information and the extent of the generalisability of the findings. In this study, the interview process continued until data saturation was reached. To aid with this decision, new BIM applications and CSFs emerging from each interview were tracked, and the interviews ceased when no new codes were identified in two consecutive sessions.

The interviews were transcribed after each session and set for thematic content analysis using QSR NVivo11 software (Braun & Clarke, 2006). As explained in Figure 6.2, this is an approach used to identify, analyse and report the themes in data. This approach was deemed fit for recognising possible BIM applications regarding the control of critical WHS areas and CSFs that could facilitate the implementation of these approaches in the construction industry of Australia.

In the first step, the researcher carefully read the transcribed interviews three times to become familiar with the data. Next, initial ideas were developed considering the two main topics of the study. For the first part of the interviews, the researcher searched for applications of BIM that experts believed were effective in improving the identified critical WHS domains. For the second part of the interviews, the researcher looked for actions described by the experts as critical for the adoption of BIM for WHS purposes in three areas: Commitment, preparation and implementation. Thematic content analysis was conducted immediately after the interview sessions to check data saturation.

6.1.5 Questionnaire Survey

An online survey method was selected to validate the findings from the interview approach. Surveys are considered a means to collect information from a particular population. Due to the non-feasibility of data collection from the entire population, a survey approach facilitates data collection from a proper sample of the whole population. An appropriate selection of the sample allows for the generalisation of findings to the whole population (37).

6.1.5.1 Data Collection

In order to reach a suitable pool of participants for the questionnaire survey, a list of major companies within the Australian context that employed BIM in their projects was extracted. This was achieved by searching the official websites of BIM-based consultant and contractor companies in Australia. In addition, LinkedIn, as one of the main professional social media sites, was searched for BIM and construction safety groups within Australia, and this led to identifying most of the active actors within the industry. The suitable target group for the survey was deemed to be a range of professionals, including project managers, safety managers, safety officers, site supervisors, architects, BIM managers, BIM coordinators, civil/structural engineers, mechanical engineers, electrical engineers and technicians. The potential participants were then approached by sending approximately 550 emails to their companies or contacting them through LinkedIn's messaging application to fill out the Key Survey online questionnaire form developed based on the findings of the interview analysis. Along with the invitation, the potential participant received a participant information sheet.

6.1.5.2 Design of the Questionnaire Survey

The questionnaire survey was designed to measure three latent variables of the research's conceptual model through their relevant observable variables. The first part described the overarching aim of the study to assist respondents in acquiring an accurate understanding of the purpose of the study; this part also included several questions regarding demographics to ensure a decent sample was approached.

The second part of the questionnaire included evaluating the importance of the CSFs identified from the interviews for three latent variables: Commitment, preparation (at the organisation and project levels) and implementation (at the organisation and project levels). The respondents were asked to state their level of agreement regarding the CSFs' effects on the successful integration of BIM with the current practice to improve WHS performance (observable variables) (Table 6.2). In the third part of the questionnaire, respondents were asked to state their level of agreement with a set of questions. To elicit agreement levels, a five-point Likert scale was used (5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree).

6.1.5.3 Analysis

From the received responses, the respondents' demographics were analysed based on the proportion of each group to understand whether the respondents had adequate knowledge regarding the target, a variety of rules and sufficient years of experience.

According to Ho (38), multivariate regressions represent an appropriate method of data analysis when the goal of a study is to look for links between variables and determine the strength of such links. For both exploratory and confirmatory research questions, structural equation modelling (SEM) is an effective approach (38). Hair Jr, Hult (39) categorised SEM methods into two broad approaches, partial least square (PLS) and covariance-based methods. The selection of an appropriate approach depends on the nature of the received data and the objectives devised for the study. Given that the practice of BIM in construction WHS is relatively new for many companies in Australia, finding the over 200 respondents required for covariance-based-SEM analysis (40) was not feasible, while PLS-SEM requires a much lower minimum data number. PLS-SEM was deemed to be the most appropriate method for this study due to the novelty of the conceptual model and the ability to analyse and explore links among a number of constructs using PLS-SEM (29). As extensively introduced by Hair Jr, Hult (39), SmartPLS v.3.2.1 was used as the main tool to run the analysis. Models in SEM are comprised of two main categories of variables: Observable, manifest variables, such as those measured through the questionnaire and latent variables showing the underlying constructs associated with manifest variables (38). The associations between manifest variables and the

Table 6.2 Questions in the third part of the online questionnaire survey

No.	***Topic***
1	Commitment of the designers to develop BIM models with possible safety features
2	Mutual trust among the parties involved in the projects to circulate required safety information in their BIM models
3	Workers' agreement to storing and using their health and safety records
4	The commitment of contractors to use BIM models in their safety management system
5	Lowering the cost of technology by vendors makes them usable for small and medium-sized companies
6	Government mandating for the use of BIM models for the safety management of the projects
7	Mandating the use of BIM models for safety in client contracts
8	The existence of financial incentives in the contracts for using BIM in the safety management process
9	Technical and Further Education (TAFE) and university initiatives for training safety officers/managers to use BIM
10	Initiatives from the Master Builders Association by introducing possible approaches to the companies
11	Vendors' initiatives in developing software that could identify unsafe designs according to national safety regulations
12	Availability of the technical hardware and software in the companies
13	Creating new roles and responsibilities within the organisations for facilitating the implementation of the BIM for safety management
14	Employing safety managers with BIM knowledge in the companies
15	Setting out clear safety goals in the contracts for using BIM in the safety management process
16	Setting the scope of the project's safety management for the entire life cycle of the projects from the first drafts
17	Allocation of additional time and budget for safety in the design process
18	Mandating the use of information provided in the BIM models for maintenance trade workers
19	Initiatives from large companies as front-liners in the industry for using BIM for safety
20	Liability of data inserted in the models for each of the parties involved
21	Continuous monitoring and modification of the process of using BIM for safety management
22	Having an effective communication and data exchange system in place among the people involved in the safety management process of the projects
23	Sufficient compatibility among the selected software packages to transfer safety features from one to another
24	Developing Intellectual Property (IP) conflict-resolving protocols to facilitate the exchange of models between designers and contractors
25	Continuous collaboration of the designers and contractors in monitoring and modifying the models during the execution of projects
26	Frequent updating of the safety information in the BIM models
27	Sub-contractors' experience and competency in using BIM
28	Engaging sub-contractors in the safety management process and providing them with required information through models

underlying constructs could be specified in formative models where it is assumed that indicators cause the constructs, as each one of the indicators captures one of the aspects of the construct. Taken jointly, the indicators determine the meaning of the construct. As a result, the breadth and comprehensiveness of the indicator's domain are central to ensuring that a construct is adequately covered and that all aspects are captured (39).

Following the submission of data to SmartPLS, several requirements about the data and the specified model should be met in order to ensure that the results of formative models are reliable. The highest priority should be given to the assessment of collinearity, which means that two or more formative indicators in a block capture exactly the same information in them. A recommended measure to evaluate collinearity is the variance inflation factor (VIF), which is calculated according to Equation 6.1, where x represents variables utilised as formative indicators. To calculate ${R_x}^2$, the indicator x is taken and regressed for all the remaining indicators of the same block (39). ${R_x}^2$ is the proportion of variance of x associated with other indicators.

$$\mathrm{VIP_x} = \frac{1}{1 - \mathrm{R}_{x^2}} \tag{6.1}$$

In cases where the level of collinearity for formative indicators of a construct is very high (VIF ≥ 5), the variable should be removed from the model prior to conducting any further analysis.

In a case where no critical levels of collinearity are observed in the model, SEM-PLS analysis should be performed to analyse the significance of outer weights and interpret the formative indicator's relative and absolute contribution to the underlying constructs. Researchers should test whether the outer weights calculated in formative models are significantly different from 0 using bootstrapping. To this end, a bootstrapping function in SmartPLS was utilised with the algorithm option of no change sign and 5,000 bootstrap subsamples as a conservative configuration to calculate the significance of outer weights (39). The critical value for the significance level of 5% ($\propto = 0.05$) was 1.96 (39).

Once the contributions of the observable variables to the latent variables were calculated, the next stage was to assess the predictive capability and association among the latent variables of the model. Since there is no goodness of fit model for PLS-SEM, Hair Jr, Hult (39) suggested evaluating the performance of a PLS-SEM model based on its ability to predict the latent variables. Therefore, the value of R^2 and the effect size f^2 for formative models were calculated to evaluate the collinearity among the latent variables and the significance of path co-efficiencies.

