maintenance activities. (HSE, 2018).

In another application, Costain, a large contractor, used BIM and GIS to identify WHS hazards when working on a live railway. GIS helped with visual images and scans, whereas BIM was used to communicate hazards and safe working practices. This was achieved by highlighting 'Hazard Triangles', which were linked to the live risk register and colour-coded based on severity (high / medium / low risks were coloured red / yellow / green, respectively). As a risk is eliminated, the colour code of the risk changes, providing a live environment for WHS communication (HSE, 2018).

Another example is the implementation of BIM by the Skanska Balfour Beatty Joint Venture and Atkins on the upgrade of selected sections of the M25 in London. Firstly, all existing infrastructure was modelled in 3D with specific details. This 3D model was then integrated in AutoDesk Navisworks and an automatic clash detection function helped identify conflicts. This resulted in hazards being identified and eliminated or reduced even before any work begun. Further, these BIM models were used onsite as well as during the construction phase to facilitate training, everyday briefings, and evaluation of the impacts of the design on WHS. This demonstrates that the visualisation capability of BIM can be harnessed to enhance creation and sharing of knowledge and understanding of WHS hazards and risks (HSE, 2018).

Spain

Cortes-Perez et al. (2020) proposed a methodology to integrate the requirements of the Spanish WHS regulations in the design phase of building projects using BIM. In this case, Autodesk Revit was used to consider WHS in a model of a building with three storeys and a basement.

A specific WHS subdiscipline was introduced to manage the graphic and non-graphic information in a WHS model. WHS parameters were created and associated with all views of the model related to WHS. The Spanish WHS regulator's risk identification criteria, which had 32 parameters, was used to assess the risks of the project in the BIM of the building, coded from 1 to 32 for each risk. These parameters were of the "yes/no" type and linked to each relevant element of the model that was to be constructed. Execution phases were then introduced to the model to allow each preventive measure to be associated with the corresponding execution phase. Based on the WHS regulator's methodology, the WHS design co-ordinator could assign a risk parameter to each BIM object of the model with a value of 1 to 32. This risk parameter is the product of the probability and severity, with probability rated as 1, 2, or 3, for low, medium, or high probability, respectively, and severity rated as 1, 2, or 3 for slightly harmful, harmful, or extremely harmful, respectively. Based on the risk parameters, preventive actions could then be adopted. Moreover, colour classification of the risk parameters helped with quick visualisation of risk management and implementation of preventive actions.

The preventive actions could take the form of work procedures, standards, instructions, and personal protective equipment. These were introduced to the model and linked to the relevant BIM objects. These actions helped the WHS Coordinator to link all risk parameters and all information of the preventive actions along with required equipment to be collected. This process facilitated the risk management by assisting identification and elimination or reduction through better understanding of the means and preventive actions required by regulations.

Procurement strategies in a Building Information Modelling-enabled environment for Work Health and Safety management

The use of procurement as an instrument to further the adoption of WHS practices using BIM has received scarce attention to date. Although several standards have been developed for WHS, only limited guidance is available on how to incorporate them into BIM and procurement. This section seeks to address how WHS and BIM can be integrated into procurement and tendering, so that compliance with WHS regulations can be effectively addressed. It focusses on describing procurement and tendering as key catalysts and drivers to adopting a WHS management approach using BIM. It also explores the important role the client can play at the procurement stage to ensure better WHS on construction projects.

Client's role in managing Work Health and Safety through procurement

Construction clients are well positioned to lead WHS management through procurement. In recent years, there has been increasing emphasis on clients to ensure WHS on their construction projects, highlighting the need to consider WHS through procurement as a management strategy. This responsibility is to a large extent dependant on all stakeholders fulfilling their obligations and extends to all participants in the construction supply chain, so that the interests of the client are safeguarded and legislative requirements are met. Clients with a significant portfolio of capital works projects can thus influence WHS behaviours and practices across the entire construction supply chain by taking a leadership role in creating a safe environment and supportive safety culture, along with good processes and procedures to meet their statutory obligations. Similarly, clients can influence BIM adoption (London, 2008) as an incentive to effective WHS management.

Client influence can manifest through communicating safety expectations, selecting consultants and contractors who are competent in designing the appropriate systems, and participating in the safety management process (Huang and Hinze, 2006). The International Labour Office Code of Practice (1992) provides that clients should nominate appropriate persons to coordinate activities relating to construction WHS and provide up-to-date information about any risks to safety. Clients can also ask bidders to include the cost of safety measures in their construction bids.

At the tendering stage, tenders are often awarded to the lowest bidders and there are various justifications for doing so. In some cases, the rationale is that the invitation to bid has only been provided to those who have already been assessed and considered to be of a certain quality to provide the services and products or systems at the appropriate standard. It is questionable that this approach is the practice maintained consistently for all projects, markets and submarkets. Bidding and procurement are complex areas of research and a large body of theory has developed over many years. However, it is useful to discuss briefly some critical concepts to aid understanding of their influence on the adoption of BIM for WHS management.

Despite the existence of national and international standards and guidelines of best practices in WHS, in many cases, attention to WHS requirements during procurement only occurs in a 'fragmented' manner. A small and focussed study by Deacon and Smallwood (2016) in the South African construction industry described this fragmented approach and established that it has resulted in a lack of integration of WHS during design, tendering and construction phases, and thus varying degrees of compliance. The lack of WHS integration and legislative compliance across construction phases places greater onus of risk on the client, should there be any injuries or fatalities linked to the lack of inclusion during design and tendering (Deacon and Smallwood, 2016). WHS should be valued by stakeholders and given equal status with project cost, quality and time. Equal status can be achieved by the client ensuring WHS requirements are met at all levels of decision making (Smallwood, 2019).

To win bids, contractors try to reduce the costs for their overall bid and WHS is often penalised in the process (Wells and Hawkins, 2010). This practice may lead to a vicious cycle of cost-cutting during the construction process and, eventually, injuries and fatalities (Rowlinson, 2004). To ensure adequate WHS, it is critical that the client develops a clear policy for safeguarding WHS on their construction project. WHS requirements should be clearly explained in the invitation to tender documents, with specific requirements detailed. The policy should be widely distributed so that the procuring officers and potential tenderers fully understand the client's priorities. The tender may need to include a site-specific WHS plan, procedures to be adopted to ensure that WHS requirements are met by all, and a system and format for recording incidents and injuries. Smallwood and Emuze (2013) indicated that clients can play an important role in setting the level of standard of WHS on projects, as they are key stakeholders and can be influential through the tone and the form of contract they enter into, from the very beginning. Lingard et al. (2019) concluded that institutional dynamics play a pivotal role in determining how clients ensure WHS safety is considered in the projects they procure. Clients who promote collaborative arrangements can enhance WHS practices on their projects and support innovative strategies that not only promote WHS but help improve overall project efficiency.

Governments play a major role in preventing work-related fatalities and injuries by promoting, legislating and enforcing WHS regulations in workplaces. Government agencies in Australia provide leadership in WHS through their commitment to the Australian Strategic BIM Framework and play a significant role in fostering safe design. As clients on major public sector projects, government procurement processes should be such that they help identify and prevent WHS risks in the workplace. The safe design process aids this by involving decision makers and considering WHS risks throughout the lifecycle of the structure.

Aligned to this, the Office of the Australian Safety and Compensation Council has developed a model of better practice WHS in procurement. The outlined model (including various tools, contract clauses, checklists, and information) acts as a guideline to encourage governments and contractors to incorporate WHS and safe design considerations into their procurement processes (Australian Safety and Compensation Council, 2006). However, the guideline does not specifically discuss project procurement strategies that provide for different contractual arrangements, roles and responsibilities. This might be a useful extension that would assist with the next phase of BIM-enabled WHS management implementation. In summary, it is apparent that clients are important change agents and their adoption of best practices for ensuring WHS during procurement can strongly influence the way industry adopts new practices to ensure better WHS management. Clients are therefore expected to use their power and influence to drive change among their project stakeholders.

Procurement methods and Building Information Modelling integration

Research into the domain of identifying optimal procurement methods for incorporating BIM for effective project delivery is gaining momentum. Kuiper and Holzer's (2013) study about the relationship between uses of BIM and procurement strategies revealed that integration across the supply chains and collaborative risk sharing are the ways forward. Their study presented various procurement strategies on a continuum, from traditional forms to relationship contracting, and indicated that the alliancing strategy yields the greatest opportunity for BIM integration. Alliancing is a collaborative type of agreement between two or more partners, which facilitates alignment of common interests for collective sharing of rewards and risks. In traditional forms, the individual responsibility of specific risks falls to the participants who individually manage them. The alliancing approach of collective risk sharing provides a good foundation for collaboration, which is essential for successful implementation of a BIM environment.

In a later study regarding the appropriateness of different procurement types that can be applied to BIM projects (e.g., Design–Bid–Build, Design and Build (DB), and Integrated Project Delivery (IPD)), Holzer (2015) extended his previous research and revealed that IPD and DB are the optimal procurement routes for integrating BIM as a project delivery tool. Design-Bid-Build is also known as Design-Bid-Construct (commonly referred to as 'traditional') and DB is often referred to elsewhere as Design and Construct. IPD is a procurement term that was developed and mainly used in the US. It is considered well-aligned to successful BIM adoption (Holzer, 2015), yet DB is the more commonly used procurement strategy (Bynum, Issa &Olbina, 2013; Holzer, 2015; Sebastian, 2011). IPD is a delivery approach that;

> *"integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction" (American Institutes of Architects, 2007).*

The key characteristic for an IPD procurement strategy is that the contractual arrangement calls for an integrated contract between the owner/client, architect and contractor. The arrangement relies upon a risk/reward and value/cost approach, which incentivises innovation and creativity in the early phases and then efficiency of execution in the construction phase.

In Australia, project organisational and procurement strategies such as Public Private Partnerships and alliances have been adapted to accommodate the integration of BIM in contracts. Public Private Partnerships are collaborative arrangements between government and the private sector for delivering public projects, such as infrastructure and related services. These type of procurement strategies fall within the umbrella of 'relational contracting' and appear to be more conducive to creating a BIM-enabled environment. To date, the combination of procurement strategy, tendering procedures and outcome has not been evaluated in Australia. Significant effort has been applied to the development of guidelines and it would be worthwhile to assess the performance of these guidelines in enabling WHS management using BIM.

Tendering and specifying for Building Information Modelling

Depending on the preferred procurement method, it is important that the client makes clear its BIM-environment intentions at the tendering and specification stage. This can be achieved by outlining WHS requirements clearly in the employer information requirements (EIR) documents. The EIR is a document that must be followed by all stakeholders on the project and on which the contractors should develop and submit their initial BIM execution plans (BEPs). In the BEP, the contractor must specify how it proposes to achieve the client requirements. Together, the EIR and BEP are crucial documents for assessing the quality of tender responses (Mirarchi et al., 2020). The EIR should define what models are to be produced at each project stage and to what level of detail. These models will then provide information to the client at all defined stages of the project lifecycle (NHS, 2017). Including BIM requirements in the tendering documents requires owners/clients to provide more clear and precise information about the required deliverables (Mayo & Issa, 2014).

Advantages to both the client and the contractor of using BIM in construction contract tendering include the ability of BIM modelling to provide an easier and clearer visualisation of the project to clients, who may not be experienced with construction and engaging with the industry. Moreover, having all project information stored in one place makes it more easily accessible and retrievable. It also makes compliance checking using model checking tools easier, more transparent, and fair.

Rule-based software are indeed powerful tools, as they enable clients to customise rules and verify both geometrical and conceptual requirements. This also benefits bidders, who can utilise the tools for self-assessment prior to submission. As an example, Bolpagi (2013) analysed the possible implementation of BIM within public procurement in Finland, with particular focus on how model checking can be applied within tendering to verify compliance between the client's requirements and the bid's content. The Solibri Model Checker, a software that provides the opportunity to customise built-in rules, was used for assessing bidders' proposals and to find possible errors and contradictory information.

More recently, Costa and Grilo (2015) developed an e-procurement system that aids clients to initiate an e-tendering process using a BIM model. In this system, a detailed BIM model is required where every BIM element must include related information. It is easy thereafter to initiate the e-procurement process by selecting BIM elements and asking user questions for the tender. Bidders can also submit tenders using the BIM model. In this way, a bidder may attach all information about products to be used and their costs. This results in improved information management flow and enhances collaboration. The level of transparency required by the e-procurement system may be challenging and perhaps naïve in response to how tendering down the construction supply chain actually takes place in extremely competitive tendering environments. Hence, relational contracting methods, like the one described above, are more common.

Summary of Building Information Modelling procurement by Australian state government agencies

Having recognised the increasing benefits and potential for the wider application of BIM, Australian governments have in recent years actively supported its use and integration through the procurement of government-funded construction and infrastructure projects. For approximately 15 years, various government agencies and professional industry organisations have actively promoted BIM awareness and skills development for construction professionals to influence the uptake of BIM and its application across all stages of the project lifecycle.

New South Wales

In NSW, Transport for New South Wales (TfNSW) implemented BIM through its digital engineering (DE) framework, having rolled out various transport cluster projects since 2018. The adoption of its DE framework has resulted in best-practice data and information management and its strategy has led stakeholders to make more informed and consistent management decisions. TfNSW has been instrumental in driving adoption of the principles of the BS EN ISO 19650 series on NSW construction projects by applying the Standard across its projects. TfNSW's framework specifically outlines procurement as a key area for development in order to ensure a consistent approach to new projects. For example, TfNSW has standard contract templates for use on DE-enabled projects and provides a suite of documents and standards to support the contractor. By adopting an integrated procurement process, complexity is reduced and consistency is developed, thus improving tender responses and clarity during project start-up (DE, 2018).

Victoria

The Victorian government released the Victorian Digital Asset Strategy (VDAS) in 2019 to aid the adoption of BIM in construction. The strategy is tailored to match that of the UK's BIM Level 2 mandate and aims to achieve standardised systems and templates. The VDAS seeks to implement BIM in line with the ISO 19650 series and its procurement and workflows document provides detailed flowcharts aligning the flow of information between the appointing and appointed parties. This document mainly outlines the steps that involve the appointing party, defining their organisational information requirements and the drafting of an EIR, which is then combined with the responsible, accountable, consulted and informed (RACI) scope checklist in the tender invitation document. The tender participants are required to prepare a response by completing a Digital Engineering Execution Plan and RACI scope checklist. The appointing party then responds with a DE execution response and awards the contract accordingly (VDAS, 2019).

Queensland

The Queensland government has approached BIM adoption with a whole-of-government focus, enabled by the document 'Digital Enablement for Queensland Infrastructure - Principles for BIM implementation', which was released in November 2018. The principles apply to all stakeholders involved in the lifecycle of any new major construction projects, including the planning, procurement, design, contract management, construction, and maintenance of the assets. The Queensland government is committed to a staged adoption of BIM through these principles over five years, from 2018-2023 (DSDMIP, 2018).

South Australia

The South Australian government introduced BIM through the procurement process for the construction of the Royal Adelaide Hospital, upon which construction commenced in 2011 under the South Australia Public Private Partnership framework. BIM was requested in the tender and tenderers were made aware of the prerequisite to provide all information in an Autodesk Revit format. Tenderers were also asked to provide relevant examples of their Revit Library Content. The model provided a centralised database that provided a single source of information throughout the whole project lifecycle. Successful completion of this project showed that the construction of large-scale buildings requires considerable collaboration strategy and clearly coordinated plans between design, engineering, construction and information technologies professionals. An integrated management system was the key element that helped successfully deliver this large and complex project (Redwood et al., 2017).

Assessment of Work Health and Safety in procurement

To date, the advice in relation to client support on WHS integration has not been extensively considered in procurement guidelines on BIM and WHS. Moreover, collaboration and sharing between project stakeholders of structured WHS information across the project lifecycle has been slow to evolve. As Australia moves towards adopting BIM for WHS management, it may gain insights from its international equivalents. It is important to understand that while the most recent ISO 45001 sets out the WHS framework at the international level, it is standards such as the UK PAS 1192-6 that outline the mechanisms by which the ISO 45001 health and safety management system may be applied using BIM. The UK PAS 1192-6 is an exemplar that provides guidance on applying WHS information through BIM processes and applications, ensuring safer worksites and reduced injuries and fatalities. The UK PAS 1192-6 models a collaborative approach, specifying the requirements of sharing of structured WHS in any construction project between the client, designer, contractor, commissioner and end user. It acts as a guide framework on how WHS information in a BIM environment should be produced and how it should flow across the project lifecycle. It places the onus on the client to clearly identify upfront the objectives and WHS requirements of the project. Where clients consider using BIM to assist in the fulfilment of their WHS obligations, they should ensure scope and risk allocation are clearly set out in their EIR. The UK EIR template has a section specifically for Health and Safety and Construction (Design and Management) Regulations, which assists the client in defining how BIM will support WHS regulations monitoring aligned with different phases of the project. Details of how all related data can be captured and recorded are also documented. Furthermore, the 'BIM 4 health & safety' working group has outlined ten questions that a client should include in its EIRs to help prioritise the key WHS issues in line with the UK PAS 1192-6 standard. The checklist is aimed at developing client understanding of how to integrate WHS management in BIM, with the assumption that it is easier to assess WHS management in a BIM-enabled environment when it is integrated in the tender documents in a holistic manner, rather than when WHS management is contained within a standalone document. All in all, there is potential for incorporating WHS management in BIM at the procurement stage as clients can more holistically and effectively identify, articulate and ensure WHS integration in the construction lifecycle and workplace.

Future directions

With the potential of BIM and the incorporation of WHS management at the procurement stage, clients can holistically and effectively identify, articulate and ensure more effective WHS management across their construction projects. Integration of information technologies like collaborative robotics, IoT and cloud computing with BIM can be utilised for effective WHS management. Government and industry clients could thus take an active leadership role to promote more collaborative arrangements among stakeholders using these technologies. They could demand the use of BIM from the early design stage, through to the end of the structure's lifecycle. WHS management could be included in the EIR tender documents to ensure bidders consider and address WHS issues in their BEPs. BIM-enabled WHS management model checking tools can then be used to verify compliance between the client's requirements and the bidder's proposal and automatically find potential errors and contradictory information. Specific, innovative, BIM-enabled, WHS management approaches such as simulations and rule algorithms, could also be documented and included as part of the tendering process. Moreover, procurement systems could be evaluated in terms of their impacts on WHS prior to their selection for projects. As leaders and exemplars in the procurement of major construction and infrastructure projects, governments and other clients should continue to collaborate with industry and professional bodies, working together towards the provision of more comprehensive and tailored approaches for BIM-enabled WHS management.

Conclusions from the literature review

The challenge to all participants in the construction industry is to find ways to reduce WHS incidents and injuries and to support a safe workplace. BIM, as a process and communication software tool, facilitates the early identification of potential WHS issues and the application of preventative strategies using automated approaches. The strengths of using BIM in construction for WHS management manifest in the embedded processes of visualisation, simulation, analytics, evaluation, monitoring and support to education and training during the design as part of the construction, operational and post-construction phases. Documenting WHS requirements in plans and monitoring compliance with regulations within a BIM-environment can result in safer working conditions, as WHS is identified as an integral part of the construction process, is made more visible to stakeholders and can be appropriately managed at the various stages of construction alongside risks to time, costs and quality.

