School of Design and the Built Environment

Integrative Trust-Based Functional Contracting:
A Complementary Contractual Approach to BIM-Enabled Oil And Gas EPC Project Delivery

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DECLARATION

To the best of my knowledge and belief, this thesis contains no material previously published by any other person except where due acknowledgement has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number #HRE2017-0143.

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Date: 8 March 2019

ABSTRACT

Building Information Modelling (BIM) should be embraced by the oil and gas projects to address their common issues of budget and schedule overruns. By embracing BIM for improving their performance, this research aims at developing a complementary contractual approach that influences BIM-enabled oil and gas projects' performance. The most common project delivery system, namely, Engineering, Procurement and Construction (EPC) project delivery system was selected. This research adopted multilevel analysis to develop a more complex understanding of phenomena for developing a complementary contractual approach. At a macro perspective level, this research reviewed three fundamental aspects that concern the effective implementation of BIM in the oil and gas projects. The first aspect related to streamlining existing uses of digital modelling and its associated technologies (DMAT), which have been exploited by the oil and gas industry and BIM, uses a thorough systematic review of 28 BIM guidelines, 83 DMAT academic publications, and 101 DMAT vendor case studies. The second aspect determined the legal issues and solutions associated with BIM by critically reviewing 55 journal articles and conference papers, BIM standard contract protocols, and relevant books. The third aspect reviewed the social network measures to identify the prominent social network measures that are commonly used in complex project management networks. Oil and gas projects possess typically complex and social network properties that have implications for BIM-enabled project performance. Sixty-five peer-reviewed publications, which consisted of 38 social network metrics and concepts across nine complex-project-management knowledge areas, were selected for review. By consolidating all the macro-level reviews, an integrative trust-based functional contracting as a complementary contractual approach to EPC project delivery system was developed. The research theorised that integrative functional contracting, which comprises contractual control (also known as safeguard), coordination and contingency adaptability, could influence BIM-enabled projects' performance via perceived fairness, interorganisational trust, and distrust. An online survey on the EPC oil and gas practitioners was conducted and partial least square structural equating modelling (PLS-SEM) was used to examine these relationships. The results revealed that whilst there is no direct effect of integrative functional contracting on BIM-enabled project performance, there are significant total and indirect effects between the two. From theoretical perspectives, the research makes a unique and significant contribution by uncovering new knowledge with regard to the functional perspective of contracting that explains how it affects the EPC BIM-enabled project performance. From practical perspectives, the research provides significant insights into the oil and gas industry with respect to the proper use and harmonisation among contract functions in order to solidify project planning and operation.

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LIST OF PUBLICATIONS INCLUDED AS PART OF THE THESIS

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Fan, S.L., **Lee, C.Y.**, Chong, H.Y., & Skibniewski, M. J. (2018). A critical review of legal issues and solutions associated with building information modelling. *Technological and Economic Development of Economy*, 24(5), 2098-2130.

Lee, C.Y., Chong, H.Y., Liao, P.C., & Wang, X. (2017). Critical review of social network analysis applications in complex project management. *Journal of Management in Engineering*, 34(2), 04017061.

Lee, C.Y., Chong, H.Y., & Wang, X. (2018). Enhancing BIM Performance in EPC Projects through Integrative Trust-Based Functional Contracting Model. *Journal of Construction Engineering and Management*, 144(7), 06018002.

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STATEMENT OF AUTHOR'S CONTRIBUTIONS

Co-author statements declaring and endorsing the candidate's contributions to each paper included in this thesis can be found in Appendix F-J.

LIST OF ADDITIONAL PUBLICATIONS NOT FORMING PART OF THE THESIS

Chong, H.Y., **Lee, C.Y**., & Wang, X. (2017). A mixed review of the adoption of Building Information Modelling (BIM) for sustainability. *Journal of Cleaner Production*, 142, 4114-4126.

T Ganbat, T., Chong, H.Y., Liao, P.C., & **Lee, C.Y.** (2018). A Cross-Systematic Review of Addressing Risks in Building Information Modelling-Enabled International Construction Projects. *Archives of Computational Methods in Engineering*, 1-33.

Lee, C.Y., Chong, H.Y., & Wang, X.Y. (2017). Making Clear Contract Functions for BIM Adoption. *International Conference on Civil and Building Engineering Informatics (ICCBEI)*, 19-21 April 2017, Taipei, Taiwan.

Lee, C.Y., Chong, H.Y., & Wang, X.Y. (2018). Effects of BIM transaction attributes on the trust-based functional contracting in engineering, procurement and construction (EPC) contracts. *Annual Conference of Australasian University Building Educators Association (AUBEA)*, 26-28 September 2018, Singapore.

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GLOSSARY OF TERMS

ASCE	= American Society of Civil Engineering
AIA	= American Institute of Architects
BIM	= Building Information Modelling
CB-SEM	= Covariance based Structural Equation Modelling
CCP	= Contract for Complex Projects
CIC	= Construction Industry Council
CIOB	= Chartered Institute of Building
CPM	= Critical Path Method
DMAT	= Digital Modelling and Associated Technologies
EPC	= Engineering, Procurement and Construction
IPD	= Integrated Project Delivery
PTI	= Project Team Integration
PLS-SEM	= Partial Least Squares Structural Equation Modelling
SDM	= System Dynamic Modeling
SNA	= Social Network Analysis
TCE	= Transaction Cost Economics
TEDE	= Technological and Economic Development of Economy

Chapter 1
Introduction

1.1 Introduction

This chapter provides a critical explanation of the thesis structure. At the beginning of this chapter, the research background and the aim of the research are elaborated. It is then followed by the exegesis of the thesis structure which discusses the five underpinning objectives that contributed to achieving the aim of the research. Research methodologies used in this research are also explained in this chapter.

1.2 Research background and aim of the research

Out of the total of 365 oil and gas megaprojects across the globe, 73% of projects were reported schedule delays and 64% of projects experienced cost overruns (Ernst and Young, 2014). Whilst the oil and gas industry exploited digital modelling and associated technologies (DMAT) such as the Plant Design Management System (PDMS) more than two decades ago (Lee et al., 2018a), it is envisaged that the oil and gas projects should embrace transformation of technological prowess and advances for the purposes of project performance improvement (Reid and Cann, 2016).

In Architecture, Engineering, Construction and Operation (AECO) sectors, Building Information Modelling (BIM) is recognised as an emerging digital tool which enables information sharing of resources for a facility to form a reliable source for decision-making throughout the project lifecycle (National Building Specification, 2015). Due to its potential values and benefits, BIM has been strongly advocated by many governments. For instance, the Singapore government has mandated the implementation of BIM since 2013 (Teo et. al., 2015). The UK government has also mandated that all centrally procured public projects deploy BIM at level 2 by 2016. In Australia, the Federal Government’s Infrastructure, Transport and Cities Parliamentary Committee has recommended all major government infrastructure projects (over the value of $50 million) to implement BIM (Infrastructure Australia, 2016). Considering the above mentioned, it is important to prepare the oil and gas projects to embrace this technological revolution in order to improve project performance.

BIM combines a set of technologies and managerial solutions that increase interorganisational and interdisciplinary collaboration to improve productivity during a project lifecycle (Miettinen and Paavola, 2014). The technological visions tend to not take into account human conditions in implementing a technology (Borup et al., 2006). Thus, the major factors that caused the failure of oil and gas projects were related to people, organisation and governance (Credit Suisse, 2014). To prepare oil and gas projects that embrace BIM, it is important to strengthen the collaboration among project stakeholders in order to deliver BIM effectively (Ratajczak et al., 2015). However, existing conventional project delivery systems, such as the Engineering, Procurement and Construction (EPC) which is one of the most common project delivery systems in the oil and gas projects (McNair, 2016), do not promote collaboration among project stakeholders (Lee et al., 2018b). In this system, participants from various disciplines transfer the necessary information they developed for the EPC main contractor to form a unique model for reviewing by the client. After the model is confirmed by the client, it was only distributed to project participants to perform clash detection, materials take-off, fabrication, construction, training, and operation. This collaboration process is rather fragmented; consequently, it does not promote collaborate behaviours. Each participant works according to his or her own procedures which consistently gives rise to various conflicts and disputes (Fakhimi et al., 2017).

The adoption of BIM requires alterations in contracting and forms of collaboration between project stakeholders (Miettinen and Paavola, 2014). The BIM implementation requires informal interfaces among project stakeholders frequently and consistently. Informal social controls push the formal contracts to the background (Larson, 1992). Formal contracts enhance the acquisition of explicit knowledge and further strengthen the effects of relational mechanisms on tacit and explicit knowledge acquisition (Li et al., 2010). These signify that a formal contract design is not only influenced by the social network relationships of project stakeholders, but also influenced by social network relationships of project stakeholders. In addition, many oil and gas project owners still prefer to use the EPC project delivery because of its inherent single point of responsibility and the certainty that financial sponsors and lenders derive from EPC contracts (McNair, 2016).

The above discussions give rise to the following overarching question that needs to be addressed by this research: How BIM can be implemented in the context of the EPC project delivery system to improve the oil and gas projects' performance? Ultimately, the aim of this research was as follows:

> *To develop a complementary contractual approach to EPC project delivery system that influences BIM-enabled oil and gas projects' performance.*

1.3 Exegesis of thesis structure

A more complex understanding of phenomena can be developed through macro and micro level analysis (Hitt et al, 2007). The remaining contents of this chapter first discuss the underpinned three "macro" objectives and the subsequent two "micro" objectives that are used to address the aim of the research. The macro perspective refers to an overall need of BIM in oil and gas projects, a generalised view of BIM legal issues and its solutions, and an overall review of social network measures that are prominent in complex project management. The micro perspective then addresses the specific need to develop a complementary contractual approach to the EPC project delivery system through integrative trust-based functional contracting approach. The objectives are as follows: -

Objective 1: Since BIM provides a set of technological and organisational solutions, the first step of macro-level review should focus on identifying the BIM uses in oil and gas projects. Throughout the review, the oil and gas project stakeholders could identify the potential investment areas for improving project performance. However, the oil and gas industry has exploited DMAT, where its functionality is somewhat similar to the BIM's function. To identify the uses of BIM in the oil and gas projects, it is important for this research ***to streamline DMAT and BIM uses for the oil***

and gas projects, whilst uncovering valuable practices that could enhance oil and gas projects' performance (published by Archive in Computational Methods in Engineering).

Objective 2: As discussed earlier, the application of BIM requires alteration in contracting and forms of collaboration among project stakeholders. To propose a complementary contractual approach to the EPC project delivery system at a later stage, the second step of macro-level review should focus on the investigation of legal issues and solutions associated with BIM which are the critical aspects that affect the contracting. Therefore, the second objective is ***to critically review of the legal issues and solutions associated with BIM*** (published by Technological and Economic Development of Economy).

Objective 3: Human factors contributed to effective BIM implementation and project success (Credit Suisse, 2014; Miettinen and Paavola, 2014; Ratajczak et al., 2015). Thus, the social capital of the projects influenced their performance (Donaldson, 2001; Wang et al., 2019; Yang et al., 2018). To discover a complementary contractual approach, the third macro-level review should focus on network theoretical perspective, which is based on the notion of how project stakeholders are tied to networks based on social relationships such as resources sharing (Moliterno and Mahoney, 2011). Hence, the third objective of this research is ***to critically review the social network measures and determine the prominent social network measures used in complex project management***. Throughout the review, the network properties that significantly influence the social capital in oil and gas projects, which are complex in nature, could be determined.

Objective 4: By consolidating all the macro-level reviews, at a micro-level analysis, a complementary contractual approach to EPC project delivery system was proposed. The contractual model created was based on the requirement to provide an appropriate contractual governance to legal issues arising from the use of BIM. The social network perspective believes informal self-enforcing such as reciprocity, norms, trust, embeddedness of relationships could safeguard the business (Dekker, 2004). Hence, a complementary contractual approach should be developed based on the functional perspectives of contracting which consist of contractual control, coordination, and contingency adaptability. Appropriate contract coordination has positive implications for calculative and relational trust through consistent interactions, reciprocity, and relationship building (Lumineau, 2017). The fourth objective of this research was ***to develop an integrative trust-based functional contracting model for EPC project delivery system which has implications for BIM performance*** (published by Journal of Construction Engineering and Management).

Objective 5: Given that integrative trust-based functional contracting, which is focused on BIM-related provisions, could possibly improve BIM performance and the BIM performances are similar with project performance, as presented in Table 5.4, the fifth objective of this research is ***to determine the influence of the integrative trust-based functional contracting on EPC BIM-enabled oil and gas project performance*** (the manuscript is under revision for second round of review by a journal).

1.3.1 Streamlining DMAT and BIM uses for the oil and gas projects

As discussed earlier, BIM combines a set of technologies and organisational solutions to increase the productivity of a project. To prepare future oil and gas projects to embrace BIM, it is important to streamline the DMAT and BIM uses and uncover valuable BIM uses for oil and gas projects before proposing a complementary contractual approach to an EPC project delivery system for BIM-enabled project performance improvement. In AECO sectors, BIM is a process that produces a model which describes every aspect of the built asset digitally. It requires the information to be assembled collaboratively and updated at key stages of a project (National Building Specification, 2016). On the other hand, DMAT, which involves three-dimensional computer-aided design (3D CAD), is used to realise a built facility in the oil and gas projects (Lee et al, 2018a). Although both DMAT and BIM have similar physical attributes and functionality, nature of work, working practices, and project goal setting of the oil and gas industry, AECO sectors are different (Muhammad, 2007). This made the application of BIM uses in the oil and gas projects ambiguous.

Also, the EPC phases in the oil and gas projects are somewhat similar in AECO projects (Lee et al., 2018a). The BIM uses applied across AECO projects may be applied to the oil and gas projects. For instance, one of the BIM uses is space management which is employed to assess the used space of a building facility (Construction Industry Council Hong Kong, 2015). For DMAT use in the oil and gas projects, spatial, raceway and cable system analyses are used to simulate the spatial, raceway and cable system in oil and gas plants. This type of use applied various segregation criteria and routing methods to determine the best path (Bentley, 2015). These two uses have the following similarity: assessing the space of a facility. Although the methods used to evaluate the space in the AECO and oil and gas projects might be different, the synergy between the similar DMAT and BIM uses could provide better effects in optimising the spatial planning and management. If DMAT and BIM uses can be streamlined by removing the duplicated uses, the oil and gas project stakeholders can focus their efforts in improving project productivity and efficiency through sharing and learning the practices from the AECO industry or vice versa. Thus, through streamlining the process, the BIM uses that could be applied in the oil and gas projects could be identified. This enables oil and gas project stakeholders to uncover valuable practices that could be used in the oil and gas projects. Hence, the first objective of this thesis is as follows:

Objective 1: To streamline both DMAT and BIM uses, whilst uncovering valuable practices for enhancing oil and gas projects' performance.

This aim was met with the publication recorded in chapter 2 (Lee et al., 2018a). Upon systematically reviewing 28 BIM guidelines, 83 DMAT academic publications and 101 DMAT vendor case studies, 36 DMAT and BIM uses in the oil and gas industry were streamlined. The study also discovered 18 BIM uses that could be applied in the oil and gas projects. Figures 2.4 and 2.5 presented the results of the streamlined DMAT and BIM uses, and potential BIM uses in the oil and gas projects respectively.

1.3.2 Critically reviewing the legal issues and solutions associated with BIM

Upon identification of BIM uses in the oil and gas projects, the legal implications arising from using BIM and its solutions required attention. This review is important, as it develops fundamental knowledge in identifying the legal issues that may occur when BIM is used, and how they should be managed appropriately, which would affect effective BIM implementation (Udom, 2012). Hence, the second objective of this thesis is as follows:

Objective 2: To critically review the legal issues and solutions associated with BIM

This objective was achieved through the publication recorded in chapter 3 (Fan et al., 2018). Fifty-five publications, which consist of journal articles and conference papers in between 2007 and 2017, were selected for review. Four common legal issues were identified and appraised critically. These include incompatible procurement systems that used BIM, liabilities arising from using BIM, BIM ownership and intellectual property rights, and ambiguity of responsibilities. The solutions to these issues were assessed using standard BIM contract protocols, journal articles, and related books, which discussed the solutions (Fan et al., 2018).

1.3.3 Social network measures in complex project management

Besides legal implications arising from the use of BIM, one of the issues discussed in the research background that constrain the effective BIM implementation in the oil and gas projects was lack of collaboration of project stakeholders in the BIM-enabled oil and gas projects. Social network relationships among project stakeholders play an important role in enhancing team collaboration (Lee et al., 2017). The network structure in a project engenders the motivations of stakeholders in the structure (Kadushin, 2002). In addition, social network properties such as team cohesion can be optimised to generate performance gains (Donaldson, 2001). Hence, a complementary contractual approach to EPC project delivery system, which could influence BIM-enabled project performance, should be developed from social network perspectives.

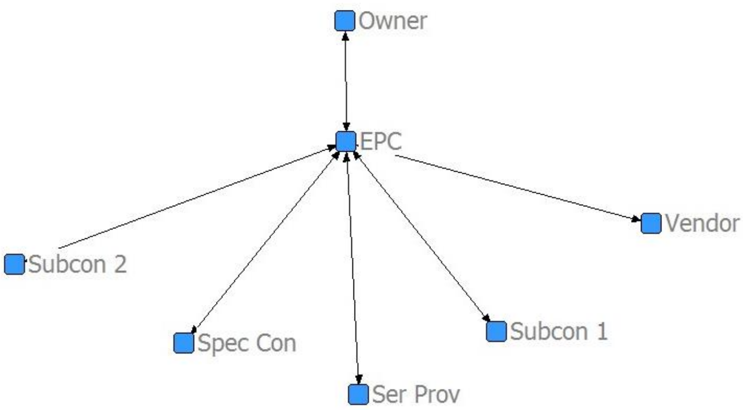
Although various social network measures, e.g., centrality and network density were included to examine team performance (Yang and Tang, 2004), it is still unclear as to what prominent social network measures influence complex project management areas. In addition, different networks would influence the interpretation of the SNA measures (Lee et al., 2017). Oil and gas projects are complex in terms of interdependency of activities, fragmentation and overlapping of works, organisational structure, and uncertainty in predicting the desired outcomes (Yeo and Ning, 2002). To propose a complementary contractual approach, it is important to understand the social network theoretical perspectives and determine the prominent social network measures that are frequently used to analyse the complex project management networks. Hence, the third objective of this research is as follows:

Objective 3: To critical review the social network measures and determine the prominent social network measures used in complex project management.

A review of social network measures in complex project management areas was conducted through the publication recorded in chapter 4 (Lee et al., 2017). The review identified 38 SNA measures from 65 journal articles across nine complex project management knowledge areas. Using the degree centrality measure (the most connected measures and project management areas), the prominent social network measures were determined in Table 4.4. The review found that network density, centrality related measures, tie strength, and average path length are the prominent measures in complex project management areas, particularly in communications and stakeholder management. These signify that these properties may influence the efficiency of both networks which are of importance in oil and gas BIM-enabled projects.

Upon reviewing the SNA measures, a contemporary understanding of SNA measures' interpretations in complex project management networks was developed. The author used the SNA measures identified from the review to discover the complementary approach to EPC contracts. To do so, the EPC project stakeholders' contractual and communication networks before and after BIM implementation were developed and analysed.

Figure 1.1 EPC contract structure

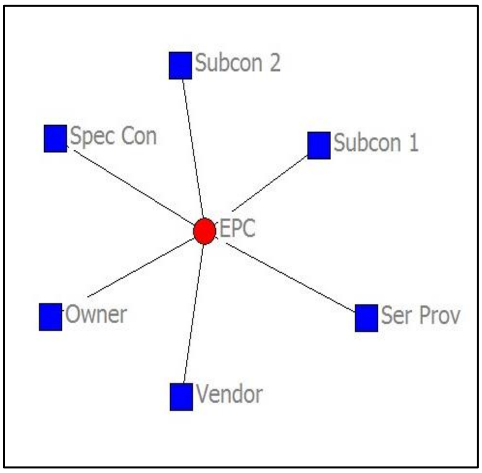


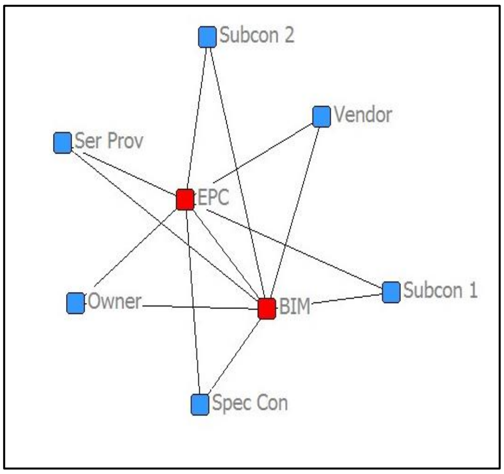
Note: Subcon, Spec Con and Ser Prov denotes Subcontractor, Specialist Contractor and Service Provider respectively

Figure 1.1 shows that the owner is the main stakeholder who contracts with the EPC contractor. The EPC contractor carries a single line of responsibilities to contract with downstream project participants such as subcontractors, specialist contractors, service providers and vendors. In this contractual arrangement, neither the owner nor the EPC contractor can play its part effectively. The owner and EPC contractor have conflicting interests. The owner strives to realise the required project functionality at the lowest capital cost while the EPC contractor aims to maximise its return from executing the work. The EPC contractor tends to get a highest possible price, taking into account any competitive pressures that may exist. This gives rise to potential opportunistic behaviours from the EPC contractor

In terms of the traditional communication network as in Figure 1.2, EPC is an ego-centric network where the EPC contractor becomes an influential stakeholder who has high degree betweenness centrality. He is a mediator between two stakeholders in the network to gain comparative advantages. This leads to situations where the EPC contractor has information about the execution of the work which the owner does not have. Information asymmetry between contracting parties contributes to the holder of the information to behave opportunistically in addressing its parties (Ahola et al., 2014). Although the network position positively provides an opportunity for the EPC contractor to combine all the ideas he receives from different downstream project participants to come up with the most innovative idea among all, it increases the asymmetric information that exposes the owner to greater opportunistic behaviours from the EPC contractor and his downstream project participants. This network arrangement reduces effective communications and tacit knowledge transfer among all project stakeholders (Lechner et al., 2010). It resulted in project owners impose more stringent contractual control (also known as safeguard) to hart the opportunistic behaviours of the contractor. Contractual control prevents the EPC contractor discloses the relevant information and enables the EPC contractor performs the work in a manner that is compatible with the owner's interests (Berends, 2007).

Figure 1.2 A comparison between traditional and BIM communication networks within an EPC contract setting





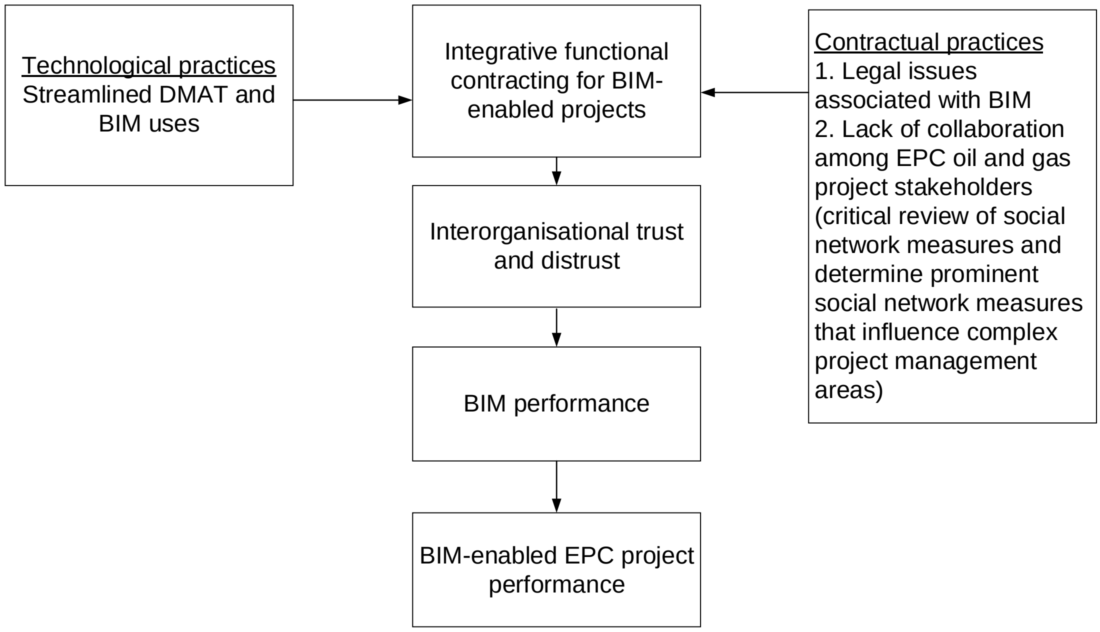
Traditional communication BIM communication

In a BIM collaboration platform, every project stakeholder would be required to contribute to the information model which leads to more transparent and open communication and thereby reducing the asymmetric information. The traditional EPC contractual setting remains. The EPC main contractor still acts as an important stakeholder for managing the information model, but its betweenness centrality and his role as a brokerage has been reduced in the presence of BIM. BIM increases the frequency of communications among project stakeholders and it enables dyadic between contracting parties and network embeddedness among project stakeholders. Embeddedness in a network influences economic action and outcomes (Granovetter, 1992). As such, project stakeholders must work collaboratively in the BIM working environment to make the project to be successful. Contractual coordination becomes important as it develops and maintains complex relationships (Ren et al., 2009). Coordination is necessary to accomplish a complex BIM task by decomposing it into simple and easily connected tasks. Nevertheless, over-embeddedness may not necessarily improve team performance. There may be an inverse curvilinear relationship exists between group cohesion and team performance (Wise, 2014). Contractual control still plays an important role in preventing the negative implications arising from over-embeddedness. Based on the social networks' analysis above, it is evident that contract functions, such as contractual control and coordination could be potentially applied effectively in the EPC contract structure.

1.3.4 Development of an integrative trust-based functional contracting model

By synthesising the results of all the macro-level reviews, an integrative trust-based functional contracting was proposed as a complementary contractual approach to an EPC project delivery system that has the potential to influence BIM-enabled oil and gas project performance. Figure 1.1 shows the synthesis process of all the macro-level reviews and the development process of an integrative trust-based functional contracting model.

Figure 1.3 Development of integrative trust-based functional contracting through synthesising macro-level reviews and micro-level analyses at an EPC project level

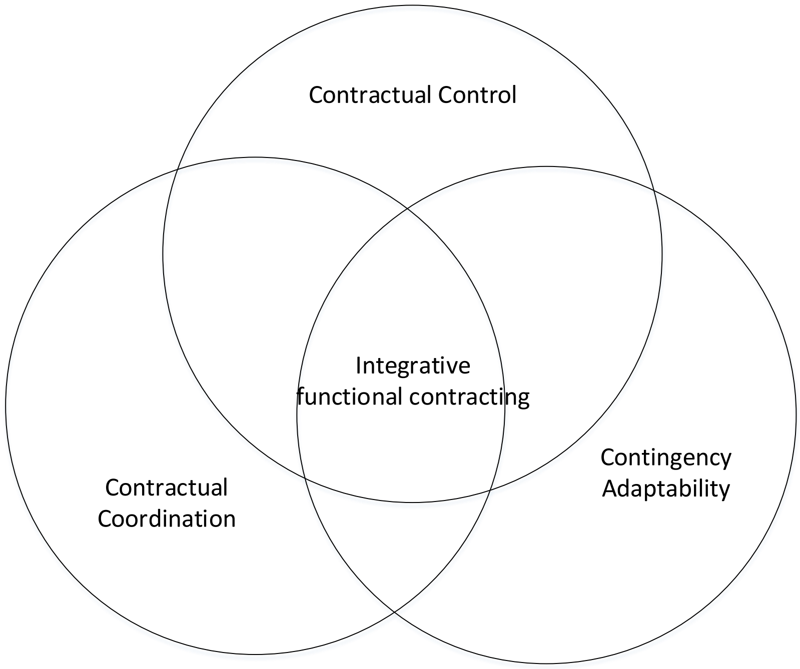


Throughout the process of streamlining DMAT and BIM uses, many BIM uses were identified that could potentially be applied in oil and gas projects. However, to implement these uses effectively, the legal issues surrounding the uses should be resolved. The appropriate contract functions such as contractual control and coordination are required to ensure the legal issues are properly managed (Lee et al., 2018b). For instance, contractual control enables BIM deliverables to be audited in order to ensure the quality of the model (Fan et al., 2018). Given that the contract functions are important in providing effective governance to the EPC project delivery system, as discussed above, it is argued that a complementary contractual approach should be developed from the functional perspective of contracting.

Contracts are efficacious if they include provisions that elucidate the different functions required for an exchange (Salbu 1997). Fundamentally, three contract functions can be formatted in the contract administration philosophy, namely, control (also known as safeguard), coordination, and contingency adaptability (Eckhard and Mellewigt, 2006). A transaction may give rise to opportunisms (risks of the exploitation) among one of the contracting parties which may potentially bring hazard to the other contracting parties (Selviaridis, 2016). The formal contract serves as a control mechanism to protect the investment of parties against the potential hazards. The control function could develop commitments of contracting parties to adopt BIM (Jap and Ganesan, 2000). Contracts also play a crucial role in reducing coordination concerns as a means of planning collaboration and clarifying mutual expectations of the partners (Sorsa and Salmi-Tolonen, 2011). In the face of environmental uncertainty, formal contracts perform an adaptation function that allows for adjustments to be made for market changes or learning endogenous to the exchange (Schepker et al. 2014).

EPC contracts are substantially influenced by the transaction cost economics (TCE) perspective which views formal contracts as mechanisms to reduce ex-ante and ex-post risks of opportunism, thereby safeguarding the contracting parties' investments (Schepker et al., 2014). Contingency adaptability and coordination are commonly perceived as contributing to transaction costs and informing the selection of optimal governance (e.g., safeguarding) choices (Schepker et al., 2014; Williamson, 1996). In a BIM working environment, contractual coordination and contingency adaptability should be viewed as mechanisms to achieve both the owner's and EPC contractor's common goals (Salbu, 1997). Figure 1.2 shows the integration of all the three contract functions (hereinafter called integrative functional contracting) that have the potential to influence BIM-enabled project performance. Moreover, the integrative functional contracting in the context of EPC contracts does not only view contractual control as an important mechanism to ensure the behaviours of contracting parties align with the expectations of each other, but also emphasise on contractual coordination and contingency adaptability as important tools to promote mutual trust and learning (Lee et al., 2018b).