6.1.6 Results

6.1.6.1 Interview Results

The interviewees were selected based on their positions and experience in the industry. It was essential to ensure that the participants could provide realistic and industry-oriented information based on their experiences in the industry. Therefore, the positions were set to find a variety of experts who used BIM in their daily practice from both consultant and contractor groups. These experts included a project manager, two BIM managers, a BIM coordinator, a national HSE manager and an architect. The sample was deemed representative of a rich variety of expertise. The sample size also met the criterion set in the research design, which was no emergence of new codes in the last two interviews.

Interviewees were asked to express the critical actions required to be taken by the client, contractor, designer, software vendors and the government. The CSFs identified from the interviews were categorised into commitments, organisational preparations, project preparations, organisational implementation and project implementation factors to be used in the questionnaire survey (Table 6.2).

Although the CSFs identified were not quantitatively ranked by the interviewees, some factors were described by the interviewees as very important for a successful adoption process. Most of the interviewees suggested that technology vendors should develop platforms that could directly address safety issues in the models, where at the current stage, WHS information is entered into the models through customisation actions taken by the construction companies. It was also suggested that technology vendors should reduce the prices of their products up to the point that the BIM software could be more attainable for smaller companies.

Interviewees described contractors as the main drivers of the innovation adoption process. This was because they were liable for construction accidents and, at the same time, could benefit from improving construction WHS. The adoption of BIM applications in projects for WHS purposes requires having people operate the technology and process. Interviewee 5 explicitly pointed out that "it is of importance to have site safety managers who have hands-on skills to use BIM tools. Also, this requires sub-contractors to be educated to use such tools." Interviewee 6 argued that "the construction projects vary one from another, and it is hard to find a fixed approach to implement these processes, and it requires continuous monitoring of the process and revising it."

Interviewees also discussed the role of the clients and mentioned that they should look at the projects as lifetime assets that require time-to-time maintenance activities. Therefore, spending some money upfront to develop the building models capable of storing WHS information in the models could save money during the maintenance phase by reducing the number of accidents.

Interviewee 3 suggested that "[the] government, which is also one of the major clients, can accelerate setting the BIM plans for construction WHS. Currently, the government has planned to implement BIM for WHS by 2023, and this plan only targets large-size projects".

Interviewees who worked for contractors argued that the designers are responsible for developing building models, and most of the developed BIM models at the current stage do not have a mechanism to store WHS information, which makes the contractors' job more difficult with regards to modifying the model to be capable of safety management. On the other hand, designers argued that they could not be held accountable for a contractor's unsafe performance. They discussed the importance of safety in design meetings and mentioned that BIM could significantly improve the efficiency of those meetings. However, this would require the allocation of additional time and effort from both parties, the consultants and the contractors. Table 6.3 presents the CSFs to leverage BIM applications in the WHS practice of the Australian construction industry, as extracted from interviews with construction experts.

Table 6.3 CSFs for the adoption of BIM WHS applications in construction projects

	Code	*Description*
Commitment	Com1	Commitment of the designers to develop BIM models with possible safety features
	Com2	Mutual trust among the parties involved in the projects to circulate required safety information in their BIM models
	Com3	Workers' agreement to store and use their health and safety records
	Com4	The commitment of contractors to use BIM models in their safety management system
	Com5	Lowering the cost of technology by vendors to make them usable for small and medium-sized companies
	Com6	Government mandating the use of BIM models for safety management of the projects
	Com7	Mandating the use of BIM models for safety in the contracts by the clients
	Com8	Existence of financial incentives in the contracts for using BIM in the safety management process
Organisational Preparation	Prep_org1	TAFE and university initiatives in training safety officers/managers to use BIM
	Prep_org2	Initiatives from the Master Builders Association by introducing possible approaches for the companies to use
	Prep_org3	Vendor initiatives in developing software that can identify unsafe designs according to the national safety regulations
	Prep_org4	Availability of the technical hardware and software in the companies
	Prep_org5	Creating new roles and responsibilities within the organisations for facilitating the implementation of BIM for safety management
	Prep_org6	Employing safety managers with BIM knowledge in construction companies
Project Preparation	Prep_pro1	Setting out clear safety goals in the contracts for using BIM in the safety management process
	Prep_pro2	Setting the scope of the project's safety management for the entire life cycle of the project from the first draft
	Prep_pro3	Allocation of additional time and budget for safety in the design process
	Prep_pro4	Mandating the use of information provided in the BIM models for maintenance trade workers

(*Continued*)

Table 6.3 (Continued)

	Code	*Description*
Organisational Implementation	Imp_org1	Initiatives from large companies as the front-liners in the industry in using BIM for safety
	Imp_org2	Liability of data inserted in the models for each of the parties involved
	Imp_org3	Continuous monitoring and modification of the process of using BIM for safety management
	Imp_org4	Having an effective communication and data exchange system in place among the people involved in the safety management process of the projects
Project Implementation	Imp_pro1	Sufficient compatibility among the selected software packages to transfer safety features from one to another
	Imp_pro2	Developing IP conflict-resolving protocols to facilitate the exchange of models between designers and contractors
	Imp_pro3	Continuous collaboration of the designers and contractors for monitoring and modifying the models during the execution of projects
	Imp_pro4	Frequent updating of the safety information in the BIM models
	Imp_pro5	Sub-contractors' experience and competency in using BIM
	Imp_pro6	Engaging sub-contractors in the safety management process and providing them with required information through models

6.1.6.2 Questionnaire Results

The survey was launched in March 2018, and 176 experts participated in this survey from across Australia. Another 153 participants began the online survey but did not submit, as the records of the Key Survey show. The response rate for this survey was 53.50%, considering the incomplete surveys. According to Hair Jr, Hult (39), G*Power software is a powerful tool for measuring the required sample size for a PLS-SEM analysis. According to the findings of the interviews, the highest number of predictors was 17, which belonged to the evaluation of BIM stage. Using a post-hoc function of the G*Power software, a minimum population effect size of 74 was required (Figure 6.3), and the collected sample size was much larger.

As stated in the research design, the first step in conducting a PLS-SEM analysis to evaluate collinearity was to calculate VIF using SPSS software, calculated according to Equation 6.1.

The VIF ranges were as follows: Commitment (1.19–1.58), project preparation (1.04–1.06), organisation preparation (1.03–1.33), project implementation (1.11–1.47) and organisation implementation (1.06–1.23). These values were found to be significantly lower than the acceptable range of VIF ≤ 5 and confirmed that there was no collinearity issue.

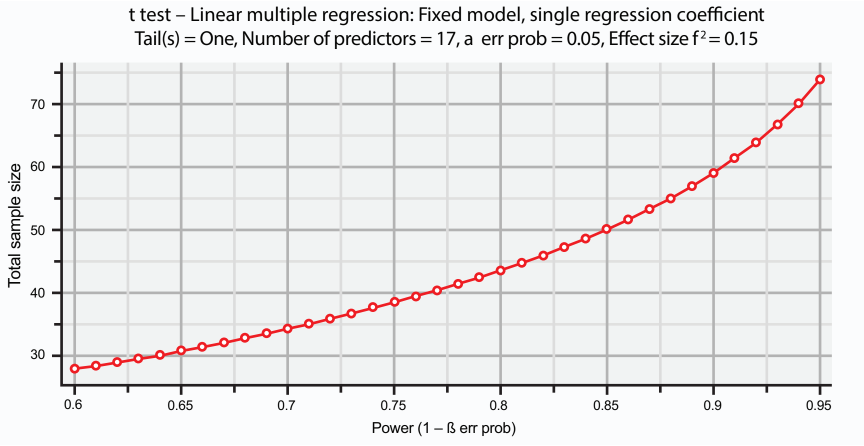

Figure 6.3 Minimum population size required for the PLS-SEM analysis

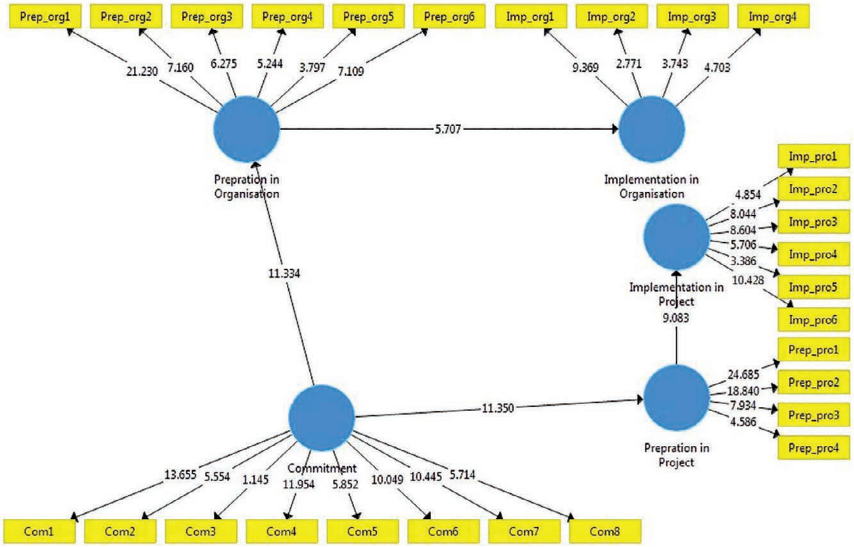

Figure 6.4 Initial calculation of t-values for outer weights based on 5,000 rounds of sub-sample bootstrapping

Figure 6.4 presents the results of running this analysis by setting the algorithm option to "no change sign" and allowing 5,000 bootstrap sub-samples as a conservative configuration.