The aim of this literature review was to identify the use cases and understand the integration of WHS into BIM and construction project procurement. The key finding from the literature search is that Australia lacks research that evaluates WHS management in a BIM-environment. Despite the scope for BIM to provide a powerful approach to the management of WHS in construction, BIM-enabled WHS management is rarely considered in construction tender requirements or in the evaluation of bidders' proposals. The management of WHS will be most effective when considered holistically across the project lifecycle and included in a BIM-enabled environment by the construction procurer, with commensurate client response at the construction tender and evaluation stage. This allows WHS requirements to be embedded early in the design and construction process and facilitates increased clarity for the management of WHS across the project lifecycle.

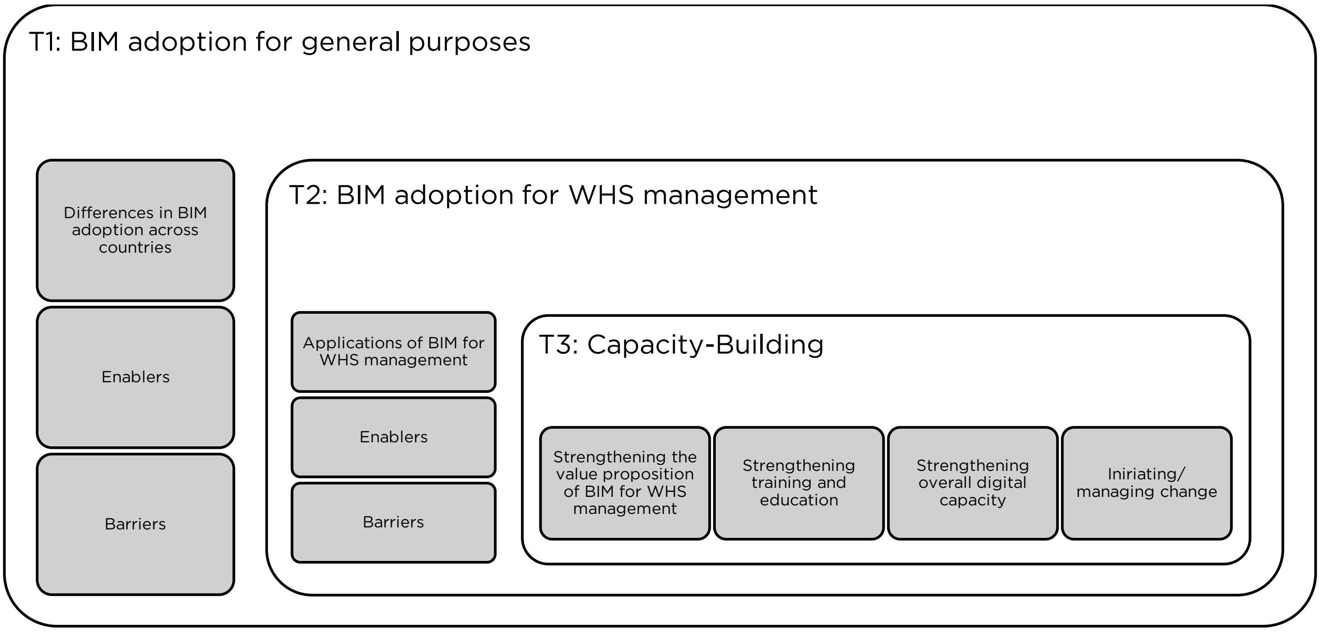
The UK, Singapore, Hong Kong and Finland public and private sectors are further advanced in the adoption of BIM for WHS management and provide valuable research sites that could enrich the information on the approaches, tools and outcomes highlighted by theoretical, prototype and evaluative studies in this area. Sufficient examples of Australian private and public sector BIM-enabled construction projects exist to allow the evaluation of BIM, from the tendering stage through to post construction, for the potential creation of management and information systems for monitoring WHS. There also appears to be sufficient stakeholder experience in the construction industry and across government agencies to develop models for the adoption of BIM-enabled WHS management systems.

This review has provided the foundation on which empirical study could further explore industry and government experiences of BIM and WHS management using BIM, nationally and internationally. Interviews with stakeholders could explore how WHS can best be factored in as a pre-requisite within BIM models at the procurement stage to strengthen WHS compliance and ensure safer practices and workplaces for construction workers.

Results from the Empirical Study

For the empirical phase of the study, themes and categories were organised according the three main topics. A map of the results of the empirical phase is shown in Figure 2.

Figure 2: Categories and their links to key topics



Topic 1 results: General application and adoption of BIM

The first interview topic focussed on interviewees' understandings and experiences of BIM adoption. This topic has been researched extensively in the literature, but the questions laid the groundwork for enhancing understanding of the context for the adoption of BIM for WHS management (T2). Again, in-depth interviews of a small sample were meant to nuance and enrich, not statistically validate, what has been found in the literature. Detailed narratives on BIM adoption experiences and understandings were thus sought to discern potential pathways towards the use of BIM for WHS management.

Differences in adoption across countries

The empirical findings echo trends that are well-researched and noted in the literature review: that there is a high level of BIM maturity in countries like the UK and Singapore, and low rates in Australia. BIM in Australia has been described as "not very popular", while BIM use has been characterised as "small and sporadic" as well as uneven across sectors:

> *"So I think generally the use of BIM is very immature in this country. It is more mature in the industry or in industrial kind of sector…That is industrial engineering, roads, infrastructure kind of sector because you generally have engineering companies. Engineers like to plan and like to do things and use tools to make sure they're doing the right kind of job. Whereas the construction sector, pretty much just takes a plan and just goes ahead and does it without much planning, if I may say so." - Interviewee 7, General Contractor, BIM Specialist, Australia*

BIM usage has also been described as uneven within sectors like construction, where the technology fails to cascade to the job site:

> *"I think the problem with what happens with BIM, is it seems to be done at an early stage where the modelling is put together and it seems to be done by a team away from the job site and then when the job site gets going, construction still seems to be very driven by, you know, pieces of paper and pencils and all of a sudden, all the technology that's been developed in the background doesn't really find its way to the coalface." - Interviewee 9, Subcontractor, General Manager, Australia*

Contrasts between Australia and "high adoption" countries like the UK and Singapore, however, need consideration. While two interviewees from the UK, along with one from Singapore and one from Australia, broadly agree that BIM adoption in the UK can be described as high, interviewees have nevertheless qualified this statement in different ways. One interviewee noted that "BIM" and "adoption" are often defined in different ways:

> *"[There is]…a link that says 75% of all designers now are using BIM in one form or another. All have been contractors claimed to have BIM capability and they will fill in tender forms and so on, saying that they use it…BIM means very many different things to many different people, so, applications of BIM vary greatly." - Interviewee 5, Government, BIM and WHS Specialist, UK*

A second interviewee noted that since 2016, the UK has not had a legislative mandate for BIM, which has made adoption far from uniform:

> *"So, at the moment, there is no legislative imperative. There are various government standards. There's a government digital standard and other bits and pieces which give a very strong steer that construction should be using these techniques and that publicly funded projects should be using them, but again, it leads to a very variable picture." - Interviewee 5, Government, BIM and WHS Specialist, UK*

An international interviewee also suggested that "*high adoption doesn't lead to better performance*". The interviewee indicated that adoption in Singapore is much higher than in the UK, possibly as high as 80% in certain industries, but with only about 20% obtaining full benefit from BIM. In the UK, adoption was described as much lower and estimated at 20%, but with most of these adopters using BIM in mature ways that "*are really advanced, and so it's very, very polarizing*". However, it is noted that although these claims were made there was no evidence to support the figures cited and so it is based upon experience and intuition. In fact, as a general rule, cost benefit analyses have been rare in terms of published studies on BIM adoption. Also, in some areas of BIM use in the UK, some practices have become reified, leading an Australian interviewee to note:

“I think we’re quite efficient [in Australia]. I know we’re working in the UK. And I find that they are really hard to get them to change the way they think. Very much about this is how we've always done it and we want to stick with that, which really surprised me. I thought they’d be quite proactive and, you know, looking at new ways and that’s fine. And that’s always been a challenge for us., I haven’t seen a lot of BIM being used.” - Interviewee 9, Subcontractor, General Manager, Australia

The claim is quite profound. While this statement might need further validation, it warrants exploration as it challenges the widely held assumption that the UK is far more advanced than Australia. The claim also carves out space for the possibility that best practices in BIM for WHS management may already exist in Australia.

BIM adoption is driven by a range of enablers and barriers, and the empirical findings point to cultural, regulatory and technological factors, as well as data quality, the client and the BIM value proposition. These enablers and barriers are summarised in Table 5.

Enablers and barriers to BIM adoption

An enabler and barrier can be linked in the sense that they could be visualised as resting on a continuum. For example, one might envision that the barrier “Resistance to change”, which emerged from the data, would be found on a hypothetical continuum with “High resistance to change” on one side and “High openness to change” on the other. Since the study is qualitative, no attempts were made to quantify these; instead detailed qualitative descriptors were provided in the table. Also, enablers and barriers were described with some specificity; “new generation open to technology” was used instead of “some openness to technology.”

This type of linking analysis of empirical barriers and enablers for BIM and e-business adoption was conducted in a study by London et al (2008), however it is useful to reflect upon the general context of BIM adoption patterns as more than a decade has passed and adoption experiences are now different one would assume It is also noted that this study is not a study on BIM adoption barriers and enablers, but it a study linking BIM and WHS management adoption through the development of a specific decision making tool.

The types of descriptors used were chosen to avoid dichotomies and because they were flexible enough to allow enablers and barriers to be juxtaposed in ways that yield a rich picture. Thus the enabler “New generation open to technology” is descriptive enough so that it is shown as an exception to the more general barrier “Construction industry resistant to change”.

Table 5: Enablers and barriers to general adoption of BIM.

Category	Themes Categorised as Enablers	Themes Categorised as Barriers
Culture	• New generation open to technology • Contractors using BIM even before mandated • Some parts of the industry already open to BIM • Development of skillsets/ specialists • Main contractor drives BIM across supply chain • Main contractors have invested heavily in BIM • Attitude towards planning supports drive for BIM • Champions 'selling' the value of BIM in the workplace • BIM becoming "business as usual'	• Construction industry resistant to change • Limited skill/ expertise • Overall skill level hard to generalise • People working in silos • Political factors in negotiating requirements • Steep learning curve • Finding the right "bar" as incentive • Some actors don't share information • BIM is a means to criticise your work • Need for information-sharing culture (by training) • Distracted by political and COVID issues
Value proposition	• Team is initially resistant then sees value after using BIM • BIM visualisation capabilities used to demonstrate value proposition • Supports Net Zero Carbon/ environmental sustainability • Supports increase in advanced manufacturing • Supports ongoing interest in developing digital twins • COVID driving need to use technology • Supports public interest in occupant safety • Supports easier way to plan complex projects • Supports avoiding scope change • BIM is a market differentiator generating competitive advantage	• Cost • Sometimes outsourced; people miss the value • Resistant people are not being reached at BIM forums • Failure to understand benefits • Hard to quantify value • Poor return on investment • Seen as a compliance matter • Unclear definition of BIM
Regulation/ policy	• UK BIM mandate • UK digital standards, even if mandate is not renewed • UK BIM Framework/ principles for coordination • Singapore legislative requirement • Standards available to support unified national and international approach • ISO compliance sets documents and reporting standards • Future standards require deliverables; incentives to prepare these early • Understanding benefits of information management frameworks • Adopted when required by government	• No clear mandate to use BIM • UK mandate not renewed • "Railway track" approach of mandating; disregard for realities

Category	Themes Categorised as Enablers	Themes Categorised as Barriers
	• Government requiring it will have snowball competitive effects • Adopted when required by contract (becomes legally enforceable)	
Role of client	• Clients helping each other • Clients helped by other stakeholders • Adopted when required by client • Clients beginning to see value • Asset management functionality for clients	• Client unaware of where to get guidance • Client confused about requirements • Client does not ask for models • Client does not require information-sharing • Client does not know what to do with information/ BIM resources • Client does not/ cannot enforce requirements • Client defines requirements/ requirements get diluted
Technology	• Technology is mostly available in Australia • Technology affordable • New capabilities from convergence in technology • Ease of use of technology/ interfaces • Gamification • Technology being tailored to the construction context • Able to test and trust the accuracy of models	• Need to start with simple technologies • Client fails to understand technology • Procurement teams fail to understand technology • Subcontractors fail to understand technology • Industry fails to understand technology • General failure to understand technology • Technology seen as complex • Technology seen as gimmicky • Technology seen as cumbersome • Technology seen as futuristic • Information quickly becomes outdated
Data	• Acknowledgement that data is foundational/ "content first" • Industry is starting to share data • Regulated/ backed/ validated data becoming available • Open data formats • Mechanisms to ensure data/ models are handed over across stages • Some quality data is available • Progressive development of BIM library • Beginnings of a common data environment	• Good data is available but not used • Lack of data quality/ consistency
Systems and processes	• Procurement: Building libraries with the latest information for tenderers • Procurement: Methods like PPP and alliances are supportive of BIM	• Many requirements • Requirements have to be designed from the start • Poor system interoperability • Not embedded in governance • Procurement: Methods like "Construct" do not support BIM

Culture

The level of adoption of BIM appears to be strongly related to workplace culture. In the UK, one interviewee noted that BIM had been widely adopted even before it had become part of a national mandate, suggesting it was already part of the industry's way of life:

> *"I mean I think it's fair to say that before the UK government its mandate in place, it was already well underway. So, I would say, if you went back to 2010, most main contractors were already using BIM, especially for coordination management within there. And then a lot of big architectural practices are already underway. So, and level of adoption, we're quite lucky. There's a, we do a national survey in the UK. It's not mandatory to do it, we do it, but it's around about 67 to 70% now are probably doing BIM to some degree now within the UK." – Interviewee 2, Government & Private, BIM Specialist, UK*

An interviewee from Singapore likewise mentioned that a large portion of their BIM initiatives were "over and beyond" what was mandated by regulation and policy, also suggesting that BIM is embedded into the industry's way of working. In Australia, the limited uptake was also explained, at least in part, by factors related to culture. Interview respondents have painted a picture of an industry culture that is slow to change, with one respondent describing the industry as "prehistoric", and that "*there's still an old guard left in construction that is still very much about paper pencils rulers rubbers sort of thing so*". Another noted that "*one of the biggest things is just a drag and an inertia where experienced project managers and experienced project teams really have to be dragged forward into new ways of working*". These observations, however, have been tempered by others who have pointed out that a new generation of tech-savvy professionals is emerging, with increased readiness to take on innovations like BIM. Also, certain types of professionals, for example engineers, have also been open to BIM adoption, in part due to their proclivity for planning. Designers and some contractors, usually large Tier 1 actors, who have seen its value for certain aspects of construction, have demonstrated openness to adoption as well. The unevenness of BIM adoption across the supply chain signals an important consideration for using BIM for WHS management; as will be shown in later sections, uneven adoption poses challenges to integration of WHS management using BIM.

Value Proposition

One possible explanation for BIM being embedded in workplace culture is the strength of the BIM value proposition. In the UK, this value proposition is compelling, as BIM is understood as a means to achieving a number of important, widely-held goals, not just as an end in itself. One interviewee noted

> *"…we're really starting to see …is [that] most clients are starting to use BIM and technologies now, I see the main driver is becoming especially about net zero carbon. So they're starting to use, if you like, you know, that's, you know, everything is we, you know, as we head towards some degree of industry reset, we can't forget about you know our, our commitment to carbon." - Interviewee 2, Government & Private, BIM Specialist, UK*

Environmental sustainability is just one driver. BIM is also seen as a means to achieving other goals: it is a tool to support public interest in occupant safety, a facilitator of advanced manufacturing and a means to achieve national digital twinning. Recently, increased BIM adoption has been met with resistance, due to the interrogation of this value proposition amidst competing issues like COVID and Brexit. That said, the use of BIM remains entrenched, one way or another, in the UK.

In contrast, the value proposition for BIM tends to be obscured or narrowly defined in Australia. One interviewee, a strong advocate of digital solutions, observed that "irrespective of company" and "across several companies" the standard questions asked are

> *"…what use is it? What's in it for me? What's the good for me for using BIM? Does it save me money? Does it save me time? That's generally – those are the key pressures that people have on site."- Interviewee 7, General Contractor, BIM Specialist, Australia*

The interviewee then went on to comment, "*'Does it help me work safer', is maybe not always at the forefront, I must say, of every person that is there*", a point that previews a challenge to the integration of WHS management in BIM that is taken up in the next section. More generally, low or fragmented adoption of BIM, according to one interviewee, is the result of "*the cost benefit argument [being] very diffuse and not well presented*". Low levels of adoption can also be seen when the value proposition for BIM is framed as a matter of compliance. However, interviewees have also noted that some people initially resistant to BIM have learned to appreciate its value after they started using and eventually made it part of their way of working.

Policy and Regulation

Interview data presents interesting contrasts of the policy and regulation landscape for BIM in different countries. Australian-based interviewees made repeated references to the lack of a clear mandate to use BIM in construction. This is despite the fact that frameworks, strategies and policy initiatives have been mobilised by state governments in various forms to support the use of BIM at procurement. What interviewees seem to be referring to is the lack of a clear, legally enforceable national mandate. Unlike the UK's strong stance, Australia's dispersed policy initiatives did not cohere into a single strong signal of national interest in BIM:

> *"It should be easier for industry, because they're not – at the moment, if they do BIM for us or for Queensland or for Victoria, for anyone else, everyone's got their own standards and it's kind of like industry's like oh, what now? What do you want?" - Interviewee 8, Government, BIM Specialist, Australia*

State endorsements of industry standards do not appear to have the strength of legislative requirements, thus apart from emerging mandates from organisations like TfNSW, BIM remains as something that is "nice-to-have", leading an interviewee to comment, "*If it's an optional thing, it ain't gonna happen*." Another interviewee pointed out

"…if the people don't want to adopt it, and the rule's not there for everyone to say this is what we're doing, then I think the process becomes too hard and the people put it to the side and decide we're too busy to do this." - Interviewee 9, Subcontractor, General Manager, Australia

A third said "there's no top-down thing saying this is the only way that we work."