Figure 1.4 Integrative functional contracting for BIM-enabled projects



The integrative functional contracting enables more open communication across the BIM collaboration platform which could result in better BIM performance. However, communication could not mediate the relationship between the integrative functional contracting and BIM performance, since communication does not promise better BIM performance. Cheung et al. (2013) identified that trust affects communication and in doing so influences project performance. It implies that trust engendered by adequate communication could impact BIM performance positively. Contractual control and coordination influence trust through information processing (Lumineau, 2017). It is also found that distrust may not necessarily be detrimental to project performance (Lee et al., 2018b). By linking inter-organisational trust and distrust between integrative functional contracting, the model (hereinafter called integrative trust-based functional contracting) may have significant impacts on BIM performance. The fourth objective of this research is as follows:

Objective 4: To develop an integrative trust-based functional contracting model that influences BIM performance

This objective was achieved through the publication (Lee et al., 2018b) in Chapter 5.

1.3.5 The influence of integrative trust-based functional contracting on BIM-enabled EPC project performance

As presented in Table 5.4, BIM performance contributed to BIM-enabled project performance. Thus, the aim of the research involved developing a complementary contractual approach to EPC project delivery system that could influence BIM-enabled project performance. Hence, the influence of integrative trust-based functional contracting model on a BIM-enabled project performance was investigated and presented in Chapter 6. The last objective of this research is as follows:

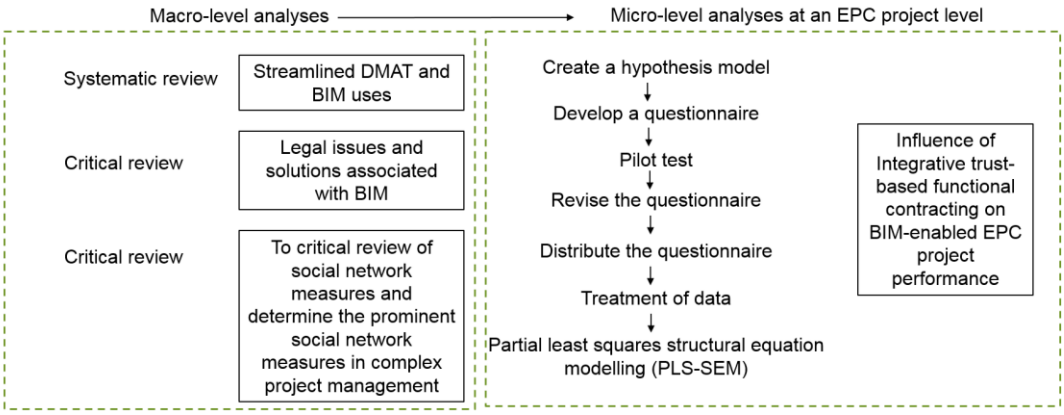
Objective 5: To determine the influence of the integrative trust-based functional contracting on BIM-enabled oil and gas EPC project performance

This objective was achieved in chapter 7 and has been submitted for review. This hypothesis model was tested by using the partial least squares structural equation modelling (PLS-SEM). The results of the research revealed that, whilst there is no direct influence of integrative functional contracting on BIM-enabled EPC project performance, there is an indirect relationship between the two through perceived fairness and inter-organisational trust.

1.4 Research Methodology

Based on the discussions above, the research methodology was summarised in Figure 1.3.

Figure 1.5 Research Methodology



This research adopted a multilevel research approach where it focuses on two levels of analysis, namely, macro (industry level) and micro (project level) analyses. For BIM-enabled projects that require extensive collaboration among project stakeholders, the multilevel approach could reveal the richness of social behaviour by explaining why and how a behaviour occurs and shed light on the multiple consequences of behaviour across the levels of social organisation. To develop a complementary contractual approach to EPC project delivery system, three fundamental reviews at a macro perspective level, which connects with effective BIM implementation, were conducted. These include technological aspect (to streamline DMAT and BIM uses), legal aspect (legal issues and its solutions of BIM), and prominent social network measures used in complex project management.

After consolidating all the macro-level reviews, at a micro-level analysis of an EPC project level, an integrative trust-based functional contracting model was developed. To test the validity of the model, an online survey on EPC oil and gas project stakeholders was performed. The collection of data involved around 1,200 construction-related practitioners who were located in different regions. They involved in the planning, construction, engineering, contract, and information management of Engineering, Procurement, and Construction of (EPC) oil and gas projects. They were approached via Linkedin and oil and gas conferences. The questionnaire was structured in two parts. The first part included the particulars of respondents and details of the oil and gas EPC project they involved. The second part was the questions related to the influence of trust-based functional contracting of BIM on the project performance. To investigate the relationship between the trust-based functional contracting and project performance, Likert scale ranging from one to five such as from strongly agree to strongly disagree were used. A two-round pilot survey was conducted to revise the questions.

Before analysing the data, an independent t-test was conducted to determine potential non-response bias (Lindner et al., 2001). Then, the Little's missing completely at random (MCAR) test was carried out to identify whether the values were missing at random or not. After confirming the data were missing at random, the rate of missing values was examined. When the missing rate was found insignificant (Schafer 1999), the missing data were removed from the dataset. The treated data were analysed using partial least squares structural equation modeling (PLS-SEM). This method was selected due to its capabilities to deal with complex models (Rigdon et al. 2017). PLS-SEM is more appropriate to be used for exploratory research. It is a precise prediction-oriented analysis that is different from covariance-based SEM (CB-SEM). In addition, the bootstrapping feature in the PLS-SEM algorithm enables a robust study of skewed data and formative measures, as it transformed data under the central limit theorem (Ringle et al. 2009). Based on the results of data analysis, conclusions were drawn and recommendations provided.

1.5 Summary

This chapter has demonstrated that a gap exists between the contractual and technological practices in EPC oil and gas projects by identifying three critical aspects. They are important in contributing to effective BIM implementation for the purpose of improving project performance. These include technological aspect (streamlined DMAT and BIM uses and discovering valuable practices for the oil and gas projects), legal aspect, and social network measures of complex project management. The complementary contractual approach to EPC project delivery system was developed from these three critical reviews. The research methodology adopted by the research was also discussed in this chapter.

Chapter 2

Streamlining Digital Modeling and Building Information Modelling (BIM) Uses for the Oil and Gas Projects[1]

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Abstract: The oil and gas industry is a technology-driven industry. Over the last two (2) decades, it has heavily made use of digital modeling and associated technologies (DMAT) to enhance its commercial capability. Meanwhile, the Building Information Modelling (BIM) has grown at an exponential rate in the built environment sector. It is not only a digital representation of physical and functional characteristics of a facility, but it has also made an impact on the management processes of building project lifecycle. It is apparent that there are many similarities between BIM and DMAT usability in the aspect of physical modeling and functionality. The aim of this study is to streamline the usage of both DMAT and BIM whilst discovering valuable practices for performance improvement in the oil and gas projects. To achieve this, twenty-eight (28) BIM guidelines, eighty-three (83) DMAT academic publications and one hundred and one (101) DMAT vendor case studies were selected for review. The findings uncover (a) thirty-eight (38) BIM uses; (b) thirty-two (32) DMAT uses and; (c) thirty-six (36) both DMAT and BIM uses. The synergy between DMAT and BIM uses would render insightful references into managing efficient oil and gas's projects. It also helps project stakeholders to recognise future investment or potential development areas of BIM and DMAT uses in their projects.

Keywords*:* Digital Modeling, Associated Technologies, Building Information Modeling, Streamline, Oil and Gas

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2.1 Introduction

Oil and gas sector contributes significantly to more than half of humanity's primary energy supply (BHP, 2015). However, out of the total of 365 oil and gas megaprojects in the world, 73% of projects were reported schedule delays and 64% of projects experienced cost overruns (EY, 2014). One of the main factors contributed to project failures is management, contracting and project delivery strategies (Credit Suisse, 2014). It is envisaged that the technological prowess and advances should be incorporated into future oil and gas projects to embrace new thinking for performance improvement (Reid and Cann, 2016).

In the built environment sector, Building Information Modelling (BIM) is recognised as an emerging digital tool which enables information sharing of resources for a facility to form a reliable source for decision making throughout the project lifecycle (National BIM Standards, 2015). It is not only the digital representations of physical and characteristics of a facility but it is also a philosophy which transforms the way facilities are designed and managed by encouraging collaboration of all stakeholders' roles in a project (Azhar, 2011). Due to its potential values and benefits, BIM has been strongly advocated by many governments in the world. For instance, the Singapore government has mandated the implementation of BIM since 2013 (Teo et. al., 2015). The UK government also required all centrally procured public projects deploy BIM at level 2 by 2016 (HM Government, 2014). In Australia, the Federal Government's Infrastructure, Transport and Cities Parliamentary Committee has recommended that all major government infrastructure projects (over the value of $50 million) to implement BIM (Infrastructure Australia, 2016). BIM is commonly viewed in 3D, but the model includes information used by other building analysis applications, such as energy simulation, computational fluid dynamics (CFD), day lighting, cost estimating and building code checking (GSA, 2015). BIM adoption goes beyond design and construction, and it extends to the project management and facility management as the files of BIM can be extracted and exchanged to support decision making in connection with a facility.

On the other hand, it has been a few decades that the oil and gas projects deployed DMAT to enhance data management and collaboration process among the interdisciplinary team. DMAT refers to 3D geometric models and/or geometric bedding models and it's associated technologies which are usually adopted by the oil and gas industry to realise its facility. DMAT in the context of this study represents a simple 3D geometric model which contains very little intelligence, or it may consist of high-level intelligence that is usually organised as a prototype of the facility to perform various functions. For exploration and production, geometry 3D bedding modeling such as the reservoir modeling has been developed to improve estimation of reserves (Abdideh and Bargahi, 2012); prediction of future production (Beeson et. al., 2014); and evaluating alternative reservoir management scenarios (Tavallali and Karimi, 2016). For design, construction and operation of the oil and gas facilities, plant lifecycle management (PLM) were deployed to allow multi-disciplinary teams like piping, electrical, mechanical, civil, structural and architectural design work concurrently under a collaboration platform (Intergraph, 2016a). Information extracted from a plant model can be used for procurement such as material management, strategic sourcing and contract management (Xue, 2015). Apart from geometry bedding modelling and PLM, other DMAT uses which also have similar functionality and physical attributes with the BIM such as a unified information model of oil loading station was created in Samara Oblast, Russia, which used a mobile device on site for accessing information of model and project planning (Bentley, 2015, p. 123). Both BIM and DMAT are observed to have common attributes such as both technologies create 3D virtual models and they could interoperate with other technologies to achieve the project outcomes.

Some BIM uses could be potentially applied in the oil and gas industry to enhance their project performance. BIM and Augmented Realty (AR) could be used for project visualisation as it allows designers and owners to gain an immersive and interactive experience (Wang et al., 2014c) prior to oil and gas plant fabrication and installation. BIM and Firefly Algorithm (FA) could be integrated to automatically develop an optimal tower crane layout plan (Wang et al., 2015b) for the oil and gas project construction. Besides, BIM and Light

Detection and Ranging (LiDAR) could be developed to provide real-time information for on-site quality control (Wang et al., 2015a). Mechanical, plumbing and electrical (MEP) are essential facility elements that formed a majority component of the oil and gas plant fabrication and installation. A practical BIM framework which integrated the MEP layout from preliminary design to construction stage was formulated to resolve the design and constructability issues (Wang et al., 2016a). To improve defect management practices in the oil and gas projects, BIM information could be linked with defects data effectively by converting it to RDF format and implementing SPARQL queries (Lee et al., 2016). Past oil and gas projects failed to deliver their desired outcomes due to many re-works, design errors, inefficiency in construction and life cycle performance failures. A total constraint management (TCM) framework which incorporated BIM and other related technologies was developed to improve oil and gas construction workflow and productivity (Wang et al., 2016b).

There were reviews on the BIM uses in building and infrastructure projects but none of the studies were carried out to identify BIM uses in the oil and gas industry. Twenty-four (24) industrial reports and more than forty (40) case studies in academic publications were collected and assessed to determine current BIM uses and the emerging BIM applications among the building, airports, bridges and roadworks (Shou et al., 2014). The BIM and its associated technologies applications of the road projects in Australia and China were also be compared to analyse the differences in the cultural and managerial practices between the projects in two countries (Chong et al., 2016).

Infrastructure Australia (2016) asserted that the best practices require a focus on the harmonisation which means the practices and standards have to be aligned to reduce duplication and improve delivery. To identify potential BIM applications and its associated technologies for improving oil and gas project performance, it is important to streamline both DMAT and BIM uses. The synergy between DMAT and BIM uses could create a better understanding for the oil and gas industry to plan, design, develop and operate its facilities whilst distinguish valuable key process areas be brought into the oil and gas industry for performance improvement. To achieve the aim, this paper outlines three objectives as follows: - (1) to synthesis BIM uses from BIM guidelines; (2) to determine DMAT uses in the oil and gas industry; and (3) to streamline BIM and DMAT uses for the oil and gas industry.

2.2 BIM and DMAT Uses

The term "uses" is originated to classify the BIM uses so that project participants who will deploy the BIM in their projects could communicate and collaborate the specific value of a particular BIM application prior to the BIM implementation. The motivation behind the identification of BIM uses is that there is no common language existed for project participants to precisely communicate the purposes among each other for implementing BIM (Kreider, 2013).

While some BIM guidelines expressed the term of BIM uses as "BIM deliverables", other guidelines used the term of "BIM applications" which in fact carry the similar meaning as the former. If we view all these terms as the synonyms of BIM uses, there are many BIM guidelines that outlined the BIM uses. However, only a few guidelines that defined the meaning of the BIM uses clearly. NATSPEC (2016) asserted that BIM uses should not link intrinsically to project phases but they should be selected to support project goals at the beginning of the project and be planned how to deploy during different project phases. The nature of BIM technology allows different stakeholders use the BIM in multiple ways depending on the specific needs they may have (NYCDDC, 2012). Hence, BIM uses could be defined as the BIM tools that are deployed to coordinate the specific purposes for realising the project objectives.

A similar rationale is applied to the DMAT uses as the ultimate goal of the oil and gas owners and/or operators are to realise a facility which would be delivered on time, within their budgets, safely, complied with the strict environmental regulations, satisfied other stakeholders and to optimise their production during operation. To achieve project outcomes, BIM and DMAT uses should be classified based on the purposes and objectives as in table 2.1.

Table 2.1: BIM and DMAT Uses Purposes

BIM use purpose	BIM use objective	Synonyms
Gather	It captures current status of a facility, quantifies the amount of a facility element, monitors the information and qualifies the status of facility elements.	administer, collect, manage, acquire, quantity take-off, observe, measure, follow, track, identify
Generate	It prescribes the need for and specify facility elements, arrange the placement of facility elements and determines the magnitude and size of facility elements.	create, author, model, program, specify, configure, lay out, locate, place, scale, engineer
Analyse	It coordinates the relationship of facility elements, forecasts the future performance of the facility and validates the accuracy of the facility information.	examine, evaluate, detect, avoid, simulate, predict, check, confirm
Communicate	It allows visualisation of a facility, transforms the information to be received by another process, draws a symbolic representation of the facility and documents the specification of the facility elements.	exchange, review, translate, draft, annotate, detail, specify, submit, schedule, report
Realise	It facilitates the facility information for fabrication, assembles the separate facility elements, controls the operation of executing equipment and regulates the operation of a facility element.	implement, perform, execute, manufacture, prefabricate, manipulate, direct

Note: This table is extracted from the National BIM Standard (2015)

2.3 Review Methodology

Figure 2.1 demonstrated a five-stage review framework which was used in this study.

Figure 2.1 Five-Stage Review Framework

Step 1: Problem Identification

There is an inconsistent language of BIM and DMAT uses between the Built Environment sector and the oil and gas industry. Hence, there is a need to bridge the semantic gap of BIM and DMAT uses between these two industries to provide a better understanding for the oil and gas industry to communicate precise purpose and context of implementing these technologies for improving project performance.

↓

Step 2 Search for Evidence

Stages	Sources	Actions	Evidences
Stage 1 Literature Search	BIM guidelines	Select	• Keyword: BIM guidelines
	<u>DMAT uses:</u> • Peer-reviewed Journal Articles and Conference Papers • DMAT Vendor Case Studies	Select	• Years: 2012-2016 • Keyword: 3D model oil gas
Stage 2 Literature Filtration	• BIM guidelines	Select	Discussed the BIM uses
	• DMAT academic publications (Peer-Reviewed) • DMT Vendor case studies	Select	Discussed the DMAT uses

↓

Step 3 Evaluate Data (Findings)

Sources	Actions	Evidences
BIM guidelines	Synthesis and Tabulate	BIM Uses
• DMAT academic publications • DMAT Vendor case studies	Synthesis and Tabulate	DMAT Uses

↓

Step 4 Data Analysis and Discussion (Streamlining and Presentation)

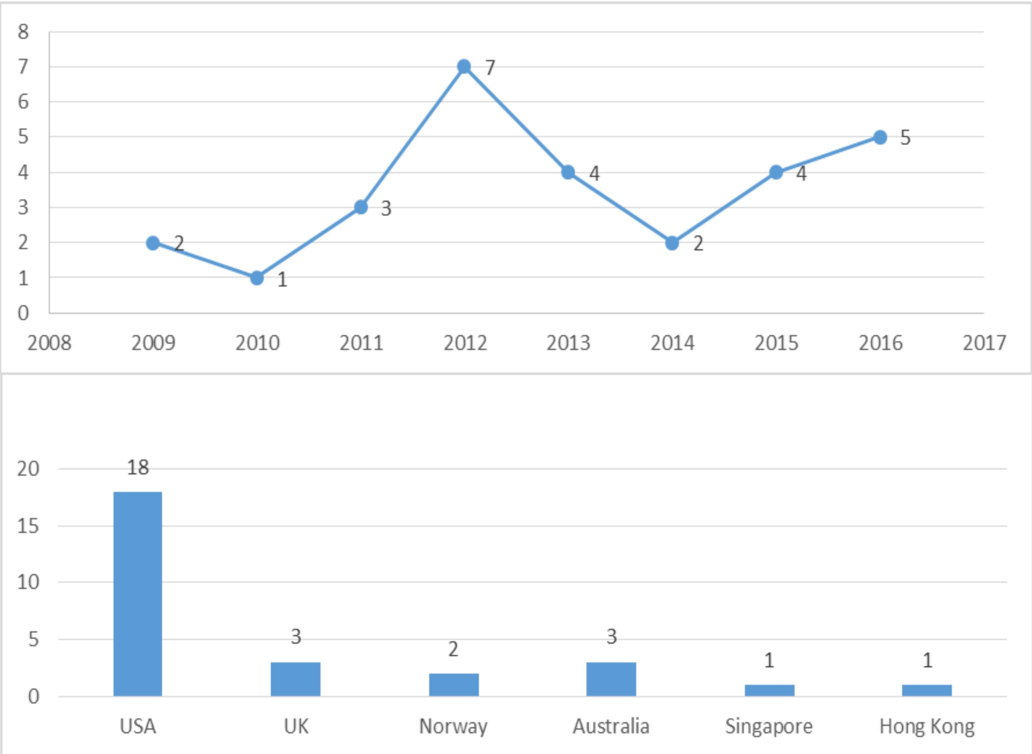
Sources	Actions	Evidences
• BIM Uses • DMAT Uses	Streamline and Tabulate	• Streamlined BIM and DMAT Uses • Distinguished DMAT Uses

↓

Step 5 Conclusion and Recommendations

The first step involved in this study was problem identification. Next, to identify the solution to the problem, an intensive literature search was carried out. The Google search engine was deployed to identify BIM guidelines. BIM guidelines were selected if they stated or sufficiently discussed BIM usability and its purpose. Figure 2.2 demonstrates the numbers of the BIM guidelines from 2012 to 2016 and also country by publications used in this study. The highest numbers of BIM guidelines were in the year of 2012.This may due to the rapid growth and use of BIM in the industry. The highest number of publications was recorded by the United States which consisted eighteen (18) articles. The significant high number of BIM guidelines in this country mainly due to the greater adoption and use of BIM in the country.

Figure 2.2: Years, numbers and country by publication of BIM guidelines



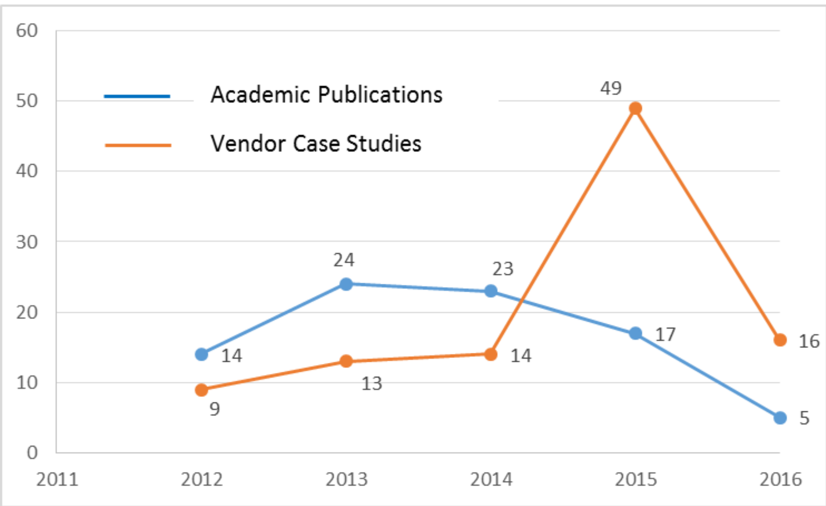
On the other hand, the usability of DMAT was determined through; (1) peer-reviewed journal articles and conference papers; and (2) DMAT vendor case studies. The Google scholar was used to identify the academic publication whereas the Google search engine was deployed to identify DMAT objective by DMAT vendors. Some of the common DMAT vendors selected in this study were as follows: -

Table 2.2: List of Common DMAT vendors selected

Disciplines	**DMAT Vendors**
Exploration and Production	Schlumberger, Landmark, Paradigm, Petex
Design, Procure and Construct	Bentley, Autodesk, Synchro, AVEVA (formerly known as PDMS and Tribon), Intergraph, Tekla, Aspentech
Commissioning, Operation, and Maintenance	WinPCS, AVEVA, Intergraph, Bentley, Autodesk, Schlumberger

All data was retrieved from 2012 to 2016 to identify the recent trends of DMAT uses in the oil and gas industry. The keyword deployed for searching the academic publications were "3D model oil gas". The data was filtered through the elimination process. The academic publications and vendor case studies were selected if they sufficiently discussed the DMAT purpose. Figure 2.3 shows the numbers and years of academic publications and DMAT vendor case studies adopted in this study.

Figure 2.3: Years and numbers of DMAT Academic Publications and Vendor Case Studies



There were total eighty-three (83) DMAT academic publications and one hundred and one (101) DMAT vendor case studies selected in the study. Both types of sources projected a very dissimilar trend. Most of the DMAT academic publications that used in the study were in the year 2013 and 2014 which accounted for 24 and 23 respectively whereas the majority of the DMAT vendor case studies adopted in the study was in the year of 2015, which recorded forty-nine (49) number.

The data gained from the BIM guidelines, academic publications and vendor case studies were tabulated for analysis. To synthesise the BIM and DMAT uses, the term adopted in the references which had a similar connotation and similar definition were classified into the same theme. The BIM and DMAT uses extracted from the BIM guidelines, DMAT academic publications and DMAT vendor case studies were presented based on the project lifecycle as outlined in Table 2.3 to ease the understanding of the readers. The data of BIM and DMAT uses were also presented according to the purpose as outlined in Table 2.1.

Table 2.3 Project Lifecycle Used In the Study

No.	Darko (2014)	Activity model of the process plant life-cycle (ISO 15926)	Oil and Gas Industry Life Cycle Tabulate in This Study (DMAT)	Description	Project Life Cycle Tabulate in This Study (BIM)	Description
	The oil and gas industry life cycle stated in this study are referred to the phases described in the above two references.					
1	Exploration	-	Exploration	It includes seismic surveys to look for potential oil or/and gas sources (Darko 2014).	-	-

2	Appraisal	Conceptual Process Design, Conceptual Engineering Design (Front End)	Appraisal	This phase determines the projects should proceed or terminate based on the results of the potential of oil or/and gas reserves (Darko 2014). It also involves feasibility study, site planning and front-end engineering design (FEED) for production, transportation and processing oil and gas facilities projects.	Plan	This phase is the most important phase to determine the feasibility of the project. It includes site analysis, determination of the project location, conceptual design and preparation of initial estimate.
3	Development	-	Development	Wells and reservoirs are developed. Production operation and maintenance strategies are also established (Darko 2014).	-	
3a	-	Detailed Process Design, Detailed Engineering Design	Design	It includes detailed engineering design.	Design	This phase includes the schematic design of a facility to the selection of contractor (Chong, 2016a).
3b	-	Procure and Control Equipment, Material and Services, Suppliers and Fabricators	Procure	It describes the ordering, purchasing and control of materials, equipment and services from fabricators and suppliers.	Procure	Same as the description of the oil and gas industry procurement stage.

3c	-	Construct Plant, Pre-Commission	Construct	This stage involves construction and fabrication of oil and gas facilities.	Construct	Same as the description of the oil and gas industry construction stage.
4	Production and Operation	Commission Plant, Operate Plant, Maintain Plant and Equipment	Production, Operate and Maintain	Oil or/and gas reserves are being extracted and transported for processing/ exported. It also involves commission, operates, modifications and maintains plant and equipment during the life of oil and gas facilities.	Operate and Maintain	This stage includes the operation and maintenance of a facility (Chong and Wang, 2016).
5	Abandonment	Decommission, Demolition Plant and Restore Site	Demolition	This phase involves well abandonment, dismantle the plants and restore the site to its original condition.	-	This section is not available as none of this phase mentioned in the BIM guidelines.

Thereafter, a streamlining process was conducted. If a BIM and DMAT use share the common function, they would be aligned with the same theme which represents its use. For the DMAT uses which did not have common functions as the BIM uses, it would be classified as the distinguished DMAT uses. Throughout the streamlining process, the BIM uses which were not commonly applied in the oil and gas projects could also be identified. The results were discussed. Limitations, conclusions and recommendations were then formulated and concluded at the end of this review.

2.4 Findings

2.4.1 BIM Uses

Table 2.4 demonstrates thirty-eight (38) BIM uses which were extracted from twenty-eight (28) BIM guidelines.