As illustrated in the figure, apart from that of one of the observable variables (Com3), all VIF values were higher than 1.96, which shows that these variables could remain in the model as they significantly contributed to the latent variables.

However, for the Com3 factor, the value of the outer loading was used to indicate whether this factor could remain or should be removed. With reference to Hair Jr, Hult (39), factors can only remain if their outer loading value is higher than 0.5. In the case of Com3, the outer loading value was 0.145, which indicated that this factor should be removed from the list.

Because one of the factors was removed from the list, a second run of the bootstrapping function was performed to ensure that all variables possessed an acceptable t-value. Figure 6.5 presents the results of the second run and shows that all variables had t-values higher than 1.96.

After this modification, the model was considered fit to develop the path coefficients and determine the relative contribution of the observable variables to their relative constructs. Figure 6.6 presents the findings of running SmartPLS software and shows which variables should be focused on for a successful adoption of BIM to reduce occupational fatalities.

In the commitment stage, the most critical factors were identified as the commitment of the designers to develop BIM models with possible safety features (Com1) and the commitment of contractors to use BIM models in their safety management system (Com4). These factors were followed by mandating approaches imposed by the clients and government (Com7 and Com6).

In the organisational preparation stage, two factors were deemed to be particularly effective: TAFE and university initiatives in training safety officers/managers to use BIM (Prep_org1) and employing safety managers with BIM knowledge in construction companies (Prep_org6). In addition, two project preparations were

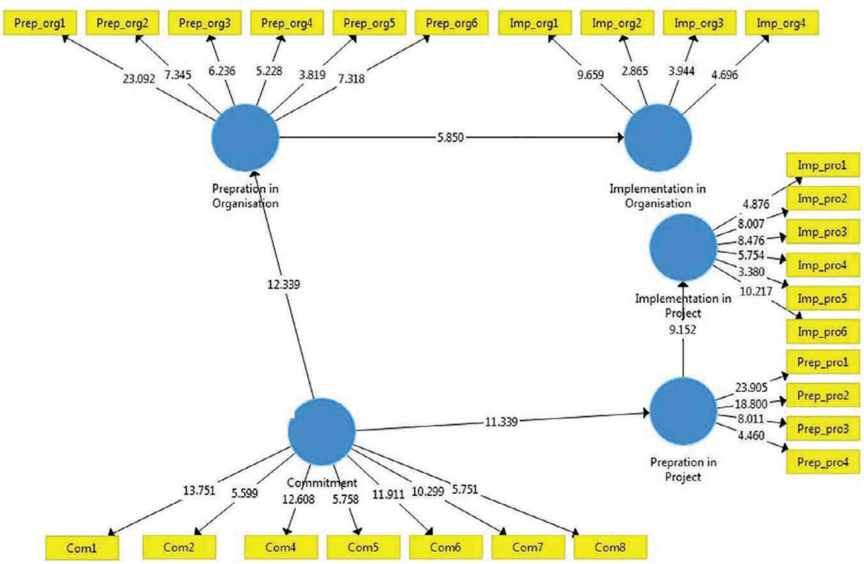

Figure 6.5 The second calculation of t-values for outer weights based on 5,000 rounds of sub-sample bootstrapping

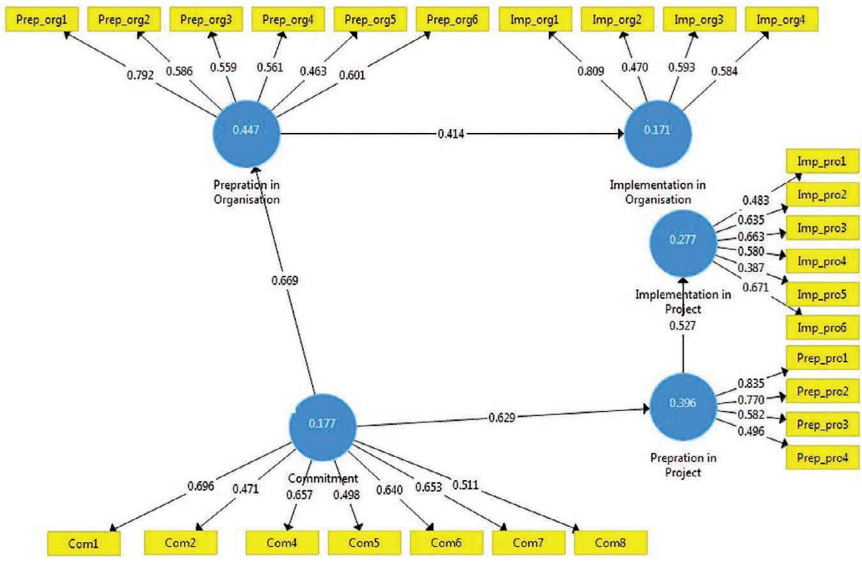

Figure 6.6 Final PLS-SEM model presenting path co-efficiencies and relative contributions of the observing variables to the constructs

determined to have significantly higher contributions than others: Setting out clear safety goals in the contracts for using BIM in the safety management process (Prep_pro1) and setting the scope of the project's safety management for the entire life cycle of the project from the first draft (Prep_pro2).

As illustrated in Figure 6.6, significant weight in the organisational implementation was given to the critical factors of initiatives from large companies as the front-liners in the industry in using BIM for safety (Imp_org1). The next two most significant factors in this construct were the continuous collaboration of the designers and contractors in monitoring and modifying the models during the execution of projects (Imp_org3) and the existence of an effective communication and data exchange system in place among the people involved in the safety management process of the projects (Imp_org4).

Critical factors in the project implementation construct were identified as engaging sub-contractors in the safety management process and providing them with required information through models (Imp_pro6). The next most significant factor in this construct was the continuous collaboration of the designers and contractors in monitoring and modifying the models during the execution of projects (Imp_pro3). R^2 values were replaced in Equation 6.1 to calculate the VIF of the latent constructs. Table 6.4 shows that all VIF values were under the threshold of 5.

Regarding the impact of the predictor constructs, (39) suggested that using the values of affect size values lower than 0.02 presents a minor impact. Table 6.5 presents the f^2 values of the latent variables, and there was no f^2 value below 0.02,

Table 6.4 R square and VIF values of the latent constructs of the model

Latent constructs	R^2	*VIF*
Commitment	0.177	1.215
Implementation at the organisation level	0.171	1.206
Implementation at the project level	0.277	1.383
Preparation at the organisation level	0.447	1.808
Preparation at the project level	0.396	1.656

Table 6.5 f^2 values for the structural model

	1	*2*	*3*	*4*	*5*
1: Commitment				0.81	0.655
2: Implementation at the organisation level					
3: Implementation at the project level					
4: Preparation at the organisation level		0.206			
5: Preparation at the project level			0.384		

which shows acceptable model fitness. Thus, the conceptual framework of the research presented in the Chapter 2 was supported, and the latent variables were positively related.

A discussion of the results of the case study is presented in the next section.

6.2 Role of Clients and Governments

As demonstrated in Table 6.6, the findings of this study show the critical role of clients among the commitments required for the successful adoption of BIM for construction safety management. Previous studies have also confirmed these findings, as clients represent the funding source of the projects, and the adoption of innovative ideas strongly requires their support (41). Contractors are less likely to employ BIM for WHS management if the clients do not support it. The existence of financial incentives in contracts to encourage the use of BIM in the safety management process was identified as a valuable commitment to be made by clients. The more experienced and demanding the client, the more likely they are to support the integration of innovations into the contracts (42).