The Singapore and UK policy and regulation landscapes are much stronger in this respect, reinforcing the relatively robust BIM cultures that are already in place with requirements and standards that push BIM uptake further. Both countries have blanket BIM mandates in some form. In Singapore, regulation has been identified as the key driver for achieving high levels of adoption:

"The good majority of the industry has adopted because the regulatory processes within Singapore and quite a lot of other Asian countries have followed suit with a similar process, is that any building over 5,000 square meters has to have a model for the submission purpose for building regulatory submission, so to meet the statutory requirement, you have to build a model. So that's how adoption has gotten very, very high." - Interviewee 6, General Contractor, BIM and WHS Specialist, Singapore

Similarly, the UK has an ecology of regulations and standards with substantial coherence. While four separate governments run different BIM programs, these are coordinated through common principles through the Whole Nations Working Group, which ensures that all parties are working towards a single UK BIM Framework. There are also a number of related policy initiatives that make BIM adoption more compelling: national initiatives towards open information, ongoing work on strengthening project information requirements and a "BIM wrapper" called Soft Landings where end users are involved in discussions about lessons learned from operations and facilities management of assets. Lessons learned are recorded as plain language questions, which are then translated into BIM inputs for future projects, ensuring that design issues identified are considered and tested. Non-technical people are thus given the opportunity to contribute to the optimisation of the design process. It is worth pointing out, though, that the government's strong line towards BIM adoption is not, strictly speaking, a mandate:

"Before 2016, in about 2014, the UK government issued a mandate, which was called a mandate, but it was essentially a strong line to all government funded projects, which makes up more than 40% of all construction work done in the UK. So all government funded projects should use BIM, and at the time, they talked in terms of level 2 BIM. So that mandate lasts until 2016, and it hasn't actually been renewed. So, at the moment, there is no legislative imperative…So the government policy is quite shy at the moment of actually mandating or making it compulsory." - Interviewee 5, Government, BIM and WHS Specialist, UK

In Singapore, the legislative mandate, which began in the 1990's as a shift to e-submission, has since expanded to BIM e-submission and has been taken up by an increasing number of government agencies over time.

Client Role

The role of the client is potentially pivotal in strengthening BIM adoption. In the absence of a strong legislative mandate, a client requiring BIM adoption can still mobilise the supply chain. An encouraging sign is that clients are beginning to show interest in BIM, perhaps in part due to their increasing concern for asset management. Client interest in BIM, however, remains limited. Interviewees pointed out how clients were often confused by BIM requirements, indifferent to its value, seemingly uninterested in asking for designers' BIM models, or weak insofar as they could not, or would not require information sharing. At times, they would define requirements at the tender stage and be unable to enforce them later. Tender requirements could end up being diluted:

> *"...and so they were passed through to a contractor and the contractor would respond with the BIM execution plan and the contractor would give the client what the contractor thought the client wanted, or worse, what the contractor wanted. And very often, we've got examples, where regardless of what the client asked for, the contractor would just give them back what the contractor did last time, or, "I can do BIM, this is what you get," and it bears no relation to what the client actually is asking for or really wants." - Interviewee 5, Government, BIM and WHS Specialist, UK*

The unexplored potential of the client as champion for BIM adoption is a topic worth exploring, particularly in light of findings where a mandate from a client could compensate for the absence of a strong legislative mandate.

Data

A number of interviewees identified good quality data and information-sharing as the foundation for BIM. Common data environments are crucial for model sharing between stakeholders and across phases of the project. But while BIM can be a powerful tool for communication and collaboration, both become impossible if parties do not speak the same language. As one interviewee noted, all BIM initiatives "*can happen when we've got the content to make it happen*." The key is "*to have information there in the first place*", then to tell people that information is there and teach them how to use it. Some interviewees have noted that good quality data has begun to be put to use. For example, TfNSW requires the use of a common data environment in its tenders, and international standards outline best practice data management, but for the most part interviewees emphasised that poor quality data is a significant hurdle but for the most part interviewees have noted poor quality data as a significant hurdle. The quality of data is reported to be much better in the UK, where an information management framework has been put in place, allowing people to look at foundation data models and to link data sets.

Technology

Promising opportunities for BIM were identified by many interviewees in relation to technology. Trends in convergence of technology and mobility have made BIM applications increasingly sophisticated and sometimes more intuitive. For example, gamification now allows BIM to be used in nimble and innovative ways. For example, with a game engine-based software:

> *"…You can import your models. You can import little things. So you can set up your temporary works quite easily, more like a game, but then you can immerse yourself into it, or you can do a training of working at heights more immersively in the environment of here's possibly a very dangerous situation of how we might want to set up a piece of equipment or we have to operate at a certain height or more tricky installation and they can virtually rehearse that." - Interviewee 7, General Contractor, BIM Specialist, Australia*

Touchscreen technologies allow models to be manipulated with ease on tablets. High definition photography allows images to be captured on cameras, and allowing for "immersive cinema" to be used as a support tool for rehearsals of dangerous tasks or for familiarisation with high risk environments. Many of these technologies are available in most of Australia and are also becoming more affordable. Three hurdles that have to be addressed in the Australian context are (1) the need to improve data quality and consistency to support BIM; (2) the need for systems to integrate more seamlessly and (3) the need to manage people's resistance to new technologies.

Systems and Processes

A key challenge about adopting BIM is that it brings about changes with far-reaching impacts on organisational systems and processes, as well as changes beyond a single organisation. Intra-organisationally, one interviewee commented on the "many requirements" that had to be in place before BIM could be adopted, saying "*You need the data, you need the equipment, you need the software and then the programs to kind of bring that in*." These requirements would translate into costs, making BIM prohibitive at times. The investment requirement could explain why BIM adoption appears to be limited to large, Tier 1 firms.

Interestingly, one interviewee reflected on the existing form-based systems and labelled them as "onerous" and inefficient, thus costly in their own way:

> *"We have a very heavy form orientated system, so there's always templates, safety plans, subplans, risk assessments, inspection checklists, it's very, very onerous, and there's some things that are required to be done daily, weekly, monthly, six-monthly. Like it's a lot to get used to, and I know from experience of people who have come from outside of our organisation and they've joined our organisation and they're like, wow, there's a lot of forms, there's a lot of stuff to do. In terms of management of that we obviously undertake audits to verify the implementation of the system and it's consistent. Like at the end of the day it's always the same non-conformances across the projects, and it comes down to there's just not enough time to implement the system." - Interviewee 1, General Contractor, WHS Specialist, Australia*

The same interviewee then emphasised that these systems could strengthen the value proposition of solutions such as BIM, although with some reservations:

> *"I think [solutions like BIM] will be a good response, as long as we have evidence that this is going to improve the way we manage it. If it's just another process that gets put in there for the sake of it, I don't think that will be received very well, but if we can prove that, yes, this type of technology will improve and make it really easy to adopt in our projects, and within our industry, I definitely think it would be welcomed with open arms." - Interviewee 1, General Contractor, WHS Specialist, Australia*

Inter-organisationally, an organisation's decision to use BIM will have, or at least should have, impact on the supply chain. Different procurement models reflect this. Empirical data appears to confirm what the literature suggests: that certain procurement models support BIM better than others. Interviewee 4 suggested that "*IPD contracts [are] probably the ones that probably most lend themselves to enabling BIM properly*". In contrast, Construct Only was seen to be problematic:

> *"So we'll send them [the design team] a report saying is 100,000 pieces of metadata missing off your models. We can't accept that because you said we would get a [LOD???] model as part of the construct only. So that this is not suitable for construction." – Interviewee 4, General Contractor, BIM Specialist, Australia*

> *"For example, we in Hong Kong will get a construct only, and a lot of the projects there tend to be construct only, not design and construct. So we will get issued with a design, we tend to get issued with a whole bunch of drawings. And then there'll be a requirement in a saying you need to hand back…[a] LOD 500 model. And then we say to them, well, hang on. You just handed us whole bunch of drawings, even though we know that the models are available, we don't receive them. We demand and then we'll receive the models and find out that they're all out of date. So the drawings have just been done. It's been done completely the wrong way around; the drawings have just been produced and they've sent it off to a low-cost centre to get it modelled. And then things have changed, and they've updated the drawings, but the models are still a year out of date. And then contractually if we sign off on that we've got to then bring those moles up…you know, so that's been an ongoing back and forth with the clients and I think they're starting to understand now, particularly Hong Kong and in Singapore." – Interviewee 4, General Contractor, BIM Specialist, Australia*

The examples above suggest a link between Construct Only as a procurement model and information fragmentation. The link is not inevitable, as Interviewee 4 has been careful to note that the model can work if participants are mature. In practice, however, handover can be profoundly problematic. In the Conclusion, a deeper consideration of information fragmentation under certain procurement models will be undertaken to explore its link to matters like dependencies, power and control, which have implications for WHS.

Summary

Understanding the context for BIM adoption is important when exploring possibilities for managing WHS using BIM. Certainly the link between more general adoption scenarios and BIM for WHS management should not be oversimplified. The relationship might be two-way: one interviewee suggested WHS could be a Trojan horse for BIM, because safer ways of working could catalyse higher levels of general BIM adoption. Also, high levels of BIM adoption do not always translate unproblematically to BIM adoption for WHS management, a point that is explored in the next section. However, the argument, that BIM for WHS management may be difficult if BIM itself is not widely adopted, is for the most part sound.

The literature review has noted that a confluence of factors shapes BIM adoption. The findings linked to Topic 1, general adoption of BIM, reinforce this. Data suggests widespread BIM adoption is achieved through the creation of a complex ecology involving culture, technology, policy initiatives, technology and data. When these factors cohere around a strong value proposition for BIM, widespread adoption can be encouraged over time, although this process is far from linear and unproblematic. The UK experience suggests strength across a wide range of factors: a strong and nationally consistent policy regime, a culture that has embraced innovation and BIM prior to the mandate, parallel initiatives in areas like open data, digital twinning, sustainability and, a point we raise shortly, WHS. Interviews have confirmed many of these, and provide a context for understanding BIM for WHS management.

The Australian BIM ecology has yet to be developed although promising examples of BIM use are emerging in certain areas, including examples in WHS, which will be discussed in the following section. Examples of barriers to BIM adoption include the unclear value proposition of BIM (i.e., "what's in it for me") as well as barriers related to data and technology. Culture was discussed as a critical barrier as well. The overall industry culture is not (yet) built on values that support BIM. Based on the literature and from interview data, it can be argued that BIM is best assimilated in cultures that value collaboration, communication, openness, data sharing, innovation and openness to technology. In Australia, much of the industry remains siloed, resistant to change, resistant to technology and rather oblivious to the value of sharing integrated information to achieve supply chain integration. Within such a culture, there is a need to catalyse solutions through mandates in the form of policy, legislation, standards or possibly contractual agreements. In Australia, no legislation mandating BIM exists, and fragmented state-based policy initiatives have not gained traction. Thus another significant barrier identified in the Australian context was the absence of strong, coherent national mandate.

That said, interviewees appear convinced that supply chains would adopt BIM if a different kind of mandate arose from other sources:

"...So a lot of BIM and digital engineering has to be sold in and it will only get done if the government wants it. So if the government wants something and the client says 'you shall do it' it gets done. If it's optional, it does not get done ...Simple as that. They are they are reluctant.. yeah, only do what they have to do." - Interviewee 7, General Contractor, BIM Specialist, Australia

A mandate, then, could come in the form of client leadership via contractual requirements and an industry wide and nationally consistent approach. Furthermore, interviewees have noted that the influence of a government client could be significant in a unique way:

"I think now the government is starting to realize it needs a step in instead of sitting back and letting the private sector try and dictate this; they need to get involved as well because, obviously, there's a lot of - especially now with the COVID thing coming on, a lot of the government projects have been pushed, which means they need to have a hand in how they're going to deliver those, they're responsible. They can't always rely on the private sector. But they – yeah, they need to. So once they do that I feel the construction industry will respond quite quickly." - Interviewee 3, General Contractor, BIM Specialist, Australia

The influence of the government client could become even more profound, with a ripple effect beyond direct client-contractor relationships, because the effects of a successful BIM-enabled government project can cascade across industry players:

"...because it becomes a competitive requirement when it comes to the tendering process, but also then they have some - they have a flag on the hill that they know that's been - that's been okay or that's been approved by the government." - Interviewee 3, General Contractor, BIM Specialist, Australia

While the role of the government client has been raised here, the question of a possible trajectory for this role through a pathway involving procurement will be explored in later sections.

Topic 2 results: BIM adoption for WHS

Applications of BIM for WHS Management

Topic 2 focussed on enablers and barriers, as well as exemplars, of BIM for WHS management. While findings largely confirm the literature, findings also orient researchers and practitioners to a potential direction that can be explored involving the role of the government client.

Data gathered from interviewees showed a diverse range of BIM applications of BIM for WHS management. The Singapore-based interviewee alone spoke extensively about wide-ranging applications of BIM to plan vehicle movement, crane hoists, people movement, COVID temperature screening, modelling temporary holding platforms, and designing scaffolding. Australian interviewees have noted the use of 360 degree cameras for immersive cinema and gamification for temporary works planning. Through the use of BIM, members of the supply team have been able to identify hazards like missing guard rails, immerse subcontractors in high-risk virtual scenarios, manipulate elements on site via gamification, rehearse complex tasks and improve cranage methodologies. In one case described as a "spectacular" example, planning with BIM allowed teams to complete eliminate the need to work at night. BIM has also been noted as a facilitator of the shift to advanced manufacturing, which mitigates safety risks by moving people away from the site, to a controlled environment.

Table 6: Examples of BIM applications to improve WHS

Activity	Example of BIM application to improve WHS
Scenario planning	"So we used immersive virtual reality to do three- or four-week look-aheads, where these health and safety. We actually did a program with a healthy health and safety specialist and there we were doing three- or four-week program look-aheads and they would virtually walk the site in a virtual reality headset and be able to identify health risks cease." - Interviewee 7, General Contractor, BIM Specialist, Australia "…we're planning all of that out. We then plan out, we plan out the movement of all the vehicles getting into these facilities, because they are actually, we're bringing construction vehicles into working factories and facilities where we need to just be able to segregate the flow of traffic and people safely. So we're visualising all of this down to vehicle entering the gate and what all the procedures will be." - Interviewee 6, General Contractor, BIM and WHS Specialist, Singapore "I think what you find will happen with, you know, safety incidents, they're usually occurring around on a building site due to the lack of planning, like a communication or change. And change is often where you have an incident where people – things didn't go as planned, because they didn't say something, or they didn't understand what was happening coming forward and all of a sudden they had a plan of what they're going to do and at a minute the job changes around them, and all of a sudden […] now collapse around them; we've got a safety incident." – Interviewee 9, Subcontractor, General Manager, Australia
Requirements briefing	"So what they did was set up a workflow which meant that they used all the tools they had. They laser scanned machines, they laser scanned sites, they went to sites which were like the one they were going to build and made models. So, when they came to design this particular site, they designed it in such a way that they presented six months before the build, the designers presented to the client and to the full project team the rehearsal of the build, and it included, it was a massively detailed thing, it included temporary works, provision to an extent, road cones, how stuff was going to be brought to the site and taken away, and in year one they did this, and it was a success." - Interviewee 5, Government, BIM and WHS Specialist, UK "Basically, they started the week on a Monday with a model. They briefed the guys of the model, this is a model, this is how you're going to work, and as the guys worked, so, on the Tuesday, the planners were then looking at the next week's needs, building next week's model, and then taking into account what's been done this week, so that by the following Monday they were presenting the model for the following week based exactly on what had been done." – Interviewee 5, Government, BIM and WHS Specialist, UK
Risk assessment	"So the first thing is the power of there's a straight board visualisation using 3D over 2D, and the enhancement that brings to design reviews throughout the construction phase. So people are able to get closer and foreseeability is enhanced and the level of detail at which people foresee and treat risk increases. So when visualisation works well, it can bring the whole process of identifying risks and treating risks closer to the design end. So that's really strong." - Interviewee 5, Government, BIM and WHS Specialist, UK "…it can also help you with your safety because you can see that you might be heading towards a safety issue coming up where you might have left out part of a structure; you might have clashes for what we're doing with the cranes." – Interviewee 9, Subcontractor, General Manager, Australia
Education and training	"And I think a good example of that, you know, when you have a large bridge or something that bridge gets put into place that gets virtually rehearsed. But that's the engineers and everybody kind of looking at that. The next step would then be ok now

Activity	Example of BIM application to improve WHS
	let's take that rehearsal, it works. How we're going to do the health and safety around this where we planning, all of that. What's happening throughout. What are you know what are the swings. All of that can be evaluated. And I think that's, that's where a large component of that would come in. It's really, it's it's using the virtual world and to to plan for the real world." - Interviewee 7, General Contractor, BIM Specialist, Australia "So that's what we're, what we were doing in that case it was a using 360 cameras. So it's not a virtual reality, but it is I would you call it, I think it's virtual cinema right? or immersive cinema and we would place the cameras in high risk areas such as a meter away from a train line, right, these, these... one railway works on to tower cranes to allow people then... so we could then take people in a safe environment and allow them to experience high danger areas. And so this is around training and allowing people to be to develop more empathy and understanding around the high safety or the, the high risk kind of areas on jobs and the response of that was very positive." - Interviewee 7, General Contractor, BIM Specialist, Australia "[We help] them understand what is the safest methodology for them to do their work. And in effect, it's part of an education process, so that they don't need to be so risks risk tolerant. We actually want them to become intolerant to taking risk. So this is part of the educational process that that we've gone through there, and then looking at things like diaphragm walls around the crane foundation, so even substructure work. So that's like a broad kind of use from, I guess from a safety perspective where we're using BIM in construction." – Interviewee 6, General Contractor, BIM and WHS Specialist, Singapore
Monitoring, surveillance and reporting	"So you've got site supervisors who have got cameras, who are capturing in real time what's happening and feeding it back and comparing it to the model and that often helps us now to actually capture lots of health and safety problems that are happening on site and it's certain to be able to ameliorate them as well." - Interviewee 2, Government & Private, BIM Specialist, UK "More recently, [we've used BIM] in terms of the people movement. In, you know, in the last couple of months, we've been working on how do you screen, temperature screen people entering the site so that from a, from a COVID perspective. So we've been building out models of these screening sort of stations and again, the workflow and the procedure, to plan that that whole movement through. And then if you spot someone who doesn't pass the test, how do you then take them aside and isolate them?" – Interviewee 6, General Contractor, BIM and WHS Specialist, Singapore
Analysis	"We've got a cranage methodology which we're constantly pushing on the clients and we always talk about how do we run that he like in a parallel universe with one methodology versus another. And I think this technology can allow us to virtually to do that because we've got, we end up with just a ton of data that we can then take away his lessons learned and saying, this is, this is where we worked efficiently." - Interviewee 9, Subcontractor, General Manager, Australia

Underpinning the discussions on diverse applications were discussions on BIM's different capabilities. For example, BIM is seen to be a powerful communication tool that can cut across language barriers:

"We work with very multi-language you know, in a project. So you can imagine, you've got maybe five different sort of languages within there and BIM helps us in terms of better storytelling, better if you like, visual methods statements are more understandable within there as well." - Interviewee 2, Government & Private, BIM Specialist, UK

BIM is also a powerful tool for coordination, with one interviewee describing it as a means for "choreographing" activities:

> *"So for anyone who's involved in a site induction, anyone that's new to a construction site, anyone that is involved in planning and staging or coordinating – I like the word choreography. You know, in terms of like – all these different parties are all working around together and how do they understand what everyone else is going to be doing?" - Interviewee 8, Government, BIM Specialist, Australia*

Several interviewees noted that much of the power of BIM rested in its ability to support visualisation in 3D:

> *"If it was just done on drawings, it probably wouldn't be enough, but actually, just that visual context. So BIM, in that regard, is superb. Just for the visualisation and communicating, here's what the activities are going to be. So everybody's on the same page, they can visualise their work well. They can visualise the site, they can have an off-site inspection before they even enter it. So they have a lot more familiarity and they're being a lot more aware of any potential hazards, well before they arise. I think in my mind, that stands out as head and shoulders above anything else." - Interviewee 8, Government, BIM Specialist, Australia*

Others have noted that 3D can be taken even further, describing the benefits of BIM for immersive experiences:

> *"[Immersion] makes the fundamental difference to me from my experience. So just the model alone isn't good enough. You have to be able to play somebody in it and have them contextually immersed or experience it, then you start getting results where people start taking this stuff seriously… [A health and safety professional] said, approximately 20% more health and safety issues were identified by being inside of the model than actually looking at the model on the screen and way more than you would have seen just looking at a plan. So a plan doesn't ….because you mentally have to transport yourself and interpret it… When you actually immersed in it, you're just reacting to what they normally do on site. Health and safety professionals are very good being inside this, allowed them to virtually be on the site." - Interviewee 7, General Contractor, BIM Specialist, Australia*

Finally, the value of BIM 4D was also noted in terms of its value in supporting planning, forecasting, rehearsal and analysis, as shown by examples in Table 6.