Table 2.4 List of BIM Uses

No.	BIM Uses/ Description	Plan	Design	Procure	Construct	Operate	References (BIM Guidelines)	BIM Use Purposes
1	Existing Conditions Modeling *A process in which a 3D model of the existing conditions for a site, facilities on a site or a specific area within a facility is developed (PSU, 2011). It includes modelling of the existing ground surface of the structures, the adjacent area and the infrastructure for project master planning, existing facilities and assets, existing spaces, building components and equipment, geotechnical elements and horizontal construction such as roadways, raised bridges, walkways and transportation is developed so that the total environment of the facilities can be modeled effectively (MPA, 2015).*	x	x		x	x	(BCA, 2013); (COD, 2011); (COSA, 2011): (CRC, 2009): (DOA/DSF, 2012); (FMS, 2012); (GISFIC, 2013); (GTFM, 2013); (Harvard, 2016); (HKCIC, 2015); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NHBA, 2012); (NRC, 2014); (NYCSCA, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Gather; Generate
2.	Site Analysis *A process in which BIM or GIS tools are used to evaluate the site location to determine :(1) an appropriate location for a future project (NYCDDC, 2012); and (2) analyse the volumes, location (placement, orientation) of the facility(s) on site (Statsbygg, 2013).*	x					(BCA, 2013); (COD, 2011);(HKCIC, 2015); (NATSPEC, 2016); (NRC, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (TPA, 2016); (USACE, 2012)	Analyse
3	Cost Estimation *A process in which BIM can be used to establish accurate cost estimate and cost effects of changes made to the design can be traced from the BIM which enables designers to curb excessive cost overruns due to project modifications (NYCDDC, 2012). It includes cost planning, quantity take-off and cost tracking.*	x	x	x	x	x	(AGC, 2009); (BCA, 2013); (CFM, 2010); (COD, 2011); (COSA, 2011): (CRC, 2009): (DOA/DSF, 2012); (HKCIC, 2015); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYSCA, 2014); (NYDDC, 2012); (PSU, 2011); (SDCCD, 2012); (SEC, 2013); (TPA, 2016); (USACE, 2012); (GTFM, 2016)	Gather; Generate, Analyse
a	Cost analysis (5D)/Cost and Schedule Forecast *A process in which a 5D BIM is deployed to link the cost data to 4D BIM (NATSPEC, 2016) for cost analysis and generating cash flow forecast report.*	x	x	x	x	x	(AGC, 2009); (CFM, 2010); (CRC, 2009); (LACCD, 2016);; (NATSPEC, 2016); (NRC, 2014); (SEC, 2013); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Analyse, Communicate
4	Phase Planning (4D Modeling)/ Scheduling *A process in which phased occupancy is planned effectively through utilisation of 4D model so that a project team can visualise and communicate for a better understanding of project milestones and construction plans (PSU, 2011). It involves early project phasing to allow for comparison of different strategies, detail phasing to sequence multi-trade installation and scheduling for project control (Harvard, 2016).*	x	x	x	x		(AGC, 2009); (BCA, 2013); (CFM, 2010); (COD, 2011); (COSA, 2011); (CRC, 2009); (DOA/DSF, 2012); (GISFIC, 2013); (GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYCSCA, 2014); (NYDDC, 2012); (PSU, 2011); (SDCCD, 2012); (SEC, 2013); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Communicate

5	Programming/ Are and Space Program Validation *A process in which area and program information is extracted from BIM to assess the space design as the design develops. It allows tracking rentable area, gross area and usable area (Harvard, 2016.).*	x					(BCA, 2013); (CFM, 2010); (COD, 2011); (COSA, 2011); (CRC, 2009); (DOA/DSF, 2012); (FMS, 2012); (GISFIC, 2013); (GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NYCSCA, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (UCASE, 2012)	Generate
6	Design Authoring *A process in which authoring tools are deployed by multi-disciplinary teams to add richness of information to a facility (HKCIC, 2015).*	x	x	x	x		(CFM, 2010); (COD, 2011); (COSA, 2011); (FMS, 2012); (Harvard, 2016); (HKCIC, 2015); (LACCD, 2016); (NRC, 2014); (NYDDC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Generate
7	Design Reviews and Constructability Reviews *A process in which a 3D model is viewed by stakeholders through different forms of presentations to provide their feedbacks for multiple design aspects validation (PSU, 2011.). It involves design selection from various options provided by the BIM, design communication through visualisation and digital mock-ups (Harvard, 2016).*	x	x				(AECUK, 2015); (AGC, 2009); (BCA, 2013); (CFM, 2010); (COD, 2011); (COSA, 2011); (DOA/DSF, 2011); (FMS, 2012); (GISFIC, 2013); (Harvard, 2016); (HKCIC, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYCSCA, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Communicate
8	Modeling *Each facility system shall be organised as a separate model linked to a common origin point for efficient coordination purposes. (LACCD, 2016).It includes an architectural model which consists of material and spatial design, structural, MEPF, interiors and any other common models for building a facility.*	x	x				(AECUK, 2015); (AGC, 2009); (CFM, 2010); (BCA, 2013); (COSA, 2011); (COD, 2011); (CRC, 2009); (FMS, 2012); (GISFIC, 2013); (GTFM, 2016); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NHBA, 2012); (NYSCA, 2014); (OFCC, 2012); (SDCCD, 2012); (Statsbygg, 2013);	Generate
a	Civil Engineering/ Infrastructure Model *A process in which civil engineering model is created to represent civil engineering or infrastructure elements which shall distinguish with building models. The civil engineering or infrastructure elements may include site topography model, landscaping elements and site utilities models (FMS, 2012) with the aids of associated technologies such as GIS (Statsbygg, 2013, LiDAR and etc. Bridge, main road, highway, railway and tunnel models (NRC, 2014) are the examples of civil engineering models.*	x	x				(CFM, 2010); (COD, 2011); (COSA, 2011); (CRC, 2009); (FMS, 2012); (GTFM, 2016); (HKCIC, 2015); (LACCD, 2016); (OFCC, 2012); (SDCCD, 2012); (Statsbygg, 2013)	Generate
b	Equipment Modeling and Maintenance Clearance Space Modeling *A process in which equipment models are created to indicate its location, sizes and details (FMS, 2012). It also includes modeling for maintenance space and consideration of typical maintenance cycles, replacement paths continuity of operations so that adjacent equipment can be serviced at the same time (MPA, 2015).*	x	x				(FMS, 2012); (MPA, 2015); (SDCCD, 2012)	Generate
c	Energy Modeling	x	x				(BCA, 2013); (CFM, 2010); (COD, 2011); (GTFM, 2015); (Harvard, 2016); (IU, 2015); (MPA, 2015); (NHBA, 2012); (OFCC, 2012)	Generate

	Due to the timing of analysis and potential model clean-up, energy analysis is often performed separately from the BIM (Harvard, 2016). It streamlines the simulation process quickly with minimal data from existing building conditions to develop an energy analysis (MPA, 2015).							
9	Design Analysis/ Engineering Analysis *A process in which the models are simulated with typical analysis software or used for structural analysis, lighting analysis, fire safety analysis etc.*		x				(BCA, 2013); (COD, 2011); (CRC, 2009); (DOA/DSF, 2009); (GISFIC, 2013); (Harvard, 2016); (HKCIC, 2015); (MPA, 2015); (NATSPEC, 2016); (NYDDC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2013); (USACE, 2012)	Analyse
a	Energy Analysis *A process in which energy simulation and lifecycle cost are analysed with the information extracted from BIM (CFM, 2010). The scope includes renewable energy analysis (SDCCD, 2012).*		x				(BCA, 2013); (CFM, 2010); (COD, 2011); (CRC, 2009); (DOA/DSF 2009); (GISFIC, 2013); (GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NHBA, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Analyse
b	Accessibility Analysis *A process of using colours, lighting conditions, acoustics and etc. which are not so straightforward to check as geometry requirements to assess the practicability and accessibility for all people which include people with disabilities (Statsbygg, 2013).*		x				(Statsbygg, 2013)	Analyse
c	Proximity Analysis *A process of deploying BIM to conduct proximity analysis for determining the appropriate travel distance between areas to another area (Statsbygg, 2013).*		x				(Statsbygg, 2013)	Analyse
d	Security and Circulation Analysis *A process in which a BIM is simulated with a security and circulation analysis software to analyse the circulation areas where the building has define security zones (Statsbygg, 2013).*		x				(Statsbygg, 2013)	Analyse
e	Acoustics Analysis *A process in which BIM is simulated with an acoustical analysis tool to perform room acoustical analysis and sound insulation calculations (Statsbygg, 2013).*		x				(CRC, 2009); (Harvard, 2016); (Statsbygg, 2013)	Analyse
f	Mechanical Analysis/ Virtual Testing and Balancing/ System Analysis/ Building Disposal Analysis *A process to compare a facility performance with the design specifications. It includes assessments of how a mechanical system operates, how much energy a project uses, conducting lighting analysis, solar gain analysis and airflow analysis using CFD (HKCIC, 2015).*		x			x	(BCA, 2013); (CFM, 2010); (COD, 2011); (COSA, 2011); (CRC, 2009); (Harvard, 2016); (HKCIC, 2015); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYDDC, 2012); (PSU, 2011); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Analyse

g	Sustainability Evaluation/Environmental Analysis/ Environmental Hazardous Products Analysis *A process in which models are used to simulate and validate facility properties such as thermal performance, energy use, structural calculations, acoustics, heat flows, Life Cycle Costing (LCC), Life Cycle Analysis (LCA) and environmental sustainability (CRC, 2009) based on the requirement of standard sustainability assessment.*	x	x	x	x	x	(BCA, 2013); (COD, 2011); (CRC, 2009); (DOA/DSF, 2012); (GISFIC, 2013); (GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (LACCD, 2016); (NATSPEC, 2016); (NYDDC, 2012); (PSU, 2011); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Analyse
h	Civil Engineering Analysis *A process in which the models of civil engineering elements can be analysed with the aids GPS, LiDAR and any other forms of technologies such as for the hydraulic design of water supply, sewerage, storm water drainage systems (HKCIC, 2015), surface analysis and traffic simulation (NRC, 2014).*		x				(CFM, 2010); (COD, 2011); (HKCIC, 2015); (LACCD, 2016); (SDCCD, 2012); (NRC, 2014)	Analyse
i	Signal Sighting *A process in which BIM can be deployed to design and test the new signaling proposals before fixing (NRC, 2014).*		x				(NRC, 2014)	Analyse
j	Code Validation/ Building Code Analysis/ Model Checking Program/ Compliance Checking/ Design Validation *A process in which code validation software is utilised to check the model parameters against project specific codes (PSU, 2011). Apart from compliance validation, it includes prescription and functionality validation (NRC, 2014).*		x				(AECUK, 2015); (CFM, 200); (COD, 2011); (CRC, 2009); (GTFM, 2016); (Harvard, 2016); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Analyse
10	Design Coordination / 3D Coordination/ Interference Management/Clash Avoidance and Detection *A process in which clash detection software is deployed to analyse the BIM for physical interferences between building systems and components, clashes are manually sorted and reported (Harvard, 2016). Automated clash detection analysis for drainage and utility networks is made possible with BIM tools (NRC, 2014).*		x				(ARC, 2009); (BCA, 2013); (CFM, 2010); (COD, 2011); (COSA, 2011); (CRC, 2009); (DOA/DSF, 2012); (FMS, 2012); (GISFIC, 2013);(GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (IU, 2016); (LACCD, 2016); (MPA, 2015); NATSPEC, 2016); (NRC, 2014); (NYCSA, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (SDCCD, 2012); (SEC, 2013); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Analyse
11	Design Documents/ Drawing Generation *A process in which design documents such as schematic, design development, construction and shop drawings are extracted directly from the BIM repositories or object libraries (PSU, 2011).*		x				(BCA, 2013); (CFM, 2010); (COD, 2011); (CRC, 2009); (Harvard, 2016); (LACCD, 2016); (PSU, 2011); (SDCCD, 2012)	Communicate
12	Digital Fabrication			x	x		(AGC, 2009); (BCA, 2013); (CFM, 200); (COD, 2011); (CRC, 2009); (GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (LACCD, 2016); (MPA, 2015);	Realise

	A process in which geometry from the BIM is extracted for shop drawings and can be sent to computer numerical control equipment for prefabrication and erected efficiently on site (Harvard, 2016).						(NATSPEC, 2016); (NRC, 2014); (NYCSCA, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (TPA, 2016); (USACE, 2012)	
13	Subcontractor/ Trade Coordination *A process in which a coordinated model is deployed for the contractor to coordinate with the subcontractors for review the design, optimise scheduling and field installation prior to installation (NATSPEC, 2016).*			x	x		(AGC, 2009); (CFM, 2010); (COD, 2011); (NATSPEC, 2016); NYCSCA, 2014)	Realise
14	Material Management *A process in BIM is used to support multiple-user access, receive, track and control all project deliverables such as prefabrication components and other small construction support materials to ensure the materials deliver on schedule and meet the quality expectations (NRC, 2014).*			x	x		(NRC, 2014)	Gather; Generate
15	Equipment Management *A process in which BIM is deployed to support construction equipment management such as scheduling the downtime to fit project workload, produce maintenance schedules, complete service history and work arrangement (NRC, 2014).*			x	x		(NRC, 2014)	Gather; Generate
16	Site Utilisation Planning/ Site and Logistic Planning *A process in which detailed logistic objects are modeled in the BIM (Harvard, 2016) and link to construction schedule (4D) (HKCIC, 2015) for permanent and temporary facilities on site (PSU, 2011).*				x		(AGC, 2009); (COD, 2011); (CRC, 2009); (Harvard, 2016); (HKCIC, 2015); (NATSPEC, 2016); (NRC, 2014); (PSU, 2011); (TPA, 2016); (USACE, 2012)	Communicate
17	3D Control and Planning (Digital Layout)/ In field Construction Layout *A process in which layout points are taken from the BIM and loaded into robotic total stations for layout. Conversely, layout points are captured in the field during construction and round-tripped back to the model for proactive quality control (MPA, 2015).*				x		(COD, 2011)); (Harvard, 2016); (HKCIC, 2015); (MPA, 2015); (NRC, 2014); (PSU, 2011); (USACE, 2012)	Communicate
18	Lift Planning *A process in which lift plan models are created through collaboration between the structure engineers and experienced site personnel such as lift supervisor to communicate the lift plan for execution (NATSPEC, 2016).*				x		(NATSPEC, 2016)	Communicate
19	Safety/ Safety Planning/Site Safety Review *A process in which BIM is deployed to develop safety plans for communication on site and off site such as information for emergency routes of public safety measures can be extracted*				x		(GISFIC, 2013); (Harvard, 2016); (MPA, 2015); (NRC, 2014); (TPA, 2016)	Communicate

	from the BIM (Harvard, 2016) and BIM-based orientation can be used to provide safety training (MPA, 2015).							
20	Construction System Design *A process in which complex building systems such as modular construction components, formwork and scaffolding can be modeled to improve planning, construction productivity and safety (NATSPEC, 2016).*				x		(COD, 2011); (NATSPEC, 2016); (NYDDC, 2012); (PSU, 2011); (TPA, 2016); (USACE, 2012)	Generate; Communicate
21	Progress Tracking *A process in which 4D BIM is integrated with laser scanning and mobile computing to assist project managers in assessing construction progress effectively and make a timely decision if schedule delay appeared.*				x		(NRC, 2014)	Gather
22	Field and Management Tracking/ Quality Tracking and Reporting *A process in which Field Management software is used during the construction, commissioning, and handover process to manage, track, task, and report on quality, safety, documents to the field, commissioning, and handover programs, connected to BIM for project compliance (PSU,n.d.).*				x		(PSU, 2011); (Statsbygg, 2013); (USACE, 2012); (NRC, 2014)	Gather; Generate; Communicate
23	Field Supplements *Data extracted from BIM can be used to support field supplements (Harvard, 2016) such as construction drawings and schedules, as-built documents and sustainability certification documentation to be submitted as part of the project deliverables.*				x		(AGC, 2009); (Harvard, 2016); (LACCD, 2016); (MPA, 2015); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016)	Communicate
24	Record Model/ As-built Model *Record Modeling is the process used to depict an accurate representation of the physical conditions, environment, and assets of a facility. It is the culmination of all the BIM Modeling throughout the project, including linking Operation, Maintenance, and Asset data to the As-Built model (created from the Design, Construction, 4D Coordination Models, and Subcontractor Fabrication Models) to deliver a record model to the owner or facility manager (PSU,2011).*				x		(AECUK, 2015); (AGC, 2009); (BCA, 2013); (COD, 2011); (COSA 2011); (CRC, 2009); (GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Generate
25	COBie/ Commissioning *A systematic process of verifying that all building systems perform interactively according to the design intent and the owner's operational needs (MPA, 2015).*	x	x	x	x	x	(CFM, 2010); (COD, 2011); (FMS, 2012); (GTFM, 2016); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (SDCCD, 2012); (SEC, 2013); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Communicate; Realise
26	Other FM information handover					x	(NATSPEC, 2016)	Communicate; Realise

	A process in which where the client and BIM Team determine that use of the COBie system is not appropriate for the project, other specific information required for facility management and the strategy for delivering it are purposed (NATSPEC, 2016).							
27	Operation and Maintenance Scheduling/ Preventive Maintenance Analysis *A process of record model/ as-built model is deployed with building management system such as building automation system, computerised maintenance management system to plan, manage and track operation and maintenance activities (PSU, 2011).*					x	(BCA, 2013); (COD, 2011); (CRC, 2009); (HKCIC, 2015); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Communicate
28	Asset Management/Facility Management *A process of bi-directionally linking an as-built model database to an organised building management system which can be used to maintain and operate a facility and its assets (HKCIC,2015).The assets include physical components, systems, surrounding environment and equipment (NRC, 2014).*					x	(BCA, 2013); (COD, 2011); (CRC, 2009); (Harvard, 2016); (HKCIC, 2015); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Gather; Generate; Communicate
29	Maintenance Training *BIM can be used during commissioning, preoccupation, and post-occupation to train staff on asset location, maintenance access and maintenance procedures. This information can be developed into a mobile accessible package (MPA, 2015).*					x	(MPA, 2015)	Realise
30	Space Management and Tracking *A process in which BIM may integrate with spatial tracking software to assess, manage and track the existing use space and associated resources within a project (HKCIC, 2015)*					x	(BCA, 2013); (COD, 2011); (CRC, 2009); Harvard, 2016); (HKCIC, 2016); (MPA, 2015); (NATSPEC, 2016); (PSU, 2011); (SDCCD, 2012); (TPA, 2016); (USACE, 2012)	Gather; Communicate
31	Disaster Planning/Contingency Planning Analysis *A process in which BIM is used in conjunction with building management system for emergency response planning (NATSPEC, 2016).*					x	(COD, 2011); (CRC, 2009); (Harvard, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Generate; Analyse; Communicate
32	Assessment Models *BIM can be used in the field for efficient data collection. Mobile software supporting BIM shall be considered by the assessment team (MPA, 2015).*					x	(MPA, 2015)	Gather
33	Resiliency Modeling *BIM can be used to create resiliency modeling particular for the projects where their assets and properties are located in areas subject to environmental change (MPA, 2015).*					x	(MPA, 2015)	Generate
34	Road/Rail Management *A process in which BIM is utilised to provide solutions to build and manage infrastructure models, analyse current working conditions of infrastructure, plan for infrastructure*					x	(NRC, 2014)	Realise

	improvement and future growth with the aids of various forms of technologies such as geospatial tracking and graphical representation of the networks (NRC, 2014).							
35	Transportation/ Logistic Management System *A process in which BIM transportation management tools are deployed to support entire transportation lifecycle ranging from creating the least cost shipment plans and maximising loading capacity to streamlining freight financial administration for match- and auto-pay or self-invoicing processes, as well as leverage end-to-end visibility for proactive monitoring and intelligent exception management for whole distribution network (NRC, 2014).*					x	(NRC, 2014)	Realise
36	Traffic Volume Simulation *A process in which performance measures generated by BIM models and BIM visualisation capabilities enable detailed operational analyses of travel corridors in the area and assist in determining the potential effectiveness of transportation projects and access management practices (NRC, 2014).*					x	(NRC, 2014)	Analyse
37	GIS Asset Tracking *A process in which BIM is deployed to monitor location and movement of objects in real time. Objects that can transmit their geographic location via Global Positioning Systems (GPS) or similar technologies can be dynamically tracked on a display map that can be shared via the Internet or intranet (NRC, 2014).*					x	(NRC, 2014)	Gather
38	Water Mitigation and Planning *A process in which BIM operation tools can be deployed to support appropriate legislation for flood plain zoning, implementation and collection of data essential for the assessment of the community's flood risk (NRC, 2014).*					x	(NRC, 2014)	Communicate

2.4.2 DMAT Uses in the Oil and Gas Industry

Table 2.5 demonstrates thirty-two (32) DMAT uses extracted from a total of eighty-three (83) academic publications and one hundred and one (101) DMAT vendor case studies.

Table 2.5 List of DMAT uses

No.	DMAT Uses/ Description	Project Phase: Exploration	Project Phase: Appraisal /Plan	Project Phase: Development: Design	Project Phase: Development: Procure	Project Phase: Development: Construct	Project Phase: Production Operate &	Project Phase: Abandonment/ Demolition	References: Academic Publications (most of the papers discussed the potential DMAT uses in the oil and gas projects or examined the DMAT uses in research, except for those with * indicates the DMAT uses were applied in the practice)	References: DMAT Vendor Case Studies	DMAT Use Purposes
1	Geological Modeling *A process in which a 3D geological model is generated through repeated seismic surveys and predictions about its properties and structures (Abideh and Bargahi, 2012).*	x	x				x		(Abideh and Bargahi, 2012); (Amanippor et al., 2013); (Besson et. al., 2014)*; (Cuba et. al., 2012);(Do Couto et.al., 2015); (Duran et al., 2013); (Fayemi and Di, 2016); (Lindsay et al., 2013); (Liu et al., 2012); (Tiruneh et al., 2013); (Turrini et al., 2014)*; (Zhu et al., 2013)	(Paradigm, 2013)	Generate
2	Reservoir Modeling *A process in which a geological model can be up-scaled to simulate with fluid behaviours under different sets of circumstances to identify the optimal production techniques. It is mainly used for charge risk assessments, locate new prospects, identify drilling targets, optimise completions and accelerate developments (Paradigm, 2016a).*	x	x				x		(Amoyedo et al., 2016); (Brigaud et al., 2014); (Bruns et al., 2013); (Cacace and Blocher, 205); (Dong et al., 2014); (Fegh et al., 2013); (Geiger et.al., 2012); (Glegola, 2013); (Kamali et al., 2013); (Katterbauer et al., 2014); (King et al., 2012)*; (Morongjiu-Porcu et al., 2016); (de Oliveira Miranda et al., 2015); (Naji and Khalil, 2012); (Norden et al., 2012); (Panfili et al., 2012); (Park and Datta-Gupta, 2013); (Senel et al., 2014)*; (Soleimani and Shokri, 2015); (Zeinalzadeh et al., 2015)	(Paradigm, 2016a); (Paradigm, 2016c); (Paradigm, 2016d); Schlumberger, 2015c); (Schlumberger, 2016c)	Analyse
3	Data or Information Management *A process in which a data or information management tool is deployed to collaborate multi-disciplinary teams in a common visualisation environment. It includes the*	x	x	x	x	x	x	x	(Baaziz and Quoniam, 2013); (Chelmis et al., 2013); (Han et al.,2014); (He and Wang, 2015); (Kim et al., 2014); (Perrons and Hems, 2013); (Perrons and Jensen, 2015); (Popa and Cassidy, 2012)*; (Sawaryn et al., 2014); (Veyber et al., 2012); (Ward et al., 2014)*; (Zhu et al., 2015)	(Aveva, 2015b); (Aveva, 2015d); (Aveva, 2015a, p.26-30); (Aveva, 2015a, p.31-33); (Aveva, 2015a, p.34-37); (Aveva, 2015a, p.42-45); (Aveva, 2015a, p.46-47); (Aveva, 2015a, p.48-51); (Bentley,	Communicate

	deployment of other advanced IT tools such as big data (Perrons and Jensen, 2015), cloud computing (Perrons and Hems, 2013) and etc.									2012, p.105); (Bentley, 2012, p.27); (Bentley, 2013, p.20); (Bentley, 2013, p.26); (Bentley, 2014, p.11 and p.73); (Bentley, 2014, p.110);(Bentley, 2014, p.115); (Bentley, 2015, p.105); (Bentley, 2015, p.122); (Bentley, 2015, p.122a); (Bentley, 2015, p.123a); (Bentley, 2015, p.124a); (Bentley, 2015, p.135); (Bentley, 2015,p.192); (Bentley, 2015, p. 201); (Intergraph, 2012); (Intergraph, 2013a); (Intergraph, 2013b); (Intergraph, 2015b); (Intergraph, 2016a); (Intergraph, 2016b); (Tekla, 2016b); (Tekla, 2016d); (Aspentech, 2015c)	
4	Well Planning *A process in which a well is interpreted and it is assessed with well-planning software and reservoir modeling through various scenarios to quantify wellbore position and precision (Paradigm, 2016a) for safe operation and at the lowest cost. A 3D drillable trajectory is designed inside a subsurface model with well control simulation software to understand and mitigate operational risks and meet drilling regulations (Schlumberger, 2016a). As drilling operation is progress, reservoir model is updated and coupled with simulation software to situate the good structure and provide a more realistic drilling (Chemali et al., 2014).*		x	x	x	x	x		(Chemali et al., 2014); (Jain et al., 2013); (Ask et al., 2015); (Odunowo et al., 2013); (Tavallali and Karimi, 2016); (Zhu et al., 2014)	(Landmark, 2016); (Paradigm, 2016b); (Schlumberger, 2013c); (Schlumberger, 2014a); (Schlumberger, 2015b); (Schumberger, 2016a); (Schlumberger, 2016b);	Generate
5	Subsurface Model Review *A process in which a 3D subsurface model and other necessary data are reviewed by stakeholders through different forms of presentations to assist in decision making for well planning, drilling and production optimisation (Schlumberger, 2013a).*	x	x	x			x		-	(Schlumberger, 2013a); (Schlumberger, 2014b)	Communication

6	Drilling Operation *Drilling operations include utilisation of drilling operations software and other services for drilling engineers and the rig site to continuously monitor and analyse drilling operations for drilling performance optimisation, wellbore assurance, risk mitigation, and operational efficiency (Schlumberger, 2016a). The result of the drilling data analysing data grid could be visualised through 3D model (Zhang and Zhang, 2012).*		x	x	x	x	x		(Downtown, 2015); (Iversen et al., 2013); (Nikolaou, 2013); (Tavallali and Karimi, 2016);(Zhang and Zhang, 2012)	(Schlumberger, 2012); (Schlumberger, 2013b)	Realise
7	Existing Conditions Modeling		x	x		x	x	x	(Ward et al., 2014)*	-	Gather, Generate
a	As-Built Model *A process in which an as-built model of an existing facility or a new built fabrication model is created through laser scanning technology (Aveva, 2015a, p.16-19).*		x	x		x	x	x	-	(Aveva, 2015b); (Aveva, 2015a, p.10-12); (Aveva, 2015a, p.13-15); (Aveva, 2015a, p.16-19); (Aveva, 2015a, p.26-30); (Aveva, 2015, p.3-5); (Bentley, 2012, p. 109); (Bentley, 2014, p.98); (Intergraph, 2014b)	Gather, Generate
8	Programming		x						(Ward et al., 2014)*	-	Generate
9	Phase Planning (4D Modeling)/ Scheduling		x	x		x	x	x	(Kim et. al., 2013); (Ward et al., 2014)*; (Zhou et al., 2015a)	(Aveva, 2015a,p.31-33); (Bentley, 2013,p.62); (Bentley, 2015,p.13); (Synchro, 2014); (Synchro, 2015)	Communicate
10	Cost Estimation		x	x	x	x	x		-	(Aspentech, 2015a); (Asptentech, 2016)	Gather; Generate; Analyse
a	Quantity Extraction *It is a process in which a 3D model is used to extract quantity for cost estimation (Aveva, 2015, p.13-15).*		x	x	x	x	x		(Ward et al., 2014)*	(Aveva, 2015b,p.13-15); (Aveva, 2015b,p.26-30); (Aveva, 2015a,p.34-37); (Bentley, 2012, p. 125); (Bentley, 2013,p.143); (Bentley, 2013,p.146); (Bentley, 2013,p.20); (Bentley,2015,p.103); (Bentley, 2015,p.122); (Bentley, 2015,p.192); (Intergraph, 2013a); (Intergraph, 2014b); (Intergraph, 2015a); (Intergraph, 2015b);	Gather

										(Intergraph, 2016b); (Tekla, 2016b); (Tekla, 2016c)	
b	Cost Analysis (5D)/Cost and Schedule Forecast		x	x	x	x	x		(Wang et al., 2014a)	-	Analyse
11	Design Authoring		x	x	x	x			(Ward et al., 2014)*; (Xie and Ma, 2015)	(Autodesk, 2012a); (Autodesk, 2012b); (Aveva, 2015a, p.48-51); (Bentley, 2012, p.105); (Bentley, 2012, p.109); (Bentley, 2012, p.27); (Bentley, 2013,p.143); (Bentley, 2013, p.143); (Bentley, 2013,p.146); (Bentley, 2014,p.110); (Bentley, 2014, p.115);(Bentley, 2015, p.103); (Bentley, 2015, p.122); (Bentley, 2015, p.122a); (Bentley, 2015, p.135); (Bentley, 2015, p.201); (Intergraph, 2013a); (Intergraph, 2013b); (Intergraph, 2014a); (Intergraph, 2014b); (Intergraph, 2015b); (Intergraph, 2016a); (Tekla, 2016a); (Tekla, 2016b); (Tekla, 2016d)	Generate
12	Design Reviews		x	x					(Carvalho et al., 2012); (Kim et al., 2014); (Muley et al., 2014); (Ward et al., 2014)*	(Aveva, 2015b); (Aveva, 2015a,p.20-22); (Aveva, 2015a,p.26-30); (Aveva, 2012,p.27); (Bentley, 2013, p. 20); (Bentley, 2014,p.110); (Bentley, 2014,p.115); (Bentley, 2015,p.103); (Bentley, 2015,p.122); (Bentley, 2015,p.124); (Bentley, 2015,p.124a); (Bentley, 2015,p.135); (Bentley, 2015,p.201); (Intergraph, 2013a); (Intergraph, 2015b); (Intergraph, 2016b); (Tekla, 2016b)	Communicate
13	Modeling , Instrumentation and Diagram *It includes mechanical, structural, piping, equipment, electrical, civil engineering and any other engineering modeling necessary for a facility. Concurrent design of different disciplines may exist under a collaboration platform (Intergraph, 2016a; Aveva, 2016). It also includes the process of facilitating the instrumentation and diagram from various disciplines to support operational tasks such as*		x	x	x	x	x		(Li et al., 2013); (Savazzi et al., 2013); (Ward et al., 2014)*; (Zhou et al., 2015b); (Norton et al., 2013); (Ma, 2014)*	(Autodesk, 2012a); (Autodesk, 2012b); (Autodesk, 2013a); (Autodesk, 2013b) (Aveva, 2015b); (Aveva, 2015d); (Aveva, 2015a,p.10-12); (Aveva, 2015a,p.13-15); (Aveva, 2015a,p.20-22); (Aveva, 2015a,p.26-30); (Aveva, 2015,p.31-33); (Aveva, 2015a,p.34-37); (Aveva, 2015a,p.3-5); (Aveva, 2015a,p.46-47); (Aveva, 2015a,p.48-51);(Bentley, 2012,p.105); (Bentley, 2012,p.125); (Bentley, 2012,p.27); (Bentley,	Generate

	generating new as-built data, offer interface for calibration and SAP (one of the ERP providers) for maintenance scheduling (Intergraph, 2016a).All tools discussed are necessary to support the changes made to ensure the information are always up-to-date.									2013,p.143); (Bentley, 2013,p.146); (Bentley, 2013,p.26); (Bentley, 2014,p.110); (Bentley, 2014,p.115); (Bentley, 2015,p.101); (Bentley, 2015,p.103); (Bentley, 2015,p.104); (Bentley, 2015,p.105);(Bentley 2015,p.105a); (Bentley, 2015,p.122); (Bentley, 2015,p.122a); (Bentley, 2015,p.123); (Bentley, 2015,p.124); (Bentley, 2015,p.124a); (Bentley, 2015,p.135); (Bentley, 2015,p.192);(Intergraph, 2013z); (Intergraph, 2013b); (Intergraph, 2014b); (Intergraph, 2015b); (Intergraph, 2016a); (Intergraph, 2016c); (Tekla, 2016d)	
14	**Design Analysis/Engineering Analysis**			x					-	-	Analyse
a	Structural Analysis			x					(Ward et al., 2014)*	(Bentley, 2012,p.105); (Bentley, 2014,p.110); (Bentley, 2014,p.95); (Bentley, 2015,p.101); (Bentley, 2015,p.102); (Bentley, 2015,p.103); (Tekla, 2016a)	Analyse
b	Offshore Structural Analysis *A process in which a structure is simulated with offshore system response such as hydrostatic, hydrodynamic, mooring, and structural behaviour, for an example, blast and explosion analysis to assess the offshore structural integrity (Bentley, 2016).*								(Munoz-Garcia, 2013); (Paris and Cahay, 2015); (Ma, 2014)*	(Bentley, 2014,p.98); ; (Bentley, 2015,p.99); (Bentley, 2015,p.99a); (Bentley, 2015,p.101a); (Bentley, 2015,p.102); (Bentley, 2015,p.105); (Bentley, 2015,p.105a); (Bentley, 2015,p.106); (Bentley, 2015,p.106a); (Bentley, 2015,p.107);	
c	Spatial, Raceway and Cable System Analysis *A 3D model can simulate with raceway and cable system analysis software to identify the best path through raceways using different segregation criteria and routing methods for plant design (Bentley 2015, p.103).*			x					-	(Aveva, 2015a,p.31-33); (Aveva, 2015a,p.34-37);(Bentley, 2015,p.103)	Analyse
d	Process Analysis *A 3D model can also be simulated with process analysis software to address engineering*			X					(Pathak et al., 2013); (Walnum et al., 2013); (Kvesic et al. 2012)	(Aveva, 2015a,p.34-37); (Intergraph, 2014a); (Intergraph, 2015b); (Aspentech, 2015b)	Analyse

	challenges such as the multiphase flow modeling, gas processing, refining and LNG process (Aveva 2015, p.34-37).										
e	Material and/or Pipe Stress Analysis *A process in which material is analysed with simulation software. One of the examples is that the piping analysis was deployed to analyse the flexibility and stress of pipe. The model created could clearly indicate areas of concern via color-coded stress models and animated displacements for any stress load case (Intergraph 2015b; Intergraph 2016a; Intergraph 2016b).*			x					(Hu et al., 2015); (Munoz-Garcia, 2013)	(Aveva, 2015a, p. 31-33); (Bentley, 2014,p.110); (Bentley, 2015, p.101); (Bentley, 2015, p. 103); (Bentley, 2015,p.105a); (Bentley, 2015,p.122a); (Bentley, 2015,p.123); (Bentley, 2015,p.124); (Bentley, 2015,p.135);(Intergraph, 2013a); (Intergraph, 2014a); (Intergraph, 2014b); (Intergraph, 2015b)	Analyse
f	Acoustic Analysis			x					-	(Bentley, 2015,p.123)	Analyse
g	Civil Engineering Analysis			x					(Ward et. al., 2014)*	-	
h	Geospatial Analysis *The analysis is used to design and installation of the pipeline, field gathering stations, gas distribution manifolds, flow and trunklines, and water and gas re-injection facilities in El Merk (Intergraph, 2016c).*		x	x			x		-	(Intergraph, 2016c)	Analyse
i	Economic Evaluation *A process in which an economic model is embedded into process modeling to assess the viability of the capital, production, operation costs and any other associated costs arising from the planning until the demolition of the oil and gas facilities (Berk, 2011)s.*		x	x	x	x	x		-	(Aspentech, 2015a); (Asptentech, 2016)	Analyse
15	Code Validation/ Building Code Analysis/ Model Checking Program/ Compliance Checking/ Design Validation			x					-	**Almost most of the common design software has code compliance checking feature.*	Analyse