As the biggest client in the country, the Australian government can have a significant influence by mandating the use of BIM for construction WHS management in public projects. Tam, Zeng (43) highlighted the critical role of governments in enforcing that companies must improve their WHS performance. Blayse and Manley (44) argued that the process of developing regulations that suit the adoption of a new technology is a complex process that mainly depends on the existence of sufficient knowledge among the industry's key players and the development of appropriate mechanisms. One of the best examples of such enforcement is the UK's enforcement of the use of BIM in projects (45). In the latest update of the

Table 6.6 The most effective CSFs to be considered by the responsible entities

Stage	*CSF*	*Responsible entity/ entities*
Commitment	Commitment to developing BIM models with possible safety features	Designers
	Commitment to using BIM models in the safety management of the projects	Contractors
	Mandating the use of BIM models for the safety management of the projects	Government, clients
	The existence of financial incentives in contracts for the use of BIM in the safety management process	Clients
Preparation at the organisation level	Training safety officers/managers to use BIM	Educational bodies
	Employing safety managers with BIM knowledge	Contractors
	Introducing potential BIM applications for WHS management to the companies	Professional bodies
	Availability of technical hardware and software	Designers, contractors
	Developing software to identify unsafe designs according to national safety regulations	Vendors
Preparation at the project level	Setting out clear safety goals for using BIM in the safety management process	Contractors
	Setting the scope of the project's safety management for the entire life cycle of the project from the first drafts	Clients
	Allocation of additional time and budget for safety in the design process	Designers
Implementation at the organisation level	Initiatives from large companies as the front-liners in the industry in using BIM for safety	Contractors
	Continuous monitoring and modifying the process of using BIM for safety management	Contractors
	Having an effective communication and data exchange system in place among the people involved in the safety management process	Contractors
Implementation at the project level	Engaging sub-contractors in the safety management process and providing them with required information through models	Contractors
	Continuous collaboration of designers and contractors in monitoring and modifying the models during the execution of the projects	Designers, contractors
	Developing IP conflict-resolving protocols to facilitate the exchange of models between designers and contractors	Designers, contractors
	Frequent updating of the safety information in the BIM models	Contractors

BIM standards, the British Standards Institute (2018) introduced BSI: PAS 1192–6 (46), which specifies collaborative sharing and the use of structured health and safety information using BIM. This standard highlights the process of integrating traditional risk management systems with BIM for use in the project life cycle. As identified in this study, it is important that governments and clients set the use of BIM for the entire life cycle of the project, as many accidents take place during the maintenance phase of projects. Having access to WHS information and having a structured risk management plan in place can prevent most fatalities.

6.3 Role of Contractors

Contractor companies hold most of the liability when a construction accident occurs. They must therefore innovate to improve their WHS performance. Blayse and Manley (44) highlighted the importance of diffusing new technologies as the main criterion for contractor companies to remain competitive in the industry and present their improvements in operations and distinctive technical capabilities. As identified in this study, the process of BIM adoption for WHS management by the industry is highly dependent on the contractors' commitment.

Safety managers in construction companies hold the prime responsibility of WHS management. Blayse and Manley (44) noted that some in-house technical competence is necessary to benefit from and absorb new technologies fully. Gann (47) argued that absorptive capacity is more important than technical capability and prior knowledge functions. Therefore, it is important for contractors to employ a safety manager with BIM knowledge to be able to interpret and act upon the WHS management of the projects. Winch (48) stated,

> Innovations need champions. Ideas are carried by people, and ideas are the rallying point around which collective action mobilises. Unless the 'systems integrator' is convinced of the merits of the new idea, and has the skills to incorporate it into the system as a whole, change is likely to be slow.
>
> (p. 274)

Safety managers with BIM knowledge can be considered the champions for a successful adoption process. Nam and Tatum (49) noted that a champion's technical competence enables overcoming the uncertainties involved in the adoption of new technologies, while power enables challenging the resistance to innovation.

Blayse and Manley (44) indicated that a limited number of construction companies have the capacity to develop a R&D programme. This places the burden on large companies that have the capability to initiate R&D programmes to devise an effective implementation process. In addition to hardware capabilities, contractor companies are required to enhance their software capabilities. A well-structured BIM model would be of no use to companies that do not have a license to use it.

Banihashemi, Hosseini (29) indicated the critical role of having an appropriate communication and information exchange system in place in the integration of Information and Communications Technology (ICT) for construction companies.

WHS data are required to be handled by the right people and responded to in a short time. Although utilisation of BIM structures the data exchange process, this requires proper management of the process. The current study also recognises the importance of the time-to-time modification of the process and updating models at the implementation stage. Integration of BIM with the current WHS management of construction projects was deemed to be a new approach and required learning from previous experiences and modifying the process. Gann (47) noted that contractor companies often have difficulty learning from previous projects. Blayse and Manley (44) suggested codifying the knowledge learned from projects so that it can be easier to diffuse into future projects.

Blayse and Manley (44) suggested that imposing strict high standards in projects can force contractors to adopt new technologies. However, Gann, Wang (50) noted that setting complex standards for projects discourages innovation adoption, and simplicity and clarity are required to enable the diffusion of good practices and encourage innovation. The current study found that setting clear safety goals for using BIM in the safety management process is a critical factor in organisation preparation.

The collaboration between contractors, sub-contractors and the design team in the implementation stage was a significant factor in the adoption process. Construction projects usually involve many sub-contractors who undertake most of the project's activities together. The main contractor's responsibility is to manage them to perform their tasks efficiently and safely. As identified in the previous section, the risk management process is highly in need of sub-contractors who are experienced in using BIM to engage in the process. Another key collaboration is between the contractor and the design team. Gambatese, Behm (51) noted the insufficient level of collaboration among the design team and contractor in the safety-in-design meetings. Gu and London (52) indicated that ownership of intellectual property (IP) and protection of copyrights is a major conflict between designers and contractors. Both groups often prefer to own the model, which might be reused to another company's advantage.

6.4 Role of the Design Team

Whether it is called "prevention through design" or "safety in design", the process highlights the high commitment of the design team in devising structures that are safe to construct. Schulte, Rinehart (53) defined this process as:

> The practice of anticipating and designing out potential occupational safety and health hazards and risks associated with new processes, structures, equipment, or tools, and organising work, such that it takes into consideration the construction, maintenance, decommissioning, and disposal/recycling of waste material, and recognising the business and social benefits of doing so.
>
> (p. 115)

A study by Tymvios and Gambatese (54) noted that architects have a much lower willingness to commit to safety in the design process than the client and contractor.

The main barriers to the design team are identified as legal, economic and contractual obstacles (54). The current study also identified the requirement for time and budget allocation as a CSF in the project preparation stage.

Although design teams might have sufficient knowledge of BIM, they often lack safety knowledge. A study by Tymvios, Gambatese (30) argued that most design team members do not have knowledge about safety in design. There are currently several BIM-based tools, such as the Solibri Model Checker, that can assist designers in applying safety rules into their designs. As a critical preparation, design teams require a good arrangement of hardware and software to make this possible.

6.5 Role of the Vendors and Technology Providers

Vendors and technology providers play a significant role in the establishment of BIM applications for construction WHS. The technology here is very new for most construction companies, and this requires the development of more user-friendly platforms. As such, Eastman, Lee (11) and Vakilinezhad, Dias (12) argued that the current tools do not address WHS issues and are more focused on design aspects, as well as the time and cost management of the projects. Tools such as Autodesk Navisworks, Asta PowerProject and Syncro 4D construction project management software and 3D BIM software allow visually detection of WHS concerns, while WHS management processes require more use of embedded information. This problem has been addressed in research projects. For example, Arslan, Riaz (55) integrated environmental sensors with BIM models to detect unsafe environmental conditions. Bahn (56), Benjaoran and Bhokha (57), Choe and Leite (58) and Dong, Wang (59) integrated traditional risk management approaches with 4D BIM tools to create accessible database of WHS management information. Additionally, some research has focused on the development of semi-automated/automated site design tools that consider the unsafe proximity of the workers to heavy equipment (60–62).

Software such as the Solibri Model Checker represents a more advanced approach that can identify unsafe designs in a semi-automated/automated way. However, the current state of these tools is limited. Vakilinezhad, Dias (12) described these limitations as highly dependent on what the IFC supports, inflexibility in rule-checking tools and inability to detect WHS issues during the initial phases of design. In the case of Australia, there is a lack of such tools that can check the models against the national WHS regulations.