The most vivid cases of BIM success cases to improve WHS management involved strong planning and monitoring. One interviewee noted that the first thing that must be done to lay the groundwork for BIM, whether for WHS or for other goals, is to establish

> *"…a clear definition of how [BIM] going to be used, so it all can be set up correctly from the start and then be utilised by everybody that needs to utilise it, not just the end client…" – Interviewee 4, General Contractor, BIM Specialist, Australia*

Defining information requirements is critical:

> *"So if they're going to be working in our project, you know, simple things like the models must all be 3D solid geometry. All content developed must be shared and published on a weekly basis, you know, everything's (properly…referenced). But all this audits and coordination issues will be resolved before publishing. So just some of the simple rules that we put into our requirements document. And then once we've got that content, then we can manipulate it we can enhance it. We can use it for virtual reality, we can use it for constructing, we can use it to drive the equipment, to drive machinery. But that is probably the key part, and the key thing is having those requirements clearly defined upfront." - Interviewee 4, General Contractor, BIM Specialist, Australia*

An important component that must take place alongside this shift to integrated information is training people, to make them "*aware, firstly, of what information is there and how it can be used*." As work progresses, BIM can then be mobilised as a potent mechanism for monitoring a range of issues, including WHS:

> *"…rather than doing safety design at the end of a four month period, every meeting that we had, we would be tagging or noting that we've, you know, we've picked up a Working from Heights issue or an accessibility issue. And we've tagged that and that goes into a central register. So it's happening in situ rather than waiting 'til the end of a milestone and everybody's forgotten a lot of the work that's been done around safety and design, or haven't even bothered to consider that during the design process. And I guess that is where BIM really helped because you're working, particularly from the 3D geometry perspective; that's probably one aspect of BIM that everyone focuses on quite a bit is the geometry, but even just from a geometry perspective, you start to understand the constraints of accessibility or Working from Heights or on a construction perspective, you know, cranes and lifts and positioning on the staff to make all that very visible. Whereas in the past it wasn't that visible on a 2D drawing; you're only looking at one plane." - Interviewee 4, General Contractor, BIM Specialist, Australia*

Interviewee 4 noted though, that the journey towards this stage has been slow in Australia. To better understand the difficulties, the next section discusses how the BIM for WHS management landscape is shaped by a number of forces.

Enablers and barriers to adopting BIM for WHS management

Enablers and barriers to BIM for WHS management were identified using the iterative process of thematic development described earlier. A full list of quotes for enablers of BIM for WHS is provided in Appendix 1 to provide a partial view of the qualitative data structure. Appendix 1, along with other data sets coded as linked to Topic 2, formed the basis for Table 7 below. When discussed in the narrative, some categories have been combined to achieve coherence.

Table 7: Enablers and barriers to BIM adoption for WHS management

Category	Themes under Enablers	Themes under Barriers
Culture	• Culture values WHS/ WHS as a way of life • Increasing interest in BIM for WHS • Training for WHS is provided in different forms • WHS seen as shared responsibility (foremen, engineers, subcontractors) • Teamwork across disciplines • Culture of innovation drives interest • Strategies to link separate WHS and technology domains • Strategies to link industry and regulator	• WHS as important but not enough to drive innovative methods • Disconnect between technology and WHS domains • Immature WHS culture; "box to tick"; "WHS is extra work" • Resistance to change • Immature WHS culture; prioritised only when there are major obvious risks • Need for specialists to do BIM for WHS • Differences in WHS cultures • Only big projects tend to do this • Fear that disclosing information will damage one's firm • Fear of getting it wrong • Lack of skills/ lack of trained people • Highly specialised skill set required • WHS combined with "other regulatory requirements"
Value proposition	• Government showcasing best practice through industry partner • Adopted when benefits outweigh costs • WHS can be balanced with other goals like cost and quality • Becomes clear when stakeholders experience its benefits over time • Increases productivity and safety • Show BIM as critical for avoiding WHS risk • Show BIM as critical for achieving required work standards • Positive health outcomes • Competitive advantage • In the contractor's own interest (legal obligation) to manage WHS	• BIM limited to construction, performance metrics • WHS as important, not enough to drive innovative methods • Failure to understand benefits • Difficult to calculate return on investment
Client role	• Adopted when required by client/ Extra requirement becomes business-as-usual • Client educated as handheld through continued BIM use • WHS capabilities assessed at procurement by client • WHS requirements outlined by government client in contract	• Lack of client stakeholder awareness about BIM • BIM WHS not important to client • Client BIM requirement get diluted • Client outsources procurement and WHS gets lost • Client WHS requirements vary greatly at procurement

Category	Themes under Enablers	Themes under Barriers
Systems, processes, holistic integration	• Prescriptive form-based system for WHS already in place • Early involvement is better	• Inadequate emphasis on WHS at design/ preconstruction • Procurement models like "Construct Only" • WHS planning not done early • Design for safety processes exist but are implemented badly • Existing form-based WHS systems are onerous • Solutions must be simple systems or they will not get implemented • Requires early involvement • WHS systems are onerous • WHS not heavily weighted at tender • WHS not involved in assessing WHS at tender; project engineer does this
Data	• WHS not a requirement at the start but info requirements end up supporting WHS anyway • Structured data • Common coding breaks down silos	• Privacy and confidentiality issues
Technology	• Technology/ mobile • Technology/ new capabilities • Technology/ practical, on-the-ground capabilities • Remote connectivity supports subcontractor involvement • Other technology starting to complement BIM, increases the perceived value	• Difficult to bring technology into safety culture • WHS representatives fail to understand technology
Regulation/ policy	• Industry standards • State-level endorsement of standards • Industry standards • Newly-published international standards (toxic substances, etc.) • Other regulations with congruent goals (e.g. Soft Landings) • Adopted when required by government • Industrial manslaughter laws enhances importance of managing WHS • Ongoing work to integrate WHS standards into project information requirements • In the contractor's interest due to legal obligations	• Government regulators have varying levels of influence • No legislation for WHS in BIM/ Industry requirements not necessarily legal requirements • Industry requirements at infancy/ still "nice-to-have" • Standards for WHS in BIM underutilised/ unsuccessful in UK BIM Framework • Inconsistent national approach • Difficult to translate legislative requirements into project requirements

Systems, Processes and Holistic Integration

Successful cases of BIM for WHS management such as the ones described by Interviewee 4 appear to have been linked to key factors, including shared requirements defined early on, as well as "everyone, not just the client" using this information, whether for construction, for WHS or for other issues. Interestingly, Interviewee 4 also noted that their information requirements did not even specify for WHS explicitly, but in the end, the level of specificity in the information they gathered still supported WHS management:

> *"I guess one thing is we don't specify directly that is for work health and safety as a requirement. That's probably not something that we're specific about; I guess we're very specific on how we want the information handed over with, I guess, keeping that in mind as one of the use cases. And it's probably something that has tended to just fall out without really being specified. So the fact that we've got this information now, we are identifying work health and safety issues without specifying that that's how it was going to be used in the first place." - Interviewee 4, General Contractor, BIM Specialist, Australia*

While the outcomes for WHS management in this example was still favourable, the tendency of WHS to just fall out without being specified should nevertheless be considered. The frequent overlooking of WHS is symptomatic of a number of barriers to BIM for WHS management in the industry. First, WHS is just "one of many things". As such, documents, standards and users often do not adequately consider WHS in planning and management. If WHS is not specifically considered, it is likely that only the blatantly obvious and costly risks to safety are mitigated and managed, for example cranes and clashes in movement on site. WHS in Australia tends to be a matter relegated to the periphery, thus it is unsurprising that one interviewee noted that the WHS management plan is just part of a long list containing other plans:

> *"[We have to do] a community management plan, an environmental management plan, an interface management plan, project management, blah, blah, blah. You know, there's all these management plans that we require. And safety management plan is one of them." - Interviewee 3, General Contractor, BIM Specialist, Australia*

A second challenge, arguably related to the first, is that WHS is not planned for in the earliest stages, because it is not a key priority:

> *"We don't do that [assess WHS at procurement]. So there's no – well, what we ask for is once the project's started, within a certain amount of timeframe, it might be two weeks or four weeks, we will require a safety management plan." – Interviewee 8, Government, BIM Specialist, Australia*

> *"But there's no – we don't tend to assess projects for safety during procurement, as far as I'm aware. So that kind of stuff when there's specific hazards, but on traditional ride or rail projects, it just skips the safety management plan once you start the job." - Interviewee 8, Government, BIM Specialist, Australia*

In the UK, the industry is different insofar as the process of WHS management begins in early stages, even before design:

"BIM starts at the very early stages in the UK. So that's well before design. In fact, to get the real value it's got to start, especially in terms of safety during assessment, assessment of need and business case. So we start it right at the very beginning of the job because your biggest decision is going to be made well before any design starts. And I think that's one of my biggest frustrations, everybody talks about BIM during design and construct. Actually, you probably got about three, four years of an advance of that of business case modelling, looking at strategic assessment of needs within there and that's where you make some of the biggest decisions. So it starts at the very early stages." - Interviewee 5, Government, BIM and WHS Specialist, UK

The need to plan WHS management in early stages also links back to procurement models. Earlier, Interviewee 4 was quoted as saying that models such as IPD and PPP were best suited to BIM. In a similar vein, the interviewee also noted procurement models such as "Construct Only" posed difficulties for early WHS planning, although these difficulties could be mitigated through early contractor involvement.

The difficulties with "Construct Only" link to a third challenge, noted across both Australian and UK-based interviewees: that WHS is still managed in a fragmented, piecemeal manner. Again, the disconnect between WHS in design and WHS in construction has been noted by a UK interviewee, who attributed it in part to designers being detached and insulated from safety issues:

"There's a mentality in design which is wishing things into place. I want a feature in my building, it's a great feature, I'm an architect, I can do this, I've drawn the feature in. How are we going to build that? Well, that's a contractor will sort that out. Ineffectively it's an assumption, a design assumption which is then carried through." - Interviewee 5, Government, BIM and WHS Specialist, UK

Other examples have also been shared, for example this time involving designers having data-rich models which are not fully utilised by the client or contractor:

So I guess one of the frustrations in the design side, like we coordinate from a BIM perspective, ensure that we're presenting information and creating rich information that a lot of the times, it just stays with the design consultant and doesn't get handed over to the construction contractor because it's not a requirement to be handed over like (a) to the client and then (b) the client then never reissues it back to the contractor. And probably the third bit is they probably don't know how to manage it or what to do with it. - Interviewee 4, General Contractor, BIM Specialist, Australia

Efforts are now being put in place to explore how WHS can be managed more holistically. In the UK, for example, designers are being encouraged to think more deeply about how something could be designed so that it can be installed, maintained and eventually disassembled in a safer manner. One relatively new solution is the introduction of the role of "principal designer" in projects, a position that is tasked with coordinating risks at preconstruction. 'Prevention through Design' principles are also now in use and demonstrate how much more can be achieved if WHS is specifically considered when using BIM for design, construction and maintenance. Holistic WHS management thus clearly requires collaboration across phases, including willingness to involve contractors early during design, and using and maintaining the data-rich design-phase BIM during subsequent phases. Similarly, handing over an up-to-date model to relevant stakeholders when handing over to operations is important.

Three barriers to BIM for WHS have thus been identified so far: (1) WHS is not foregrounded, and is seen as one of many requirements; (2) WHS planning emerges in a perfunctory manner after a project has begun and (3) WHS is managed in a piecemeal manner, for example with design and construct stages.

Client's Role, Regulatory Factors and the Emerging Role of the Government Client

The three barriers noted in the previous section point to broad contours of a remedy: WHS must be adequately foregrounded, must be considered at the start and must be managed in a holistic manner. These issues can be simultaneously addressed by client leadership: if the client and/or principal contractor demonstrate leadership, they can drive a collaborative culture, encouraging (or enforcing through a contract) the use of BIM, in general, and WHS planning and management using BIM, specifically.

The current reality in Australia, however, is that for the most part, client interest in WHS management remains weak. The situation is not unusual; even in the UK, where WHS already plays an important role, clients still prioritise other more pressing goals over WHS:

> *"If you look at most projects, in my view, if you talk to the client, the client will be listening to his cost consultants and to his money people very closely. He'll hardly be listening to his risk advisor at all, and that balance needs to be somehow pulled together a bit." - Interviewee 5, Government, BIM and WHS Specialist, UK*

In Australia, one subcontractor noted:

> *"We don't see in the role that we do, which is really cranage, we're not seeing any proactive push from the client or anything where they're saying we want you to work with them the model that just doesn't happen were asking them for saying, can we please get it like I think some of the time we're getting it sometimes we can't do that where we can. It's definitely more value for us and for them." - Interviewee 9, Subcontractor, General Manager, Australia*

In other cases, WHS gets overlooked by clients because they have outsourced the procurement process:

> *"So, it's a frustration but a lot of the time, these employers' information requirements were written in very general terms by consultants, information consultants who didn't really understand health and safety at all." - Interviewee 5, Government, BIM and WHS Specialist, UK*

There have also been occasions where a client has had sincere interest in requiring WHS, but is overruled by contractors, a point that was mentioned earlier.

Yet despite these entrenched ways of dealing with WHS, one interviewee commented that "clients need to understand, *especially government clients,* that they really are in such a leading role" [italics added]. The government client is uniquely positioned to foreground the importance of WHS through a number of instruments. In theory, one of these could be legislation, but the regulatory landscape remains in its infancy. Both the literature and interviewees noted that the only mandate that has made a strong link between BIM and WHS was UK PAS 1192-6. One interviewee from Australia commented that industry would not voluntarily take it up if the standards were not "legally enforceable". The only way to compel industry, according to this interviewee, was to make sure the standards were referenced in the National Construction Code, or explicitly required in a contract:

> *"So you're going to have to have that relationship of the national construction code, maybe including a digital space that says Work Health Safety management is a mandated objective for any project and you must include reference to this standard and that standard. That's one of the barriers, because obviously if it's not there, people won't do it... this is the sad fact of it, if it's not an enforceable requirement, because anything of deliverable takes effort and time and costs, it sometimes doesn't get included and that will actually tie in to our tender questions as well." – Interviewee 3, General Contractor, BIM Specialist, Australia*

In the absence of legislation, another instrument the government client can use, then, is procurement, that is, making WHS a requirement at tender for BIM-enabled projects. Specifying BIM for WHS management requirements at tender could drive a number of critical elements for success stories recounted by Interviewee 4 earlier in this section: the stage would be set for requirements for WHS to be defined at early stages, for commitments to these requirements to be secured across the supply chain early on, and for monitoring mechanisms to be put in place to allow WHS management on a holistic, ongoing basis. This shift could be a profound change.

It is beyond the scope of this study to discuss all of its implications exhaustively. However, the Discussion section lays some groundwork by focussing on critical points linked to procurement: the need for specificity in decision-making at tendering and subsequent construction phase monitoring.

Data and Technology

Information is central to the success of BIM, whether for operational, construction, or WHS management. A key issue about WHS information is that it tends to be dispersed across different systems:

> *"I know there's many other datasets we manage on a project, requirements management, risk management, especially for managing hazards and safety assessment and documenting many others. And the key takeaway is that they all use siloed software, but more than that, they have siloed business practices. So each different business party – or so a project party, uses their own descriptors, their own breakdown to describe the same projects." – Interviewee 8, Government, BIM Specialist, Australia*

At times, WHS management systems are detailed and comprehensive, but unwieldy and tedious because they are manual or form-based. The interviewee who had earlier described their WHS systems as “onerous”, “extremely detailed” and “prescriptive” noted that

> *“So in terms of the management of WHS it should not change from job to job, but sometimes when there’s elements that have been, or requirements that have been passed down from clients that are outside of our requirements, that’s where we get to a bit of a sticking point.” - Interviewee 1, General Contractor, WHS Specialist, Australia*

Interviewees acknowledge that a key capability of BIM is the potential to integrate all project information into a single source. The model in particular becomes

> *“…the primary source of truth and everything else is secondary. Drawing is secondary; reports, everything else is secondary to the model. The model is always going to be the prime source of truth, because we basically said to the consultants that we are going to be building off those models.” - Interviewee 4, General Contractor, BIM Specialist, Australia*

Of course, the value of the model is maintained only when users update the information and maintain its accuracy regularly. Interviewee 4 mentioned a case where this was done on a weekly basis. Again, the important thing was getting the content in place, after which

> *“…we [could] start to interact with technology like virtual reality. So we do that a lot now where we will take designs and we’ll take stakeholders; we’ll put these sort of headsets on and they'll be able to see things at full scale. And I think that gives you then the next level of appreciation. When you’re seeing things a full scale, you'll start to pick up that hang on, I can't get through here or is too high or this is too low. I’m not going to be able to get that plan unit out in a safe manner or whatever else it might pick up that you wouldn’t typically see ‘til you start the construction and it’s too late or too expensive then to rectify. Or we work around it.” - Interviewee 4, General Contractor, BIM Specialist, Australia*

The use of increasingly sophisticated tools for augmented reality, virtual reality and immersions has been fruitful. However, interviewees have also emphasised that there are benefits to be gained by also exploring simple, intuitive ways to interact with the technology. Tools do not have to be the latest or the flashiest; in fact, some interviewees reported feedback from users that technology came across as “too gimmicky” or “too futuristic.” There is value, then, in exploring straightforward, affordable solutions:

> *“So every project has a virtual reality set that allows stakeholders and any worker that wants to, to actually be able to experience the model or walk the site differently. That's really how it how it should be. And the technology isn't expensive compared to a lot of other things. The 360 camera means that $1000 or $2000 for a complete kit that allows you to go and capture the site. That was relatively cheap again. So I think that should be accessible to anyone.” - Interviewee 7, General Contractor, BIM Specialist, Australia*

Other solutions involve simple extensions of BIM capabilities to mobile phones, allowing BIM for WHS to move to the coalface:

"We are talking about this thing, but you've got to find tools that are relevant to smaller businesses and to people doing the work. So if you had an application on your mobile phone, for example, with the ladder which somehow was able to measure the height of where he's got to go, it could measure the angle of his ladder, if he's operating outside of some sort of indication of the centre of gravity isn't right, do you know what I mean.... But the actual BIM angle on that is very much about setting a requirement early that you then follow through." - Interviewee 5, Government, BIM and WHS Specialist, UK

Simplicity, then, is a key strategy, when incorporating BIM for WHS management into organisational practices

Culture and Value Proposition

Simplicity is a strong enabler for adoption of BIM for WHS management, particularly when cultural considerations are taken into account. The previous section of this report already discussed how large segments of the industry in general tend to be resistant to technology. WHS professionals, specifically, have also been described by interviewees as resistant to the technology. Interviewee 5 linked this to a deeper problem: that the domains of technology and WHS are fundamentally disjointed:

"...you can go to a very big reputable contractor and talk to their health and safety people and say, 'Well, look, what do you know about digital in your company,' and the answer is not a lot. And you go to the digital people and say, 'Well what do you know about health and safety,' and again, they just aren't talking." - Interviewee 5, Government, BIM and WHS Specialist, UK

The gap between domains must be addressed, because a strong WHS culture could be a powerful enabler for BIM adoption. In the UK, WHS has already been described as the "number one" driving force for BIM:

"...if someone said to me, what's the number one priority [for adopting BIM]? It's health and safety, above all, and then comes it's health and safety and then sustainability, you know, without a doubt. You know, everybody has got the right to stop a project, you know, no matter what they're doing, if there's something that is not safe. It's prioritised, now the reason being, you know, what happens if you get it wrong, well, you can go to jail. And I think that's the message I think any contractor, it's not just the person on the site that will go to jail, it will be the person at the top of the company." - Interviewee 2, Government & Private, BIM Specialist, UK

According to Interviewee 2, then, BIM adoption is driven by a strong WHS culture, which in the UK appears to be driven by a regulatory landscape where industrial manslaughter laws make WHS a priority. It is a point worth noting that interviewees from Australia and Singapore did not make any reference to such strong penalties. One possible explanation is that a number of interviewees were specialists in BIM and not in WHS.