16	Design Documents		x	x	x	x			(Ward et al., 2014)*	(Aveva, 2015b); (Aveva, 2015d); (Aveva, 2015,p.10-12); (Aveva, 2015a, p. 13-15); (Aveva, 2015a, p. 34-37); (Aveva, 2015a, p. 46-47); (Aveva, 2015a, p. 48-51);(Bentley, 2012, p.125); (Bentley, 2012,p.27); (Bentley, 2013,p.143); (Bentley, 2013,p.146); (Bentley, 2014,p.140); (Bentley, 2015,p.101); (Bentley, 2015,p.102); (Bentley, 2015,p.103); (Bentley, 2015,p.104); (Bentley, 2015,p.105); (Bentley, 2015,p.122); (Bentley, 2015,p.122a); (Bentley, 2015,p.124); (Bentley, 2015,p.124a); (Bentley, 2015,p.135); (Bentley, 2015,p.192); (Intergraph, 2013a); (Intergraph, 2013b); (Intergraph, 2014b); (Intergraph, 2015b); (Intergraph, 2016a); (Tekla, 2016a); (Tekla, 2016b)	Communicate
17	Design Coordination / 3D Coordination/ Interference Management/Clash Avoidance and Detection			x	x	x			(Ward et al., 2014)*	(Aveva, 2015b); (Aveva, 2015d); (Aveva, 2015a,p.10-12); (Aveva, 2015a,p.13-15); (Aveva, 2015a,p.26-30); (Aveva, 2015a,p.31-33); (Aveva, 2015a,p.34-37); (Aveva, 2015a,p.46-47); (Aveva, 2015a,p.48-51); (Bentley, 2012,p.27); (Bentley, 2013,p.143); (Bentley, 2014,p.110); (Bentley, 2014,p.115); (Bentley, 2015,p.101); (Bentley, 2015,p.103); (Bentley, 2015,p.105); (Bentley, 2015,p.105a); (Bentley, 2015,p.122); (Bentley, 2015,p.122a); (Bentley, 2015,p.123); (Bentley, 2015,p.124); (Bentley, 2015,p.124a); (Bentley, 2015,p.135); (Intergraph, 2013a); (Intergraph, 2014a); (Intergraph, 2014b); (Intergraph, 2015b); (Intergraph, 2016b);(Synchro, 2015); (Tekla, 2016a); (Tekla, 2016d)	Analyse
18	Digital Fabrication				x	x			(Bedair, 2014); (Kul'ga and Men'shikov, 2015); (Ward et al., 2014)*	(Aveva, 2015b); (Aveva, 2015a,p.10-12); (Aveva, 2015a,p.20-22); (Aveva, 2015a,p.26-30); (Aveva, 2015a,p.34-37);(Intergraph, 2014b); (Tekla, 2016d)	Realise

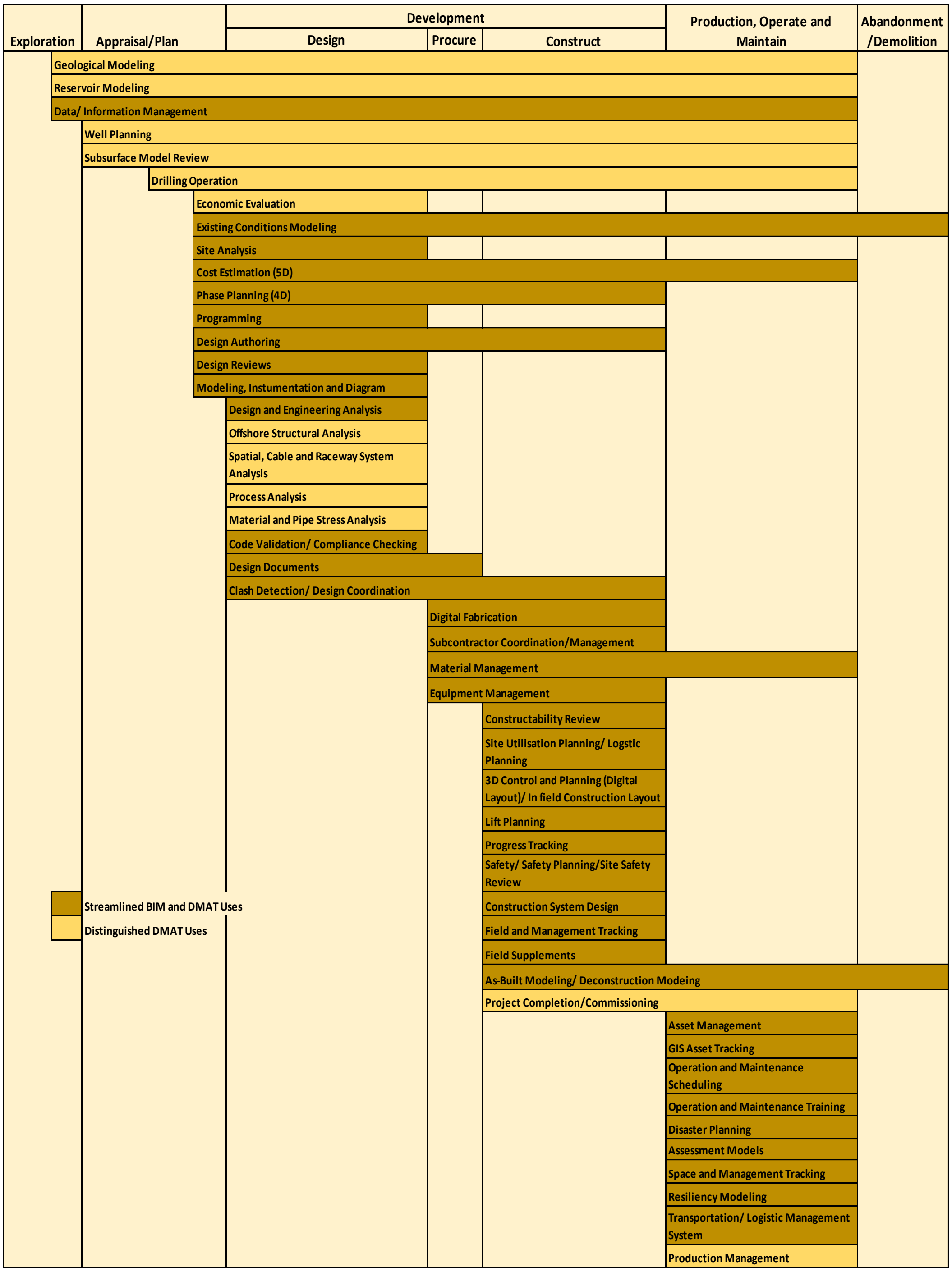
19	Supplier and Subcontractor Management				x	x			-	(Aveva, 2015a,p.26-30); (Aveva, 2015a,p.34-37); (Aveva, 2015a,p.48-51); (Intergraph, 2013a); (Intergraph, 2015a)	Gather; Generate
20	Material management				x	x	x		(Chi et al., 2015); (Trujens et al., 2014); (Xu et al., 2012)	(Aveva, 2015a,p.23-25); (Aveva, 2015a,p.26-30); (Aveva, 2015a,p.34-37); (Aveva, 2015a,p.48-51); (Aveva, 2015a,p.40-41); (Bentley, 2013,p.62); (Intergraph, 2013a); (Intergraph, 2015a)	Gather; Generate
21	Equipment management				x	x			-	(Bentley, 2015,p.13)	Gather; Generate
22	Constructability Review *The real-time data integration on project development allows clients and other team members review construction progress from time to time (Bentley, 2015, p.13) to curb the schedule overrun.*					x			(Carvalho et al., 2012); (Muley et al., 2014); Wang et al., 2014a)	(Bentley, 2015,p.13); (Synchro, 2015)	Communicate
23	Progress Tracking					x			(Wang et al., 2014b)	(Bentley, 2015,p.13)	Gather
24	Safety/ Safety Planning/Site Safety Review					x	x	x	(Albert et al., 2014); (Carvalho et al., 2012); (Chen et al., 2015); (Muley et al., 2014); (Norton, 2013); (Ward et. al., 2014)*	(Bentley, 2015,p.13)	Communicate
25	Deconstruction Model *A deconstruction model is developed to assist in the analysis of the future deconstruction and reinstatement work. The model provides a central location for quantitative technical, environmental and cost data (Ward et al., 2014).*						x	x	(Ward et al., 2014)*	-	Generate
26	Project Completion/ Certification Tracking System/ Commissioning *It is a process in which structured database management system is used to track the engineering data from all disciplines. It provides a portal to import, sort, analyses and quality*					x	x		-	(WinPCS, 2014); (WinPCS, 2014a); (WinPCS, 2014b)	Realise

	control the data before the engineering data is accepted and move into the database. It also reports the completion and certification of design changes (WinPCS, 2014).										
27	Asset Management *It involves asset management for onshore and offshore production, and downstream facility. It includes the scope for enterprise asset management (Aveva, 2015a,p.40-41), asset tracking (Autodesk, 2012a, outage analysis (Autodesk, 2012b) and etc.*						x		(Perrons and Richard, 2014); (Savazzi et al., 2013)	(Autodesk, 2012a); (Autodesk, 2012b); (Aveva, 2015c); (Aveva, 2015a,p.23-25); (Aveva, 2015a,p.40-41); (Aveva, 2015a, p.42-45); (Aveva, 2015a,p.48-51); (Bentley, 2015,p.123a); (Bentley, 2015,p.135); (Intergraph, 2013b); (Schlumberger, 2015a)	Gather; Generate; Communicate
a	Asset Visualisation *A process in which asset visualisation software is deployed to allow team members to assess to detail and up-to-date asset information for planning and controlling of the facility (Aveva, 2015c).*						x		-	(Aveva, 2015c); (Aveva, 2015a,p.26-30); (Aveva, 2015a,p.31-33); (Aveva, 2015a,p.34-37); (Aveva, 2015a,p.38-39); (Aveva, 2015a,p.3-5); (Aveva, 2015a,p.42-45); (Aveva, 2015a,p.48-51); (Aveva, 2015a,p.6-9);(Bentley, 2015, p.123a)	Communicate
28	GIS Asset Tracking						x		-	(Autodesk, 2012a); (Autodesk, 2012b)	Gather
29	Operation and Maintenance Scheduling						x		-	(Aveva, 2015a,p.23-25); (Aveva, 2015a,p.40-41)	Communicate
30	Disaster Planning						x		(Huang et al., 2016)	-	Generate, Analyse, Communicate
31	Operation or Maintenance Training						x		(Colombo et al., 2014)	-	Realise
32	Production Management						x		(Allan et al., 2014); (Tavallali and Karimi, 2016); (Veyber et al., 2012); (Zhang and Zhang, 2012)	(Landmark, 2012); (Petex, 2014)	Generate, Analyse, Communicate; Realise

2.5 Analysis and Discussion

By streamlining the table 2.4 and 2.5, there is a total of thirty-six (36) BIM and DMAT application (as shown in figure 2.4) which could be applied in the oil and gas industry.

Figure 2.4: Streamlined BIM and DMAT Uses for the Oil and Gas Industry



2.5.1 Exploration/Appraisal/Plan

Distinguished DMAT application shown in Figure 2.4 indicates that the practices which are commonly applied in the oil and gas industry but are rarely adopted in the built environment such as for the building and infrastructure projects. These include geological modeling, reservoir modeling, well planning, subsurface model review, drilling operation in the exploration and appraisal phases. These DMAT applications are distinguished from the BIM uses as it is not adequate to be adopted by the building and infrastructure projects due to the natural work process. These DMAT practices are mainly used in (1) exploration and production, and (2) process and production facility. Besides, sustainability evaluation is important to most of the building construction as it is the significant process informing the life-cycle cost of a building (Gourlis and Kovacic, 2016). However, for the oil and gas industry, evaluating the life cycle cost such as the capital, operation and production costs of the projects is the ultimate aim. Accurate economic models embedded in the process modeling is essential in assessing the viability of the oil and gas facilities such as for the LNG projects (Beck, 2011).

BIM and DMAT application in the oil and gas industry for data and information management become prominent. Some evidence of this application include hybrid cloud computing system (Bentley, 2012, p.27, p. 105) was deployed to accelerate communication across the project teams; for energy refinery in Alberta, Canada, an innovated information plant management system was established to gather, store and connect the facility's technical data, engineering resource planning information, and documents in a single, reliable system supporting the day-to-day operations and maintenance decisions; and the system encompasses electronic documentation management system, lifecycle server, SAP asset management system and plant design tools (Bentley, 2013, p. 26). Also, a master tag registry and engineering data warehouse were developed in Queensland Curtis LNG project to supply the commissioning team with critical information related to various systems, tags, and documents (Bentley, 2014, p.11 and p.73).

During the feasibility stage, existing conditions modeling and site analysis are required to model the existing site and the facilities in the surrounding for project master planning. However, these uses are not apparent in the oil and gas industry. Only a case study demonstrated the development of 3D model using BIM tool to produce photomontages for inclusion in the environmental impact statement (Ward et. al., 2014). The majority of the existing conditions modeling are used for modeling the as-built oil and gas facilities. The adoption of the laser scanning for develop existing 3D models are gaining important in the oil and gas projects (Aveva, 2015b; Aveva, 2015a, p.10-12; Aveva, 2015a, p.13-15; Aveva, 201a5, p.16-19; Aveva, 2015a, p.26-30; Aveva, 2015a, p.3-5; Bentley, 2012, p. 109; Bentley, 2014, p.98; Intergraph, 2014b) as there are getting more facilities required alterations and refurbishments. The laser scan data is easily imported into the design software and could be viewed effortlessly by the designers (Aveva, 2015a, p.13-15). For process facility located in Bakersfield, California, laser scanning was utilised as verification tools at fabrication and construction process. Laser scan data in fabrication shop was imported to check against any deviations of the design model by informing decisions to reject or accept non-compliant piping components (Aveva, 2015a, p. 16-19). Nevertheless, BIM uses such as cost estimating using model-based estimating software for 5D cost analysis and update the cost when there are changes made to the design (NYCDDC, 2012); and programming to track the design space (Harvard, 2016) which are important in planning a facility are not evident in the oil and gas projects.

2.5.2 Design

The practices of the oil and gas industry in modeling its facility is distinguished with that of the BIM in the built environment. The main focus of the oil and gas projects is to develop logic models so that the schematic design diagrams for piping and other MEP components are built according to the functional requirements of a facility and without any deviations among the facility elements. The plant life cycle management model used by the oil and gas projects enabled multi-disciplinary teams design simultaneously in a collaboration platform. The oil and gas industry is moving towards design integration. Diagram of engineering design could easily export information to other software and integrate with other engineering design tool (Aveva, 2015b; Aveva, 2015a, p.10-12; Aveva, 2015a, p. 13-15; Aveva, 2015a, p. 26-30).

Apart from that, the use of 4D modeling for planning, scheduling and sequencing the works in the oil and gas industry is also noticeable. A real-time pipe tracking system which utilised the radio-frequency identification (RFID) and 3D digital models in a handheld mobile device was developed to allow more efficient task management (Kim et al., 2013). Also, a 4D model for scheduling activity and operation of mega LNG construction projects was proposed to improve process planning and control (Zhou et al., 2015a). The engineering data such as the 3D model, piping isometrics and structural steel data were exported to a scheduling tool to create field installation work packages from a virtual construction model (Bentley, 2013, p.62). Another two important functions of BIM are the design review and design authoring which are commonly used in the oil and gas industry. Design review tool was deployed to review the plant design so that installation errors could be reduced (Aveva, 2015b). Design authoring is also used heavily in the oil and gas projects as it is the tool which adds richness of information in the oil and gas facility model. One of the examples is that the tool was used to enable the structure and piping design information to be integrated into the model (Bentley, 2012, p. 105).

Some distinguished DMAT uses which are not commonly used in the built environment include offshore structural analysis; spatial, cable and raceway system analysis; and process analysis. Besides, code checking, design documents and clash detection are the important DMAT uses which are usually embedded into the design software as parts of their supplementary functions. It is important to note that BIM is not about the technology, but it improves project management and collaboration among multi-disciplinary teams. To optimise the functions of the BIM and DMAT such as the clash detection, the regular meeting may be necessary to discuss the collaboration process among different design disciplines.

2.5.3 Procure

Modular construction is very common in the oil and gas projects. Several examples of modularisation strategies for steel designs have been proposed to maximise project savings of the oil and gas projects (Bedair, 2014). It is evident that digital fabrication has become important in the oil and gas industry, particularly in the steel fabrication components. Corrib onshore gas pipeline project deployed digital fabrication software (Ward et. al., 2014) to provide rapid detailing automation, automatic fabrication shop drawings and computer numeric control (CNC) machinery production deliverables. The software allows effective collaboration between engineers, detailers and fabricators.

Also, the information of plant life cycle model could be exported to into the oil and gas enterprise software for resource management such as the subcontractor and/or supplier management, material management and equipment management. In the BIM context, subcontractor coordination means it is a process of coordination among subcontractor for reviewing the design and optimising the scheduling prior to installations (NATSPEC, 2016). However, this process is not observable neither in the DMAT academic publications nor DMAT vendor case studies. This may due to both sources are technology-oriented, therefore, it is hard to find the discussion on the technology management practices in the oil and gas projects.

In the research and development, a conceptual framework was proposed to assure modular construction quality through introducing a situation awareness construction environment with well-defined sensing and tracking technologies (Chi et. al., 2015). A study investigated the RFID solutions was also conducted to identify the positions of onsite materials and components (Trujens et al., 2014). In practice, various procurement software were adopted in the oil and gas projects such as VPRM procurement and logistics (Aveva, 2015a, p.48-51), oracle primavera (Aveva, 2015a, p.24-27) and smartplant materials. With the material and supplier/ subcontractor management tool, bills of materials are extracted from the plant design tool to verify its completeness in the tool; supplier past performance can be assessed, new suppliers can be selected based on the selection criteria and maintain their record in the tool; the tool can also allow material status to be tracked, record, updated and activities from inviting subcontractor to manage the sub-contracting are also the functions of the tool (Intergraph, 2013a). An integrated supplier management system was set up to include an eSupplier portal, activities from a request for quotation (RFQ)s to award, all post-agreement workflows, and progress control for each subcontract. This allows teams to collaborate more effectively across the engineering, procurement, and construction disciplines (Intergraph 2015a). The integrated supplier and subcontractor management were used in Thailand where the procurement office in Bangkok would have to handle suppliers in the Sattahip onshore base to support Bualuang wellhead project (Aveva 2015a, p.40-41). 4D modeling and mobile tools were deployed to manage and schedule the equipment for the construction of a new facility to connect to the existing oil and gas facility (Bentley, 2015, p.13).

2.5.4 Construct

Constructability review is important to the design and construction of the oil and gas projects. 4D modeling was used by Abreu e Lima refinery (Synchro, 2015) to analyse the execution and concreting sequence of the ramp and the substation implementation. Wang et al. (2014a) proposed the use of AR and BIM to enable walk-through functionality for facilitating design and constructability review process on the site. Apart from constructability review, the integration of these tools allows on-site progress monitoring to detect real problems, such as low productivity and the tendency of committing an error in assembly. Nevertheless, other BIM uses are not apparent in the oil and gas projects. The BIM use in planning and controlling the construction layout, logistic planning, lift planning and construction system design are not observable in the study. Construction system design is particular significant to the oil and gas projects given the complexity of the design and construction of the facilities. With the adoption of the construction system design, complex facility system such as modular components, formwork and scaffolding can be modeled to improve productivity and safety (NATSPEC, 2016).

Safety element is one of the main concerns of the oil and gas industry. 4D modeling was deployed to sequence the work packages in the NAG Project at the ExxonMobil facility in Texas enabling planning for access and egress routes that contributed to maintaining safety and reducing risk (Bentley, 2015, p.13). The 3D model was also deployed innovatively to review the operational and safety aspects of the surrounding during the design phase (Ward et. al., 2014) and the model could be coupled with various tools such as AR (Albert et.al., 2014; Chen et al., 2015), and hybrid-desk in a semi-immersive environment (Carvalho et al., 2012).

For the completion and commissioning management system (CCMS), the common practices for the built environment sector is the Construction Operations Building Information Exchange (COBie), which is a non-proprietary platform for the exchange of life cycle data needed by facility managers (Kensek, 2015) and it was developed by a number of US public agencies to improve the handover process to building owner-operators (Buxton, 2015). For the oil and gas projects, the industry has their own commissioning system which differs from the building. The facilities and data format involve in the oil and gas projects are large and complex, hence, a real-time tracking system for project commissioning is more appropriate to ensure fast and accurate delivery. The tools carry similar functions of the BIM use such as the field and management tracking and prepare for project completion and commissioning. The examples of common CCMS system used in the oil and gas projects include WinPCS, ContinuumEdge (CE) and qedi.

2.5.5 Production, maintain and operate

Pertaining to the asset management, the oil and gas projects have a more complex facility management system. Enterprise asset management was deployed by the oil and gas exploration and production firm for (1) procurement and materials management; and (2) maintenance planning (Aveva, 2015a, p.40-41). It also referred to Computerised Maintenance Management (CMM) system which was used to order materials from anywhere and track the delivery status enabled the operators to take informed actions to reduce the impact on operations. The system could also integrate with another system to ensure the reliable information provided for shutdown maintenance planning or any unplanned downtime. GIS asset tracking was deployed to enable safer and better gas pipeline management in Romania. An integrated 3D map, map server system, pipeline management system and sensors tracking system were established to manage the asset updates (Autodesk, 2012a). Another similar system was used to analyse the outage which enabled better customer service (Autodesk, 2012b).

For operation and maintenance training, it is observed that the immersive virtual reality (IVR) which deployed the 3D plant model was proposed to enable the control-room operator (CROP) and field operator (FOP) to be trained simultaneously. Besides, the IVR enables the performance to be assessed by eliminating the subjectivity and the trainees were trained under an experimental approach instead of classical approach (Colombo et al., 2014). For disaster planning, a 3D visualisation model was integrated with other advanced technologies to monitor and forecast the disaster. By integrating sensor technologies, spatial information technologies, 3D visualisation technologies, and a landslide-forecasting model, it was used to monitor and forecast landslides in the Danjiangkou Reservoir area (Huang et. al., 2016). In the context of BIM, disaster planning is in connection with the BIM use with building management system for emergency response planning (NATSPEC, 2016) which is not apparent in the oil and gas projects. Other BIM uses such as assessment models, space and management tracking, resiliency modeling and logistics management system are not apparent in the oil and gas projects.

Production management is a distinguished DMAT use which is not commonly applied in the built environment. An integrated system which consisted of an up-to-date 3D geological model, production management software such as ERP system (Veyber et al., 2012), grid-based production management system (Zhang and Zhang, 2012) was proposed for the upstream oil and gas production management. Information extracted from well data was used to establish cost estimate of drilling and production via Cost

Estimate Request (CER) database. The combination of Well Planner and FracScheduler was also proposed to streamline the production scheduling and value stream discipline so as to determine which well is ready for rig work (Allan et al 2014).

2.5.6 Demolition

When the oil and gas field is near the end of its life cycle, it shall prepare for restoring the site to its original condition. The process and production plants would also have to be dismantled. Both the BIM and DMAT uses are not apparent at this stage. The existing conditions modeling and/or deconstruction modeling (Ward et al., 2014) could be used to present the existing as-built model and site conditions to plan for the demolition works. Other DMAT and BIM uses which were used for planning, designing and construction works could be possibly used in this stage to streamline the demolition process.

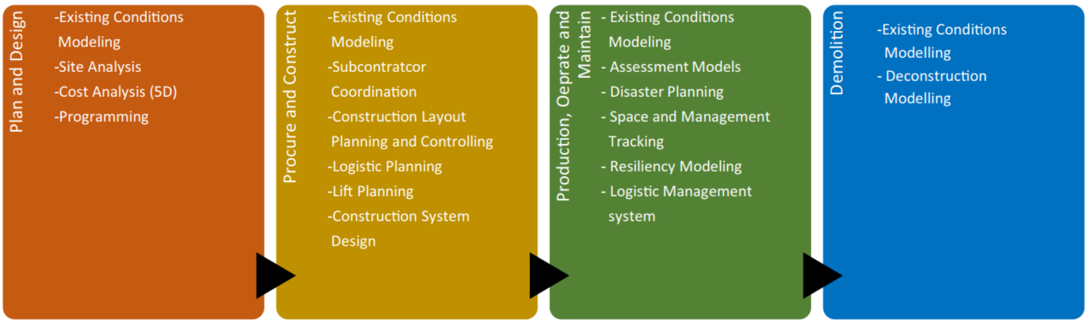
2.5.7 Summary

In the planning and design stage, while design reviews, 3D plant modeling, phase planning (4D), design coordination, design documents and code checking become prominent in the oil and gas projects, other BIM uses such as existing conditions modelling, site analysis, cost analysis (5D) and programming for assessing design space can also be deployed to provide more reliable information for the owners, designers and contractors (if they are involved during the early design stage) to make an informed decision on the oil and gas project development. Existing conditions modeling should not only use to model the as-built oil and gas facilities but it should extend to model the surrounding site conditions during the project planning stage and fabricated items before delivering them to a site. During the procure stage, digital fabrication is an essential element to speed up the oil and gas projects while reducing the deviations among the design, fabrications and installations. Subcontractor and supplier management, material and equipment management are also significant to smoothen the procurement process.

However, subcontractor coordination is important too to ensure effective model coordination and resolve constructability issues between the different trades. In the construction stage, apart from constructability reviews, progress tracking, safety planning and field and management tracking which are commonly used by the oil and gas projects to improve project performance, other BIM uses such as planning and controlling the construction layout through creation of digital layout; logistic planning which involved detailed logistic objects that linked to construction schedule (4D model); lift planning model that allows the structure engineers and experienced site personnel to communicate the lift plan execution; and construction system design for modeling the complex construction could be implemented to improve the overall productivity of the construction process. In the production, operation and maintenance phase, it is noticed that asset management,

GIS asset tracking, operation and maintenance training and production management are usually implemented in the oil and gas projects. Other uses such as assessment models for efficient field data collection; disaster planning for emergency response; space and management tracking to evaluate, manage and track the existing use space and associated resources within an oil and gas facility; resiliency modelling for the remote areas subject to environmental change; and logistics management system to support entire transportation lifecycle from creating the least cost shipment plans to monitoring the whole distribution network proactively can also be adopted to improve overall operation efficiency. As in the final stage of a project life cycle, existing conditions modeling and de-construction model can be used to plan for the demolition works. Figure 2.5 shows the potential BIM and DMAT uses for performance improvement in the oil and gas projects.

Figure 2.5: Potential BIM and DMAT Uses for the Oil and Gas Projects



2.6 Conclusion and Recommendations

The conducted literature review of twenty-eight (28) BIM guidelines, eighty-three (83) DMAT academic publications and one hundred and one (101) DMAT vendor case studies have streamlined thirty-six (36) BIM and DMAT uses for oil and gas projects. The findings reveal that they are many potential applications of DMAT and BIM uses (figure 2.5) can be applied in the oil and gas projects for performance improvement. Data and information management system which are commonly implemented in the oil and gas projects could be deployed in the built environment sector to improve the collaboration among multi-disciplinary teams from planning until operation and maintenance phase.

Few limitations need to be considered in this research. This study does not take into account the effective measures of the BIM and DMAT uses. The highlighted technology practices are only applicable to the technologies, which have a similar taxonomy of (1) DMAT such as the geometry bedding used for oil and gas exploration and production and also PLM system used for design, construction and operation, and (2) BIM. The scope of this study is not extended to the common enterprise computational tools such as the enterprise resource planning (ERP) which is commonly used in the oil and gas firms. Also, the study may overlook some BIM and DMAT uses as per the BIM guidelines, DMAT academic publications and vendor case studies. Future studies may investigate the efficiency use of the BIM and DMAT technologies for the oil and gas project improvement; examine the potential DMAT applications in the built environment sector; and study the technical possibility of linking the PLM, BIM and ERP system for performance improvement in both the oil and gas and built environment sectors.