6.6 Role of the Professional and Educational Bodies

For the Australian construction industry, Hardie and Newell (63) noted the professional bodies' effectiveness in the adoption of new technologies. The results of the current study showed that professional bodies can support joint problem solving that can encourage the sharing of tacit knowledge related to BIM's WHS potential. The intervention of such organisations can reduce the risk of adoption, which can lead to higher consumption of the technology. On the other hand, Blayse and Manley (44) argued that construction companies are discouraged from adopting innovative approaches when professional bodies introduce inflexible guidelines.

Educational bodies such as universities and TAFE institutions have recently started to provide BIM courses, with this now becoming a more common practice. However, the training of project/safety managers to incorporate BIM into their WHS management practices is missing in the current stage. Although there are some initiatives from universities, such as the University of Newcastle, which has two courses on BIM-enabled safety management for construction management students at the bachelor level, the units are more about using the visual aspect of BIM models rather than the embedded information.

6.7 Implementation Framework of BIM for Construction WHS

This section describes the overarching aim of the study, which was to map the process of diffusing BIM in construction WHS management (Figure 6.7). This process began with the identification of the critical causations of fatal accidents within Australian construction projects. The factors of risk management, workers' actions and behaviours, worker's capabilities, immediate supervision, temporary and permanent work design, construction process, workers' health and fatigue and equipment condition were found to be the most critical causations. This recognition was achieved by drawing accident causation networks based on the ConAC model for each of the accident cases collected from the NCIS database.

The second phase of innovation adoption model development was to evaluate BIM applications regarding causations. It was determined that risk causation management could be controlled using a suitability assessment of the dynamic equipment/machinery via 4D BIM simulations; planning ahead for the required materials and equipment for safer execution of the projects using 4D BIM planning; communication of safety issues through software such as BIM 360 Field, which circulates information through tablets and smartphones and informs people that are responsible for taking actions; and using BIM as a digital library of the site condition. BIM can support workers' actions and behaviours by testing and improving workers' safety culture in situations such as reporting unsafe conditions on the site, recognising the required PPE, communicating safety concerns with their colleagues, etc., and using BIM as a digital library of workers' safety track records. Workers' WHS capabilities can be improved by training workers in an interactive virtual environment, which can involve all existing risks, unlike traditional classroom-based training, and assessment of workers and sub-contractors' capabilities by conducting a walkthrough of the 4D simulations and discussing their approach to safely performing their tasks.

Immediate supervision at construction sites can be further automated by monitoring workers and equipment using attached location tracking sensors that are connected to a BIM model and controlled by the project management team. Other possibilities include frequent monitoring of the site and equipment conditions using flying drones and tracking of environmental conditions such as temperature, humidity, wind speed, etc., in the indoor and outdoor locations through sensors that are linked to a BIM model.

BIM can improve temporary and permanent work designs through automated or semi-automated checking of the building designs in BIM models to avoid unsafe designs or identify possible hazards as early as possible. Further option includes automated or semi-automated designing, checking the design of on-site temporary structures using validated algorithms to avoid design related failures and using BIM models provided by suppliers to assess the suitability of the materials and equipment they provide for the construction site.

The construction process can be made safer by developing safe work method statements for companies and trade unions. BIM can also support workers by monitoring their health and fatigue conditions using remote health monitoring sensors that can capture the location and health condition of workers and show them in a BIM model, using BIM to develop a digital library of the workers' health. Equipment conditions can be monitored through using BIM as a digital library of the equipment/machinery maintenance information. An external database can be created to store operation and maintenance information on the equipment/machinery, and this can be linked to the relevant equipment/machinery used in the 4D BIM models.

The commitments identified in this study for successful diffusion of an innovation were: Designer commitment to developing BIM models with possible safety features, contractor commitment to using BIM models in the safety management of the projects, government and clients mandating the use of BIM models for safety management of the project and client provision of the financial incentives in the contracts for using BIM in the safety management process.

Two types of preparations were deemed to be required: Organisational- and project-level preparations. Educational bodies must train safety/project managers to use BIM for the WHS management of projects. Meanwhile, contractors should employ safety managers with knowledge of BIM. This also requires preparations by professional bodies such as the Australian Institute of Building to promote BIM applications for construction WHS management. Design and contractor teams must prepare suitable software and hardware that can support the implementation of BIM-based WHS management. Additionally, technology providers should adjust their products to an extent that can support WHS management in the design, construction and maintenance of the project.

During projects, contractors should set clear safety goals for using BIM in the safety management process, and clients should set the scope of the project's safety management for the entire life cycle of the project. In addition, the design team should allocate additional time and budget for safety in the design process.

As in the preparation stage, implementations also fall into categories of project-level and organisational. Large companies should begin the implementation of BIM for WHS management, as they have the required resources. Where an innovation is adopted by a company, the process of implementation requires monitoring over time. Organisations should also apply effective communication and data exchange systems among the people involved in the safety management process.

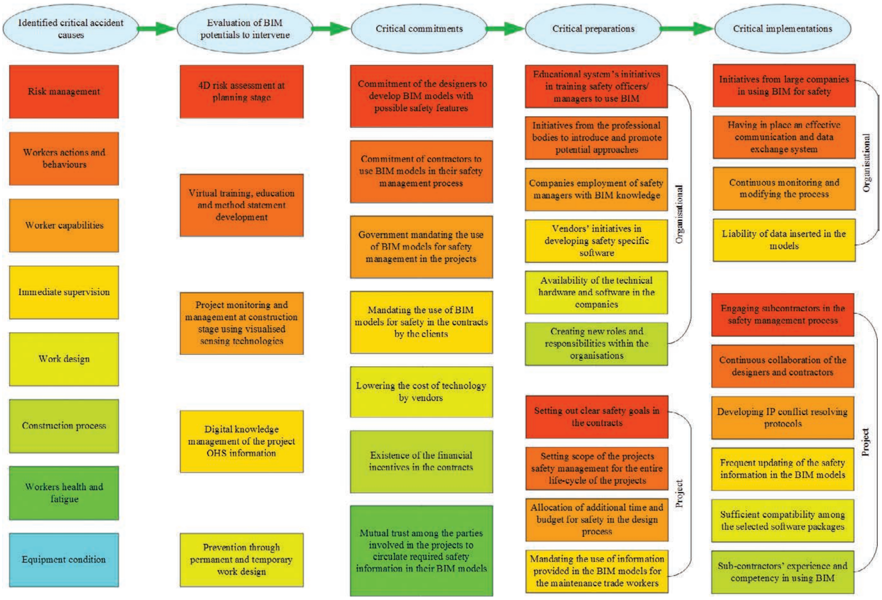

Figure 6.7 Innovation adoption model for diffusion of BIM in the WHS management of construction projects (factors are organised from the highest to lowest criticality)

The project implementation of an innovation requires that the contractor and the design team collaborate and monitor the models during the execution of the projects. These two teams should develop IP conflict-resolving protocols to facilitate the exchange of models. On the other hand, sub-contractors must be engaged in the safety management process and provided with the required information through models. Models developed for the WHS management of projects are required to be updated frequently by contractors.

6.8 Summary

Using a mixed-method research approach, this chapter examined the BIM adoption process in the Australian construction industry. A description of the study's process was provided, which included a description of how data were collected, the methodologies used to analyse data and the results that were achieved. An analysis of the existing literature revealed 27 critical factors for successful adoption. Through the semi-structured interviews as well as questionnaires, these factors were revised according to the current realities of the industry. Based on these findings, a number of parties involved in the process are required to take action, including clients, governments, contractors, design teams, procurement methods, technology providers and educational institutions. Furthermore, the role that each of these parties is required to take is described and discussed. By building off the findings from Chapter 5 regarding BIM applications for construction safety and the findings of this chapter, this research book describes a comprehensive model of innovation adoption for diffusion of BIM within safety management.

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7 BIM for the Future of Construction WHS

7.1 Review of Processes, Objectives and Findings

7.1.1 Research Background, Aim and Methods

The potential uses of BIM can drastically alter WHS practices in the construction industry, which is currently suffering a sad reputation due to its high number of associated injuries and fatalities. BIM facilitates project information exchange and management and supports better collaboration and project planning by enabling virtual visualisation of the construction process (1, 2). All of these attributes have resulted in an exponential growth in interest towards the digitalised management of construction safety in the past five years (3).