In other cultures, linking BIM to WHS could be more difficult, possibly because WHS is not a priority, or because the benefits of BIM for WHS are not self-evident:

"…sometimes it can be a hard link… you're building a model in order to remove clashes and therefore reduce abortive work therefore put people at risk for less time. Yeah, okay, but there's a lot of dots to join there and that's kind of hard for people to get, to wrap their heads around…" - Interviewee 6, General Contractor, BIM and WHS Specialist, Singapore

The gap between WHS and technology domains could thus be exacerbated when WHS professionals feel forced to engage with highly complicated technologies, or when they find themselves needing a technology expert as an interface. Simple ways to link the two domains are thus being explored:

"See, health, and safety people love spreadsheets, so they'll tend to produce risk registers on spreadsheets for a project and then it's completely independent of the model. So how do you link a risk from your risk register to your actual model you're building with. So I was just looking at a simple technique which provided a two way flow of information. So you could alter something in the spreadsheet and it automatically updates the model or vice versa. If you want to put something in the model and it automatically comes through on the spreadsheet, and that's the kind of development which the technology has got to catch up and provide the ways of integration between these different disciplines." - Interviewee 5, Government, BIM and WHS Specialist, UK

Summary

Findings for this section have laid out several enablers and barriers for BIM for WHS management. The barriers are highlighted here, as these are actionable matters are further explored in the Discussion section. Briefly, barriers include (1) the challenge of WHS management still being a fragmented process. This fragmentation, coupled with the practice of submitting safety plans weeks after a project has begun, could be indicative of (2) a "weak" safety culture, perhaps one that sees WHS as a compliance matter, rather than as a normal way of working. (3) Clients themselves remain confused, ambivalent or indifferent to WHS as a priority in projects, a process that has been described as ticking box unless there are obvious and major WHS risks involved. BIM can support the integration and informatisation of WHS practices across the supply chain, however (4) there is no mandate for it, which makes BIM use less compelling since using BIM for WHS management comes with considerable investment. (5) The value proposition of BIM for WHS management remains obscure to many actors who continue to see BIM as a tool for productivity. (6) Stakeholders, in particular WHS professionals, remain resistant to technology and (7) data quality and integrity remain significant issues. Once again, a solution is found in the leadership of the client. The specific interest of this report is on the government client.

Findings from the previous topic highlighted the leadership role of the government client in catalysing BIM adoption across the industry. In this section, the recommendation that emerges is that this leadership role now be taken in a specific direction: to elevate WHS standards across the industry through requirements at tendering for BIM-enabled projects. WHS management would be significantly strengthened because such requirements would (1) foreground WHS goals which are usually pushed to the background; (2) compel WHS planning to take place at early stages, instead of weeks after a project has commenced and (3) drive a holistic approach to WHS management that cuts across all stages of the project lifecycle, starting with pre-construction. In addition, requiring WHS standards at tendering would also (4) be instrumental in bridging fundamental gaps between two disjointed domains: the domain of technology and the domain of WHS.

Change management-wise, there is considerable latitude for exploring the possible implications of this approach. In the government client domain, for example, one could speculate that practitioners would have to learn how to prioritise WHS, define WHS requirements at tender, incorporate proper criteria for contractor selection, implement this criteria, provide support across the supply chain and set up governance mechanisms so that compliance with requirements is monitored, reported and enforced. In the contractor arena, contractors would have to come to a renewed appreciation of the value proposition for WHS management, engage early in WHS planning activities, informatise their WHS processes and share data through interoperable systems. These are just examples of specific implementation issues that have not been deeply explored in the literature and are part of the purpose of this empirical study. In the next section (T3), macro-level recommendations for capacity building that emerged from the interviews will be discussed.

Topic 3 results: Capacity building

Following the topics on BIM adoption and participant experiences of BIM for WHS management, interviewees were asked about their views on building capacity for BIM for WHS management across the industry. This segment of the report summarises interviewees' practical, mostly macro-level change strategies. The value of these findings is that they provide clarity on areas that are currently supported by limited research. Change management strategies that were discussed are categorised into four groups, summarised in Table 8.

Table 8: Areas for capacity building in using BIM for WHS management

Area	Recommendations
Strengthening the BIM-WHS value proposition	• Highlight the consequences, communicate the "why" • Use plain language, videos • Use BIM capabilities to showcase its value Ways to make BIM more attractive would likely be the opportunity to "sell" the construction approach to clients and contractors using visuals and associated "impressive" high-tech (like VR). • Build case studies and use compelling storytelling • Develop a metric for the benefits of using BIM for WHS • Show how BIM for WHS supports business objectives: GMs, reduced costs from rework, "Getting It Right" initiative, Soft Landings
Strengthening training and development	• Increase breadth of skillsets • Train people to value, use and manage information • Encourage direct use of BIM for WHS applications through simple, intuitive technologies • Educate the workforce, with an emphasis on the existing workforce

Area	Recommendations
	• Strengthen the use of specific techniques, for example virtual rehearsal • Educate on the benefits (see value proposition)
Strengthening digital capacity	• Push for technology for everyone • Emphasise the need for data quality and consistency • Plan for governance for digital • Consider WHS as another layer of information for BIM
Managing/ initiating change	• Begin with quality content and data as the foundation • Begin with focussed, flexible requirements • Provide a clear time frame for the implementation of new requirements • Build up to a set of clear, consistent requirements • Begin with Tier 1; the rest of the industry will follow • Combine top-down and bottom-up approaches • Balance between defining goals vs. pathways • Provide support to clients, for example making them more data-centric • Make WHS the default: "Opt out" rather than a "bolt on" at procurement • Use WHS as a Trojan horse for BIM

Strategy 1: Strengthening the BIM value proposition

There is a clear need to communicate the value proposition for BIM for WHS more clearly. One barrier that was mentioned earlier was that it takes significant work to "connect the dots" between BIM use and improved WHS outcomes. A second and related barrier is that the contribution of BIM to improved WHS outcomes is very difficult to quantify:

"We're trying to work out...[the] business case. You now, what has it saved or – and safety is always a tough one because you don't know what you've saved really. How many incidents have you avoided if you didn't do it this way. You can't just measure that because you don't know when that incident is going to happen. So you've just got to go on statistics." - Interviewee 4, General Contractor, BIM Specialist, Australia

"You have to go through the history of why safety incidents happens. And which ones of those could have been avoided if BIM was [used] on the job. Trips and falls are always going to happen but hitting a utility and causing an incident or staging was done poorly and all that kind of stuff, maybe you can attribute it. But it's not a direct correlation, so it's a harder one for us to match up." – Interviewee 8, Government, BIM Specialist, Australia

That said, people who have ventured into the BIM-WHS space realise that the value proposition is there, "...it's just not visible", according to Interviewee 9. The benefits are real, but are only reported in case studies and may, at this stage, be coming across as anecdotal. The fact that they are anecdotal, though, does not mean they are not valuable. Interviewee 5's reference to a "spectacular" example of how BIM use eventually negated the need to work at night is just one of "many good stories that are coming through." Different approaches must be mobilised to communicate these cases in vivid ways. Four approaches have been proposed.

One approach is to present BIM using compelling storytelling. Factual reporting or the language of policy frameworks have a purpose, but can only take one so far and are not seen to "move" people into using BIM for WHS management:

> *"…what we're rubbish at in terms of the growth of the built environment is storytelling communication. We tell it very much from very technical language within there and we need to use much more plain language that people are going to understand within there. And number one is why, you know, why we're doing this is hugely important. And also remember back, you know, when I was a contractor and we were at this conference and we're into there's maybe four or 500 people in this room and the lights went off, it's completely dark and this person started speaking and were telling a story and basically it was about an accident that had and it was unusual and they put the lights on and he had, I can't remember when this was, probably 2015 year and he was on the stage with a guide dog, and he said, 'This is what I see, nothing, it's black every day.' - Interviewee 2, Government & Private, BIM Specialist, UK*

A second is to use the technology itself to show what BIM is capable of doing. BIM has powerful visualisation capabilities, and resistant people who have engaged with it directly have found themselves convinced of its value:

> *"And there are those that are converted because they've experienced it on a project and they've seen what they can learn from, you know, having those aerial views from a drone on a regular basis. And, you know, the kind of problems we solve when we have a well-coordinated design, so that we're not, you know, we're minimising the amount of time on site because we're doing the work one time only and getting it right. All of these things have OH&S benefits, but until you experience it first-hand, you can remain sceptical. And so we still have that transformational process to take within our own business, as well as across the industry." – Interviewee 6, General Contractor, BIM and WHS Specialist, Singapore*

A third approach is to demonstrate how BIM and WHS goals align with requirements that are already in place. For example, a multinational organisation with global standards for WHS frames BIM against these requirements, and has found that this leads to high levels of subcontractor engagement with BIM. Interviewees also noted how framing BIM's broader benefits eventually strengthened the case for using BIM for WHS management:

> *"I think the key is not just focus on WHS; it's everything that spawns out of this makes the business case 50 times over." - Interviewee 4, General Contractor, BIM Specialist, Australia how BIM*

The final, and perhaps most challenging, approach that was suggested for building the value proposition for BIM is the development of a metric that quantifies its value. The difficulty of measuring "slips and trips" avoided has already been raised and work in this area has just begun. However, there are other indirect measures that might still capture BIM's benefits by approaching the issue from a different angle. For example, one interviewee mentioned that reduced Requests for Information from the designer could be one measurable benefit for BIM and, depending on the case, for BIM for WHS management:

"They use RFI, so, Request for Information on their projects. Once the designer has handed over, if a request comes back to a designer from the contractor, they call it a Request for Information, and they've cost those as being very expensive to the business. So, it starts at 1000 pounds and then starts rising very fast, and some of them are astronomical costs. But one of their measures of success is to reduce and they're able to show how when BIM is well managed these Requests for Information drop dramatically so that the need for rework, re-doing stuff is reduced dramatically, and that's quite a powerful measure. So whether there are some metrics you could find, which you could start promoting, which would really help, I'd be interested to see." - Interviewee 5, Government, BIM and WHS Specialist, UK

Strategy 2: Strengthening training and development

A second strategy for capacity building is training. The importance of training is a counterweight to the barrier of 'limited expertise" on BIM and/ or on WHS that were raised in previous topics. Training is important because it overcomes a basic hurdle to BIM for WHS management: resistance from people who do not know how to use, or do not want to use, the technology:

"Well, there definitely needs to be more training and access to it because I think that's where the pushback constantly comes is that you've got – you just got a lot of subcontractors particularly and builders who only got a really small amount of staff that can actually use it. I think that's where you're constantly get the pushback."- Interviewee 9, Subcontractor, General Manager, Australia

"We've only got a couple of people who are actually trained to drive it. So although we can all sit around and talk about what we're doing once we're there we got, you know, it's having enough people in the business who can actually understand how to how to use the system." - Interviewee 9, Subcontractor, General Manager, Australia

Training can come in different forms. Singapore places an emphasis on industry-led, rather than university-led education, an approach which is seen to be beneficial:

There is actually a facility called BCA Academy where they are teaching everyone from literally trade contractors, they're teaching them, like this is certified, you know, the safe way as an electrician. We're certifying you as an electrician, were certifying you to operate a digger, a JCB or crane. You know, how do we use technology in that setting with those people? But they also then run courses that are for the designers for the general contractor trades. You know, this is how you use technology, or this is how you, these are different certification courses for various things. Building this into an educational process there, where it's industry education, rather than degree level, right, is very doable. It's very approachable. – Interviewee 6, General Contractor, BIM and WHS Specialist, Singapore

Training that crosses narrow specialisations has also been raised as an important intervention, as it addresses the concern of "railway track" approaches to BIM and other topics like WHS or project management. One interviewee described hyperspecialised people as T-shaped, and pointed to the need to branch out to other disciplines in order to make BIM work:

"A lot of the sort of BIM experts in our industry, they were people that knew how to make 3D models. They were like the early adopters in the office who are doing things in 3D, so then they became the 3D guy or the BIM manager and then, they became the BIM strategists. But if you scroll down on their profiles on LinkedIn, they're still just – their vertical on capital T is still just CAB. And they still didn't understand how to create a strategy that others can follow. So a strategy that links in with the way government works. And you have to be able to approach it so it's not just a technical thing." – Interviewee 8, Government, BIM Specialist, Australia

One interviewee stressed the importance of training the current work force to use BIM, for two reasons: educating the current workforce means more people can use BIM sooner, as opposed to training the "future" workforce that is still in university. Also, training the current workforce meant that they could be trained out of their bad work habits, which they pass on to others.

Training in specific BIM capabilities for WHS management was also noted. One interviewee pointed to training people specifically to do virtual rehearsals:

"The training or virtual rehearsal is another one. And I think that is as important. You could, you could start extending it. I mean, think of it as a game engine. Most of these things are game engines anyway. That you can start identifying pinch points you can identify and certain areas because it's as objects come together. Can we highlight those?... And I think a good example of that, you know, when you have a large bridge or something that bridge gets put into place that gets virtually rehearsed. But that's the engineers and everybody kind of looking at that. The next step would then be ok now let's take that rehearsal, it works. How we're going to do the health and safety around this where we planning, all of that. What's happening throughout. What are you know what are the swings. All of that can be evaluated. And I think that's, that's where a large component of that would come in. It's really, it's it's using the virtual world and to to plan for the real world". - Interviewee 7, General Contractor, BIM Specialist, Australia

Finally, one interviewee has suggested specialised WHS training that is rooted in a larger foundational strategy of building a "digital engineering" culture. The idea of digital engineering is taken up in the next section.

Strategy 3: Strengthening the capacity for "digital"

In earlier sections, the matter of the industry's resistance to technology was raised and one interviewee's response to this challenge went well beyond capacity building for BIM. Instead the interviewee outlined a four-pronged approach towards capacity building centred on digital engineering. BIM is just one component of this. The four-pronged strategy is worth considering as it proposes solutions that have been linked to BIM concerns raised elsewhere in this report. The four-pronged approach comprises technology for all, open data, governance and training. "Technology for all" involves

"…get[ting] really simple technologies for people to use to even if it's not the best product with the best outcomes, but it's very easy for people to use just to start getting adoption of technology. So that's one part. Because then once they start using it, very quickly you start getting questions, oh, can I also do this, can I also do that. It's actually allowing them to overcome that initial barrier of using technology." - Interviewee 7, General Contractor, BIM Specialist, Australia

Direct use of simple technology avoids the costs of establishing specialised roles and departments, and the inefficiencies of adding layers of interfaces between technologies and the people who do not have the skills or the confidence to use them.

Training in digital engineering is also important, and should target as broad an audience as possible. However, generic training for "digital" capability is not an end in itself. Digital engineering training must eventually be harnessed and customised to inform specialisations, one of which could be WHS:

> *"So we are developing our own training for different parts of the business. Digital engineering itself. It sort of is a foundation understanding and then each different discipline actually should be using digital engineering in a different way. Construction managers different to planning managers different to project engineers, different people on site. So health and safety could be one of those as well. I know we are working with our health and safety team here to explore what that means and how we could use that and then have those embedded into our competency levels. So that's essentially the strategy". - Interviewee 7, General Contractor, BIM Specialist, Australia*

A third component of the approach is governance, ensuring that digital engineering becomes embedded in strategic and operational decision-making in a manner that makes it a way of working:

> *"Do we have our proper templates, right, all of those kinds of processes properly in place that allow us to manage, monitor and then also report how the company's actually using digital engineering, but also making it easy for the project managers who really ultimately have to use this stuff to understand it and use it." - Interviewee 7, General Contractor, BIM Specialist, Australia*

Finally, the fourth prong of the strategy is open, consistent data.

> *"…working around consistency in data across the entire lifecycle and also across the value and supply chain. So how do we work with dozens or hundreds of different companies and start standardising that we can get the data in and out." – Interviewee 7, General Contractor, BIM Specialist, Australia*

Data consistency is a persistent problem in the industry and this is a point that will be raised shortly. But once consistency is achieved, the potential for building on integrated data opens up avenues for WHS management:

> *"If the underlying data structures aren't consistent… you'll get a whole bunch of models in a 3D GIS, which you can visualise, but they're going to be useless at the same time, until there's that layer of structured data. And then you can build all sorts of metrics on top of it, including hazards and safety and so forth." – Interviewee 8, Government, BIM Specialist, Australia*

In the long run, a strong foundation of integrated data, coupled with a vision for mature WHS standards in the country, could lead to the possibility of WHS being another information layer for BIM:

"The design is very much around design information in models about what has to be built and certain, some Australian standards, how we meeting those and if health and safety becomes an Australian standard that might be another layer that could actually be added to BIM that might be a requirement to be recorded, of how did you ensure certain things. So looking at BIM as really layers of information that go on top of it. It could be a layer that becomes specific towards the information that require to be able to work with. So creating an open standard of what would be required for government to be able to interpret whether certain things had been planned correctly, could be an option. And that's, yeah, this, this, thinking about data and how we can use technology to kind of capture some of these things." – Interviewee 7, General Contractor, BIM Specialist, Australia

Strategy 4: Initiating and managing change

In the discussion on capacity building so far, a number of strategies have been explored, two of which are emerging as central. The first is training, discussed earlier. The second is integrated information. All the other recommendations are useful, but data is quite clear that any change management strategy around BIM for WHS management at procurement must focus on information integration and training. Interviewee 4 put it succinctly: "*get the content first that we need to make it happen, and then just training people*."