Chapter 3

A critical review of legal issues and solutions associated with building information modelling[2]

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Abstract: Although there are many discussions of the legal implications of BIM, none of the studies provides a comprehensive review of the legal issues associated with BIM; nor do they evaluate the solutions currently available to address the issues. This paper aims to provide a critical review of the legal issues arising from using BIM and of their associated solutions. A systematic review was conducted of fifty-seven (57) journal articles and conference papers published from 2007 to 2017 to identify the legal issues. The identified legal issues were then analysed in relation to the solutions provided by the construction industry. The results of the study revealed that (1) an alternative project delivery approach that does not modify the original orientation of the design-bid-build procurement structure is required to deliver BIM effectively. (2) The potential change in the standard of care for project participants due to additional roles required in delivering BIM needs further investigation. (3) The roles for auditing a BIM delivery system must be included in the contracts to ensure the quality and compliance of BIM deliverables. The study not only

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reviews the legal issues associated with BIM, but more importantly, it also offers significant insights for future research.
Keywords: BIM, Legal Issues, Contract, Procurement, Liability, Risks

3.1 Introduction

Building information modelling (BIM) has become prominent as a significant element of operations in many construction projects (Ku and Taiebat, 2011). It has proven one of the most effective computing tools for establishing and managing digital information over a project life cycle. However, BIM will not deliver significant improvement in existing procurement practices unless the issues surrounding its legal frameworks have been defined clearly and have been made more usable for procurement and contract management (Olatunji, 2014). The legal issues commonly discussed include incompatibility of procurement systems with BIM (Sebastian, 2011), liability of project participants arising due to design error, non-compliant design, translation error or data misuse, model ownership and intellectual property rights (IPR) (Arensman and Ozbek, 2012) and unclear rights and responsibilities of project participants (Simonian and Korman, 2010). To date, none of the conducted studies have compiled existing studies or comprehensively reviewed the legal issues discussed.

Thus, although the characteristics of BIM continue to evolve, many efforts have been made such as the development of standard contract protocols to address the legal concerns and the promotion of relational contracting approaches such as Integrated Project Delivery (IPD) to improve collaboration among project participants involved in BIM-enabled projects (Jones, 2014). However, none of the studies appraises how far these efforts have developed in addressing the legal issues. This gap in the current literature accelerates the need for a critical review on the legal issues associated with BIM to identify current developments in the construction industry to address the associated legal issues and discuss how current efforts could be improved.

This paper aims to critically review the legal issues arising from using BIM and their associated solutions. Through systematic reviews, fifty-seven

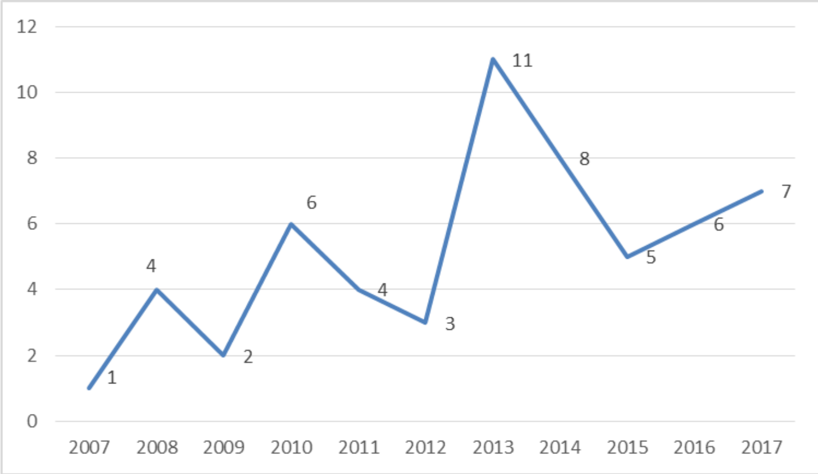
(57) journal articles and conference papers published from 2007 to 2017 were selected to identify the legal issues associated with BIM. Thereafter, each issue was critically reviewed using the existing documents such as journal articles, books and BIM contract protocols to discuss the current approaches to addressing the issues. Based on the results of the review, we then discussed future areas for research in the discussions and conclusions section.

3.2 Review Methodology

To identify the legal issues arising from using BIM, a systematic review was conducted. This method was selected because it synthesises the research evidence by systematically adhering to guidelines for conducting the review (Grant et al., 2009). The steps of systematic reviews were modified from Moher et al. (2009). First, one of the authors identified the relevant papers via the Scopus database and Google Scholar. The keywords used to search the relevant academic publications were “legal issues BIM”, “BIM legal”, “BIM law” and “BIM contract”.

Second, the downloaded papers were screened and checked for quality and eligibility to determine whether they discussed legal issues arising from using BIM. If the papers only briefly mentioned BIM’s legal issues and did not elaborate details or types of legal issues, the papers were excluded. Thus, fifty-seven (57) journal articles and conference proceedings that discussed the legal issues were selected for this study. Among the 57 papers, 30 papers were identified as journal articles. Figure 3.1 shows that the number of papers that discussed the legal issues from 2007 to 2017 increased unevenly, with the highest number (11) recorded in 2013.

Figure 3.1 Papers Published by Year



Third, to prepare for the synthesis study, the legal issues discussed in the article were categorised according to the four common classifications as mentioned in the introduction, namely, (1) incompatibility of procurement systems with BIM, (2) liabilities arising from BIM use, (3) model ownership and IPR and (4) unclear rights and responsibilities. If the themes discussed in the articles were similar and formed the logic behind the theme, they were grouped into a similar theme within the four categories. However, if themes were identified that did not fit into the above four categories, a new main category of legal issues was created.

Additionally, the authors realised that legal issues and their solutions can vary across localities. For instance, the legal positions in the United States and the United Kingdom on the application of the economic loss doctrine are different. Hence, we decided to address the issues based on the two pioneer countries, namely, the legal application in the United States and in the United Kingdom. The similarities and the differences of the legal positions in these two countries also form parts of the central focus of the discussions.

There is no standard or guideline for a critical review of solutions because a critical review seeks to identify the most significant items in the field and goes beyond the description to include the degree of analysis and conceptual innovation (Grant et al., 2009). Hence, the authors searched the relevant literature to assess the current solutions. The common standard contract protocols from pioneer countries such as the AIA document E203TM-2013 (2013) and ConsensusDocs 301 (2008) from the United States and the CIC BIM Protocol (CIC, 2013) and CIOB contract for use with complex projects

(CCP, 2013) from the United Kingdom, published journal articles and relevant books were used in the discussions of the solutions.

After the reviewing process and the analysis were recorded, the content was then audited and validated by the other two authors, who were knowledgeable in BIM-based contract administration, to ensure the credibility of the systematic review. Finally, the findings were abstracted based on the aim identified in the Introduction, and the Discussions and Conclusions discussed the existing gaps and highlighted future research.

3.3 Findings of Legal Issues Surrounding BIM

Table 3.1 shows the results of findings obtained from fifty-seven (57) academic publications. The legal issues were classified into four categories, namely, (1) incompatibility of procurement systems with BIM, (2) liabilities, (3) model ownership and IPR and (4) unclear rights and responsibilities.

Table 3.1 Legal Issues Identified from the Papers

No.	Legal Issues	References	No. of Papers
3.3.1	Incompatibility of procurement systems with BIM	(Areshidi et al., 2017); (Ashcraft, 2008); (Chew and Riley, 2013); (Eadie et al., 2013); (Gu and London, 2010); (Greenwood et al.,2010); (Ku and Pollalis, 2009); (Kuiper and Holzer,2013); (Liu et al., 2016); (Liu et al., 2017); (McAdam, 2010); (Olatunji,2011); (Olatunji, 2014); (Palos et al., 2013);(Pandey et al., 2016); (Sebastian, 2010); (Sebastian, 2011)	17
3.3.1.1	Design-bid-build procurement impedes effective adoption of BIM	(Sebastian, 2011); (Pandey et al., 2016)	2
	More preparation time to formulate the collaboration process is required	(Sebastian, 2011)	1
	Project participants' responsibilities to work closely with end users remained limited	(Sebastian, 2011)	1
	Lack of early involvement of contractors	(Elhag and Al-Sharifi, 2014); (Palos et al., 2013) ;(Sebastian, 2011)	3

3.3.1.2	Lack of contract forms to clearly mandate the BIM practices and address legal concerns	(Abdirad, 2015); (Ahn et al., 2016); (Alreshidi et al., 2017); (Ashcraft, 2008); (Bataw, 2013); (Bosch-Sijtsema et al., 2017); (Bui et al., 2016); (Chao-Duivis, 2011); (Chong et al., 2017a); (Enegbuma et al., 2014); (Greenwood et al., 2010); (Hamdi and Leite, 2013); (Hsieh et al., 2012); (Holzer. 2007); (Hossain et al., 2013); (Hsu et al., 2015); (Kuiper and Holzer, 2013); (Kurul et al., 2013); (Lowe and Muncey, 2009); (Manderson et al., 2015);(McAdam, 2010); (Meharan, 2016); (Ngo,2012); (Olatunji, 2014);(Redmond et al.,2010); (Sankaran et al., 2016); (Sebastian, 2010); (Sun et al., 2015); (Wang et. 2011)	29
	The use of "co-contract document", "inferential document", "geometry statements", and “reference only” in the contract documents	(Ashcraft, 2008); (Ku and Pollalis, 2009); (Pandey et al., 2016)	3
	Conflicts in terms between protocols and principal contract if the standalone amendment contract is used	(Ghaffarianhoseini et al., in press)	1
	Inaccurate, insufficient and inappropriate level of BIM details when delivering models to owners	(Hamdi and Leite, 2013)	1

	Total		**58**
3.3.2	Liabilities	(Ashcraft, 2008); (Chao-Duivis, 2011); (Joyce and Houghton, 2014); (Hossain et al., 2013); (Hsu et al.,2015); (Ku and Pollalis, 2009); (Kuiper and Holzer,2013); (Laishram, 2013); (Lowe and Muncey,2009); (Mehran, 2016); (Mignone et al., 2016); (Sebastian, 2010); (Sebastian, 2011); (Smith,2014); (Wang et al., 2011)	15
3.3.2.1	Liability exposures to design errors, non-compliant design, transition errors, loss of data or data misuse	(Abdirad, 2015); (Alreshidi et al., 2017); (Ashcraft, 2008); (Azhar, 2008); (Bataw, 2013); (Chao-Duivis, 2011); (Greenwood et al., 2010); (Ghaffarianhoseini et al., in press); (Hamdi and Leite, 2013); (Hsieh, 2012); (Hsu, 2015); (Kuiper and Holzer, 2013); (Ku and Pollalis, 2009) ; (Laishram,2013); (Lowe and Muncey, 2009); (McAdam, 2010); (Olatunji, 2011); (Olatunji, 2014); (Pandey et al., 2016); (Sebastian, 2010);(Smith, 2014); (Walaseka and Barszez, 2017); (Wang et al., 2011)	23
3.3.2.2	Standard of care	(Arensman and Ozbek, 2012); (Ashcraft, 2008); (Hsieh, 2012); (Hsu, 2012); (Liu et al., 2016); (Lowe and Muncey, 2009); (McAdam, 2010); (Pandey et al., 2016); (Simonian and Korman, 2010)	9
	Total		**47**

3.3.3	Model Ownership and IPR	(Abdirad, 2015); (Ahn et al., 2016); (Alreshidi et al., 2017); (Al-Shammari, 2014); (Arensman and Ozbek, 2012); (Ashcraft, 2008); (Azhar, 2008);(Bataw, 2013); (Chao-Duivis, 2011); (Davies et al., 2017); (Eadie et al.,2014); (Elhag and Al-Sahrifi, 2014); (Enegbuma and Ali, 2011); (Fan, 2014); (Greenwood et al., 2010); (Ghaffarianhoseini et al., in press); (Hossain et al. , 2013); (Hsieh, 2012); (Hsu, 2015);(Joyce and Houghton, 2014); (Ku and Pollalis, 2009);(Kuiper and Holzer, 2013); (Kurul et al., 2014);(Laishram, 2013); (Lowe and Muncey, 2009);(Mahamadu et al., 2013); (Manderson et al., 2015); (Mignone et al., 2016); (McAdam, 2010); (Mehran, 2016); (Ngo, 2012); (Olatunji, 2011);(Olatunji, 2014); (Pandey et al., 2016); (Sebastian, 2010); (Simonian and Korman, 2010); (Smith, 2014); (Sun et al., 2015); (Walaseka and Barszez, 2017)	39
3.3.3.1	Infringement of Another's IPR	(Elhag and Al-Sharifi, 2014); (Fan, 2014); (Lowe and Muncey, 2009); (Pandey et al., 2016); (Rogers et al., 2015)	5
3.3.3.2	How can business knowledge be protected?	(Chong et al., 2017a); (Fan, 2014); (Pandey et al., 2016)	3
3.3.3.3	Protection for a creation that requires hard work	(Fan, 2014); (Pandey et al., 2016)	2

3.3.3.4	Security and Access Control	(Abdirad, 2015); (Alreshidi et al., 2017); (Azhar, 2008); (Bataw, 2013); (Chong et al., 2017a); (Eadie et. Al., 2013); (Eadie et al., 2014); (Ghaffarianhoseini et al., in press); (Gu and London, 2010); (Hossain et. al., 2013); (Joyce and Houghton,2014); (Lowe and Muncey, 2009); (Mahamadu et al.,2013);(Manderson et al., 2015); (Ngo, 2012);(Olatunji, 2011); (Pandey et al., 2016); (Sun et al., 2015); (Yaakob et al., 2016)	19
	Total		**68**
3.3.4	Unclear Rights and Responsibilities	(Alreshidi et al., 2017); (Chong et al., 2017); (Ghaffarianhoseini et al., 2017); (Hamdi and Leite, 2013)	4
3.3.4.1	Design delegation	(Ashcraft, 2008); (Enegbuma and Ali, 2011); (Pandey et al., 2016); (Sebastian., 2010); (Simonian and Korman, 2010)	5
3.3.4.2	Roles involving coordinating, maintaining and controlling the model	(Hamdi and Leite, 2013); (Kurul et. Al., 2013); (Ku and Pollalis, 2009); (Liu et. al., 2016); (Lowe and Muncey, 2009); (Pandey et al., 2016); (Sebastian,2010); (Sebastian, 2011)	8
3.3.4.3	Auditing models	(Hamdi and Leite, 2013)	1
3.3.4.4	Additional costs arising from BIM implementation	(Arensman and Ozbek, 2012); (Ashcraft, 2008);(Chao-Duivis, 2011); (Elhag and Al-Sharifi, 2014);(Holzer, 2007); (Hamdi and Leite, 2013); (Hossain et al., 2013); (Kurul et al.,2013); (Manderson et al., 2015); (Mehran, 2016); (McAdam, 2010);(Ngo, 2012); (Olatunji, 2011); (Olatunji, 2014);(Sebastian, 2010); (Walaseka and Barszez, 2017)	16

3.3.4.5	Rights of owners to change the design	(Chao-Duivis, 2011)	1
3.3.4.6	Privity of contract and rights to rely on the accuracy of the models	(Abdirad, 2015); (Al-Shamamari, 2014); (Arensman and Ozbek, 2012); (Ashcraft, 2008); (Azhar,2008); (Greenwood et al., 2010); (Hsieh, 2012); (Joyce and Houghton,2014); (Ku and Pollalis, 2009); (Laishram, 2013); (Lowe and Muncey, 2009); (Manderson et al, 2015); (McAdam, 2010); (Olatunji, 2011); (Simonian and Korman, 2010)	15
3.3.4.7	Avoidance of responsibility under means and methods	(Arensman and Ozbek, 2012); (Ku and Pollalis,2009);(Laishram, 2013); (Lowe and Muncey, 2009)	4
3.3.4.8	Spearin Doctrine	(Ashcraft, 2008); (Lowe and Muncey, 2009);(Pandey et al., 2016); (Simonian and Korman, 2010); (Wang et al., 2011)	5
	Total		**59**

3.3.1 Incompatibility of procurement systems with BIM

How a facility is designed, built and maintained has evolved due to the attributes of BIM (Elmualim and Gilder, 2013). BIM practices are said to collide with the design-bid-build professional responsibility principles (Ashcraft, 2008) because in this procurement system, the design responsibilities are assigned to a single entity such as the architect, structural engineer, or MEP engineer, whereas the contractor is in charge of construction. In a collaborative design, the model is no longer directed or supervised by any single entity. Responsibilities could be shared among the model contributors, which raises a critical question: can BIM still deliver its technical benefits without modifying the existing legal framework (Olatunji, 2011)? Two main common legal issues arise when the design-bid-build method is used. First, the nature of the design-bid-build method is viewed as impeding the effective adoption of BIM (Sebastian, 2011). Second, there is a lack of contract forms that clearly mandate BIM practices and address legal concerns (Abdirad, 2015; Ashcraft, 2008; Bataw, 2013).

3.3.1.1 Design-bid-build procurement impedes effective adoption of BIM

There are two distinct viewpoints of the adoption of the design-bid-build method of delivering BIM. Ku and Pollalis' (2009) study revealed that the line of responsibilities of project stakeholders (for example, each discipline creates its own derivative model) can still be maintained well in the design-bid-build procurement system (Ku and Pollalis, 2009). However, another empirical study has shown that there a few limitations remain when adopting this method to deliver the full potential of BIM (Sebastian, 2011). Three main implications arise from these limitations:

(a) More preparation time to formulate the collaboration process is required

To engage design-bid-build interdisciplinary teams in a collaboration for implementing BIM effectively, more preparation time was required to define common project goals, outline the integrated working process and formulate a semi-formal contract that specified the commitments of project participants. Thus, even an architecture firm has an in-house structural engineering department to collaborate using the same software application selected to undertake the design. There is no guarantee that other project disciplines such as the MEP consultants and the contractors would be capable of using their own BIM tool to link directly with the BIM software used by the architecture and structural designer (Sebastian, 2011).

(b) Project participants' responsibilities to work closely with end users remained limited

Even when the means of collaboration were defined at the beginning of the project, limited contractual responsibilities in the design-bid-build setting did not proactively engage project participants such as designers and contractors to work closely with the end user to address project lifecycle requirements (Sebastian, 2011).

(c) Lack of early involvement of contractors

The design-bid-build system hinders early contractors' involvement. In the hospital projects that deployed the design-bid-build procurement method, the contractor's ICT system was only known after the tender stage. Particular attention was then given by the contractor to developing the object libraries (Sebastian, 2011).

3.3.1.2 Lack of contract forms to clearly mandate the BIM practices and address legal concerns

Traditional legal frameworks such as the design-bid-build method are used to accommodate fragmented conventions rather than to share contemporary contractual risks (Olatunji, 2011). Similarly, there is a surge of new legal frameworks or contract documents to address the legal concerns and to outline the roles and responsibilities of parties.

(a) The use of "co-contract document", "inferential document", "geometry statements", and "reference only" in the contract documents

In an effort to incorporate BIM in contract documents, a question was also posted by the industry concerning whether the contracting parties can choose not to incorporate BIM into their contract documents. Typically, project participants used the model as a co-contract document (which governs affairs between the parties), or they used the model as an inferential document (which provides visualisation of the design intent inferable from the contract documents) and/or as an accommodation document (Pandey et al., 2016), such as the geometry statement or "reference only" documents. In the absence of a BIM contract protocol, project participants used BIM by only attaching geometry statement rules to describe the geometry requirements (Ashcraft, 2008). However, deployment of the geometry statement rules in a contract raises a critical issue. The geometry statement rules are not able to convey certain geometric complexities effectively. The best approach is to represent them in the digital model. When the complex geometry in a 3D model is maintained individually without residing in a central data repository, there is a high potential that a geometric discrepancy could occur (Ku and Pollalis, 2009). Another approach is for the designer's CAD file to be used in support of the fabricator's proprietary CAD formats; this service is treated as "reference only" or "information purposes only". The designer's model remains the contract model. With this approach, the designer could warrant the accuracy of his model, but this approach of using the translated file exposes the fabricator to a significant liability (Ku and Pollalis, 2009) that could affect the overall project collaboration. A recent survey performed by Pandey et al (2016) indicated that one of the legal issues encountered was that majority of the designers were confused concerning the component parts of BIM that constitute a record of the contract. Hence, it is evident that potentially adverse consequences exist in project coordination if BIM is not included or is only "somewhat included" as part of a contract.

(b) Conflicts in terms between protocols and principal contract if the standalone amendment contract is used

Some legal terms in the BIM protocol can conflict with clauses of the principal contract. For instance, a BIM protocol might require a more comprehensive intellectual property licensing procedure than that provided under current construction contracts (Ghaffarianhoseini, in press). In a legal case of Fenice Investments Inc. [2009] EWHC 3272 (TCC), the court ruled that the JCT standard building contract (refer to Clause 1.3, which gives priority to the terms of the JCT contract) shall prevail over the Employer's Requirement. This priority means that in the event of a conflict between the JCT contract and the standalone BIM protocol amendment, the JCT would prevail.

(c) Inaccurate, insufficient and inappropriate level of BIM details when delivering models to owners

A significant benefit of using BIM is that the owner can use it for operating and maintaining the facilities. However, in reality, although the delivered models were contractually required by the owners, the owners still could not use the model due to (1) inappropriate detail for facility management needs, which was either more detailed than that provided by the contractor's model or incorporated insufficient details (particularly space and outside buildings) for owners to make strategic decisions; and/or (2) inaccuracy of the model delivered by the contractors because the contractors do not perceive the benefits of updating the model, although they are contractually required to do so (Hamdi and Leite, 2013).

3.3.2 Liabilities

In a BIM collaboration platform, project participants are typically required to share their design information through a common file format to enable other project participants to combine the data with their own data to produce a federated BIM model. Liability arises when there is a requirement for information exchange among project participants. If the BIM information is transferrable to be used by other parties, the designers are at a greater risk of exposure to professional liability (Haynes, 2009). Additionally, other project participants such as contractors are exposed to liability for file translation errors, loss of data or data misuse.

3.3.2.1 Liability exposure to design errors, non-compliant design, transition errors, loss of data or data misuse

It is necessary to determine whether liability or negligence becomes prominent in the contracts with respect to a duty to owner, contractor, designer or a third party (Kuiper and Holzer, 2013). The most significant concern in this area is the liability of the designers' exposure for design error and non-compliant design. If errors in a BIM-related software package result in economic loss to a designer, the designer's recovery is limited to the amount paid to the manufacturer for the software purchase (Pandey et al., 2016). However, this limitation does not exist for designer liability; designers are exposed to greater risks because design error due to imperfections of software can result in a defective model or other deliverable items. Additionally, BIM has common functions to pre-load the data; these functions comply with local building regulations (McAdam, 2010). However, a liability issue can arise when the pre-loaded data are non-compliant. Other project participants including contractors and downstream contractors will also be exposed to greater liability in model sharing due to for example file transaction errors, loss of data or data misuse.

3.3.2.2 Standard of Care

Liability for design is traditionally based on the "Standard of Care" for each discipline. "Standard of Care" is a tort law concept which contract law borrows to define the reciprocal responsibilities of each contracting party. The adoption of BIM gives rise to design issues such as how much collaboration can a designer have on a BIM-related project and still meet his professional standards? To what extent can he rely on his collaborators' contributions and still meet this standard (Pandey et al., 2016)? Design and construction professionals are legally bound to a standard of care that requires them to perform with professional skill and care. Refer to PAS 1192-2 (2013), Specification for information management for the capital/delivery phase of construction projects using building information modelling. Rendition of the native-format model file is being used specifically for spatial coordination processes. It is used to achieve clash avoidance or for clash detection (between, for example, structure and services) between Building Information Models prepared by different disciplines. The key benefit is in reducing errors, and hence costs, before construction commencement. Presumably, if performing clash detection has become a standard BIM use by the designers in the BIM working platform, expectations of the reasonable skill and care of the designers in checking deviations will be higher than with previous practices. To illustrate further, in another example given by Hsieh et al. (2012), the standard of care can arise in the circumstance of BIM software imperfections. If the contract requires the project team members to review the output of the BIM software and discover any inconsistency or error produced by the software, the members would have a higher standard of care based on the rationale that the team members are capable of exercising their care in addressing the adverse ramifications caused by software imperfections. The use of BIM in the working platform of multi-disciplinary teams can potentially change the standard of care of the project participants, which requires further investigation and future research.

3.3.3 Model Ownership and IPR

Compared with other legal issues, the issues of model ownership and IPR were heavily discussed by a majority of the authors. The project participants' output must be shared with others through a common file format, giving rise to the issue of who should own the model and how should the IPR of the designers be protected. In an absence of contract language, the party who creates the model owns it (Larson and Golden, 2007). It is also argued that the owners of the construction projects should own the native model and all of the exported data at the handover stage (Mordue et al, 2015). In a BIM platform, the issue of ownership also arises when each model contributor can potentially have ownership concerns with respect to their repurposing model and data (Arensman and Ozbek, 2012). Bataw (2013) was of the view that the model should be legally retained by the client if the parties classify the BIM model as a product. Chao-Duivis (2009) asserted that the IPR is similar to a traditional collaboration. The model results from a joining of pieces of work from different parties, although the design appears to be unified. Therefore, the IPR of each element should be owned by its creator. The position of this legal issue is difficult to determine because there is no case law to establish a precedent (Eadie et al., 2014).

This issue is also noticeable in the empirical studies (Ku and Pollalis, 2009). A portion of the architect's model belonged to the structural engineer's steel model. The model was shared to the contractor and other downstream subcontractors without including the fabricator and the subcontractors' derivative models. At the same time, the architect remained the owner of the principal geometry, and the detailed fabrication contributions in the model were controlled by the contractor. The model ownership and IPR issues become complicated because there are frequent exchanges and sharing of the models among different project team members. This complication includes the issue of who shall be responsible for the design and fabrication defects. Who among the different project team members ultimately owns the digital models that are part of the integrated work? In the illustrated case, should the model when in the midst of design, of fabrication, and of the final model stage belong to the structural engineer? Architect? Sheet-metal fabricator? Steelwork contractor? Or to the owner who paid for the work? These legal issues are very important from the perspectives of the authors of academic publications. In fact, protecting the BIM contributor's IPR is protecting their business interest against any competitor from using the contributor's ideas for their own profit without the contributor's consent. Additionally, another issue exists that pertains to intellectual property and copyright licences, which typically are either irrevocable/non-terminable, or to licences subject to the payment of fees. As the name implies, an intellectual property licence subject to fees can be suspended or revoked for non-payment, whereas the opposite is true with an irrevocable licence. Hence, there is a high demand from the industry to define these issues in contracts if BIM is used. There are five legal implications identified that pertain to model ownership and IPR issues.

3.3.3.1 Infringement of Another Party's IPR

The individual or organisation can generate profit by suing in instances of patent infringement when copyright is acquired (Lee et al., 2013). In the BIM working platform, the designers must share their design model with other project participants. Moreover, other project participants must use and access the model for the various purposes of the project. Hence, there is a potential for a party to claim infringement against other project participants based on the use of his copyright models (Fan, 2014).

3.3.3.2 How can business knowledge be protected?

In addition, in a BIM working platform, it is difficult to protect business knowledge. Designers are worried that the general contractors will use and modify their design model and sell it to the clients (Pandey et al., 2016). A BIM design model can consist of confidential trade information such as how a model of a manufacturing plant is planned to build and process. Hence, the question of how to protect business knowledge arises (Fan, 2014).

3.3.3.3 Protection for a creation that requires hard work

Another legal issue arises that is seldom discussed but is raised by Fan (2014) is, how does one protect his BIM element creations that require hard work? Most copyright acts indicate that only a unique expression can be protected. Despite the nature of BIM characteristics, an author could encounter an issue when registering a pattern and claiming copyright on BIM elements because he put a great deal of hard work into it.

3.3.3.4 Security and Access Control

The security issue is a hindrance to technology advancement. As the BIM becomes prominent and is stored in a central data repository that is shared with relevant project participants, the risk that data might be exposed to third parties or hackers or affected by viruses will increase. How well can the information be protected if the data are widely disseminated in a collaborative team (Ashcraft, 2008)?

3.3.4 Unclear Rights and Responsibilities

In a common data environment, the deployment of BIM to support multi-disciplinary information transfer has created new dimensions of the rights and responsibilities of project stakeholders in the construction industry (Kurul et. al., 2013). Particularly in the design-bid-build procurement context, it is difficult to ensure that the designers will always be responsible for the creation and amendment of the digital model data (Simonian and Korman, 2010). New roles such as a model manager are discovered and emerge. The model manager has the rights to coordinate the model elements and send and receive model data (Liu et al., 2016), but this point also raises the legal issue of how responsibilities are allocated among the designers, model managers, project managers and other relevant project participants.

3.3.4.1 Design Delegation

BIM is evolving, and it is a challenge for contract documents to keep pace with the new development of BIM. Nonetheless, the contract should address a few basic questions in connection with design delegation. For example, in the design-bid-build procurement system, does the architect remain the leading designer in the collaboration platform? Who shall be responsible for design quality? Who shall ensure that all deviations are resolved and that the model is reliable? How are the responsibilities and input-output workflows of project participants determined if they are involved simultaneously in the process (Sebastian, 2010)? For BIM uses such as automatically detecting changes in the other disciplines and responses to the owned design software, none of the designers checked the information before it is incorporated into the model. In such a case, should the standards committees who create the BIM protocols be “the designer”? What are the responsibilities of another designer? The coordination function of the contracts is to outline the roles and responsibilities of the parties involved in BIM projects to enable them to coordinate the relationship formally. Appropriate limitations of liability and waivers should be considered when developing contract documents (Ashcraft, 2008).

3.3.4.2 Roles involving coordinating and maintaining the model

One of the design delegation issues that are commonly discussed is the role of a model manager. There is no doubt that a model manager will be useful to support greater coordination for developing an integrated model (Gu et al. 2008). However, lack of clarity in the responsibilities of a model manager might impede the full advantage of this role (Liu et. al., 2016). The implications were observed in two hospital projects studied by Sebastian (2011). An independent model manager had been appointed in one of the hospitals, whereas the other hospital assigned the architect to undertake the role of the model manager. The model manager in the former hospital was responsible for consolidating and coordinating all models for clear information exchange. However, this task was not common for the architect in the latter hospital. To perform the tasks of the model manager, ICT knowledge is required to handle the information. This requirement undoubtedly raised an issue concerning the division of roles among the designer, project manager and model manager. It also has implications for designers such as architects who must cope with the BIM ICT system so that they are capable of maintaining their creativity and conducting the design processes.