BIM-enabled approaches towards WHS management are extensive and, at the same time, relatively new to the construction industry of Australia. Therefore, the diffusion of such innovative interventions with the current practice of the industry in a practical manner requires the proper identification of effective areas and evaluation of their impact on key criteria of the projects and organisations. In the construction industry context, Slaughter (4) describes innovation as the actual use of a nontrivial alteration in terms of an enhancement of a system or working procedure that is new to the corresponding organisation. As suggested by Slaughter (4), the first step for implementation of an innovation in a project or organisation is to identify the areas that require intervention. Therefore, in the case of the diffusion of BIM-enabled approaches to reduce fatalities in the construction sector, unearthing how construction causalities occur is key to prioritising areas that require intervention (5). Furthermore, BIM is not a magic bullet that can hit all WHS targets of construction fatalities. Such adoption in the industry requires a careful evaluation of the potential of BIM to be effective in terms of the identified WHS concerns. Finally, the adoption of innovations in construction organisations and projects requires an understanding of the CSFs of commitments, preparations and implementation methods (6). These factors are fundamental for tackling the major obstacles of leveraging BIM applications towards improving the WHS performance of construction projects.

This research book was aimed to develop an innovation adoption model for the diffusion of BIM in the WHS management of the construction industry to reduce occupational fatalities. To achieve this aim, the following objectives were set:

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1) To identify the causes of fatal accidents in the construction industry.
2) To evaluate the effectiveness of BIM-enabled approaches to reduce the identified causes of fatal accidents in the construction industry.
3) To determine the CSFs of adopting BIM to improve construction WHS performance.
4) To develop an innovation adoption model to integrate BIM's WHS aspects with the current practice of the industry.

In order to achieve the designed aim and objectives of this research book, a mixed-method approach was designed for each objective. For the first objective of the research, a $QUAL \rightarrow QUAN$ approach was undertaken. Having access to the NCIS data made it possible to identify the fatal accident causations of real accident cases by conducting a thematic content analysis. To identify the most critical causations, standardised degree centralities were then calculated for each of the accidents, and this led to the identification of medium- and high-priority central factors for the categories of accident mechanisms. For Objectives 2, 3 and 4 of the study, another $QUAL \rightarrow QUAN$ approach was considered. First, a preliminary review of the literature was conducted to identify BIM's potential for controlling accident causations and determine CSFs for BIM adoption in construction WHS management. The findings of the literature review were then subjected to a qualitative analysis approach through interview sessions with industry experts from Australia. To validate the outcomes of the qualitative approach, the quantitative approach of an expert survey was carried out. The interview results were subjected to thematic content analysis and the collected survey results were subjected to PLS-SEM analysis.

7.1.2 Review of Research Processes and Findings

As mentioned, the overarching aim of this research was to develop an innovation adoption model for diffusion of BIM in the WHS management of the construction industry and reduce occupational fatalities. Hence, the key processes and findings presented in Chapters 4 and 5, which enabled achievement of the research aim, are discussed in the following sub-sections.

7.1.2.1 Objective 1: To Identify the Causes of Fatal Accidents in the Construction Industry

The primary focus of this objective was to understand the nature of fatal construction accidents and to identify the areas that require the intervention of an innovation. The Australian construction industry was used as a case study for this research. National accident surveillance reports published by organisations such as Safe Work Australia do not provide enough detailed information for researchers to develop possible preventive measures. For instance, Safe Work Australia (7) reports on construction accidents classify fatal accident causations by their mechanisms and occupation of the deceased workers and lack analysis of the causations behind the accidents.

Reviewing the existing literature on accident theories showed that there has been a paradigm shift among safety researchers from examining single causations of accidents to systematic accident models, as these are more robust and comprehensive. Unlike sequential models, systemic accident causation models describe the existence of dynamic interaction among cultural and organisational factors in creating a hazardous situation (8). For construction accidents, the ConAC model developed by a research team from the Loughborough University was found to be the only well-known systematic accident model that had been employed by several researchers to diagnose construction accident causations (1, 8–10). Therefore, the current study took advantage of the ConAC model to identify the critical areas in the occupational fatalities of the Australian construction industry.

Out of 287 fatal accident cases collected from the NCIS database for the period of 2007–2016, 105 cases were deemed suitable for the thematic content analysis, as the removed cases did not contain coroner findings regarding the accidents and police reports did not describe the causations behind the accidents. Accident cases were categorised and described based on their locations, times and accident mechanisms. Only two cases from NSW were suitable for the analysis, and most of the accident cases were from the period of 2007–2014. Fall from height and contact with electricity were the two major mechanisms of accidents among the collected cases, as the Safe Work Australia (7) report also indicated.

Using the terminologies of the ConAC model described by Behm (11) and later by Golizadeh, Hon (1), the fatal accident cases were set for deductive content analysis. The analysis found that the highest proportion of causations was related to immediate supervision (in 60 cases) and workers' actions and behaviour (in 58 cases), followed by risk management (in 54 cases), construction processes (in 48 cases) and permanent work design (in 45 cases) from the originating influences group. In addition, causations were analysed for accident mechanisms. For instance, in fall-from-height accidents, immediate supervision, permanent work design, workers' actions and behaviours and construction process were the highest contributing factors. In contact-with-electricity accidents, permanent work design, construction process and risk management were found as frequent factors in the cases.

Many past studies have considered accidents as the result of a network of causations, whereby their linkage leads to an accident (8–10, 12). Therefore, those accidents that had the highest number of linkages were considered the most critical causations, and degree centrality was deemed to be an appropriate approach to discover such causations (13, 14). In order to compare the value of centralities, standardised degree centrality values for the causations of each accident network were calculated. Standardised degree centrality values were then categorised for each accident mechanism in a four-scale format of very low, low, medium and high centrality. Based on the findings, risk management, workers' actions and behaviours, workers' capabilities, immediate supervision, temporary and permanent work design, construction process, workers' health and fatigue and equipment conditions were the most repeated high and medium central causations in the accident mechanisms. These causations were considered critical areas that required intervention via an innovation, which in the case of this study, is employing BIM.

7.1.2.2 Objective 2: To Evaluate the Effectiveness of BIM-Enabled Approaches and Reduce the Identified Causes of Fatal Accidents in the Construction Industry

The second stage in the innovation adoption theory was to evaluate innovation capabilities to elevate the identified areas for intervention. Hence, BIM capabilities for construction WHS management were identified by reviewing the existing peer reviewed journal papers on the topic. Six types of BIM applications that may support construction WHS management were found: 3D tools for preliminary risk assessment; automatic/semi-automatic model checkers; 4D (3D+time) construction planning; knowledge management systems; AR and VR; and RTLS.

The next step for this objective was to identify applications of BIM that could specifically improve the identified critical accident causations. Semi-structured interviews with highly experienced industry experts were employed as an appropriate approach to collect sufficient data. In essence, this study used purposeful sampling techniques for the selection of participants instead of random sampling (15). The population of interest for this part of the study consisted of construction safety and project managers from the contractor sector, as well as BIM managers, architects and design engineers from the consultant party that had engaged with several BIM-based projects and were familiar with the regulations and industrial settings of the Australian construction industry. Having at least 10 years' experience was identified as the main criterion for the selection of participants, along with their availability in the planned interview period. Overall, six highly experienced industry experts were interviewed and provided with sufficient information regarding the progress of the research and existing approaches found in the literature. This was to ensure that the study was consistent in structure and data collection processes and therefore contributed to the reliability of collected data (16).

After conducting each semi-structured interview, the recorded interviews were transcribed and subjected to thematic content analysis to identify BIM applications related to the critical accident causations. The interviews continued until no new codes emerged in two consequent sessions. After finalising the results, five main domains were recognised that may be useful in improving the critical accident causations. The first approach was virtual training, education and method statement development, including:

- training workers in an interactive virtual environment that can involve all existing risks rather than the traditional classroom-based settings;
- testing and improving worker safety culture in situations such as reporting unsafe conditions on the site, recognising the required PPE, communicating safety concerns with their colleagues, etc.; and
- developing safe work method statements for companies and trade unions.

The second approach was prevention through permanent and temporary work designs that include:

- automated or semi-automated checking of the building designs in BIM models to avoid the unsafe designs or identifying possible hazards as early as possible; and

- automated or semi-automated designing and checking the design of the on-site temporary structures using validated algorithms to avoid design related failures.

The third approach was 4D risk assessment at the planning stage, including:

- suitability assessment of the dynamic equipment/machinery using 4D BIM simulations;
- planning ahead for the required materials and equipment for safer execution of the projects using 4D BIM planning; and
- assessing workers and sub-contractors' capabilities by conducting a walk-through of the 4D simulations and discussing their approach on safely performing their tasks.