Six of the nine interviewees identified integrated information as among the most important ingredients for BIM success. Interviewees 5 and 7 also noted it was the most difficult:

"…one of the big things is the UK is now moving to an information management framework. Which starts to look at foundation data models, data seeds to start to connect, if you like data sets together." – Interviewee 2, Government & Private, BIM Specialist, UK

"If everyone's using the right structured data that's all talking to each other as well effectively." –Interviewee 3, General Contractor, BIM Specialist, Australia

"…it only can happen when we've got the content to make it happen." – Interviewee 4, General Contractor, BIM Specialist, Australia

"…the only way that we can make this normalised is if there's a common foundation of structured data. And that we don't want different clients doing different things, because then it makes it hard for industry." – Interviewee 8, Government, BIM Specialist, Australia

"… the most fundamental and useful thing of all, and it's also the most difficult thing and the thing which the industry finds most difficult to do, is to integrate information through a common data environment." - Interviewee 5, Government, BIM and WHS Specialist, UK

"The reason that BIM has failed as a lot of people said, is because the data is always different. So you get data from one company and you get from another, but actually they don't work together at all. So, frankly, the data and the BIM model itself becomes useless. It just becomes a 3D geometry representation and everything else is kind of rubbish. That coming in, now with transport and government requiring certain outputs that are starting to streamline a few things. But that's what we're strongly working on, so it's consistency and quality of data throughout. And having that data in open data formats so we can work with it and we don't have to pay a software company to access it." – Interviewee 7, General Contractor, BIM and WHS Specialist, Australia

To address this challenge, some guidance might be obtained from examining the UK experience, which has embarked on large-scale efforts for building strong foundational data. For example, a task force is looking more closely at ways to ensure that WHS requirements do not fall away from project information requirements:

> *"Our current preoccupation on our working group is to see whether we can write high level project information requirements in a way which would really help the client to ask for and get something closer to what they want. One of the big issues with risk management, health and safety risk management is around disciplines not talking to one another…and often the health and safety person gets forgotten. That's a bad situation to be in, really. So we're trying to write these requirements in such a way that – there's two risk discipline which we were aware of, which are not well integrated." – Interviewee 5, Government, BIM and WHS Specialist, UK*

Apart from capacity building through training and information integration, a number of other recommendations have emerged. Interestingly, some of the recommendations of different interviewees, when taken collectively, appear at least initially to send conflicting messages. For example, contrasts in UK and Singapore practices have emerged with respect to incentives for the industry for BIM adoption. These contrasts are not necessarily problematic; deeper discussions may have resolved some of them but interviewers were limited by time constraints. Resolved or not, even the conflicting recommendations raised are valuable because they can sensitise one to possible decision points that the Australian industry may have to consider in the future, as it navigates through the implications of implementing BIM for WHS management at procurement. These decision points include:

- Whether to define broad, long-term goals relative to WHS management, or shorter-term moving goals
- Whether to define means and methods for achieving these goals, or leaving these open ended
- Whether incentives for the industry in the form of grants or funds for training are beneficial, or if the industry should be more self-driven
- Whether or not a mandate for BIM for WHS management should be rolled out
- Which agencies should require BIM for WHS management; what project size should be covered by the mandate; and in what time frame
- Whether BIM for WHS management should be an "opt out" rather than "opt in"
- Whether requirements should specify a model at procurement or whether a flexible open-ended requirement might be more viable at early stages

Summary

This section has presented macro-level change management strategies to support an industry undergoing transformation from changes in procurement led by a government client. Data suggests that training and information integration are fundamental elements of the change effort. Data from the Singaporean interviewee shows large-scale, top down efforts involving industry-led training. Data from UK interviewees shows large-scale, top down efforts, through standards, to move towards integrated information. Two additional points are worth noting. One, change interventions do not have to be exclusively top-down. Bottom-up, everyday efforts can contribute to skill-building and to a stronger information-driven culture. Regular, ongoing meetings can become opportunities to train partners and for getting them increasingly comfortable with data use and models. "Workshopping" in particular was mentioned by two interviewees as being very useful. One interviewee noted:

> *"…we would run every workshop we would run on the projects …we would bring the model up. It would always be up, whether it's a security workshop or a safety workshop, the model was always up on the screen so that we can just check. From a security perspective, you can check visibility lines, for example. So, you know, you just have it up there and then you start to talk to it, and it starts to become accepted that, okay, we can do that…. we did all of our safety workshops with the model. I make sure the model was open and then we'd check, you know, how are we going to get this piece of equipment in and out of that room, for example…" – Interviewee 4, General Contractor, BIM Specialist, Australia*

A second related point is that it is beyond the scope of this study to explore the contours and implications of all these change interventions. In the Discussion section, the focus will be on interventions identified as priorities for Phase 2 of this study.

Discussion

The two aims of the empirical study were (1) to validate and nuance the review findings and (2) provide a practical context for Phase 2, that is, a platform of practical knowledge that could inform recommendations for Phase 2. This Discussion section addresses (1) while the Conclusion addresses (2).

In discussing how the empirical phase of the study relates to the literature review, it is useful to first note that T1, T2 and T3 findings move from broad to more focussed topics. Specifically:

- T1 focuses on experiences and understandings of general BIM adoption. T1 findings on barriers and enablers to BIM adoption confirm well-established literature and point to the catalytic role of the client in mandating BIM adoption through contracts.
- T2 then focuses specifically BIM for WHS management. While the literature review proposes a novel conceptual novel conceptual thread that ties together procurement, the government client role, WHS and BIM, T2 findings show early stage support for this thread, but the picture is still emerging. The picture centres on the role of the government client who does the work of foregrounding and integrating WHS management. The fact that empirical evidence supports a very early stage picture confirms the need for the work of Phase 2.
- T3 then presents macro-level change management strategies to support the proposed strategy in T2.

"New" insights increase progressively from T1 to T3, with many T1 findings confirm the literature review, while many T3 findings yield a body of practical knowledge which can support future, rather than current, research.

New insights from T1: BIM adoption

Government client as catalyst

Empirical findings for T1 *mainly confirm* the main points of the literature review on BIM adoption: that adoption is high in Singapore and the UK, and low, fragmented but slowly increasing in Australia. Empirical findings also point to a complex ecology that supports BIM adoption: technology, culture, regulation, value proposition and other factors such as data, cost and governance matters. Multiple references have been made to the importance of a single, strong national mandate. Singapore's legislated mandate was seen as a key driver for high adoption levels. The UK's government policy mandate for public works was also seen as important, but a closer look at the data supports the view that the mandate is not monolithic, nor is adoption uniformly high and undifferentiated. In Australia, interviewees upheld the view that a clear national mandate was absent. Only one interviewee acknowledged state-led policy initiatives, but did so only to comment that their fragmentation caused confusion. Other interviewees saw BIM as "optional". The weak policy landscape, a culture averse to change, technology and impervious to the value of data-sharing, foundational problems with data integration and a narrowly-framed value proposition for BIM all contributed to limited BIM adoption.

In the discussion of findings for T1, the government client was discussed as having a catalytic role, since a government contract requiring the use of BIM could be the much-needed mandate needed to push the industry towards increased BIM adoption, stimulating the sluggish BIM-averse culture. There is significant foundation for this premise and there are enough findings that justify moving to the next level, which is "stepping up" the capacity of government clients for executing this.

New insights from T2: BIM for WHS adoption

New procurement pathway

Findings from T2 move beyond confirming the literature towards *orienting both research and practice* towards a viable and relatively unexplored trajectory: the government client taking up a leadership role in elevating WHS management requirements through procurement. As mentioned earlier, much research has been done on BIM adoption, WHS, procurement and (to a lesser extent) the role of the government client, but most of this work has explored these domains separately and limited work has been done to explore the nexus of these areas. A key contribution of this study's literature review is that it makes a clear conceptual argument that threads these areas together. Support for this conceptual thread through empirical study has just begun. The case of TfNSW is one possible example. More empirical work is needed to explore how this WHS-focussed procurement process could unfold. The lack of empirical knowledge in this area thus justifies the need for Phase 2 of the study.

While empirical findings do not provide many examples of government clients using procurement in this way, data does suggest that it is logical and plausible. The T2 section "Systems, Processes and Holistic Integration" in particular shows examples of how a client, and by extension a government client, could act as foregrounder of WHS and integrator of WHS management. Foregrounding involves the dual task of making WHS management a priority and moving WHS management to the earliest stages of planning. Integrating involves ensuring WHS management is carried out from pre-construction through all phases of the project lifecycle. Integration also means bridging the persistent divide that is seen to exist between the domains of technology and WHS. The enablers and barriers to BIM for WHS strengthen this argument. A government client championing BIM for WHS management at procurement could again counter the cultural indifference to WHS. The BIM requirement could compel stakeholders to move away from fragmented WHS management and drive early contractor involvement. The government mandate also adds weight to the BIM-for-WHS-management value proposition, or may even render it moot since tenderers would be bound to requirements, whether or not they believed in its value.

New insights from T3: Change management

Government client and capacity building

Findings from T3 show detailed, practical insights on the implementation of the new pathway identified in T2. This pathway has *not yet been deeply explored* in the literature, thus findings in this section provide the grist for future research. The section contains a range of macro-level strategies to initiate and manage large-scale transformation across an industry that is resistant to change, to new technologies and to new ways of doing things. Some findings point to possible starting points for the daunting new task of implementing new WHS requirements at tender. Interviewees have, intentionally or otherwise, identified important decision points: which agencies to start with, what size of projects must be considered, what level of notice will be given to industry, how tendering requirements should be framed. Interview findings also present interesting contrasts between countries that have already taken the journey, at least as far as "mandating BIM" is concerned. In the UK, the process that was undertaken involved setting an aspirational five-year goal, refraining from defining specific tools and methods, and choosing not to incentivise the process through funding and grants, presumably because the industry was already invested and motivated to take on BIM. In many ways, the Singapore experience was quite the opposite: government set a moving target with clearly specified requirements, provided incentives and "moved the bar" every few years to prod an industry that is seen to be sluggish. These different experiences map out potential pathways for Australia and provide directions and choices for moving forward. Such findings are valuable because they provide a platform for researchers and consultants to explore in the future. For this project, however, a decision has been made to focus on specific aspects of procurement in Phase 2. A discussion of next steps is provided in the following section.

Conclusion from the empirical study: Directions for Phase 2

Both the literature review and empirical findings have laid a robust foundation for the next phase of the project:

- Phase 2: Evaluation of WHS management in BIM-enabled project proposals, as part of a procurement process

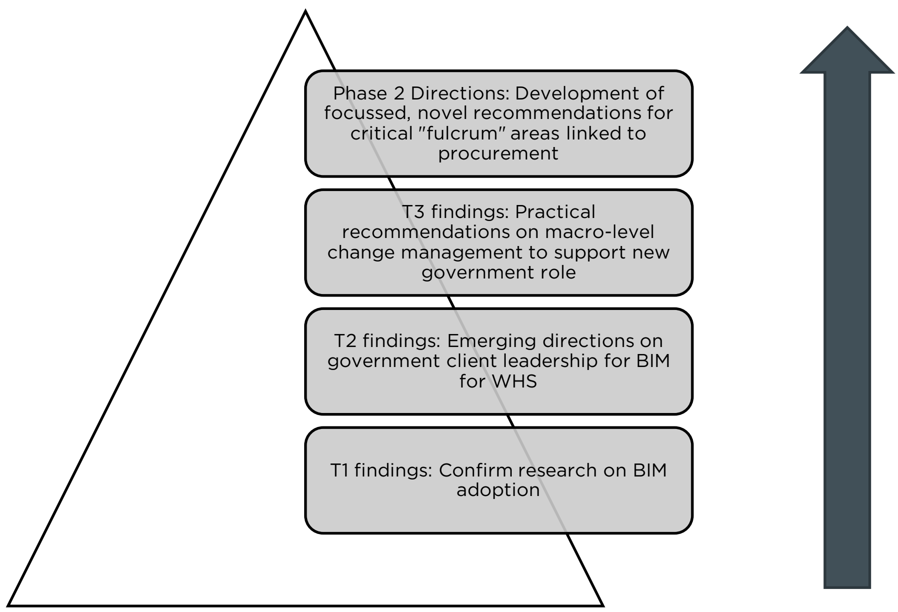
  Identify preferred procurement models and best practices to evaluate WHS management in BIM-enabled project proposals and recommend best way for government agencies to evaluate the quality of WHS management in BIM-enabled project proposals.

The main deliverable for Phase 2 is a Decision Making Framework which will support tender evaluation and monitoring delivery performance of the primary contract with respect to supply chain delivery.

The identification of tender evaluation and monitoring of the primary contract as areas of focus is not arbitrary. Tender evaluation is a fulcrum in the procurement stage while the performance of the primary contract is a key driver during project delivery. The final form of the Framework will be determined after research has been completed at Phase 2, but at this stage it is envisioned to be supported by a Protocol or BIM Execution Plan and Responsibility Matrix.

The Conclusion shifts the discourse from the macro-level strategies of T3 to focussed recommendations on the study's areas of concern: specificity on decision-making at tender and monitoring of the supply chain during the project lifecycle. Future work for Phase 2 thus build on earlier parts of the document, as shown in Figure 3:

Figure 3: Linking the Discussion section and the Conclusion



To be clear, this Conclusion does not attempt to define specifics of the Framework's contents at this stage. Past research on BIM adoption frameworks indicates that contents can be very flexible and can encompass a broad swathe of tools: roadmaps, checklists, assessment tools, flowcharts (London et al., 2010).The specifics of the proposed Framework can only be determined through further empirical work in Phase 2 and analysis and critique of existing frameworks. There are Australian guidelines for BIM however they do not include WHS. The UK PAS (Publicly Available Specifications) and EIR (Employer's Information Requirements) are useful as they present well-developed existing integrations of BIM and WHS. An analysis on their potential for adaptation for the NSW context will therefore be explored. Through interviews in Phase 2, we will also critique other decision frameworks currently in use.

Based on Phase 1 findings, the proposal is that the Framework will explore the following propositions with respect to adaptation of existing exemplars:

Best practice

- Identifying exemplars in Australian major public and private sector client-led projects
- Identifying key decision areas in exemplars with respect to Project Information Integration Requirements

Client leadership

- Establishing WHS management requirements prior to tendering as a priority, based on best practice
- Developing clear alignment to six knowledge domains of WHS management: scenario planning, requirement briefing, risk assessment, education and training, monitoring/surveillance and reporting, and analysis.
- Ensuring client expectations on BIM for WHS management are clearly developed prior to tendering to enable client leadership
- Developing Client Information Expectations/Requirements and Responsibility Matrices for BIM for WHS management

Tendering proficiency

- Ensuring tender criteria and evaluation are transparent and authentic with respect to BIM for WHS management, to ensure communication and expectation-setting
- Framing BIM for WHS management outcomes and strategies across different procurement strategies
- Analysing and assuring supply chain capacity to deliver as well as appropriate supply chain monitoring during other project phases

Supply chain monitoring

- Identifying key areas of capacity building across all levels of stakeholders for implementing BIM for WHS management in Australia
- Monitoring the main contractor to ensure that the supply chain is delivering to the original expectations, a function critical to implementation

Client leadership and tendering proficiency

Data suggests that the proposed Framework should include principles and guidelines that will assist government clients in defining WHS management requirements to be incorporated into EIRs. A starting point for this is UK PAS 1192-6:

> *"…So we have fast tracking a standard within [the UK BIM Framework] and we have within there, as you said, it says, bringing BIM and health and safety together and that's starting to use a, you imagine, we're using the model for identifying risks within there, comes a great way of identifying risks, but also embedding if you like the methods and how we're going to control it within the model as well within there." - Interviewee 2, Government & Private, BIM Specialist, UK*

More information about UK PAS 1192-2 can also be obtained, as this was the standard that required the inclusion of a section on WHS/ Construction Design Management in the EIR.

Guidance in drafting the EIR is critical because it draws together BIM and WHS requirements. Requirements for BIM alone can already be daunting and adding WHS requirements may add a layer of complexity to a process already fraught with detail:

> *"…in fact, even now, there's massive confusion amongst clients about BIM. I have met some really quite well informed and very knowledgeable clients who are almost tearing their hair out. They're saying I don't know how to get what I want out of this BIM thing." - Interviewee 5, Government, BIM and WHS Specialist, UK*

It is worth noting that the example of a client struggling was set in the UK, where BIM adoption is higher at least relative to Australia. In Australia, clients have been described as being lacking in vigilance, knowledge or interest about WHS management at procurement. A premise of Phase 2 is that government client knowledge in this domain will be limited and anecdotal, thus significant support will be required.

One suggestion that was made by an interviewee is that if the new WHS management requirements are implemented, requirements should be kept simple, flexible and open ended. The interviewee suggested requirements could be framed along the following lines:

> *"…[it could be]…we want you to use BIM and Health and Safety in combination, it will be an example of this. And this all we require you to have, you know, identify critical installation or critical kind of areas and actually be able to have maybe a simulation or, you know, proof of Virtual Training in those areas. That might be might be part of it or demonstrate how will you would be using BIM and health and safety throughout your project in order to improve health and safety outcomes and also how you would then demonstrate that you're actually doing it because it's the one thing is nice that you're telling us how you would do it is, how do you demonstrate that you actually do it is the other thing." – Interviewee 7, General Contractor, BIM Specialist, Australia*

Empirical work can also explore what has been done by Australian organisations that have already initiated the process of requiring WHS at procurement. One interviewee noted that TfNSW has only very recently begun to include an EIR item referring to the use BIM to aid WHS management. The requirement was again very simple and open-ended, with clients being asked to provide an overview of how digital engineering and the comment data environment were being mobilised to support WHS. This practice is clearly an emerging one. Also, as the industry matures, the government client's requirements may eventually evolve, possibly becoming more specific and differentiated. The Phase 2 empirical study will be designed to cover multiple cases, so a small set of varying practices may emerge and will be used to inform the development of the requirements definition component of the Framework.

So far the discussion has emphasised the point that WHS requirements must be included as a requirement at tender. Another area worth exploring in Phase 2 is how much weight must be given to these WHS requirements, relative to other goals. Interviewees have made references to WHS goals being overshadowed by other objectives and Interviewee 5's comment on "*the health and safety person being forgotten*" must not be overlooked:

> *"On a big and complex project, you can easily have 10 consultants, 10 design consultants sitting around a table in a design review meeting, and the one whose voice gets heard is the one who shouts the loudest or is the most assertive, or is the most switched on." – Interviewee 5, Government, BIM and WHS Specialist*

Another consideration in developing the framework, then, is exploring mechanisms that help ensure that WHS requirements are weighted appropriately relative to time, cost and quality targets in the EIR.