3.3.4.3 Auditing models

Auditing models is currently a significant issue. Although BIM simulation software has the ability to audit the database fields, an apparent issue is that there is a lack of building-code-review compliance analysis. Consequently, no design will be executable until construction permits are issued and have passed all requirements (Hamdi and Leite, 2013). Additionally, standard protocols stipulate the responsibility of the model contributor to ensure model integrity (ConsensusDocs 301, 2008 and CCP, 2013). However, it is not necessary that a party such as the Contractor comply with the requirements of model deliverables at the end of the models, because there is no provision in the contracts mentioning the consequences and the liabilities of non-compliance. Nor do the contracts define the penalty for non-compliance of the model. Hence, the roles of auditing models to ensure compliance with not only building codes but also employer requirements become significant.

3.3.4.4 Additional costs arising from BIM implementation

A certain level of investment is required to implement BIM. The costs include those of purchasing the software and hardware associated with BIM, management and operation costs, the cost of appointing a model manager and any other associated costs. A legal question that arises is, who shall be responsible for the extra cost? If the project owner requires the team members to use BIM, shall he bear the cost of appointing the model manager? Additionally, whether the project participants are compensated for the additional cost of BIM remains undetermined (Arensman and Ozbek, 2012).

3.3.4.5 Rights of owners to change the design

Another important legal issue is, what rights does the employer receive when the model is delivered to him? A client has the right to realise the design using BIM. However, a more critical question is, does he have the right to alter the design that used BIM? If he has that right, does it mean that he has an exclusive right to alter the BIM design before and during construction (Chao-Duivis, 2011)?

3.3.4.6 Privity of contract and rights to rely on

In risk allocation, one of the main legal concerns is “privity of contract”. The issue of “privity of contract” applies to both the United States and the United Kingdom. The “privity of contract” rules indicate that rights or obligations on anyone can only be granted or imposed on the parties who are involved in the contract (Hsieh et al., 2012). The project team members’ ability to access the shared model gives rise to the right to rely on the contributions of other members. Therefore, is privity an issue? In the presence of this principle, downstream project participants such as the contractor or subcontractor in the traditional procurement who used to rely on the designers' model might not have the right to bring an action against the designer for damages caused by negligent errors because there is no contract bond between the contractors or subcontractors and the designers (Ashcraft, 2008). Moreover, whether the Employer can rely on the accuracy of the information models provided by the project participants is another issue. In the BIM platform, the owners must rely on not only the designer's model but also the information model for other uses such as the model used for quantity take-off and facility management.

3.3.4.7 Avoidance of responsibility under means and methods

In the United States, a central principle of design-bid-build construction contracts is that when a contractor commits to construct in accordance with plans and specifications that are provided by the owner in exchange for payment of a fixed price, the contractor controls his means and methods unless the plans and specifications clearly dictate a particular means or method. In the empirical studies examined by Ku and Pollalis (2009), a fabricator of metal cladding was appointed to provide design advice during the design and construction stages. A proprietary prefabrication of a cladding system was included to define the building skin geometry, whereas the architect was responsible for creating a design model. Hence, there is a greater risk exposed to the Employer pertaining to damages if there is a design defect in the cladding system, but the fabricator was found to have no liability for the defect because he controls the means and methods of the cladding system based on the geometry statement supplied by the designer.

3.3.4.8 Spearin Doctrine

In the United States, the *Spearin* doctrine protects a contractor against a client's assertion of faulty and noncompliant work (Simonian and Korman, 2010). The *Spearin* doctrine ruled that it is adequate for a client's intended purpose if he impliedly warrants the information to the contractor. In other words, the contractor is not responsible if he builds according to the owner's

BIM model. When there is a defect, *Spearin* properly shifts the responsibility to the owner's design team (Foster, 2008). However, note that this principle does not apply if the contractor contributed relevant information in designing a facility. The *Spearin* doctrine is contrasted with the legal position in the United Kingdom, in which the common law is more willing to assign the risk to the contractor (McAdam, 2010).

3.4 Associated Solutions

Table 3.2 shows the solutions associated with the legal issues identified from the standard protocols, guidelines, journals and other relevant references.

Table 3.2 Associated Solutions to Legal Issues

No.	Legal Issues	Associated Solutions	References
3.4.1	Incompatibility of procurement systems with BIM		
3.4.1.1		Amendments to existing contracts	(AIA E203TM-2013, 2013); (ConsensusDocs 301, 2008); (CIC, 2013); (CCP, 2013); (Udom, 2013); (Sebastian, 2011)
3.4.1.2		Adoption of relational project delivery systems	(ACIF, 2014); (AIA Doc. C191, 2009) ; (ConsensusDOCS 300, 2007); (Lahdenpera, 2012); (PPC 2000, 2000)
3.4.1.3		Early contractor involvement	(Palos et al., 2013)
3.4.2	Liabilities		
3.4.2.1		Principles of economic loss doctrine and common law	(Ashcraft, 2008); (Simonian and Korman, 2010); (McAdam, 2010)
3.4.2.2		Addressed by contracts	(ConsensusDocs 301, 2008); (CIC, 2013); (CCP, 2013); (Udom, 2013)
3.4.2.3		Professional Indemnity Insurance	(Ashcraft, 2008) ; (Bataw, 2013); (ConsensusDocs 301, 2008); (CIC,

			2013); (CCP, 2013); (Eadie et al., 2014)
3.4.3	Model Ownership and IPR		
3.4.3.1	Model ownership and IPR	Addressed by contracts	(AIA E203TM-2013, 2013); (CIC, 2013); (ConsensusDocs 301, 2008) ; (CCP, 2013)
3.4.3.2	Infringement of Another's IPR	Addressed by contracts	(AIA E203TM-2013, 2013); (CIC, 2013); (ConsensusDocs 301, 2008) ; (CCP, 2013)
3.4.3.3	Protection of Business Knowledge	Addressed by contracts	(AIA E203TM-2013, 2013); (CIC, 2013); (ConsensusDocs 301, 2008)
3.4.3.4	Protection for a creation that requires hard work	Set up a coding system of parameters or information structure of all BIM elements	(Fan, 2014)
3.4.3.5	Security and Access Control	Addressed by contracts	(AIA E203TM-2013, 2013); (CIC, 2013); (ConsensusDocs 301, 2008) ; (CCP, 2013)
3.4.4	Unclear Rights and Responsibilities		

3.4.4.1	Design Delegations	Addressed by contracts and standard guidelines	(CIC, 2013); (ConsensusDocs 301, 2008) ; (CCP, 2013); (PAS1192-2, 2013)
3.4.4.2	Roles of Coordinating and Maintaining Model	Addressed by contracts	(CIC, 2013); (ConsensusDocs 301, 2008) ; (CCP, 2013)
3.4.4.3	Auditing models	Addressed by contracts	(CIC, 2013); (CCP, 2013); (Hamdi and Leite, 2013)
3.4.4.4	Additional costs arising from BIM implementation	(a) Addendum to professional scales of fees is required. (b) Additional payment to designers is not required if using BIM makes design process more efficient. (c) Employer should responsible to appoint the model manager	(Olatunji, 2011) (Arensman and Ozbek, 2012) (CCP, 2013); (CIC, 2013); (ConsensusDocs 30, 2008)
3.4.4.5	Rights of owners to change the design	The owner may or may not grant the license to change the design which is subject to the agreement.	(Chao-Duivis, 2011)
3.4.4.6	Privity of contract and rights to rely on the accuracy of the models	<u>Privity of contract</u> (a) In the US. Restatement of Torts (Second) Section 552 allows non-contratcual parties claim damages	(Ashcraft, 2008)

		against the other party who aware that the party rely on the accuracy of its model. (b) Also addressed explicitly by contracts. (c) In the UK, the existence of tortious liability for pure economic loss depends on the precise factual nature of the relationship between the parties instead of its designation. <u>Rights to rely on the accuracy of model</u> (a) Parties have rights to rely on the accuracy of the model which are stated in the contracts. (b) Contactor may rely on the information provided by the Owner which depends on the status identified in the Special Conditions.	(ConsensusDocs 301, 2008) (McAdam, 2010) (AIA E203TM-2013, 2013); (ConsensusDocs 301, 2008) CCP (2013)
3.4.4.7	Avoidance of responsibility under means and methods	Only applicable in the US. Deploy contracts to prevent any liability for construction means, methods, techniques, sequences, or procedures.	(Ku and Pollalis, 2009)

3.4.4.8	Spearin Doctrine	Only applicable in the US. Addressed explicitly by the Addendum that it is not intended to restructuring contractual relationship. Hence, the traditional responsibilities and risk allocation of the parties are still remain.	(ConsensusDocs 301, 2008); (Lowe and Muncey, 2009)

3.4.1 Incompatibility of procurement systems with BIM

In addressing the legal issues discussed above, three alternative approaches were adopted by the construction industry: (1) amendments to existing contracts, (2) adoption of relational project delivery systems and (3) early contractor involvement.

3.4.1.1 Amendments to existing contracts

Amendment to the existing contracts without altering the original orientation of the design-bid-build framework is perhaps the most plausible solution in the eyes of most of the project stakeholders because they can still deliver the BIM at the same time, maintaining their conventional lines of responsibilities with a minimum adjustment of their current roles. However, the question to resolve beforehand is whether project stakeholders should develop a principal contract directly by including the BIM related provisions such as the approach adopted by CIOB contract for complex projects (CIOB, 2013), or should they develop a standalone amendment contract such as ConsensusDocs 301 (2008), CIC BIM Protocol (2013) or AIA Document E203TM-2013 (2013). If a standalone amendment contract is required, a statement that mentions the priority of the BIM protocol over other contract documents should be included to avoid an unwanted outcome as mentioned previously. Additionally, elements such as provisions of waivers, indemnities, and liability for contribution should be included in the contract to make it appropriate as a stand-alone amendment (Udom, 2013).

Moreover, it is suggested that the owner and his consultants should define the requirements of the type of BIM software used in the tender documents to avoid requiring additional effort by contractors and fabricators to translate the files at a later stage of the project. Additionally, the owner should set out detailed requirements for model deliverables for his use during the facility operation, emphasise the importance of the deliverables and appoint consultants or a third party to verify the models to overcome cultural pitfalls, for example, contractors not following the model deliverable requirements. Prior to BIM implementation, the agreements which project participants must achieve at minimum include the desired modelling approach, the level of detail of models, and any supporting tools that are required to resolve the complexity of the project and achieve the project objectives by the project participants (Sebastian, 2011). AIA E203TM-2013 (2013) specified that the services of providing a post-construction model shall only be required if a table that defines the types of post-construction model uses, the responsibility of project participants to create or adapt the model to achieve the uses and the location of a detailed description of requirements and services is created. Construction Operations Building Information Exchange (COBie) published by the UK National Building Specification (NBS) is a non-proprietary data format for the publication of a subset of building information models (BIM) focussed on delivering asset data distinct from geometric information. COBie can also be treated as guidelines for project stakeholders involved in delivering the final model.

Although various standard contract protocols have been developed to facilitate BIM implementation, project participants should be aware that the collaboration processes in a building project cannot be standardised – and neither can BIM – because every project has its own characteristics governed by factors such as local building law, project stakeholders' behaviours, and any other external and environmental factors. The standard contract protocols must be tailored carefully to suit the needs of each project.

3.4.1.2 Adoption of relational project delivery systems

Aligned with the BIM implementation in construction projects, the Australian Construction Industry Forum (ACIF, 2014) promotes a project delivery strategy called Project Team Integration (PTI). PTI is a process to facilitate integration, encourage collaborative behaviour, harness the talents and insights of all participants, and reduce waste and optimise project outcomes through all phases of design, fabrication, construction, project handover and facilities management. PTI principles can be applied to a variety of contractual arrangements. IPD, which is heavily promoted in the United States, is one possible end state or result of work to integrate the project team. Apart from IPD, another relational procurement system such as project partnering has been the subject of many development efforts due to the frustration felt towards the opportunism inherent in traditional contracting (Lahdenpera, 2012). Project partnering such as the standard form of contract for project partnering PPC 2000 (2000) creates a single contractual hub that allows all team members to contract on the same terms. The contract aligns project management processes, methods and behaviour, covering all project stages from design to completion. Trust and cooperation are encouraged and promoted through PPC 2000. A standard form of contracts was developed for Integrated Project Delivery (IPD), such as the Standard Multi-Party Integrated Project Delivery (IPD) Agreement (ConsensusDOCS 300, 2007) and the Multi-Party Agreement for Integrated Project Delivery published by the American Institute of Architects (AIA) Doc. C191 (2009). Compared with project partnering, IPD has a more formal decision process, shared liability, a waiver of consequential damages, and gain and pain sharing, which might be optional to limit loss. Both types of relational project delivery systems have common features such as promoting a cooperative culture that leads to mutual respect and good faith, open and active communication and commitment to improvement (Lahdenpera, 2012).

3.4.1.3 Early contractor involvement

Early contractor involvement is heavily promoted by PTI. This practice supports the design-bid-build contractor involved in the design stage in resolving constructability issues. An absence of this practice could lead to an unwarranted dispute. A lawsuit was filed over construction of a life science building (Palos et al., 2013), in which the mechanical, electrical and plumbing (MEP) contractor suffered a loss because no one informed the contractor about the specific sequence that was needed for the system to fit. In this case, the designers used BIM to fit the MEP system into a ceiling plenum without informing the contractor. Consequently, the MEP contractor filed suit against the owner, the owner sued the architect, and the architect’s insurance carrier joined the engineering firm that designed the MEP system. Apparently, if the MEP contractor was involved during the design of the MEP system with BIM, the dispute could have been avoided.

3.4.2 Liabilities

Three approaches were used to address the issues of liability, namely, (1) the application of economic loss doctrine and common law, (2) the use of governing contracts and (3) liabilities covered by Professional Indemnity Insurance.

3.4.2.1 Principles of economic loss doctrine and common law

In addressing the issue of liabilities, application of the economic loss doctrine is different in the United States and in the United Kingdom. In the United States, if a party would like to sue for pure economic loss, he must have a contract with the defendant (Simonian and Korman, 2010). Additionally, purely economic losses cannot be recovered through a cause of action in negligence. The economic loss doctrine is specifically addressed in a restatement provision, and parties with the intention to rely jointly on BIM information are usually in an unfavourable position to apply such damage (Ashcraft, 2008). In contrast, in the United Kingdom, the existence of tortious liability for pure economic loss relies on the parties' factual relationship; such liability is not merely based on their 'contractor' designation (McAdam, 2010). Thus, the legal liability is based on the extent of participation of team members, although there is no direct contractual relationship.

Addressing the issue of standard of care in both countries is based on the contributions of each party to the use of a model in the BIM contracts. The issues pertaining to standard of care are usually determined by the common law or governing contract (Lowe and Muncey, 2009).

3.4.2.2 Addressed explicitly by contracts

Liability related to model corruption was addressed by most of the protocols. ConsensusDocs 301 (2008) Clause 5.1 states that each party shall be responsible for any contribution it makes to a model or that arises from that party's access to that model. Clause 5.8 further grants an extension of time to the party to rectify the error due to the defect in the software and expressly mentions that the grant is only limited to the party who could not avoid any delay or loss by the exercise of reasonable care. Similar to the position of ConsensusDocs 301 (2008), CCP (2013) Clause 10.8 states, "*[T]he Contractor shall ensure that there is no potential or actual clash, conflict, discrepancy, omission, error, inconsistency and/or ambiguity in its design and, where it designs a part of the Works, between the Contractor's Design and any other part of the design.*" Clause 11.3.4 also specifies, "*[T]he Contractor who designs the whole of the works shall select and remain responsible for the suitability and integrity of the selected software and any information, drawings, specifications or another information extract from any model.*"

The provision of CIC (2013) appears to be in conflict with the legal positions of the protocols discussed. CIC (2013) Clause 5.1 states that the project team members shall not be liable for any data corruption except failure to comply with the protocol. Clause 5.2 further specifies, "*[T]he Project Team Member shall have no liability to the Employer in connection with any corruption or any unintended amendment, modification or alteration of the electronic data in a Specified Model which occurs after it has been transmitted by the Project Team Member, save where such corruption, amendment, modification or alteration is a result of the Project Team Member's failure to comply with this Protocol.*" Although the protocol requires the Project Team Members to adhere to the Information Requirements and Model Production and Delivery Table (MPDT), the Project Team Members accept no liability for the accuracy of the model. This provision is close to the liability-avoiding practice in the past, in which the designer's model was marked for "information purposes only". This provision might lead to inefficiency if the Project Team Members feel the need to verify the integrity of an information model that has been submitted into the Common Data Environment (Udom, 2013).

3.4.2.3 Professional Indemnity Insurance

The liabilities encountered by the designers can be insured against. Professional Indemnity Insurance is necessary for the designers in construction projects (Eadie et al., 2014; Bataw, 2013) and for the contractors

(Ashcraft, 2008). ConsensusDocs 301 (2008) Clause 5.7 takes a proactive approach by requiring each party to procure and maintain a minimum value of insurance coverage to cover the party's contributions or intended contributions, include this requirement in the contracts with any other project participants and provide the other with a certificate of insurance demonstrating compliance with the requirements. Although there is no explicit requirement in CIC (2013) to request project participants to procure Professional Indemnity Insurance, CIC (2013a) still provides a best practice guide to indicate what project participants might be required to do to ensure that their professional indemnity insurance arrangements are in order.

3.4.3 Model Ownership and IPR

3.4.3.1 Model ownership and IPR

To address the model ownership and IPR issues, most of the protocols specified that the ownership of the model shall be vested in its original contributor. CIC (2013) Clause 6.2 states that "*any rights (including but not limited to any copyright) subsisting in the Material and any proprietary work contained in the Material shall, as the case may be, vest or remain vested in the Project Team Member.*" If the Employer wants to own all Project IPR, then the protocol will must be amended, and further changes can be required in the project team agreements. ConsensusDocs 301 (2008) Clause 6.4 states that the entitlement of the client to use the full design model shall be governed by the contract between the owner and the designer. The similar approach applied by AIA E203TM-2013 (2013) Article 2.1 states that the transmitting party of digital data is the copyright owner of the digital data; otherwise, he has permission to transmit the data for his use in the project.

To resolve the issue that each model contributor can potentially have concerns with respect to ownership of their repurposed model and data, ConsensusDocs 301 (2008) Clause 6.6 specifies that other parties and project participants who contribute to a model shall not be deemed co-authors of contributions to other project participants unless otherwise stated. AIA E203TM-2013 (2013) Article 2.3 also states clearly that the transmitting party does not convey any ownership right in the digital data or in the software used to generate the digital data. CCP (2013) Clause 10.2.2 applies a similar approach by stating that if the contractor proposes the change to the design, the contractor shall retain the copyright and all other intellectual rights to his design, except that the contractor hereby irrevocably waives any moral rights he might have in the design. Clause 11.3 also states that the copyright of the model of the contractor who designs the whole works shall remain vested in the contractor. However, the solution to the issue of ownership of a model contributor who repurposes the model and data provided by CIC (2013) remains unclear. Although clause 6.2 emphasises that the copyrights or any rights subsisting in the model shall remain vested in the project team members, it does not state clearly whether the party who repurposed the model and data has any right to these elements.

3.4.3.2 Infringement of Another's IPR

To prevent the claim of infringement of another's IPR, most protocols require project participants to grant a license to other project participants to use and access the model. CIC (2013) Clause 16.3 requires project team members to grant a license to the employer and other team members to transmit, copy and use the material, whereas ConsensusDocs 301 (2008) Clause 6.2 specifies that the party of contribution shall grant a license to the project participants to use, reproduce and display or distribute for the project only. AIA E203TM-2013 (2013) Article 2.1 stipulates that "*the transmission of digital data constitutes a warranty by the Party transmitting digital data to the Party receiving digital data … in accordance with the Authorised Uses of Digital Data established pursuant to the terms of the Exhibit*" CCP (2013). Clause 11.1.2 states that if the model is owned by the Employer, the Employer shall grant a license to use the model to the Contractor. In addition, clauses 6 and 7 emphasise that no liability shall arise from using a model that is licensed.

3.4.3.3 Protection of Business Knowledge

Various approaches have been adopted by the standard protocols to prevent the model from being reused by non-proprietary owners. ConsensusDocs 301 (2008) Clause 6.6 stipulates that if the project participants wish to use the model for marketing or educational purpose, this use should be clarified in the contract; otherwise, the license is limited to keeping an archival copy. AIA E203TM-2013 (2013) Article 2.2 also provides protections to the model owner by requiring the receiving party to keep the digital data strictly confidential and not disclose it to any other person who is not involved in the project. Article 2.3 further limits the rights of the receiving party to use, modify, or further transmit the file for designing, constructing, using, maintaining, altering or adding to the project consistent with the Exhibit. Moreover, CIC (2013) Clause 6.5 specifies that the licence granted by the party shall not include the right to amend or modify the Material without the Project Team Member's written consent (not to be unreasonably withheld) save when such amendment or modification is provided for in the Information Requirements or when made for the Permitted Purpose following the termination of the Project Team Member's employment under the Agreement. Nor does the licence include the right to reproduce any proprietary work contained in the Material for any extension of the Project.

3.4.3.4 Protection for a creation that requires hard work

To protect the hard work of the designers, a coding system of parameters or information structure of all BIM elements should be set up by the company involved in the BIM-enabled project. This structure would be similar to the concept of the BIM Object Element Matrix (OEM). Although the geometric expression of a BIM element remains universal, its non-geometric information is expressed uniquely in the coding system. The company could assert its copyright ownership and solve the problem of protecting elements whose creation requires hard work (Fan, 2014).

3.4.3.5 Security and Access Control

Prior to BIM implementation, careful consideration should be given to whether the integrity of the electronic data is guaranteed. It is necessary to have a certain level of insurance protection against financial losses due to breaches of data security (Manderson et al., 2015). Moreover, most of the protocols take a proactive approach to ensuring data security and access control. For instance, ConsensusDocs 301 (2008) Clause 3.2.7 requires the Information Manager to run information system scans routinely to maintain model security. AIA E203TM-2013 (2013) Article 4.8.2.8 requires that project participants responsible for managing the model shall facilitate the establishment and revision of mode management protocols by including model security requirements. CIC (2013) Appendix 2 requires that security requirements and access rights procedures shall apply to the project procedures. CCP (2013) Clause 11.1.4 stipulates that the model shall be maintained in accordance with the BIM protocol under the direction of the Data Security Manager.

3.4.4 Unclear Rights and Responsibilities

3.4.4.1 Design Delegation

ConsensusDocs 301 (2008) Clause 1.1 stipulates, "*[T]he addendum does not effectuate or require a restructuring of contractual relationships or shifting of risks between or among the project participants other than as specifically required per the addendum and the attachments.*" Apparently, this clause suggested that the use of BIM does not require the parties to assume any roles other than their traditional roles. In other words, the architect remains the leading designer in the collaboration platform and remains responsible for the design quality.

In terms of who shall ensure that all deviations are resolved and that the model is reliable for BIM uses such as automatically detecting changes in other disciplines and responding to the owned design software, none of the designers checked the information before it was incorporated into the model. As discussed previously, CIC (2013) has a different position on other protocols; it mentions that no liability shall arise from issues with model integrity. Other protocols such as ConsensusDocs 301(2008) and CCP (2013) require project team members to be responsible for maintaining the integrity of the model. The PAS 1192-2 (2013) information management protocol can be treated as a guideline for parties included in the contracts, defining the responsibilities and input-output workflows of project participants.

3.4.4.2 Roles of Coordinating and Maintaining Model

CIC (2013) Guidance 4 suggests that the information manager function is likely to be performed by either the Design or Project Lead, who could be the consultant or contractor to different stages of the project. This approach is similar to ConsensusDocs 301 (2008); the role of information manager shall likely be performed by the Architect, Engineer or Construction Manager. Both protocols also define the list of roles of the information manager, who shall be responsible for coordinating, updating and maintaining the information model. Both protocols also require the information manager to manage and maintain the model integrity and security in the Common Data Environment or Data Transfer Protocol. However, there is a slight difference in the roles assigned in the CCP (2013). CCP (2013) requires that the design coordination manager shall not only coordinate, update and maintain the information model but also be responsible for part of the role in risk management. The responsibilities of managing and maintaining model integrity and security shall rest with the Data Security Manager. Both the Design Coordination Manager and the Data Security Manager shall be appointed by the Employer; if neither is appointed, the responsibilities shall be assigned to the Contract Administrator. If the Contractor designs everything, the responsibility to appoint the design coordination manager and data security manager shall rest with the contractor.

Although the responsibility to update, review and maintain the consistency of the protocol shall rest with the information manager per 3.7 of CIC (2013) and the design coordination manager in Clause 10.13.2 of CCP (2013), ConsensusDocs 301 Clause 4.1 specifies that these responsibilities should rest with all project participants. Apart from appointing the information manager, CIC (2013) Clause 3.1.1. requires the employer to create and arrange the protocol, which includes the employer information requirement and MDPT (CIC, 2013). However, ConsensusDocs 301 (2008) Clause 4.1 requires all project participants to be responsible for creating and arranging the protocol. For CCP (2013), if the contractor contributes to design the whole works, he is responsible for obtaining the employer's confirmation of acceptance of each level of development. He shall also review the elements that link with the model, notify the Contract Administrator of the person in charge of design coordination, create and range the protocol, and archive the as-built model (CCP, 2013).

3.4.4.3 Auditing models

Auditing here means to audit the quality performance of the model to ensure model compliance with building codes. For instance, CIC (2013) in the MDPT requires contractors to conduct regulation compliance analysis during the project definition and handover stages. Additionally, apart from complying with building codes, the model shall be audited to ensure that it complies with the timeline or model deliverables required by the Employer. CCP (2013) Clause 35.2.1 provides a feasible example by stating that the project time manager shall submit the contractors' design execution plan to the auditor for quality assurance. A management or audit system of all inputs into the BIM model that allocates the responsibilities of the various design consultants, constructors and/or clients is advisable and will assist when addressing liability issues should they arise (Hamdi and Leite, 2013).

3.4.4.4 Additional costs arising from BIM implementation

Olatunji (2011) contended that an addendum to the professional scales of fees is required and that standard remuneration must be defined for BIM projects. However, there is an opinion that the service of the designer is typically billed at the hourly rate; if BIM eventually makes the design process more efficient, the billable hours will decrease (Arensman and Ozbek, 2012). Note that one of the main functions of the contract is to safeguard the parties' transaction cost. Transaction cost arises from an economic exchange (Li et. al, 2013). An example of the transaction cost is the cost arising from using the BIM, as mentioned previously. When a transaction such as the use of BIM becomes more complex and uncertain, parties to the contracts are more likely to enforce a stronger mechanism to safeguard their investments (Parmigiani and Rivera-

Santos, 2011). Hence, it is unsurprising that one of the important legal concerns raised by the authors is who shall pay for the cost of appointing the model manager and any other associated cost. CCP (2013) states that the Design Coordination Manager and Data Security Manager shall be appointed by the Employer. Both CIC (2013) and ConsensusDocs 301(2008) also state that the Employer and its representative shall appoint the Information Manager. This point implies that the Employer shall be responsible for paying the cost of appointing these roles. Concerning who pays the additional cost arising from using BIM, such as the costs of purchasing the BIM software and implementing the BIM, the protocols generally only mention who shall be responsible for appointing the model manager; the payment is required to be paid by the Employer if he would like to use the model of the contributor. Other additional costs shall be paid by the project participants who use BIM in the projects.

3.4.4.5 Rights of owners to change the design

Based on the existing contract practices, it is apparent that clients have the right to change the design. However, if this right is compared with the rights between a website's builder and the employer for whose organisation the website was built, it is possible that the employer has the right to change anything. It is also possible to limit the rights, in which case the owner might only be licensed 'limited use of the website'. A proper contract strategy is required to address such issues (Chao-Duivis, 2011).

3.4.4.6 Privity of contract and rights to rely on the accuracy of the models

In addressing the issue of "privity of contract", the legal solutions provide by the United States and the United Kingdom are different. However, using the collaborative model in both countries lessens the likelihood that the defence of using "privity of contract" will be successful. In the United States, the Restatement of Torts (Second) Section 552 defines the requirements for a misrepresentation claim. Therefore, in the context of the design-bid-build, contractors and subcontractors relying on a model from a designer lacking a direct contractual relationship with them are likely to be able to bring an action against the designer for damages caused by negligent errors because the designer is aware that other parties are relying on the model's accuracy (Ashcraft, 2008). In addition, ConsensusDocs 301(2008) clarifies its position on the issue of "privity of contract". Clause 1.2 states, "*[T]he addendum is not intended to create privity of contract among any project participants beyond that which otherwise exists at law or in the terms of the governing contract.*" In other words, the addendum is not intended to create privity of contract between the design professional and the contractor. As discussed previously in the UK legal position of economic loss doctrine, the existence of tortious liability for pure economic loss depends upon the precise factual nature of the relationship between the parties rather than its designation. The key issue that must be addressed in the BIM working platform is the extent to which participation can give rise to legal liability, even when no contractual relationship might exist (McAdam, 2010). Hence, the best practice is to define in the contracts expressly and clearly the models, levels of model detail and accuracy that project participants can rely on.

Pertaining to the solutions to the issue of rights to rely on the models, the approaches adopted by protocols are different, but they imply a similar meaning – that is, the project participants have rights to rely on the accuracy of the provided models or data only after the agreement or any digital data protocol is formed. AIA E203TM-2013 (2013) Article 3.4.1 states that the party is at his sole risk if he uses the digital data without authorisation before the agreement is finalised or any digital data protocols are established. ConsensusDocs 301 (2008) Clause 5.3 specifies that the project participants can rely upon the accuracy of the dimensions provided as defined in the Contributor's Dimensional Accuracy Representation. CCP (2013) Clause 10.5 specifies, "… [*when*] *the Employer has provided the Contractor with any investigation report, data, maps, Drawings, historical records or any other information of any kind concerning existing structures, the physical ground conditions, subsurface conditions, geology and/or below ground services, it shall have the status identified in the Special Conditions. If no status is stated, such investigation report, data, maps, Drawings, historical records or other information may be relied upon by the Contractor."* Nevertheless, the right of project participants to rely on the model stated in CIC (2013) is rather unclear. CIC (2013) Guidance 5 states, "*[I]t is the responsibility of the Information Manager to agree and issue the Information Requirements, which should be prepared before the Agreements are concluded, as otherwise, the parties will have to rely on the other contractual arrangements, which may not address the items covered by the Information Requirements.*" There is no provision in the protocols that explicitly mentions which models' accuracy the project participants can rely on or that if the Information Manager failed to prepare the Information Requirements, the parties must rely on the accuracy of information provided by other contract documents.