The fourth approach dealt with project monitoring and management at the construction stage using visualisable sensing technologies, including:

- monitoring workers and equipment through attached location tracking sensors that are connected to a BIM model and controlled by the project management team;
- performing frequent monitoring of the site and equipment conditions using flying drones;
- communicating safety issues through software such as BIM 360 Field, which circulates information through tablets and smartphones and informs the responsible parties to take action;
- monitoring workers' health and fatigue conditions by using remote health monitoring sensors that can capture the location and health condition of the workers and show them in a BIM model; and
- monitoring environmental conditions such as temperature, humidity and wind speed in indoor and outdoor locations through sensors linked to a BIM model.

The last approach was digital knowledge management of the project's WHS information, including:

- Using BIM as a digital library of the site's condition. An external database that stores site safety information is created, and the required safety information is linked to the objects in the BIM model. This provides project/safety managers with a comprehensive understanding of the situation.
- Using BIM as a digital library of equipment/machinery maintenance information. An external database is created to store operation and maintenance information about the equipment/machinery used in the 4D BIM models.
- Using BIM as a digital library of the workers' safety track record. An external database of the workers' health and performance track records is created and linked to the 4D BIM models. This shows workers' health and safety performance records when assigned to different activities.
- Using BIM models for suppliers to assess the suitability of the materials and equipment they provide for construction sites.

To evaluate the effectiveness of the identified approaches/types of BIM on critical causations, a survey was conducted among a larger subset of industry experts. Using PLS-SEM analysis, BIM applications under 4D risk assessment were found to be the most effective at the planning stage. Accordingly, applications related to virtual training, education, method statement development, project monitoring and management at the construction stage using visualised sensing technologies, digital knowledge management of the project WHS information and prevention through permanent and temporary work design approaches were, in that order, the most to the least effective at the current stage.

7.1.2.3 Objective 3: To Determine the CSFs for Adopting BIM to Improve Construction WHS Performance

This objective dealt with identifying CSFs at the commitment, preparation and implementation stages of the innovation adoption model devised in this study. The research method conducted for this objective was the same as that used for Objective 2. First, a comprehensive review of the existing literature was conducted on the CSFs for successful implementation of BIM for construction WHS management. Since there were limited sources due to the newness of the topic, a search was undertaken to find literature related to CSFs for the adoption of ICT, BIM and innovations in construction WHS management. The search yielded 27 CSFs related to different stakeholders of the contractor, design team, client, government, professional and educational bodies and technology providers.

As for Objective 2, semi-structured interviews were conducted to identify CSFs that were specifically related to the adoption of BIM to reduce the incidence of fatalities in the construction industry of Australia. Using the same research method, the CSFs were identified by reaching saturation in data. Regarding the commitment stage, the following seven CSFs were required:

- commitment of designers to develop BIM models with possible safety features;
- mutual trust among the parties involved in the projects to circulate the required safety information in their BIM models;
- workers' agreement regarding the storage and use of their health and safety records;
- commitment of contractors to use BIM models in their safety management system;
- reduction in the cost of technology by vendors to make the technology usable for small and medium-sized companies;
- Australian government mandating for the use of BIM models for safety management of the projects;
- mandating for the use of BIM models for safety in the contracts by the clients; and
- the existence of financial incentives in the contracts for using BIM in the safety management process.

In the preparation stage, two categories of preparations were identified. The six types of identified organisational preparations were:

- TAFE and university initiatives in training safety officers/managers to use BIM;
- initiatives from the Master Builders Association for introducing possible approaches to the companies;
- vendors' initiatives in developing software that can identify unsafe designs according to national safety regulations;
- availability of technical hardware and software in the companies;
- creation of new roles and responsibilities within organisations for facilitating the implementation of BIM for safety management; and
- employment of safety managers with BIM knowledge in the companies.

Project-related preparations included:

- setting clear safety goals in the contracts for using BIM in the safety management process;
- setting the scope of the project's safety management for the entire life cycle of the project from the first draft;
- allocating additional time and budgeting for safety in the design process;
- mandating the use of information provided in the BIM models for maintenance trade workers.

At the last step of the innovation adoption model of the research, two types of implementation are required. For organisational implementation, four CSFs were identified: initiatives from large companies as the front-liners in the industry in using BIM for safety, liability of data inserted in the models for each of the parties involved, continuous monitoring and modification of the process of using BIM for safety management, and existence of an effective communication and data exchange system in place among the people involved in the safety management process of the projects.

Six CSFs were found to be required for project-wise implementations:

- sufficient compatibility among the selected software packages to transfer safety features from one to another;
- development of IP conflict-resolving protocols to facilitate the exchange of models between designers and contractors;
- continuous collaboration of the designers and contractors in monitoring and modifying the models during the execution of the projects;
- frequent updating of the safety information in the BIM models;
- sub-contractor experience and competency in using BIM; and
- sub-contractor engagement in the safety management process and access to required information through models.

Finally, the findings of the qualitative approach were set to a broad survey among industry experts. The results employing PLS-SEM to quantify the importance of the identified CSFs are shown in Figure 6.7. In the commitment stage, factors related to the commitment of designers to develop BIM models with possible safety features and the commitment of contractors to use BIM models in their safety management process had the highest importance. Significant preparations included the educational system's initiatives in training safety officers/managers to use BIM and initiatives from professional bodies to introduce and promote potential approaches of organisations while setting out clear safety goals in the contracts and setting the scope of the project's safety management for the entire life cycle of the project. The weightiest project-related and organisational implementation CSFs were engaging sub-contractors in the safety management process, promoting continuous collaboration of the designers and contractors, creating initiatives from large companies in using BIM for safety, and having an effective communication and data exchange system in place.

7.1.2.4 Objective 4: To Develop an Innovation Adoption Model to Integrate BIM's WHS Aspects with the Current Practice of the Industry

The overarching objective of this research was to develop a framework that describes the critical stages for the adoption of BIM to reduce fatalities in the current Australian construction industry. Because practice and research may evolve over years, the identified CSFs and BIM applications were considered recent. Combining the findings of Objectives 1, 2 and 3 of the research into one framework resulted in the development of the innovation adoption model of this research (see Section 5.4 and Figure 5.2). Objective 1 fulfilled the first step of the innovation adoption model by identifying the areas that are currently the most critical for fatal occupational accidents in Australian construction projects. This objective involved analysing real fatal accident cases that were investigated by coroners. Objective 2 focused on how BIM can improve those critical areas by introducing the potentially effective applications of BIM. Combining the recent advances of BIM in construction WHS management and experts' opinions led to the identification of BIM applications at the current maturity level that could improve the identified critical WHS areas. Objective 3 of the research formed the remaining three stages of the innovation adoption model, which were commitment, preparation and implementation. Due to the novelty of the topic, CSFs from similar topics were collected from the literature and modified by industry experts to be suitable for the topic of this research. As a result, a five-stage framework was developed that suits Australian construction projects and organisations in reducing the number of occupational fatalities.

7.2 Originality, Contributions, Implications and Limitations

7.2.1 Originality

Contributions to the body of knowledge on this in three originality measures are described as follows.

- *Conducting research in an unexplored area*. Outcomes of Objective 1 of the research present causations behind recent occupational fatalities in Australia that were previously investigated by Cooke and Lingard (17) in a similar method for accidents took place between 2000 to 2009, and there were no recent investigations on this area. This allowed for understanding of the current occupational accident causations in this study and will support future research in developing preventative measures. Objective 2 of the research included a search for BIM-enabled applications within peer-reviewed journals, and these were categorised by their potential for preventing construction accident causations (1). There was no previous research on this area, and this study therefore provides better understanding of current BIM applications for construction WHS management and the gaps remaining for future investigations. In addition, Objective 2 assessed the effectiveness of BIM applications at the current stage, which had not previously been investigated. Guo, Yu (3) noted that the popularity of BIM-enabled WHS management research has exponentially increased since 2012, and yet no research has assessed the effectiveness of these applications for controlling accidents. This enables researchers to direct their focus to the areas where BIM can be practical and avoid unnecessary areas. Overall, there is a very limited number of innovation adoption models for construction WHS management, and no previous research has been undertaken regarding the adoption of BIM to improve construction WHS management. This is an important research gap, as many countries are launching their BIM standards for construction WHS management, and yet a successful adoption process remains unexplored. Objectives 3 and 4 of the research tackled this lack of information by exploring CSFs for successful diffusion of BIM in construction projects and organisations to reduce occupational fatalities. The framework established in Objective 4 is the first of its kind in Australia and describes the adoption process in five steps: Identification of critical causations, evaluation of BIM capabilities to control the critical causations, commitment CSFs, preparations CSFs and implementation CSFs.