Tender evaluation

WHS requirements will be linked to assessment criteria, which can again take different forms ranging from qualitative rubrics to quantitative scoring systems. Empirical data was silent on this matter. However, one interviewee discussing a different topic did point to a useful "Guidance Note" developed by the BIM 4 Health & Safety Working Group (2018). The note, titled "Guidance Note for Clients writing an Employers Information Requirements (EIR)" was developed to assist clients, but some of its features could be useful in developing the tender evaluation component of the Framework.

The Guidance Note was built around ten guide questions. One question was "Have you set the design risk objectives for this project?" The note then defines first steps that the client/ tenderer should be taking, for example "Client states those hazards or risks they want eliminated by design" and "The client to require designers to explain how BIM methods will be used to aid H&S in design through the BIM Execution Plan." (BIM 4 Health & Safety Working Group, 2018).

Two important things are worth noting: principle-centeredness and simplicity. The Note, as mentioned, identifies only 10 questions, which are then translated into clear, observable behaviours undertaken by the client. An assessment tool developed as part of the Framework could, likewise, begin with a few key principles that could cut across all projects, regardless of size or procurement model. A principle-centred approach could be mobilised so that even single, open-ended requirements, such as that posed by TfNSW, could still be systematically assessed.

The Note also makes use of plain language. Framing both the requirements and the assessment criteria in simple, everyday language could make both compliance and assessment more feasible.

Decisions across procurement models

Another consideration in developing the Framework is the extent to which WHS requirements and the decisions that surround them vary due to procurement models. Earlier sections of this report showed examples suggesting that procurement models like Construct Only were problematic because they could make information integration difficult.

The claim that different procurement models lead to different information flows is uncontroversial. In the state of Victoria, Australia, four procurement models have been identified: Alliance, PPP, Design and Construct, and Construct Only, and the differences in their information flows have been captured in flowcharts in a document called "VDAS Lifecycle Across Procurement Systems" (VDAS, 2019). These flowcharts show where information handover should be taking place; these junctions, arguably, are where information sharing might break down. Importantly, the handover points also show junctions where work processes have been uncoupled from other work process, resulting in some tasks becoming independent, or at least asymmetrically dependent (London et al. 2008). The uncoupling of work processes translates into the distribution and possible loss of power and control over specific work processes. For example, a Construct Only procurement model means that construction teams lose the ability to exercise influence on many matters of safety:

> *"The problem with construct only is designers will go and design something as a construct only contract, and then give it to a contractor where the contractor has had no input into design. So there's no input on how is it going to be constructed, is it safe to construct, and you've got very limited ability then to influence that… Even a construct only, you're told you just need to build with what we've given you. There's no opportunity then to influence it to make it safer." - Interviewee 4, General Contractor, BIM Specialist, Australia*

These findings point to at least two possible elements to include in the Framework: a diagram that maps procurement models to BIM for WHS outcomes and strategies, and a responsibility matrix for each procurement model, showing who is responsible for specific information requirements across different project phases as well as points of dependence.

Supply chain monitoring

Finally, the Framework will include guidelines for monitoring the main contractor in relation to supply chain performance. Questions on supply chain performance were not raised directly with any of the interviewees, but because BIM and WHS were seen to be so dependent on the overall supply chain performance, mechanisms for improvement inevitably came up. For example, one interviewee spoke of the importance of regular "workshopping" with subcontractors:

"Workshopping the BIM Work Health Safety manager requirements and procedures with the teams who will be participating with the use of the BIM technology that promotes the Work Health Safety management; workshopping's so important. I see more than ever that, 'Here you go, here's the document.' It's assumed that you know what you're doing and then they go along and then obviously, too scared to raise their hand and be the only one, they go across and go – an issue might arise, and they might try and sweep it under the carpet or whatever. If we workshop it, it promotes that involvement from the team, but it also ensures us from our end that they understand. And I think it's very important that if you demonstrate this and workshop with the teams that you can identify, but you can also communicate in a comfortable environment that you get a better result and more of a teaching process and everyone's on that same playing field as well. So the workshopping, I find, is very, very important." – Interviewee 3, General Contractor, BIM Specialist, Australia

Workshopping served a number of purposes: it strengthened involvement, supported communication and provided a "safe space" for subcontractors to raise concerns. The Framework to be developed not necessarily explore if the main contractor used workshopping per se, but it could examine what equivalent mechanisms had been put in place to achieve similar goals for improved supply chain communication, collaboration and involvement.

The same interviewee also noted the value of remote connectivity for subcontractors:

"I was able to give access on remote devices like on iPads; not phones at the time, to the model. So when they are installing it they can do pre-install checks, but they can actually have a look at the proposed construction that's going to happen in the next three weeks, and that gives them more insight on what's going to happen in that area. And, again, that can promote - and that worked really well. I was - it was good to see though, actually, and I walked past, and they were all looking at the iPads and they were all doing that. And you know what? It enables and it actually empowers the subcontractors on site, and you find the human factor is amazing. If you treat them as you're doing your job and that's it, and we segregate you from the information, you find they have that attitude, like, we'll just do our bare minimal, but if you if you have an overlap and collaborate and have that mentor say that we're a team - and it sounds very cliché, you find that their productivity level and also the ability to contribute more transparent information will be promoted.

Again, strategic use of technology led to profound changes: improved information integration, increased accountability, increased empowerment. The Framework developed could also explore whether or to what extent a main contractor found ways to increase empowerment and accountability in the supply chain.

While the details of supply chain performance have not yet been finalised, a number of possible areas have been identified from the data as potential indicators of performance: levels of empowerment, collaboration, communication. A preliminary set of potential indicators is presented in Column 1 of Table 9. Column 2 shows possible questions that could inform the development of the monitoring toolkit. Table 9 is not exhaustive and will be expanded based on findings in Phase 2.

Table 9: Monitoring the main contractor

Project stage	Possible Issues
SUPPLY CHAIN ASSESSMENT	What criteria were used by the main contractor for supply chain assessment? (Assessment of hardware, software, capacity?) What tools were used (Contractor interview checklists; WHS management assessment checklists)
COMMON DATA ENVIRONMENT	How and to what extent was a common data environment established? At what point were subcontractors brought in to discuss WHS?
EARLY CONTRACTOR INVOLVEMENT	What mechanisms were put in place to identify design safety issues as pre-construction? How were BIM WHS requirements communicated alongside methodology and contracts?
SUBCONTRACTOR MONITORING	How did the main contactor monitor the performance of high-risk tasks? (Regular meetings? How frequent were these meetings?) What were the contractual obligations that were defined? What mechanisms were put in place to ensure that quality data is submitted at the right time? How, if at all, were data audits conducted for WHS information requirements? To what extent were BIM specialists used to ensure that teams are meeting WHS requirements?
EDUCATION/ TRAINING	What training/ education was made available to subcontractors, especially in relation to data and technology use? What arrangements (e.g. “workshopping”) were used to discuss BIM WHS requirements?
SUPPLY CHAIN EMPOWERMENT	How were subcontractors made accountable for WHS outcomes? What mechanisms were used to support remote connectivity of sub-contractors?
COMMUNICATION/ COLLABORATION	What governance mechanisms were put in place for design coordination and issue management? How was sharing of issues and concerns encouraged? How were models handed over across different project phases?

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Appendix 1. BIM for WHS enablers: Quotes, themes and categories.

CATEGORY	THEME	QUOTE	INTERVIEWEE
CULTURE	CULTURE VALUES WHS/ WHS AS A WAY OF LIFE	[WHS is] number one, if someone said to me, what's the number one priority? It's health and safety, above all, and then comes it's health and safety and then sustainability, you know, without a doubt. You know, everybody has got the right to stop a project, you know, no matter what they're doing, if there's something that is not safe. It's prioritised, now the reason being, you know, what happens if you get it wrong, well, you can go to jail. And I think that's the message I think any contractor, it's not just the person on the site that will go to jail, it will be the person at the top of the company.	Interviewee 2
CULTURE	CULTURE VALUES WHS/ WHS AS A WAY OF LIFE	We focussed our attention actually very heavily on BIM for safety and BIM for construction coordination, right? That's where we feel that as a business, we get the most value out of it.	Interviewee 6
CULTURE	CULTURE VALUES WHS/ WHS AS A WAY OF LIFE	But we realised something then, which was not so much BIM related but it was health and safety related in so far as that project took health and safety as almost its main thing, and forced it down, and the board members, right from the board down, they were really, really committed to good standard of health, and it had a knock on effect across the board.	Interviewee 5
CULTURE	CULTURE VALUES WHS/ WHS AS A WAY OF LIFE	I think there's, there's a lot of good movement in the last five years towards safety first culture.	Interviewee 7
CULTURE	CULTURE VALUES WHS/ WHS AS A WAY OF LIFE	What I would like to see through this research as well is really understanding how can this become something that becomes second nature, that it becomes super easy to use and it's not a tick box. But people walk away and go, actually, I do want to virtually rehearse that first. Let's just all quickly have a have a look here. How can we use this? Have we covered all of our bases here? How we do that I think is more of a psychological and a cultural challenge than a technological challenge.	Interviewee 7
CULTURE	CULTURE VALUES WHS/ WHS AS A WAY OF LIFE	And subcontractors quite often aren't as sophisticated with some of the digital tools. So we are more than happy to actually work with them and help them overcome those barriers and bring them up to speed, because it benefits us ultimately. And so I think that's a much better way of working than going you guys are required to do this and this and then not helping them. It's in our interest to help them how to do this.	Interviewee 7
CULTURE	INCREASING INTEREST IN BIM FOR WHS	In recent years it's started to shift towards quality and safety and that productivity story is, not taking a backseat, but just toned down ever so slightly	Interviewee 6

CATEGORY	THEME	QUOTE	INTERVIEWEE
CULTURE	TRAINING IN WHS IS PROVIDED IN DIFFERENT FORMS	We have a plethora of training available. One of our mandatory training modules at the moment is a WHS legislation, and it's a requirement, a mandatory requirement for all Lendlease employees. We also have a thing which is – it's called GMR, which is our Global Minimum Requirements training. This is all very high-level training, it's not specific to how things are managed on our sites, and you wouldn't dig down into detail on a project during that training. When you get on to a project, you do project specific training. So depending on what's required of the project. Yeah, so we obviously have a training matrix competency requirement planner.	Interviewee 1
CULTURE	WHS SEEN AS SHARED RESPONSIBILITY	So WHS requirements management adherence is actually across the board from foreman, engineers, EHS coordinators, subcontractors, site managers. So it's not as if all WHS management is solely on the shoulders of a WHS manager or coordinator.	Interviewee 1
CULTURE	TEAMWORK ACROSS DISCIPLINES	So that's very difficult, but actually, the stuff you saw there wasn't done by a scheduler. It was literally done by construction manager sitting down going well you know, I literally have to lift, you know, this water tank onto a roof. This is how I would do it normally, can you help me visualize it, right, and we sit down, and we work it through.	Interviewee 6
CULTURE	CULTURE OF INNOVATION DRIVES INTEREST	And actually using them differently to where people originally thought that they were useful quite often makes sort of the difference.	Interviewee 7
CULTURE	CULTURE OF INNOVATION DRIVES INTEREST	It was like, oh, that's interesting, you guys are doing some, you know, innovative kind of things.	Interviewee 7
CULTURE	STRATEGIES TO LINK SEPARATE WHS AND TECHNOLOGY DOMAINS	this group we've got is very much the – there are always the leaders, there's the earlier adopters, the enthusiasts, and I think we've gathered around ourselves quite a few of those from the industry who just see how the digital techniques can – I mean, simple things like, for example, very recently I was being demonstrated a very simple API for linking a spreadsheet. See, health, and safety people love spreadsheets, so they'll tend to produce risk registers on spreadsheets for a project and then it's completely independent of the model. So how do you link a risk from your risk register to your actual model you're building with. So I was just looking at a simple technique which provided a two-way flow of information. So you could alter something in the spreadsheet and it automatically updates the model or vice versa. If you want to put something in the model and it automatically comes through on the spreadsheet, and that's the kind of development which the technology has got to catch up and provide the ways of integration between these different disciplines.	Interviewee 5
CULTURE	STRATEGIES TO LINK SEPARATE WHS AND TECHNOLOGY DOMAINS	Some of it is going to come through standardisation, to be honest, because people talk about risk. It's a very confusing language, sometimes, the way people talk about risk and how to manage health and safety problems, and	Interviewee 5

CATEGORY	THEME	QUOTE	INTERVIEWEE
		there is an ontology. In academic terms, there's an ontology issue about understanding the language so you can talk to designers.	
CULTURE	STRATEGIES TO LINK SEPARATE WHS AND TECHNOLOGY DOMAINS	The HSE, we're much more pragmatic. We just want to get the basics right, a lot of the time, on smaller sites, and we can see the potential for basic technology available on mobile phones, which actually links people up between the activity they're doing, the risks they may be creating and how to help solve those risks. So I don't think we have a grand strategy, as such, but we do have a desire to keep it real, if you like, keep the solutions close to where the risks are manifesting, and try and find the simple things that will keep people safe onsite.	Interviewee 5
CULTURE	STRATEGIES TO LINK INDUSTRY AND REGULATOR	we've got to keep close to the industry to understand them and what they do and how to. So, very much, that's part of our core values if you like. So these groups are about the industry teaching the regulator and the regulator, but there's also people like myself who are steeped in health and safety, there is a need for us to teach people what's really important...So, terms of reference, very, very basic, and actually, our working group is pretty – as a group, and in terms of bureaucracy, it's very, very light weight.	Interviewee 5
CULTURE	INNOVATION DRIVES INTEREST	And actually using them differently to where people originally thought that they were useful quite often makes sort of the difference.	Interviewee 7
CULTURE	INNOVATION DRIVES INTEREST	It was like, oh, that's interesting, you guys are doing some, you know, innovative kind of things.	Interviewee 7
CULTURE	INNOVATION DRIVES INTEREST	BIM is just one part of it. There's an opportunity then to bring more technology on top of that, to actually see where you are, day-to-day and then predicting what you're doing, going forward. And I think that's really the missing link in this. But it's coming; that technology is coming.	Interviewee 9
VALUE PROPOSITION	GOVERNMENT SHOWCASING BEST PRACTICE THROUGH INDUSTRY PARTNER	And then because of the reputation that we built around construction safety, it also means that our interaction with government has been very good. They've been very proactive in speaking with us and getting us to engage with other parts of, even our competitors, you know, we're more than happy to share our knowledge in terms of construction safety with our competitors, because we actually fundamentally do believe that it's an industry wide issue that we need to resolve. It's not about the competitiveness of Lendlease, it really is, you know, how do you keep people safe and able to return home to their family at the end of every day in an environment where unfortunately there are fatalities in construction. So that's been, that's been pretty good.	Interviewee 6
VALUE PROPOSITION	ADOPTED WHEN BENEFITS OUTWEIGH COSTS	Yes, it costs more time (to use technology to rehearse high risk tasks). But if you've got repetitive or highly difficult sequences that are also have a higher high safety, risk aspect, you'll be spending time preparing anyway. If	Interviewee 7

CATEGORY	THEME	QUOTE	INTERVIEWEE
		you don't prepare you know properly. To do that, you're, you're, you're running major risk.	
VALUE PROPOSITION	ADOPTED WHEN BENEFITS OUTWEIGH COSTS	Yes, it costs more time. But if you've got repetitive or highly difficult sequences that are also have a higher high safety, risk aspect, you'll be spending time preparing anyway.	Interviewee 7
VALUE PROPOSITION	ADOPTED WHEN BENEFITS OUTWEIGH COSTS	At the moment, it gets applied when you have high value items being put in place.	Interviewee 7
VALUE PROPOSITION	WHS CAN BE BALANCED WITH OTHER GOALS LIKE COST AND QUALITY	So the fact that we've got this information now, we are identifying work health and safety issues without specifying that that's how it was going to be used in the first place. And it's just from a construction risk perspective, safety and quality are probably the two main drivers. Time's the one that we're trying to reduce and cost, but they're trying to balance it out against quality and safety.	Interviewee 4
VALUE PROPOSITION	BECOMES CLEAR WHEN STAKEHOLDERS EXPERIENCE ITS BENEFITS OVER TIME	And so it's, there is a, you require the builders to want to engage and want to get the insight. And there are those that are converted because they've experienced it on a project and they've seen what they can learn from, you know, having those aerial views from a drone on a regular basis. And, you know, the kind of problems we solve when we have a well-coordinated design, so that we're not, you know, we're minimising the amount of time on site because we're doing the work one time only and getting it right. All of these things have OH&S benefits, but until you experience it firsthand, you can remain sceptical. And so we still have that transformational process to take within our own business, as well as across the industry. You know, I think it's pretty endemic.	Interviewee 6
VALUE PROPOSITION	BECOMES CLEAR WHEN STAKEHOLDERS EXPERIENCE ITS BENEFITS OVER TIME	And there are those that are converted because they've experienced it on a project and they've seen what they can learn from, you know, having those aerial views from a drone on a regular basis. And, you know, the kind of problems we solve when we have a well-coordinated design, so that we're not, you know, we're minimising the amount of time on site because we're doing the work one time only and getting it right. All of these things have OH&S benefits, but until you experience it firsthand, you can remain sceptical. And so we still have that transformational process to take within our own business, as well as across the industry. You know, I think it's pretty endemic.	Interviewee 6
VALUE PROPOSITION	INCREASES PRODUCTIVITY AND SAFETY	we're seeing directly from that is we're seeing increases in our productivity that we finish a project and we're seeing a safer result at the end of it, without a doubt, yes.	Interviewee 9