3.4.4.7 Avoidance of responsibility under means and methods

In the United States, it is advisable that project participants involved in BIM-enabled projects include the BIM contract protocols in their contracts to avoid responsibility under means and methods. In an empirical case study by Ku and Pollalis (2009), a contractual provision with respect to the use of BIM to provide information to the contractor and subcontractors was incorporated by the architect. The authors also referred to the AIA standard contract to prevent any liability for construction means, methods, techniques, sequences, or procedures. Including the BIM contract protocol assists the architect in using his design model within the limit of conventional design responsibilities.

3.4.4.8 Spearin Doctrine

In the United States, although BIM contract protocols such as ConsensusDocs 301 (2008) allocate certain responsibilities among the parties, the legal position of ConsensusDocs 301 on the risk allocation of the parties is clear. The document is not intended to restructure the contractual relationship. Hence, in design-bid-build BIM-enabled projects, the architect remains the person in charge of design, and the owner remains responsible per *Spearin* for loss or damage that results in insufficient information supplied by the owner, which includes plans and specifications (Lowe and Muncey, 2009).

3.5 Discussions and Conclusions

Common legal issues fall into four categories, namely, (1) incompatibility of procurement systems with BIM; (2) there is an increasing liability for design errors, transition errors, loss of data or data misuse; (3) model ownership and IPR; and (4) unclear rights and responsibilities of project participants.

The findings revealed that most of the legal issues faced in both the United States and the United Kingdom are similar except for certain issues such as those pertaining to avoidance of responsibility in means and methods – and the *Spearin* doctrine is not applicable in the United Kingdom legal context. Although both countries also experienced the issue of “privity of contract”, the application of the economic loss principle to recover damages for the suffering party due to using the collaborative model was rather different in each country.

The study has several implications. From the perspective of contract drafting, the legal issues and the discussed solutions provide general guidelines for practitioners to select the best option that is appropriate for them to incorporate in their project delivery systems and contracts, which should lead to greater BIM adoption and effective use of BIM. The paper also contributes to conflict management prior to BIM implementation by providing various solutions to the legal issues discussed. The paper fundamentally contributes to the development of knowledge in BIM-based contract administration because it not only establishes knowledge on what is currently applied in the industry but also, more importantly, provides significant insights to practitioners and future researchers on the existing gap found in the findings.

None of the procurement systems is perfect in the eyes of the project stakeholders. However, as is evident in the empirical case studies by Sebastian (2011), despite the protocols indicating that BIM should be defined at the beginning of a project, the use of the design-bid-build method still has its own weaknesses. For example, designers and contractors continue to work within the ambit of their traditional responsibilities without committing to satisfying the needs of end users, which is important in delivering sustainability to a hospital. It is true, therefore, that relational contracting is considered appropriate in applying BIM effectively to deliver project outcomes. Relational contracting such as the IPD project, delivered by most of the project key players engaging on a single contract, with remuneration based on cost-plus expenses and profit only earned if the project was delivered at less than an agreed target cost, can resolve the issue of "privity of contract" (McAdam, 2010). However, the design-bid-build contract delivery method continues to be used in the majority of BIM-enabled projects (Pandey et al., 2016). Thus, early contractor involvement does not mean that the designers are obliged to share their model with the contractor unless express contract provisions to that effect are included in the contracts. However, most clients remain afraid that they might not be able to transfer risk that emerges later in the construction phase as the information is built up in the early contractor appointment (Mosey, 2009). Given the limitations of these alternative approaches to the design-bid-build procurement, a more innovative project delivery system without altering the original orientation of the design-bid-build structure is required so that it can be widely accepted by the industry to deliver BIM effectively. Future research might investigate approaches for improving the trust among contracting parties in the design-bid-build system, because trust is one of the essential elements that promotes collaboration among parties and thereby enhances project performance.

The result of the study also reveals that the standard of care for the designers and other project participants can be altered due to additional contractual responsibilities loaded on the project participants. With respect to the liability issues, the approaches adopted by the protocols in addressing the issue pertaining to the liability for model integrity are different. On the one hand, ConsensusDocs 301 (2008) and CCP (2013) state that the model contributor shall be responsible for model integrity. ConsensusDocs 301 (2008) even provides a provision to grant an extension of time to project participants to address errors that did not result from their defaults. On the other hand, CIC (2013) specifies that project participants shall accept no liability for the model integrity that does not result from non-compliance with the protocol. Both approaches have their limitations. It is unfair for project participants to be liable for the model and data, which are out of their control. Moreover, if the project participants accept no liability for the model integrity, the practice of delivering BIM effectively will become less effective because project participants accept no liability for model accuracy. Further investigation is required to evaluate which approaches can bring the best project outcome. Future research is also required to examine the potential for alteration of the standard of care to reinforce the confidence of the construction industry in addressing the legal issues arising from using BIM. It is also evident that some improvements are required in the existing protocols, such as outlining the roles of the relevant party in auditing the model to ensure compliance with the building regulations and employer's requirements from the beginning of the project until project completion. This role is significant and should be provided in the protocols to ensure that project participants deliver the model according to the requirements, particularly during the handover stage, so that the Employer can use the model for facility management. Current protocols focus on allocating responsibility to the information manager for ensuring the security of the model and data. However, the protocols should also spell out the minimum model and data security requirements.

Certain limitations must be considered because some of the related publications might not be retrievable. In addition, the review of the legal issues and their solutions is based on the literature identified from the fifty-seven (57) conference papers and journal articles based on certain keywords and databases as highlighted in the review methodology, standard BIM contract protocols and other relevant literature sources. It is possible that this study has overlooked certain legal issues and solutions that might also be suitable for inclusion in the papers. Thus, the classification of legal issues can vary depending upon the individual perspective. At present, a considerable amount of time is required to ensure that a virtual model and its associated data are transferred without error. The best contract practices could be achieved if the interfacing issues are resolved and the project participants are willing to accept the legal implications arising from the adoption of BIM.

Chapter 4

Critical Review of Social Network Analysis Applications in Complex Project Management[3]

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Abstract: Social Network Analysis (SNA) is a significant tool for analysing networks in complex project management that examines the actors' interdependence in iterative and interactive social structures. It can also be used for non-social structure analysis. The potential of SNA could be extended significantly if its application to complex project management could be clarified. The objectives of the present review are threefold: (1) to clarify the interpretation of SNA metrics; (2) to identify its applications to complex project management knowledge areas; and (3) to reveal its uses in the non-social structures of complex networks. The authors conducted a qualitative systematic review based on 65 peer-reviewed publications to identify 38 SNA metrics and concepts in nine complex project management knowledge areas. The findings show that SNA is a useful tool for application to the analysis of non-human resource networks and can be used for strategic planning and the

improvement of project transmission efficiency and interdisciplinary interactions. The authors also delineated the future studies and the potential applications of SNA to provide new insights into advancing the use of SNA for analysing and mitigating complex project management issues.
Keywords: Social Network Analysis; Complex Project Management; Metrics; Concepts; Application

4.1 Introduction

One of the reasons for project failure is the increasing complexity of projects (Williams, 2002, 2005), or the underestimating of project complexities (Neleman, 2006). A project is said to be complex when it is structurally complex with many varied elements and interdependencies between those elements (Bacarrini, 1996), when there is uncertainty in the goals and methods (Williams, 1999), and when it is dynamic in nature (Whitty and Maylor, 2009). As such, construction projects are often categorised as being complex due to their inherent characteristics such as their occurrence in an ever-changing, complex environment, often with a high degree of risk (PMI-Construction Extension, 2015). The United States Federal Highway Administration (FHWA, 2010) defined complex projects as those projects that "have a high level of public or congressional interest; are unusually complex; have extraordinary implications for the national transportation system; or which are likely to exceed $500 million in total cost." Cost and schedule overruns for such complex projects are common. For instance, the £798-million reconstruction of Wembley Stadium ran 80% over budget and was delivered four years later than originally planned (Brady and Davies, 2014). The College of Complex Project Managers (CCPM) (CCPM, 2008) defined complex projects as the projects with costs exceeding £1 billion with at least two criteria that are classed as being high. On the other hand, the Chartered Institute of Building (CIOB) Complex Projects Contract (CCP, 2013) did not define complex projects based on their capital value. Instead, they defined complex projects as those that involve the management of a construction period of more than twelve months, a design that is only completed during the construction, have multiple prime contractors, more than 20 subcontractors, multiple possessions and/or access dates, short-period possessions and multiple key dates and/or sectional completion dates. In the context of this paper, complex projects refer to construction projects with structural complexity, high uncertainty, and which require constant change in terms of progress and activity.

Given the complexity arising from the above three features of construction projects, an effective network analysis tool is, therefore, necessary to examine the interrelated elements involved in complex projects and their interdependencies for formulating project management strategies. However, the network analysis methods that the industry uses for the analysis of the complexity of construction projects' networks are subject to limitations. System models such as a flow chart that indicates the communication system of a mass-production firm (Stinchcombe, 1959) and a workflow diagram that demonstrates the project tasks and organisational model (Wong et al., 2009), are capable of conceptualising and constructing a system that deals with linear processes and activities. Directed acyclic graphs (DAG), such as Bayesian networks, which the industry used to analyse safety risks under uncertainty in tunnel construction (Zhang et al., 2014), as well as fall accidents in steel construction sites (Leu and Chang, 2015), are more appropriate for modeling networks that contain no cycles. These techniques are less suitable for modeling more complex and interactive processes in a network that requires repeated and multiple ways of communication. Social network analysis (SNA), the focus of the present study, is a quantitative and qualitative analytical approach that emphasises the integration of social science variables into complex project management. It is a network analysis tool that is appropriate for application to the analysis of the complexity of construction projects' networks which involve many objects and their interdependency relationships which are iterative and interactive (Pryke, 2012). For instance, Brass (1984) and Brass and Burkhart (1993) used it to examine the network influence, while Brass (1981) used it to examine the work flows related to positions. Brass et al. (1998) also used it to investigate how a relationship between actors can affect unethical behaviors while Labianca et al. (1998) and Nelson (1989) used it to examine conflicts between actors. The examination of social capital is important as individuals' social contacts convey benefits that create opportunities for competitive success for them and for the groups of which they are members (Labianca and Brass, 2006). Thus, the rapid increase in network research in management (Borgatti and Foster, 2003) has created a need for a review and classification of the work that is being done in this area.

Nevertheless, the potential of SNA cannot be realised if its potential applications have not been made clear to users. To date, researchers have developed many SNA metrics and concepts but their interpretation and application are rather unusual and complicated. For instance, *degree centrality* is a measure of the direct ties between one actor and other actors and is used to analyse the importance of stakeholders (Doloi, 2012), as well as identify leadership and influence positions within a network. On the other hand, another study asserted that *degree centrality* may not necessarily be a proxy for an actor's leadership position (Solis et al., 2013). *Betweenness centrality*, a measure of the extent of a node that stands between other nodes based on the shortest path, is an important indicator for actors having a major influence and control over the communication flow (Chowdhury et al., 2011). The way in which traffic flows in a network provides a useful means of determining centrality measures (Borgatti, 2005). This indicates that, to understand the application of different SNA metrics and concepts, particularly for centrality measures, it is essential to determine the types of networks and their flows.

None of the studies conducted to date have identified the state of development of SNA in complex project management. The common perception of the use of SNA is that it is limited to networks related to the social sciences. The nature of SNA, however, which analyses the interdependencies of network objects, particularly of the network centralities, is such that it could be used to examine complex networks other than social structures, such as risk factor networks in which the causes of risks interact with each other. Reviewing the development of SNA in complex project management knowledge areas could reveal the usefulness of SNA when applied to diverse types of networks, which could help to enhance its application to complex project management.

Several previous review studies have been conducted to discuss the application of SNA to construction project management. Mead (2001) presented several ways of applying the results of SNA to the visualisation of communication patterns in project teams. Chinowsky and Taylor (2012) reviewed SNA-related publications in engineering project organisations to demonstrate the evolution of the use of SNA. Zheng et al. (2016) conducted a review of SNA applications from the aspects of organisational and individual contributions, coverage topics, research methods, and citations in construction project management research. Nevertheless, none of the studies examined the application of SNA metrics and concepts in detail; nor did they explore their application to complex project management knowledge areas.

Based on the discussions above, the authors conducted a qualitative systematic review to: (1) clarify the interpretation of SNA metrics; (2) identify the application of SNA to complex project management knowledge areas; and (3) reveal its use in the non-social structure of complex networks. The authors selected sixty-five (65) SNA academic publications related to complex project management research from which the authors identified, analysed, and discussed thirty-eight (38) SNA metrics and concepts related to nine (9) complex project management knowledge areas consisting of diverse types of networks. The focus of this study was not merely the exploring of SNA applications and analysing current trends in complex project management knowledge areas, but the provision of significant insights to practitioners and researchers for advancing the application of SNA in future complex project management research.

4.2 Literature review

4.2.1 Complex project management

A complex project is distinguished from a traditional project in terms of its structural complexity, that is, its many and varied interrelated parts, to be operationalised in terms of differentiation and interdependency (Bacarrini, 1996). Williams (1999) asserted that uncertainty should be added to the dimension of project complexity due to the instability of the assumptions upon which the tasks are based. However, structural complexity and uncertainty are not sufficient to give the full dimensions of a project's complexity without considering the dynamic effects of changes to the structural elements. The elements interacting as they change (dynamic nature), cause further changes in other parts of the system (Whitty and Maylor, 2009). The complexity is apparent in technological (Davies and Mackenzie, 2014), organisational (Qureshi and Kang, 2015), environmental (Nguyen et al., 2015) and knowledge sharing (Ahern et al., 2014) aspects. Construction projects are typically viewed as complex projects as they produce complex products which involve the interaction of many systems. A change to one system will affect other systems (Williams, 1999).

There are two distinct viewpoints as to how complex projects should be managed. On the one hand, it is asserted that project complexity will influence the use of processes and techniques (Yugue and Maximiano, 2012), such as strategic design to project delivery, choice of contracting model, criteria and process selection of team members, and the tool sets used in the planning and delivery of the project as outlined in the Complex Project Manager Competency Standards (CCPMS, 2012). Hence, complex projects cannot be managed based on the principles of traditional project management. Various complex project management frameworks and related research have been developed to deal with the complexity of the projects. For instance, Shenhar (2001) identified four levels of technological uncertainty from low-tech to super-high-tech and three types of projects, namely, assembly projects, system projects, and array projects, to address the various levels of complexity from an assembly component with a defined function, such as a computer console, to an integrated dispersed collection of systems used to achieve a common goal such as an airport. Each type of project requires different organisational arrangements and project processes corresponding to the level of complexity. Bosch-Rekveldt et al. (2011) developed a framework for analysing 50 elements contributing to the complexity of the technical, organisational, and environmental (TOE) aspects, in which the elements are divided into various categories, subcategories, and elements, thus allowing stakeholders to discuss the various levels of aggregation and aspects, which make a specific project complex. Vidal et al. (2011) proposed project complexity scales and subscales to highlight the most complex alternatives and their principal sources of complexity within a set of criteria and sub-criteria, which exist in a hierarchical structure**.** Geraldi et al. (2011) presented a contingency framework consisting of five dimensions, namely structural, uncertainty, dynamics, pace, and socio-political complexity, to help individuals and organisations make the right choices on addressing the complexity of each project. Gsansberg et al. (2013) developed a “complexity footprint” that helps the complex transportation project manager identify the sources of complexity; this was developed to allocate appropriate resources for addressing the factors that constrain project delivery. Davies and Mackenzie (2014) developed a two-integration framework, consisting of the “meta-systems integration” level and “system integration” level to allow organisations to understand an overall system with external interfaces with multiple stakeholders and thus coordinate the integration of the component parts and self-contained subsystems to coordinate the interdependencies with other parts of the overall array. The analysis of different project complexities allowed the further study of its impact on technological learning and new product development outcomes, namely project success, development speed, and product entry timeliness (Ignatius et al., 2012). It also enabled the proposal of a quantitative risk assessment methodology to analyse the emergent risks associated with the interactions in a system of complex systems (Naderpajouh and Hastak, 2014) and the examination of organisational control theory (Liu et al., 2014). On the other hand, it is argued that knowing whether a system is complex does not mean that the manager requires complex tools to control or manage it. Traditional methods may continue to be appropriate provided they work well for stakeholders (Whitty and Maylor, 2009). CCPMS (2012) acknowledged the importance of project management knowledge areas from Project Management Body of Knowledge (PMBOK) in managing complex projects and defined a standard that should be observed by complex project managers.

4.2.2 Network analysis methods used in complex project management

Common network analysis approaches applied to complex project management take the form of linear graphical representations such as the Critical Path Method (CPM) (Tavakoli and Riachi, 1990). This task network analysis allows continuous progress monitoring in a changed environment to identify the critical activities. Various scheduling methods are then developed to deal with uncertainty in activities and project durations such as reactive scheduling (Sabuncuoglu and Bayiz 2000), stochastic scheduling (Demeulemeester and Herroelen 2002), fuzzy scheduling (Slowinski and Hapke 2000), proactive scheduling (Davenport et al. 2001), and sensitivity analysis (Hall and Posner 2004), but they fail to consider the logical relationship among the activities (Wang et al., 2014d) and ignore the most important interface management function in complex project management.

Directed acylic graphs such as Bayesian networks are typically used to predict probabilities and determine why causal networks are not cyclic. For instance, Gerassis et al. (2017) used a Bayesian network to quantify and predict the specific causes of different types of accidents. Again, it is less appropriate to analyse whether a network contains a cycle. As discussed earlier, complexity arises in a project and organisational context due to many interrelated parts. These depend on each other to accomplish the tasks. These parts include social elements such as stakeholders, human resources, communications, knowledge sharing, trust, and risks. The social context is interactive and the social elements influence each other.

System Dynamic Modeling (SDM) is very useful for analysing complex structures, which consist of many interrelated variables with non-linear and non-dyadic relationships. It offers the opportunity to simulate a problem by investigating its results and behavior, making the framework useful for policy testing, what-if scenarios, or policy optimisation (Barranquero et al., 2015). Although SNA is clearly very different from SDM as it focuses on social actors and their interrelationships, SNA can indeed be incorporated into the structure analysis of SDM as a complement to SDM. One the disadvantages of SDM is that it lacks operational detail (Williams, 2002). The SDM modeler is often confronted with two problems, namely, (1) how to best describe or model the system and, (2) where to change the system to produce more favorable system outcomes. Centrality analysis of SNA can help SDM modelers address the latter problem by providing a screening tool for finding effective levers in large SD models (Schoenenberger and Schenker-Wicki, 2014).

SNA can complement other research methods for examining uncertainty elements, which are non-social structures in complex projects, and thus present a richer diagram. For instance, SNA can integrate with a link probability model such as the Monte Carlo simulation method to provide a more accurate prediction for network data (McCulloh et al., 2010). SNA allows the examination of project governance using a common methodology for all aspects of governance (Pryke, 2005) in an analytically quantifiable manner, principally through the application of centrality measures (Pryke and Pearson, 2006). The basic structure of SNA consists of nodes (vertices/actors) and ties (a line/ link between two nodes in a network) which are used to detect and interpret patterns related to social ties between vertices. The line is directed (arc) or undirected (edge). For SNA, de Nooy et al. (2001) represented a network by a graph and additional information on the nodes or the lines of the graph. Chowdhury et al. (2011) demonstrated SNA in a one-mode or two-mode network with two types of nodes. An example of the two types of nodes in a network would be stakeholders and their associated risk factors involved in a project (Li et al., 2016).

4.3 SNA application

The SNA metrics and concepts applied in complex project management research can be classified into four categories depending on their role in a network: formation mechanisms of a network, centrality, the connectedness of a network, and the network topology. The formation mechanisms of a network are related to the status of a node and the degree of its power as represented by ties in a network. *Direct tie* measures the number of a node’s direct links to other nodes (Wasserman and Faust, 1997), whereas indirect tie measures the number of links of a node that can be reached through its immediate nodes (Ahuja et al., 2003). *Tie strength* is a measure of the strength of a relationship between two nodes. It is the sum of the frequency of interaction, the intensity of emotion, rapport, and reciprocity (Granovetter, 1973). In terms of the overall network, *network density* is used to indicate the strength of the connections in a network (Marsden, 1993). Typical measures of cohesion include *network density*, *reciprocity*, *clique*, and *structural equivalence*. Alba (1973) also measured the cohesiveness subgroup ratio by comparing the strength of the ties within a subgroup to nodes outside a subgroup.

Faust (1997) used *centrality* to indicate the centralised position of a network. In a network with high centrality, only a limited number of actors function socially, while the others receive, transfer, and deliver information (Liao et al., 2014a). At the node level, *degree centrality* is used to represent the structural position of actors in a network (Hossain, 2009b). *Bonacich power centrality* refers to actors who are tied to central actors having higher prestige or centrality than those who are not (Bonacich, 1987). *PageRank* is another centrality measure devised by Brin and Page (1998) that counts both the quantity and quality of the followers of a node to determine the degree of influence of that node. Depending on whether an actor has more incoming or outgoing ties in a network, the actor is said to have a high *in-degree centrality* or high *out-degree centrality*, respectively (Liebowitz, 2006). Another type of centrality measure is *2-step reach*, which sums the number of nodes within two steps (thus including the adjacent nodes' degree centrality) of a node (Borgatti et al. 2002). *Closeness centrality* measures the length of the path from one node to all other nodes (Hossain and Wu, 2009). The measurement of distance includes *diameter* and *geodesic distance*. *Geodesic distance* is the shortest path between two vertices (De Nooy et al., 2011), whereas *diameter* is the longest geodesic distance between any pair of nodes (Torres et al., 2016). As the path between two nodes becomes shorter, the efficiency with which information is transmitted will increase. Therefore, the *average path length* is an indicator of the network efficiency (Lin, 2014). An actor with a high *betweenness centrality* value has some control over the network as other actors depend on this actor to connect to each other, as in the case of *brokerage* (Chowdhury et al., 2011). If there is a *structural hole* (a form of discontinuity in the flow of information) in a network, the person holding the *brokerage* position can capture a strategic position to connect or disconnect a group, and thus, enjoys a competitive advantage relative to other nodes (Maoz, 2010). *Eigenvector centrality* is an extension of *degree centrality* and is proportional to the sum of the centralities of a node's neighbors (Estrada and Rodríguez-Velázquez 2005). *Status centrality* (also known as Katz centrality) is similar to *eigenvector centrality* in that it also reflects a stakeholder's influence within a network. It measures the number of direct successors and predecessors of a node, as well as the secondary nodes that are indirectly linked to the focus node via the node's immediate neighbors (Katz, 1953).

SNA is also capable of assessing the level of connectedness among actors and subgroups in a network. At the node level, the *clustering coefficient* is the percentage of two paths in a network that are closed (De Nooy et al., 2011). *Structural equivalence* describes any two nodes that have similar and identical ties (McCormick et al., 2010). *Reciprocity* is the ratio of the number of reciprocated node pairs to the number of connected node pairs (Lee et al., 2016). *Transitivity* indicates the possibility of node A having a connection with C, if A knows B and B knows C. It is the proportion of triads and the number of triples (Bruggeman, 2013). *Point connectivity* represents the minimum number of nodes that must be removed from the graph to cause the graph to become disconnected (Wasserman and Faust, 1997). *Partitioning* is used to classify the nodes in a network (De Nooy et al., 2011). It involves the assignment of a similar color to nodes or edges that share the same values for a given SNA parameter or node/edge attribute (Hernandez-Garcia and Suarez-Navas, 2017). *Modularity* measures the strength of the division of a network into modules (groups or clusters). It distinguishes the number of existing links in a *partition* and the expected number of links that could appear between the nodes of the partition (Nik-Bakht and El-Diraby, 2016). *Homophily* explains how, when offered a choice, people prefer to choose others who are similar to themselves (Kleinbaum et al. 2013). When the relationship between the nodes is compact, it is said to form a *core*. When the relationship between the nodes in another group is loose, it is regarded as being a *periphery* (Chang and Zhang, 2013). *Boundary spanner* is another term that is typically used to describe the role of an actor as a mediator to conciliate the negative effects arising from differences in status and culture (Di Marco et al., 2010).

This study addresses the concepts of *components*, *small-world* networks, *scale-free* networks, and *egocentric* networks with respect to network typology. A *component* is a maximally connected sub-network (De Nooy et al., 2011). A *giant component* represents the largest isolated sub-network usually identified in a random SNA network (Liu et al. 2015). In contrast to the *giant component*, Blackburn (2002) observed a *small-world* network when most nodes are not neighbors, but they can reach each other in a small number of steps. An *egocentric* network is a personal network. This *scale-free* network has a degree distribution determined by the social group's size distribution. It presents SNA data using a random graph model to observe the expected network structure within a collected data set (Comu et al., 2013). Note that, although the SNA metrics and concepts have been discussed in various categories, there are always interrelated dependencies in the context of a study.

4.4 Complex project management knowledge areas

The complex project management knowledge areas discussed in this study were obtained from the specific project and organisational applications. The classification of the SNA applications was performed in accordance with the project management knowledge areas categorised by the Project Management Institute (PMI)-construction extension (2016) and management knowledge areas as stated in the PMI (2013). The PMI-construction extension (2016) considers the complex nature of construction projects in its deliverables. Moreover, the authors believe that analysing the state-of-the-art of SNA in complex project management should begin with its application to each project management knowledge area. Network behavior is added as one of the knowledge areas in the present study if the references found are rather general and could not be applied to any of the areas stated in the PMI references. Thus, network behavior is classified as an independent area as the network analysis for understanding organisational behavior is also important in complex project management. The mapping of complex project management knowledge areas to SNA applications provides an easy reference for educators, practitioners, and researchers who need to learn about the types of networks to which SNA is applied and which could help to uncover any non-social structure networks that are applied to the SNA in complex project management knowledge areas. Table 4.1 lists the complex project management knowledge areas identified in this study.

Table 4.1 Complex Project Management Knowledge Areas

Knowledge Area	Description
Network Behavior	Involves the analysis of human interaction behaviors (Pryke and Smyth, 2006) such as inter- and intra-project or organisational relationships
Stakeholder Management	Relates to the management of stakeholder engagement such as the processes of identifying people, groups, or organisations that could impact or be impacted by the project, and adopting effective project management strategies to engage them actively in project decisions and execution
Schedule Management	Covers any time-related processes and activities that contribute to project completion, and involves the definition of the activity, sequencing the activity, activity resource and duration estimating, schedule development, monitoring, and controlling
Quality Management	Ensures that all processes involved in the complex project system satisfy project requirements such as quality planning, quality assurance, and quality monitor and control. The quality planning described in this paper extends the scope to include the improvement of quality in the works involved from planning to completion.
Resources Management	Refers to the management of human resources, machinery and tools, equipment, bulk materials, etc., and includes the mobilising, utilising, and demobilising of resources
Communications Management	Involves the communication planning, managing, monitoring, and controlling of the information flow to ensure the effective and efficient generation and distribution of information
Risk Management	Deals with the identification, planning, analysis, management, monitoring, and controlling of positive

	and negative events connected to stakeholders' interests
Procurement Management	Deals with the procurement of contractual arrangements between a multitude of clients and contractors, sellers, and buyers, and includes the procurement of capital, project equipment, and materials
Health, Safety, Security, and Environmental (HSSE) Management	Involves the planning, execution, monitoring, and control of the health, safety, security, and environmental aspects of complex projects

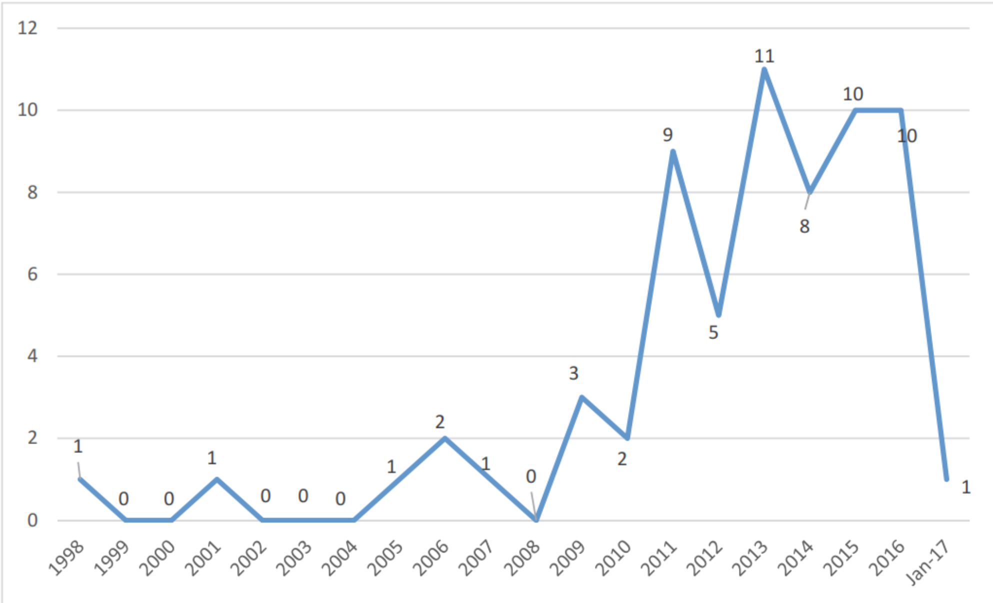
Main sources: PMI-construction extension (2016) and PMI (2013)

4.5 Review methodology

A qualitative systematic review method is selected as it not only integrates and compares the findings from the papers identified, but it also looks for themes that lie in or across the papers (Grant et al., 2009). The systematic review procedures were simulated from the steps outlined in Moher et al. (2009). The steps of systematic review begin with identification of the primary studies through database searching. Then, the authors conducted an intensive literature search of relevant papers listed in the Scopus database. The keywords used in the search were “SNA project management,” “SNA complex project,” “SNA engineering project,” and “SNA construction project” with no limitation regarding the year. The authors obtained 95, 30, 30, and 56 document results found using these four keywords, respectively. The papers selected for the study were all peer-reviewed to ensure the quality of the data obtained. Thereafter, the authors screened the papers found from the database to identify and confirm whether the SNA application described in the papers was related to construction projects. The authors assessed the full text of articles to identify their eligibility to be included in the study. The selection of papers was based on the context of construction projects as such projects consist of many complex elements which could be applied to complex projects. If a paper provided only a general discussion of SNA without showing the application of SNA in construction project networks, the paper was excluded from the study.