- *Showing a novel empirical approach*. Handfield and Melnyk (18) noted that knowledge creation is generally handled by the emergence of a new theory or by partial or whole rebuttal and/or modification of an existing theory through the employment of empirical data. This research modified Slaughter's (19) innovation adoption theory to achieve the overarching aim, which was developing a BIM adoption model for the construction industry of Australia to reduce occupational fatalities. In addition, diffusion of a well-established accident theory with the innovation adoption theory was another theoretical contribution of this research that supported the identification stage of the model. This allowed for the identification of the most central accident causations among fatal occupational accidents in the Australian construction sector. Previous studies, such as those by Behm and Schneller (9), Gibb, Lingard (8) and Cooke and Lingard (17) used the ConAC terminologies to determine the causations behind accidents in different regions while neglecting the systematic connections of the causations. As many systematic accident models, such as those of Reason (20) and Gibb, Haslam (12) suggest, eliminating those accidents that have more connections can significantly reduce the likelihood of accidents.

- *Genuine synthesis*. This research yielded a set of empirical findings that are novel. First, this research took advantage of the ConAC model's connections among accident causations to develop an accident network of the analysed cases. This led to identifying critical areas that require intervention, whether using BIM or other controlling measures to reduce the number of occupational fatalities. In addition, previous studies into construction accident causations in Australia have analysed the accident cases for the period of 2000–2009 (17), and yet there was no recent practice in this period. Objectives 2, 3 and 4 involved syntheses of the literature survey and viewpoints of industry experts regarding the effectiveness of BIM applications to mitigate the critical accident causations and CSFs for the adoption of BIM and reduce fatalities in Australian construction projects. Although there have been many studies on different applications of BIM for construction WHS management, no research has assessed BIM applications or CSFs for diffusing this innovation in the industry. Hence, the genuine synthesis rule for research was satisfied, which Walker (21) described as "making a new interpretation of existing material" (p. 150). Last, but not least, the BIM adoption model of this research represents the first attempt in this area, and no previous studies have described the process of such adoption within the construction industry of Australia or any other countries.

7.2.2 Implications for Practice

Implications for practice are another expectation for research to describe the practical knowledge extracted from this research. Yi and Chan (2013) noted that such contributions are of importance in the construction management of the built environment because there is an urgent necessity for elevating its efficiency. The implications of the current research for practice are described herewith according to taxonomies described by Bartunek and Rynes (22), which include enhanced awareness, potential audience and identification of new learning areas.

- *Potential audience*. Drawing upon the practical applications of the BIM adoption framework to reduce occupational fatalities, contractor companies can be considered the first-tier audience, as they hold most of the liability in accidents. Contractors are required to pay further attention to the critical WHS areas that lead to fatal accidents, be aware of the potential applications of BIM to reduce such fatalities and address the CSFs required for a successful adoption of BIM in their organisation and projects. Second tier audiences are the government and local organisations that are seeking to employ BIM as an innovative approach to improve the WHS management of the construction industry. The recent introduction of PAS 1192–6 in the UK (23) may encourage the local and federal governments of other countries to develop an adoption framework for employing BIM for construction WHS management. This research also can draw the attention of US and UK practitioners, as the rate of occupational fatalities in the construction industries of these countries is higher than that of all other industries.

- *Enhanced awareness*. Due to growing concerns about the number of occupational fatalities in the construction industry, this research identified the critical areas that require improvement. Risk management, workers' actions and behaviours, worker capabilities, immediate supervision, work design, construction process, workers' health and fatigue and equipment conditions were found to be the most critical areas that the industry is required to be aware of. Additionally, this research raises awareness among the parties involved in the project that collaboration between several parties is required to achieve a smaller number of fatalities. The model developed in this study shows that without the support of other parties, contractors do not have the ability to handle the adoption process. This study also highlights the rule of technology providers, as the current applications of BIM do not suit the requirements of safer practice. This research has pinpointed the areas that technology providers should pay more attention to and areas that are executed safely at the current stage.
- *New learning areas identification*. Underlining the practical problems and results of research is a resource of learning and gaining further knowledge for industry audiences. Revealing the critical causations behind occupational fatalities can challenge the industry audience to pay further attention to those areas. The identified CSFs are also challenges that the Australian construction industry faces in the adoption process of BIM for WHS management. The current research can also be informative for practitioners of other countries, as many countries employ BIM in their projects, and yet construction stands at the top of the list of hazardous industries.

7.2.3 Limitations

This section acknowledges the limitations of the current research despite the important contributions it makes to the current body of knowledge. Therefore, the limitations of this research are as follows:

- First and foremost, the current study can only be considered valid in the context of the Australian construction industry. The BIM applications identified in the current research were discussed and devised by industry experts to tackle the accident causations found for occupational fatalities of Australia. As many previous studies have shown, WHS management issues may differ from one country to another (8). The critical commitments, preparations and implementation factors were also modified for the context of current Australian construction practice. These factors may vary from time to time, as technology and working environments are dynamic.
- Accidents covered in this research are fatal occupational accidents, and the findings may or may not apply to non-occupational or non-fatal occupational accidents. Due to the availability of data for fatal occupational accidents and the limited duration and resources of the study, the scope of this research was set to this type of accidents. However, the procedures used for this research can be reused to develop innovation adoption models to reduce other types of accidents.

- The accident cases selected for the current research did not involve most cases in NSW. This was due to the lack of coroner's reports among the NSW cases, as this was one of the case selection criteria for this research. Overall, 182 accident cases found for the selected duration of the research were deleted due to this criterion; however, the trends in accident mechanisms found among the selected cases was similar to the national trends.
- Although the first objective of the study was satisfied by analysis of real accident cases, the rest of the objectives were addressed through opinion-based approaches of semi-structured interviews and a questionnaire survey. This might be a drawback of the current research method when compared with conducting action-based research. This research could be used as a base for future action-based research in the Australian construction industry.

The majority of the participants who completed the questionnaire survey had less than five years of experience using BIM in their usual practice, even though they had many years of industry experience. This is probably due to construction organisations in Australia having only recently adopted BIM.

7.3 Knowledge Gaps Within the Domain of BIM and WHS

The limitations found in this research can pave the way for future research in this area. Zou and Sunindijo (24) noted that research has a cyclical feature and does not stop at a point. Thus, the recommendations for future research driven by this study are described as follows:

- The BIM adoption model devised in this study deals with occupational fatalities in the Australian construction industry. The procedure adopted for the current research could be readopted for a wider purpose of BIM and digital engineering adoption to improve national WHS management. Additionally, this procedure could be good practice for international adoption processes, as many countries, such the UK, are initiating BIM implementation for construction WHS management (23). It is noteworthy that for the successful implementation of any innovation, appropriate diagnosis of the problems is crucial, and this may vary from one country to another.
- The theoretical approach of the current study provides a sound structure for future research into WHS management. Integrating systematic accident models with innovation adoption theories can potentially support a sound background for future research and lead to the modification of adoption frameworks. Accident models such as the ConAC system not only provide the terminology for comprehensive accident analysis but also describe the importance of the linkages among the actors. The latter requires further attention from researchers, as accidents take place through a chain of events and the central actors are the most critical ones. Thus, measuring the degree centralities of accident causations is a good approach to identifying central links.
- As mentioned by Guo, Yu (3) and Golizadeh, Hon (1), research into the domain of BIM-enabled WHS management has grown over the last five years.

However, many of these studies have overlooked what the current practice of the industry requires most and which areas of WHS management are currently doing well. Identification of the critical WHS management areas in this study led to recognition of what BIM-enabled research should be focused on in the future. Thus, further research is required on the topics of 4D risk assessment at the planning stage, virtual training, education and method statement development, project monitoring and management at the construction stage using visualised sensing technologies, digital knowledge management of the project WHS information and prevention through permanent and temporary work design.

- CSFs identified in the current research can be tested in real-world practice and evaluated. Identifying these CSFs did not benefit much from the previous research due to limited resources and potential future research could investigate CSFs in different regional contexts other than Australia.
- Finally, the innovation adoption model of the research was mostly developed by employing opinion-based approaches, and as such, conducting field research, such as action research, could further enhance the accuracy of the model.

7.4 Summary

This chapter summarised the existing gaps in the literature, research aims and objectives and the process undertaken to address the research objectives. The findings and discussions made around the objectives of the research were also provided. Finally, this chapter outlined the contributions of this research to the body of knowledge, as well as discussing the implications for practice, recommendations for future research and limitations of the current research.

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Index