CATEGORY	THEME	QUOTE	INTERVIEWEE
VALUE PROPOSITION	INCREASES PRODUCTIVITY AND SAFETY	I think it'll be I think it'd be better, and it will be more productive, and I think will be safer.	Interviewee 9
VALUE PROPOSITION	INCREASES PRODUCTIVITY AND SAFETY	I think there's an opportunity to use used technology through BIM, through whatever else falls out or covers over the top of that to drive health and safety, I think that it will come in time. I think that, you know, obviously, obviously, there are numerous benefits for it that are just that, you know, soft fall outside of strictly program and clash detection and design and everything. And I think safety is one of those that will sort of fall at the bottom of it.	Interviewee 9
VALUE PROPOSITION	INCREASES PRODUCTIVITY AND SAFETY	In recent years it's started to shift towards quality and safety and that productivity story is, not taking a backseat, but just toned down ever so slightly.	Interviewee 6
VALUE PROPOSITION	INCREASES PRODUCTIVITY AND SAFETY	The, in terms of the rhetoric that comes from building regulation from policy, government policy, is that it's all about productivity.	Interviewee 6
VALUE PROPOSITION	SHOW BIM AS CRITICAL FOR AVOIDING WHS RISK	we think a similar argument will apply to risk management in BIM, that people will be persuaded that this is a good tool for risk management, and therefore it's a good tool for construction management. I think, one of the barriers, one of the problems has been applications of BIM, where there's been a generation of huge amounts of paperwork and huge amounts of data, but it hasn't actually solved the problems that the guys on site have encountered and seen. So they say, well, what's the point of that then. It doesn't actually make a difference. I think, if risk management becomes a main thing, that's a very compelling driver for people to adopt BIM.	Interviewee 5
VALUE PROPOSITION	SHOW BIM AS CRITICAL FOR AVOIDING WHS RISK	Tenders might be if there's a client, a government client that has neighbouring assets, they might want to see that the tower cranes don't impact certain things, or how health and safety, you know, hoarding is being used in order to properly shield off the public areas.	Interviewee 7
VALUE PROPOSITION	SHOW BIM AS CRITICAL FOR AVOIDING WHS RISK	Now, in the year two they built on it and improved their methods and technology, but they've done, for example, 25 million, that's over the three years. Over those three tests projects, that's in excess of 25 million pounds worth of work and they've hardly had an incident at all, certainly not a reportable incident. What they say is, everything has gone well, and everybody is happy.	Interviewee 5
VALUE PROPOSITION	SHOW BIM AS CRITICAL FOR AVOIDING WHS RISK	maybe we used to call Work Health and Safety the Trojan horse. If you can basically use work health and safety to introduce certain methods or ways of working, then the company would quite often take that on, because there's, there's serious liabilities involved right and people, people can die so that would normally create an uptake of the technology.	Interviewee 7

CATEGORY	THEME	QUOTE	INTERVIEWEE
VALUE PROPOSITION	SHOW BIM AS CRITICAL FOR AVOIDING WHS RISK	Basically, they started the week on a Monday with a model. They briefed the guys of the model, this is a model, this is how you're going to work, and as the guys worked, so, on the Tuesday, the planners were then looking at the next week's needs, building next week's model, and then taking into account what's been done this week, so that by the following Monday they were presenting the model for the following week based exactly on what had been done, what the needs were, what they'd learnt this week, and they were modelling very precisely logistics, waste flows, ins and outs, and what they managed to do by pre-fabrication off site and by some clever thinking, they completely negated the idea to work at night. So, normally, they would have needed a possession of the railway line, but they managed to persuade network rail, because they were working in this way, that it was safe for them to actually leave the line open and they could do everything during the daylight. So you cut out night working you cut out risk.	Interviewee 5
VALUE PROPOSITION	SHOW BIM AS CRITICAL FOR ACHIEVING REQUIRED STANDARDS	And what we've been doing is making sure that we can apply our BIM skill set against the GMRs to assist the GMRs in every instance, so that we have a consistent procedure for BIM whenever we have a use case, a safety use case. So we're in that process of making sure we can deliver that. What that allows us to do is that as long as we're framing BIM against GMRs, we find the engagement can be very high across our business, because safety is the number one priority. Anything that assists it then also comes along for the ride.	Interviewee 6
VALUE PROPOSITION	POSITIVE HEALTH OUTCOMES	Now, this is in connection with health actually, because one of the problems, when things are predicted and managed, health issues tend not to come to the fore. So, you can predict if there's going to be dust exposure or something like that, you can predict it and prevent it far more effectively. The problems with dust is when something untoward happens, somebody grabs a concrete cutting saw and starts using it on site and you get – so you're getting – and there's also a link across to mental health as well, which we've noticed.	Interviewee 5
VALUE PROPOSITION	COMPETITIVE ADVANTAGE	So, and as a global business we really do need to set the bar at a, at a level that can be achieved in all regions, but that it can't be too low. So we actually set it, we actually set it roughly to where we think the industry is in Australia and in the UK, which are two of our biggest markets.	Interviewee 6
VALUE PROPOSITION	COMPETITIVE ADVANTAGE	It's fast follow industry and as soon as somebody starts doing this and if it becomes a differentiator for a company, then others will start following. I think that's sort of at the tier 1; possibly also at the tier 2.	Interviewee 7

CATEGORY	THEME	QUOTE	INTERVIEWEE
VALUE PROPOSITION	IN THE CONTRACTOR'S INTEREST DUE TO LEGAL OBLIGATIONS	But the reality is most good contractors and respect for the client wants, we do it anyway, you know, because they've got a legal obligation, you know in terms of health and safety, but unfortunately, clients can be variable in terms of what they're asking for and putting governance about it, but at the same thing most mains contractors and special subcontractors are very good at doing BIM for health, safety, because you know it's in their own interest to do it.	Interviewee 2
CLIENT ROLE	ADOPTED WHEN REQUIRED BY CLIENT/ EXTRA REQUIREMENT BECOMES BUSINESS-AS-USUAL	If we make this see the complexity, like remove that complexity, you'll find during the procurement and you take that stigma or fear away from it and it's well informed, it shouldn't be an issue, it'll just be another item to go, listen, yes, we understand it's a requirement. This is how much it's going to cost for us to have the skills in place to adhere to that and achieve that requirement. And it will just be like anything else.	Interviewee 3
CLIENT ROLE	CLIENT IS EDUCATED AS HANDHELD THROUGH CONTINUED BIM USE	From a security perspective, you can check visibility lines, for example. So, you know, you just have it up there and then you start to talk to it, and it starts to become accepted that, okay, we can do that. So it starts to educate our client. ...where we did all of our safety workshops with the model. I make sure the model was open and then we'd check, you know, how are we going to get this piece of equipment in and out of that room, for example.	Interviewee 4
CLIENT ROLE	WHS CAPACITIES ASSESSED AT PROCUREMENT BY CLIENT	Yes, so it is assessed as part of our procurement. So that is typically managed by project engineers or senior project engineers on a project. [Also EHS professionals don't typically get involved in the procurement process, it's done outside of that, and it's done very early on in a project.]	Interviewee 1
CLIENT ROLE	WHS REQUIREMENTS OUTLINED BY GOVERNMENT CLIENT CONTRACT	We have a number of obviously WHS requirements that are outlined within our contract schedules, our scopes of work, which are all [00:08:55] to subcontractors during that procurement phase.	Interviewee 1
SYSTEMS/ PROCESS/ HOLISTIC INTEGRATION	PRESCRIPTIVE FORM-BASES SYSTEM FOR WHS ALREADY IN PLACE	Because Lendlease is such a – we have such a prescriptive environmental management system, it outlines exactly what we have to do across the board, across all projects - I don't think there's big differences between projects.	Interviewee 1
SYSTEMS/ PROCESS/ HOLISTIC INTEGRATION	EARLY INVOLVEMENT IS BETTER	So the earlier, we can get involved in that, the better it is, because then we can then inform the builder and tell them where they need to be doing their work in order to support the future work that we've got to do.	Interviewee 9
SYSTEMS/ PROCESS/ HOLISTIC INTEGRATION	EARLY INVOLVEMENT IS BETTER	This idea of the integration between pre-construction and construction is part of the key. So getting designers early contractor involvement, getting those conversations happening earlier, even between the end users of a building, people are going to maintain the property and the designers is so, so important.	Interviewee 5

CATEGORY	THEME	QUOTE	INTERVIEWEE
SYSTEMS/ PROCESS/ HOLISTIC INTEGRATION	EARLY INVOLVEMENT IS BETTER	the steel frame is taken for granted, and specialist steel contractor is brought in at the last minute with very little direction, and nobody really cares what they do because they're just putting up a steel frame which the pretty stuff hangs on, and actually, some of the practice around the management of steel, steel work construction is actually appalling, and we've had examples of frame, steel frames being built, requiring 50 tonnes or more of temporary bracing during the build. So it's up there during the build and when they've got to take it away and then the rest of the construction starts, and then they can't take it away, and they create a huge health and safety problem, and it's all because the steel work contractor is treated like, they just come in and do their job and then we'll do our job, and for some reason, it's a bit like there's a blind spot.	Interviewee 5
SYSTEMS/ PROCESS/ HOLISTIC INTEGRATION	EARLY INVOLVEMENT IS BETTER	Steel is very interesting because if the steel guys are quite imaginative and creative, and if they're talked to early they can find ways of building a temporary bracing into steel so it's not temporary, so it's permanent, do you know what I mean, and all costed in at the beginning, and it takes a lot of the strain out of the situation if those things are thought through and agreed right up front.	Interviewee 5
DATA	WHS NOT A REQUIREMENT AT THE START BUT INFO REQUIREMENTS END UP SUPPORTING WHS ANYWAY	I guess one thing is we don't specify directly that is for work health and safety as a requirement. That's probably not something that we're specific about; I guess we're very specific on how we want the information handed over with, I guess, keeping that in mind as one of the use cases. [00:27:52] And it's probably something that has tended to just fall out without really being specified. So the fact that we've got this information now, we are identifying work health and safety issues without specifying that that's how it was going to be used in the first place.	Interviewee 4
DATA	STRUCTURED DATA	So that goes back to the element matrix and also the LOI as well, which is what metadata is supposed to be delivering and that can go from CoBIE, it can go from, you know, your classification which uni class, 2015, are they putting that right information in because, again, it's quite important. And this will come back to Work Health and Safety as well. If everyone's using the right structured data that's all talking to each other as well effectively.	Interviewee 3
DATA	COMMON CODING BREAKS DOWN SILOS	I know there's many other datasets we manage on a project, requirements management, risk management, especially for managing hazards and safety assessment and documenting many others. And the key takeaway is that they all use siloed software, but more than that, they have siloed business practices. So each different business party – or so a project party, uses their own descriptors, their own breakdown to describe the same projects.	Interviewee 8

CATEGORY	THEME	QUOTE	INTERVIEWEE
DATA	COMMON CODING BREAKS DOWN SILOS	What that allows us to do is that as long as we're framing BIM against GMRs, we find the engagement can be very high across our business, because safety is the number one priority.	Interviewee 6
TECHNOLOGY	TECHNOLOGY/ MOBILE	And if anything. I think one of the big things is BIM is becoming more on the site, that you know if you went back 10 years ago, it was something that sat on a screen on a designer's or an architect's there. But now, I think it's fair to say that with site mobility, we're seeing it much more now, you know on the job site on mobile devices within there as well.	Interviewee 2
TECHNOLOGY	TECHNOLOGY/ EASY TO USE	Technology complexity; so that's another one. So, yes, technology. Whether it's software or whether it's the actual hardware on site which promotes Work Health Safety management, they need to be more user friendly. Otherwise you pigeonhole power users, which again is a pointy end of the pyramid, which again those people, because it's higher demand, that will again affect the costs as well because they're going to go well, skillsets - again, this all kind of leads - it all kind of gels together that if they're in high demand and they're limited, they'll raise their cost because they know there's no one else out there.	Interviewee 3
TECHNOLOGY	TECHNOLOGY/ NEW CAPABILITIES	I think the other big thing from a safety point of view, is it used to be omni directional. It used to be a case of here's a model and this is what you get from it. But now, we're doing much more data capture. So you've got site supervisors who have got cameras, who are capturing in real time what's happening and feeding it back and comparing it to the model and that often helps us now to actually capture lots of health and safety problems that are happening on site and it's certain to be able to ameliorate them as well.	Interviewee 2
TECHNOLOGY	TECHNOLOGY/ NEW CAPABILITIES	So we call it head up hands free. So you've got all your information within your glasses and your hands and your feet you're not carrying an iPad or anything within there, you've got a view of your data.	Interviewee 2
TECHNOLOGY	TECHNOLOGY/ NEW CAPABILITIES	We are talking about this thing, but you've got to find tools that are relevant to smaller businesses and to people doing the work. So if you had an application on your mobile phone, for example, with the ladder which somehow was able to measure the height of where he's got to go, it could measure the angle of his ladder, it could almost give him a [00:30:12] if he's operating outside of some sort of indication of the centre of gravity isn't right, do you know what I mean, so it's a use of the digital technology going much more into the [00:30:23] type approach and saying. But the actual BIM angle on that is very much about setting a requirement early that you then follow through.	Interviewee 5

CATEGORY	THEME	QUOTE	INTERVIEWEE
TECHNOLOGY	TECHNOLOGY/ PRACTICAL, ON-THE-GROUND CAPABILITIES	So having the technology which provides the prompts, provides the – an awful lot of the big contractors quality arrangements, as you know, are down to discipline and to application of standardised rules, and BIM makes that possible because it defines the rules and then provides you with ways of following those through.	Interviewee 5
TECHNOLOGY	TECHNOLOGY/ PRACTICAL, ON-THE-GROUND CAPABILITIES	Again, it's not so much standard BIM technologies, but getting workers engaged in the work they're doing through remote tools and techniques and models is very powerful extension. So, using that, this digital technology, it is possible for a designer to have a direct consultation with the guys onsite about problems they see, almost in real time, and this, kind of, thing is for the workforce engagement angle on this is potentially a real winner in the future as well.	Interviewee 5
TECHNOLOGY	REMOTE CONNECTIVITY SUPPORTS SUBCONTRACTOR INVOLVEMENT	So the first one I got remote connectivity of BIM model to subcontractors on site, having the teams have real time access and input to the latest data. You don't understand how important our factor is. Now, I've seen this work. This is a success story. So I've seen this work well when people understand that the connectivity to remotely access it to the subcontractors on site is crucial.	Interviewee 3
TECHNOLOGY	OTHER TECH STARTING TO COMPLEMENT BIM INCREASES THE PERCEIVED VALUE	And so, I think what you've got BIM has gone that direction with all these other things and start to converge and then that's when I start to see the value.	Interviewee 2
TECHNOLOGY	OTHER TECH STARTING TO COMPLEMENT BIM INCREASES THE PERCEIVED VALUE	I think is what we want to be looking at, sort of drone-based digital site capture, real-time progress and performance, tracking of plant personnel and activities, pollution, environment, geofencing and workplace isolation, pre-fab installation, geolocation and new assets, autonomous plants and machine control, waste management, temporary works monitoring, work site intruder detection and worker PPE, so wearables and biometrics. This is what the digital twin is for construction.	Interviewee 8
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TECHNOLOGY	OTHER TECH STARTING TO COMPLEMENT BIM INCREASES THE PERCEIVED VALUE	Oh, the other thing I'd say is that for us in transport, we don't just look after single sites, we look after transport networks. And so, we see GIS being a lot more relevant. And so, we want to see some convergence about the BIM space and the GIS space.	Interviewee 8

CATEGORY	THEME	QUOTE	INTERVIEWEE
TECHNOLOGY	OTHER TECH STARTING TO COMPLEMENT BIM INCREASES THE PERCEIVED VALUE	There is new technologies which is coming out. And we're seeing geo-fencing being used a bit more, but this is moving into more the IOT space.	Interviewee 8
POLICY/ REGULATORY	INDUSTRY STANDARDS	It's only PAZ1192-6 is probably the only thing I've seen which has a very concrete relationship to structured BIM data in relations to Work Health Safety.	Interviewee 3
POLICY/REGULATORY	STATE-LEVEL ENDORSEMENT OF STANDARDS	With respects to the government regulators, it seems to be being addressed at a state – oh, I've already mentioned this - at a state level with endorsed in the documents, such as PAZ1192 2018.	Interviewee 3
POLICY/ REGULATORY	NEWLY-PUBLISHED INTERNATIONAL STANDARDS	there was a new international standard published, which has now looking at product technical data sheets and interconnected dictionaries. And that means that suppliers and much more structured and how they're providing information, and that includes any, you know, control of substances harmful to health that we can start to look at as well within there and start to be able to mine the information, especially with construction products to understand if there's any issues as well within there	Interviewee 2
POLICY/ REGULATORY	OTHER REGULATIONS WITH CONGRUENT GOALS	we call it the golden thread. Information that is going to demonstrate, especially for the end occupant of that asset that it's going to be safe to use so it's increasingly becoming and it's not there yet, but the regulators are getting to the point where they will be asking for a mandatory data set that demonstrates compliance from a safety point of view.	Interviewee 2
POLICY/ REGULATORY	OTHER REGULATIONS WITH CONGRUENT GOALS	soft landings is now became part of BIM. So it's a child of our when we talk about the UK BIM framework, Soft landings is part of the BIM wrapper. What that means is from a soft landings point of view, I'll give you an example. This is a project with our health service. You look at, you know, previous projects, look at lessons learned and so one of the examples was we're doing all these new, called elective care hospitals. And we do a lessons learned workshop and all the stakeholders and the facilities management team said on previous projects, the boilers, the space between all the, sort of, you know, gas boilers is insufficient, is not safe for us to go between and you know people to maintain it. So we put that in the lessons learned and we record it as a plain language question, but what we then do through BIM, to make sure that it's something that's tested, the design is tested.	Interviewee 2
POLICY/ REGULATORY	OTHER REGULATIONS WITH CONGRUENT GOALS	But ISO 19650 has introduced a concept of a project information requirement. So it has four – it has the organisational information requirement, which is what the client, the originating company has as its organisational values and core requirements, and then it has an asset	Interviewee 5

CATEGORY	THEME	QUOTE	INTERVIEWEE
		information model or set of requirements, and from these is supposed to be derived the project information requirements.	
POLICY/ REGULATORY	OTHER REGULATIONS WITH CONGRUENT GOALS	We have the law which says designers must foresee risk, so this plays absolutely into that regulation. We also have a regulation which talks about predicting risks which arise from sequences of work or where work has to be carried out simultaneously or in sequences, and this is another very strong point because 4D modelling, we're very keen on animations, sequencing through 4D modelling, because 4D modelling itself, you can talk about simulation or a real engineers approach, which is extremely strong, where you literally have to show the transitional states. If you want to move from state A to state D, then the engineer has to show B and C in between and how they relate. Now, if you're forced to do that, engineers have nowhere to hide.	Interviewee 5
POLICY/ REGULATORY	OTHER REGULATIONS WITH CONGRUENT GOALS	I think that will that will be accepted. Reluctantly, but it won't be accepted if the government, government requires it. If it's an optional thing ain't gonna happen.	Interviewee 7
POLICY/ REGULATORY	INDUSTRIAL MANSLAUGHTER LAWS ENHANCES IMPORTANCE OF MANAGING WHS	It's health and safety, above all, and then comes it's health and safety and then sustainability, you know, without a doubt. You know, everybody has got the right to stop a project, you know, no matter what they're doing, if there's something that is not safe. It's prioritised, now the reason being, you know, what happens if you get it wrong, well, you can go to jail. And I think that's the message I think any contractor, it's not just the person on the site that will go to jail, it will be the person at the top of the company. So you can imagine if you're managing director of a construction company, probably the last thing you want to do is go to jail. And that's the reality of it, you know.	Interviewee 2
POLICY/ REGULATORY	ONGOING WORK TO INTEGRATE WHS STANDARDS INTO PROJECT INFO REQUIREMENTS	So we're trying to write these requirements in such a way that – there's two risk discipline which we were aware of, which are not well integrated. There's fire, fire engineering and fire risk management is often not well integrated into design or hasn't been well integrated into mentioning design in the UK, and that's interesting. But also, steel work erection is another one.	Interviewee 5