Sixty-five peer-reviewed journals that discussed the SNA applications in complex project management ranging from 1998 to January 2017 were identified in the present study (Figure 4.1).

Figure 4.1 Number of SNA journals from 1998 to January 2017



From 1998 to 2010, the numbers of papers that mentioned SNA in relation to complex project management research were within a range of 0 to 3 per year. After 2010, SNA becomes a popular analytical tool as the number of papers making mention of it increases sharply, reaching a peak of 11 in 2013. Table 4.2 lists the journals that were reviewed as part of the study.

Table 4.2 Titles of Journals

Title of Journals	**No. of Papers**
Building and Environment	1
Building Research and Information	2
Computer-Aided Civil and Infrastructure Engineering	1
Construction Economics and Building	1

Construction Management and Economics	6
Engineering Project Organization Journal	2
Engineering, Construction and Architectural Management	2
Ergonomics	1
Facilities	2
Industrial Marketing Management	1
International Journal of Networking and Virtual Organizations	1
International Journal of Project Management	7
Journal of Civil Engineering and Management	1
Journal of Cleaner Production	1
Journal of Construction Engineering and Management	17
Journal of Infrastructure Systems	2
Journal of Management in Engineering	10
Journal of Professional Issues in Engineering Education and	1
Practice	1
KSCE Journal of Civil Engineering	2
Project Management Journal	1
Safety and Health at Work	1
Safety Science	1
Technology and Investment	
Total	65

The authors then categorised each paper into different knowledge areas based on the main purpose of the SNA study. Although a paper may span several knowledge areas, the authors grouped it into a certain knowledge area based on the main purpose of the study, which contributes to the output of the knowledge area. Table 4.3 lists the papers reviewed in the study which were grouped into different knowledge areas.

Table 4.3 Papers Reviewed in the Study

Knowledge Area	**References**	**No**

Network Behavior	Akgul et al. (2016); Cao et al. (2016); Liu et al. (2015); Lu et al. (2015); Park et al., (2011); Sedita and Apa (2015); Son and Rojas (2011);	7
Stakeholder Management	Almahmoud and Doloi (2015); Doloi (2012); Nik-Bakht and El-Diraby (2016); Solis et al. (2013); Yang et al. (2011); Swan et al. (2007); Williams et al. (2015)	7
Schedule Management	Wambeke et al., (2012); Wambeke et al. (2013)	2
Quality Management	Aljassmi et al. (2013); Dunn and Wilkinson (2013); El-Adaway et al. (2016); Lin (2014); Pishdad-Bozorgi et al. (2016); Woldesenbet et al. (2015)	6
Resources Management	Badi et al. (2017); Larsen (2011); Li et al. (2011); Lin and Tan (2014); Pryke et al. (2011)	5
Communications Management	Arriagada and Alarcón, (2013); Chinowsky et al. (2010); Chinowsky et al. (2011); Comu et al. (2013); Di Marco et al. (2010); Di Marco et al. (2012); Dogan et al., (2014); Heng and Loosemoore (2013); Hossain (2009a); Hossain, (2009b); Hossain and Wu (2009); Houghton et al. (2015); Javernick-Will (2011); Loosemoore (1998); Pauget and Wald (2013); Priven and Sacks (2015); Ruan et al. (2012); Tang (2012); Thorpe and Mead (2001); Wanberg et al. (2014); Zhang et al. (2013)	21
Risk Management	Li et al. (2016); Mohammadfam et al. (2015); Yang and Zou (2014)	4
Procurement Management	Chowdhury et al. (2011); Lee et al. (2016); Pryke (2005); Pryke (2006); Pryke and Pearson (2006); Santandrea et al. (in press); West (2014); Zhang et al. (2015)	8

HSSE Management	Alsamadani et al. (2013a); Alsamadani et al. (2013b); Liao et al. (2014a); Liao et al. (2014b); Wehbe et al. (2016); Zhou and Irrizary (2016)	6
TOTAL		65

During the data analysis process, the authors prepared the data according to the purpose of the SNA study in each knowledge area, the type of network study and SNA metrics, and the concepts discussed in each paper. One of the authors compared, investigated, and discussed the application and interpretation of the SNA metrics and concepts that were used for similar types of networks and their purpose in each knowledge area in the manuscript. The other two authors audited and validated the analysis to ensure the credibility of the systematic review. Finally, the authors abstracted the findings based on the three objectives identified in the Introduction.

4.6 Analysis of SNA applications in complex project management

The authors grouped the SNA metrics and concepts identified from the 65 journals according to the knowledge area and then aggregated them into Microsoft Excel. The authors conducted the analysis based on two modes, with one representing the knowledge areas and the other describing the SNA metrics and concepts. After summing the SNA metrics and concepts in each knowledge area, the authors exported the data in the Excel spreadsheet to UCINET v. 6 for two-mode analysis. *Degree centrality* was used to identify the most connected SNA metrics and concepts in each of the complex project management knowledge areas. The *degree centrality* in this two-mode network study represents the maximum degree of a node given by the number of nodes in the opposing set (Borgatti and Everett, 1997). This implies that the maximum degree for an SNA metric or concept is the total number of knowledge areas, while the maximum degree for a knowledge area is the total number of SNA metrics and concepts. Table 4.4 lists the results of the analysis.

Table 4.4 Degree centrality of SNA metrics and concepts in complex project management knowledge areas

Rank	SNA Metrics/Concepts in the Complex Project Management Knowledge Areas	Degree
	SNA Metrics/ Concepts	
1	Network Density	0.889
2	Degree Centrality	0.889
3	Betweenness Centrality	0.889
4	In-Degree Centrality	0.778
5	Tie Strength	0.667
6	Average Path Length	0.667
7	Brokerage	0.667
8	Out-Degree Centrality	0.556
9	Power	0.556
10	Closeness Centrality	0.556
11	Eigenvector Centrality	0.556
12	Cohesion	0.444
13	Diameter	0.444
14	Clustering Coefficient	0.444
15	Structural Equivalence	0.444
16	Core or Periphery	0.444
17	Ego Network	0.444
18	Components	0.444
19	Scale-Free/Power-Law	0.333
20	Structural Holes	0.333
21	Clique	0.333
22	Small-world	0.333
23	Direct Ties and Indirect Ties	0.333
24	Modularity	0.222
25	Homophily	0.222
26	Boundary Spanner	0.222
27	Cluster Analysis	0.222
28	Transitivity	0.222
29	Reciprocity	0.222

30	Giant Component	0.222
31	Partition	0.222
32	Centrality	0.222
33	Status Centrality	0.222
34	Out Status Centrality	0.222
35	Gap-Degree	0.111
36	2-step reach	0.111
37	Point Connectivity	0.111
38	PageRank	0.111
	Knowledge Areas	
1	Communications Management	0.632
2	Procurement Management	0.579
3	Network Behavior	0.526
4	Stakeholder Management	0.474
5	Quality Management	0.368
6	Risk Management	0.368
7	HSSE Management	0.342
8	Resources Management	0.263
9	Schedule Management	0.079

Table 4.4 lists the centrality position of the 38 SNA metrics and concepts in 9 knowledge areas. A higher centrality value indicates that more SNA metrics and concepts are applied to the analysis of a network. From the viewpoint of knowledge area, the results show that most of the SNA metrics and concepts discussed applied to communications management. A wider application of the SNA metrics and concepts is also evident in procurement management and network behavior. With respect to SNA metrics and concepts, *network density*, *degree centrality*, and *betweenness centrality* recorded the highest centrality values relative to the other nodes. This implies that these metrics are the most influential measures in the analysis of complex project networks. *In-degree centrality* also has the second-highest centrality values, suggesting that it is also significant to complex project networks. The authors discuss the application of SNA metrics and concepts to complex project management knowledge areas in the subsections below.

4.6.1 Network behavior

In the context of network behavior, SNA was used extensively to analyse a firm's collaborative behaviors. Network density was used to determine the connectivity level of firms (Lu et al., 2015). A low-density network has a dispersed structure (Akgul et al., 2016), suggesting a low level of cohesion (Sedita and Apa, 2015). However, this is subject to the network size (Park et al., 2011). This metric was also used to perform measurements in conjunction with *degree centrality* to identify state-owned organisations such as designers and contractors. Cao et al. (2016) identified these by observing nodes that had large linkages with those occupying central positions. Lu et al. (2015) used *degree centrality* to identify the importance of nodes such as the clients of private projects and the prestige gained by firms owing to their winning of public projects (Sedita and Apa, 2015). Large firms who had higher *out-degree centrality* and *betweenness centrality* were more likely to make a profit as they attracted more partners and had a higher social influence (Park et al., 2011). However, the *betweenness centrality* of firms had no impact on the likelihood of their winning public projects (Sedita and Apa, 2015). Park et al. (2011) identified *closeness centrality* as being an insignificant measure for small firms who wanted to gain by engaging in diversification and close cooperation and for firms who wanted to win public projects (Sedita and Apa, 2015). Akgul et al. (2016) used *Eigenvector centrality* to determine the significance of firms that typically had the most experience and which were thriving in terms of international collaboration. The numbers of *direct ties* and *indirect ties* were also seen to boost the capabilities of a firm (Park et al., 2011).

Liu et al. (2015) used the *average path length* to investigate the extent of the connectivity of two firms over different time spans. This enabled the assessment of the evolution of collaboration behaviors. The *average path length* and *clustering coefficient* identified the *small-world* properties of firms that exhibited a high possibility of forming *small-world* properties (Cao et al., 2016). Akgul et al. (2016) used *connected components* to identify the leading companies and *giant components* to determine the appearance of large contractors' components in the collaboration network. Liu et al. (2015) found that the *scale-free* network was particularly important in determining certain revolutionary regularities such as the regional, professional, and social capital preferential attachment of firms engaging in collaborative behaviors. *Homophily* also proved useful in ascertaining owners' tendencies when selecting new project partners with specific similarity attributes like firm ownership and relevant BIM experience. Cao et al. (2016) used a *core-periphery* analysis to understand the persistence of the uneven distribution of collaborative ties for networks over different time spans.

4.6.2 Stakeholder management

To examine stakeholders' influence networks, Doloi (2012) used *degree centrality* in conjunction with the social performance index to determine the importance of stakeholders. As a result, it was found that *degree centrality* could be associated with the stakeholders' power and interest in a project). However, in another influence network, *status centrality* was identified as being a significant measure for determining the stakeholders' prominence, while using the *out-status centrality* to identify the degree to which one stakeholder affected others. Yang et al. (2011) used the *status centrality* to adhere to the project management team's roles.

To analyse trust networks of contractual and non-contractual relationships between project stakeholders and their impact on project performance, Swan et al. (2007) used *direct ties* to determine the trust between two nodes. It should be noted that trust is not equivalent between two nodes given the fact that while A may trust B, B may not necessarily trust A.

To analyse the social core functions of project stakeholders (Almahmoud and Doloi, 2015), the researchers used *eigenvector centrality* to quantify the importance of the stakeholders and social core functions. It was incorporated into a stakeholder's social sustainability health check dynamic assessment model to identify problems affecting project performance enhancement.

To investigate the communications networks of the community of interest, researchers used various measures to determine the influence of the nodes. *Betweenness centrality* was used at the initial stage to identify the online community that has a major influence on information flow, while *degree* *centrality* was used at a later stage to determine the users' influence based on their occupations, affiliations, and locations (Williams et al., 2015). However, in another study, the researchers integrated *PageRank* with semantic analysis to determine the members' degree of influence and to detect a community in a complex project discussion network. The network consisted of a knowledgeable e-society in which members could freely access information about a complex project and discuss its different aspects. Furthermore, the *modularity maximisation* algorithm was used to determine the communication density of a partitioned community (clusters) by performing matching with high computational efficiency and accuracy (Nik-Bakht and El-Diraby, 2016).

Although *degree centrality* was viewed as being the determinant of influence and prominence position in the stakeholders' influence networks, it was not necessarily a proxy in an information exchange network. In this context, it indicated actors through whom information frequently flowed, and was used to identify the drivers of stakeholder behavior associated with their roles in projects such as *central connectors*, *boundary spanners*, *information brokers*, and *peripheral persons*. *Cluster analysis* was used to demonstrate stakeholders' tendencies to develop ties with those who shared disciplinary knowledge (Solis et al., 2013).

4.6.3 Schedule management

There were very few studies about the use of SNA in schedule management. Only two studies were conducted to analyse the interactions of trades for identifying the key trades to be used in a critical path method (CPM) schedule (Wambeke et al., 2012; Wambeke et al., 2013). Both selected *degree centrality* and *eigenvector centrality* as important measures for identifying the key trades. In addition, trades having greater frequencies were identified as having stronger ties as they often worked together with other trades that were close to each other (Wambeke et al., 2013).

4.6.4 Quality management

The application of SNA to quality management was found to be related to the improvement of project deliverables. To analyse the interrelationships between the defect causes of a complex engineering system, Aljassmi et al. (2013) used *in-degree centrality* to determine the extent of a cause that originated from other causes directly linked to it. This was particularly important for determining the initiating causes of the defect. *Closeness centrality* determined the closeness of a cause to all other latent conditions by considering its preoperational capacity. *Tie strength* was used to determine the causal strengths of the causes of defects based on conditional probabilities.

To determine the essential quality management practices of flash-track projects, *out-degree centrality* to identify the extent of a practice that enabled other practices. On the other hand, the extent to which a practice depended on other practices was measured by applying the *in-degree centrality* measure. *Eigenvector centrality* was also used to identify the importance of a practice by determining the feasibility of the said practice as a consequence of other practices. *Tie strength* was measured to determine the relational intensity of a practice with other practices. (Pishdad-Bozorgi et al., 2016).

To uncover the latent job-site management problems of a dam project, Lin (2014) investigated the order management network, technological-consultation network, personal social networks of the owner, joint venture partner, engineering consulting firm, and sub-contractors involved in the project. The *network density* in the order-management network represented the abundant resource infusion and institutional enforcement of the projects. *Degree centrality* was used to analyse the structure positions of the three networks to discover any unrealised social patterns. For instance, the site manager and principal engineers were found to be the central figures in the order-management and technological consultation networks, but they became outliers in the interpersonal social network. Two network topologies were proposed to ensure the effective execution of the project. One was a *giant network* of two interconnected hierarchical structures consisting of the owner and contractor that could increase the order and information transmission efficiency within the networks. A *small-world* architecture was proposed for the technical consultation network to promote interaction between the interdisciplinary teams that might lead to a technology revolution while avoiding engineering errors caused by the misalignment of technological interfaces (Lin, 2014).

Woldesenbet et al. (2015) used SNA as a complementary tool for improving construction project planning in addition to the existing complex project SNA. For a highway data-information-decision network, efficient highway infrastructure data was determined by using the network density to determine the reliability of the information used to support the decision-making process. *Degree centrality* was used to determine the most influential highway data that generated decision-making information. Furthermore, *betweenness centrality* was deemed important in the context of highway data management as it measures the degree to which nodes acted as mediators between data and decisions. High *eigenvector centrality* data indicated data that had the greatest number of connections, while high *eigenvector centrality* information provided the greatest number of paths to create a bridge between the data and decisions that were considered critical (Woldesenbet et al, 2015).

To improve the quality of traffic planning, El-Adaway et al. (2016) used tie strength to identify the impact on a traffic intersection network. The *nodal degree* was used to determine the criticality of intersections by determining the opportunities and alternatives to reach anywhere in the network. The *2-step reach* was used to determine the importance of intersections in the local area when the connection strengths of the nodes were very close to each other. Intersections located on a loop roadway had a lower *betweenness* value than the intersections of a roadway that passed through a city center and connected many other roadways. *Eigenvector centrality* was also useful as it considered the high-traffic-count connections to a node (El-Adaway et al., 2016).

There is very little evidence of the significance of SNA measures in the application of SNA to the improvement of the quality of water distribution network planning in vulnerable areas. Previous studies were unable to prove that the most connected node was that with the highest centrality (the most important node) (Guimera et al. 2005; Cadini et al. 2009). The studies under consideration did not consider the service of network flows nor did they remove the nodes to gauge the effect on performance. Graph theories such as *scale-free/power law*, *small-world*, and the *random graph* model, as well as centrality measures such as *degree centrality, betweenness centrality*, and *closeness* *centrality* were used to simulate the distribution flow in a hydraulic model. A strong correlation between the distribution flow through the nodes in the network and the network *average path length* suggested that parts of graph theory were applicable to the engineering network. Dunn and Wilkinson (2013) found a strong correlation between the three centrality measures and the flow through the corresponding node in the *scale-free* network.

4.6.5 Resource management

In the analysis of actors' innovation awareness and the influence of their opinions, centrality measures were not found to be significant but the network orientations became important. An overtly *egocentric* network adversely affected awareness and influence because of the actors' ignoring messages from outside the network (Larsen, 2011).

Network density was used to assess the connectivity in the case of other types of resource networks. This included the client, referral, financing, authority, supplier, and internal market networks of construction firms (Badi et al., 2017); order-oriented networks and social networks of complex construction firms (Li et al., 2011); advice networks, trust networks, friendship networks, information networks, sharing willingness networks, and cognitive networks of public employees (Lin and Tan, 2014); information, advice, brokerage, and funding networks of owners of small construction firms (Pryke et al., 2011). For an *egocentric* firm network, a high *network density* value indicated that the firm was better placed to access an exclusive market. In contrast, a low *network density* indicated that the firm had fragmented suppliers and client markets (Badi et al., 2017). Pryke (2011) used this metric together with *degree centrality* to determine how small firms developed essential resources to survive and grow. Badi et al. (2017) used *degree centrality* to determine the prominence and privileged position of a firm for controlling resources in the business environment (Pryke et al., 2012), and that firm's competitive ability to manage complex projects (Li et al., 2011). *In-degree centrality* was useful for identifying the importance of public employees who were recognised by others and who retrieved information from others.

Employees with high *betweenness centrality* were found to be important connective candidates (Lin and Tan, 2014).

Tie strength was significant in resource networks as an indicator of the potential use of resources of firms in a network (Badi et al., 2017). Weak ties were advantageous for the individuals in a resource network as they could exert their power and control over resource flows while breaking their connection with others. A *brokerage* is an actor who facilitates the complementary interests of unconnected actors. Although not a resource itself, a *brokerage* formed a crucial aspect of a small business's resource provision network. Nevertheless, Pryke et al. (2011) proved that the frequency of communication for any resource was an imperfect proxy to *tie strength* given that there was no correlation between them. In addition, in a resource network, Li et al. (2011) deployed *structural equivalence* to determine the key actors in a network who had cliqued to set a specific control strategy.

4.6.6 Communications management

Most of the SNA studies were applied to communications management. Flows in communication networks represented coordination, information, negotiation, and knowledge exchanges that created trust. A low-density value indicated that the network focused on individuals rather than on collaboration over the network (Chinowsky et al., 2010). *High density*, high *degree centrality*, and low *betweenness centrality* in communications networks indicated fewer *structural holes* (Heng and Loosemoore, 2013). High-density and strong ties in information exchange networks developed trust. Therefore, the information required by actors was easily acquired (Pauget and Wald, 2013).

Various types of centrality applications were found in different communication networks. Just as degree centrality indicated the prominence and influence of actors' positions, centrality for the whole network was used to enable a comparison of knowledge exchange networks in collaborative and comparative procurement systems (Ruan et al., 2012). For negotiation networks, a node occupying high *degree centrality* indicated its importance to project participants' discussions (Di Marco et al., 2012). In information networks, it represented the roles of project team members when information flowed through them (Thorpe and Mead, 2001). A superintendent officer associated with a high degree of centrality typically played a crucial role as almost all the communication between trade contractors was found to flow through him/her (Priven and Sacks, 2014). The *in* and *out-degree centrality* could be measured simultaneously based on the number of ties connected to an actor. If an actor in a network was an important provider of information (*out-degree centrality*) and he/she had enough connected ties, then his/her network position visibly corresponded to the role of a coordinator (Pauget and Wald, 2013). In coordination networks, it was proven that actors who had a high degree of centrality were more capable of coordinating a project (Hossain, 2009a; Hossain, 2009b; Hossain and Wu, 2009).

In communications networks, actors with high *betweenness centrality* could utilise their network advantage to manipulate the information flow for their own interests (Loosemoore, 1998) and this was viewed as a position of control and leadership (Heng and Loosemoore, 2013). Although an actor with a higher *closeness centrality* was interpreted as depending on others to act (Loosemoore 1998), it was viewed as an advantageous position for an actor. Efficient solutions corresponded to one firm having the shortest communication paths to the other firms (Dogan et al., 2014).

In communications management, network constraints and tie strength were viewed as being tools for identifying the potential value of brokering a structural hole. A high potential to broker a *structural hole* existed when a facility manager had strong connections with the IT and security departments but direct communication with each other was difficult (Heng and Loosemoore, 2013). The *clustering coefficient* was useful for determining the density of negotiation networks when there was repeated emphasis on the boundary objects made by the project participants (Di Marco et al., 2012). The communications efficiency was determined from the *average path length* and *network density*. When the average path length was long and the density was low, knowledge transfer was not effective (Tang, 2012).

To strengthen the communications, Di Marco et al. (2012) developed *reciprocity* and *transitivity* to create trust and alliance formation that would lead to a better negotiation outcome. Pauget and Wald (2013) used *homophily* to identify the roles of members who shared a common culture and language with others in the network, and thus acted as mediators in the network. Loosemoore (1998) used *structural equivalence* to identify actors who had similar communications patterns. However, Borgatti and Everett (1989) also showed that actors with the same connection patterns might not be playing a similar social role. Rather, they may be in competitive positions. *Clique* enabled the team to work collaboratively. The manager had to be aware that the introduction of new communications systems or the separation of teams into separate locations could affect the cliques in a network (Houghton et al., 2015).

4.6.7 Risk management

SNA was used to investigate project stakeholders' risk networks and examine the coordination networks of those emergency response teams who constituted part of the elements in risk control. A higher *network density* indicated that there were more stakeholder risk interactions in the risk networks (Li et al., 2016) and better coordination for members' social control in the coordination networks (Mohammadfam et al., 2015).

The determinants of the nodes' influence when using centrality measures in risk and coordination networks were different. For coordination networks, network Mohammadfam et al. (2015) used *out-degree centrality* to identify those members who had a greater influence. On the other hand, for risk networks, stakeholders who had a larger gap degree tended to exert a stronger influence on their neighbors (Li et al., 2016). Furthermore, Yang and Zou (2014) identified *out-status centrality* as being a significant measure as nodes with a higher value had a greater degree of influence. *Betweenness centrality* was important for enabling the reaction of a gatekeeper when controlling influence. The absence of nodes with a high value of this measure reduced the influence of stakeholders' risks in the network (Li et al., 2016).

The cohesion levels of risks and coordination networks were also dissimilar. The cohesion level in a risk network was represented by the *network density* and *average path length*. A high cohesion value indicated that a complicated risk network, corresponding to a longer distance, was required to incur a risk that would trigger the involvement of another member (Li et al., 2016). In a coordination network, cohesion was indicated by *network density*, *degree centrality*, *reciprocity*, and *transitivity*. A high *reciprocity* indicated better mutual connections with another member, while high transitivity showed that each member was equally interested in maintaining their coordination. These two measures were significant in that they contributed to network stability by developing trust among members (Mohammadfam et al., 2015).

For a risk network, Yang and Zou (2014) used *brokerage* to denote the roles of risks (coordinator, gatekeeper, representative, consultant, and liaison) while partition provided a means of influence mechanics among the various types of risks. For instance, in a *brokerage* relationship with a coordinator, if node A received a link from node B within a given partition, and then sent a link to node C in the same partition, then node A gained 1 coordinator score. Nodes with high *brokerage* scores in dissimilar roles required more attention as they had a propagating effect and complicated the overall network (Li et al., 2016). The *partition* metric helped project managers to identify the interactive characteristics among various risk types, improve coordinated decision-making, and enhance communications between the stakeholders when dealing with risks (Yang and Zou, 2014).

4.6.8 Procurement management

The networks studied related to procurement management consisting of the contractual networks and project governance networks involved in project delivery. Lee et al. (2016) used *network density* to model the likelihood of private and government contracting. If private contracting had a higher value, the private clients were more likely to enter a contract with a construction firm. Pryke (2005) used *degree centrality* to indicate the extent of an actor's power associated with his/her specialised knowledge and positions conferred under the contract terms and conditions. West (2014) used *betweenness centrality* to test the extent of a broker's role in the market power diffusion among alliance partners. Partners with limited alliances had a low *closeness centrality*, and consequently a restricted information flow through them. The actor with the highest *eigenvector centrality* score was considered the most important member affecting the main pattern of the distances of all actors, whereas actors with a low *eigenvector centrality* score were considered as peripheral actors (Chowdhury et al., 2011).

With respect to the interconnectedness of contractual members, the point connectivity measured the vulnerability of a firm in a network to determine its interdependency in a network (West, 2014). *Component* analysis enabled the analysis of connectivity between nodes when the network was configured. For instance, Lee et al. (2016) segmented a network consisting of one component into more components once the cut points were removed. Zhang et al. (2015) used *clique* analysis to identify Integrated Project Delivery (IPD) candidates with a high centrality in the team member selection system. Clique analysis investigated the mutual interactions among the project members and their willingness to share their experiences. Through clique analysis, good combinations of IPD team members were identified.

Contractual networks were also contextualised using network topologies such as *small world* and *scale-free* networks. By analysing a network with respect to its clustering coefficient, *average path length*, and *diamete*r, the *small-world* property could be identified. This determined whether the number of competitors affected the link closeness between firms, and indicated monopoly in the construction market. *Scale-free* networks were characterised by a limited number of well-connected hubs where the rich got richer. Lee et al. (2016) used this to identify the preferential attachment of new firms that tended to connect with firms that had many links.

4.6.9 Health, Safety, Security, and Environmental (HSSE) management

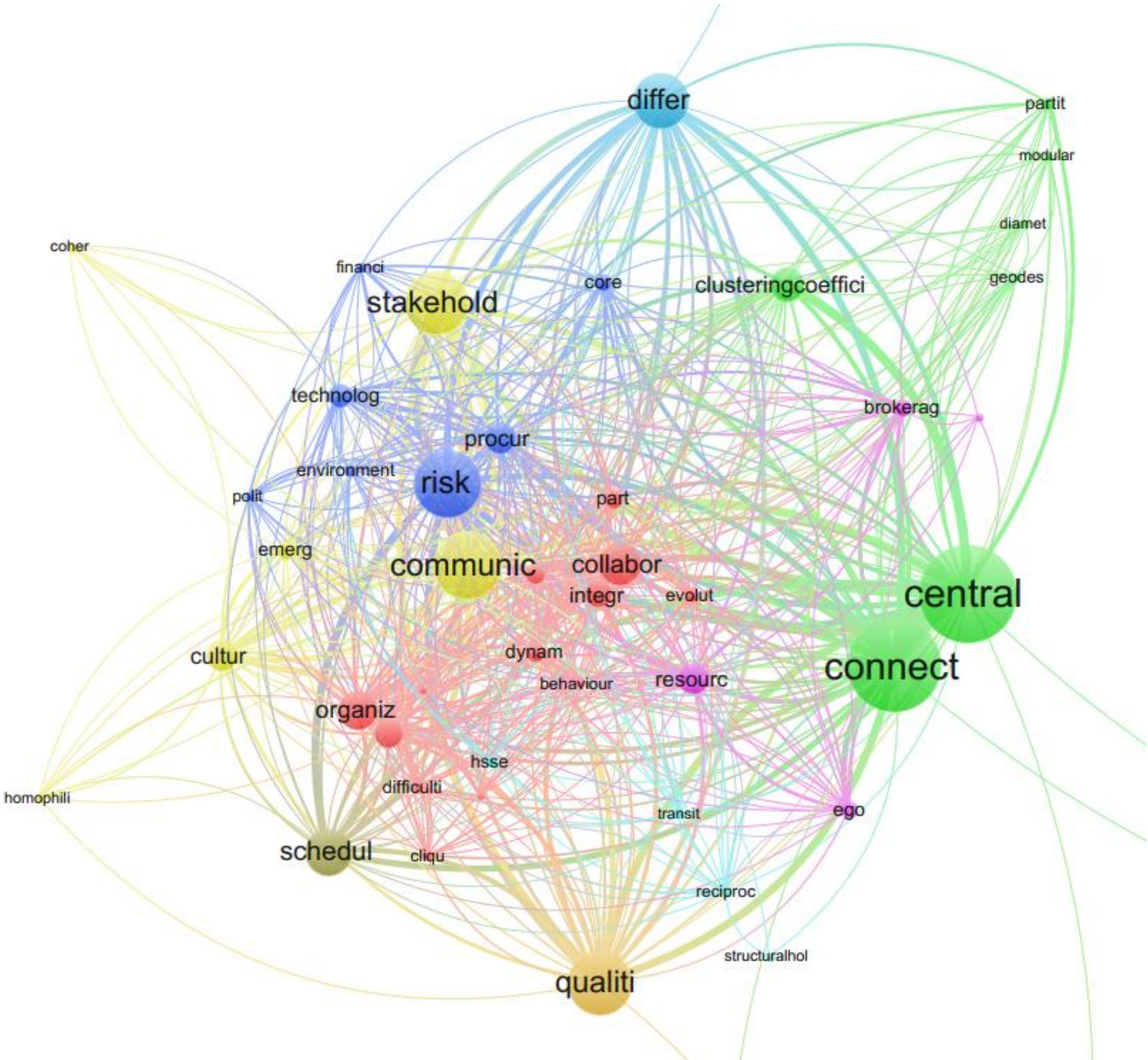
SNA studies of HSSE management involved analysing safety teams' communication patterns and an accident network. *Network density* (frequency of interaction) was applied to safety communication and training networks to understand the low- and high-performing teams' connectivity in resolving safety problems. Other metrics such as *degree centrality* and *betweenness centrality*, which were used to determine the control and influence flow of networks, were not important differentiators of the high and low safety performing teams (Alsamadani et al., 2013a). On the other hand, *network density* and centrality measures were significant measures when used to investigate the correlation between the safety communication networks and safety climate. Subcontractors who exhibited a higher density and lower *betweenness centrality* in a communication network had better safety climates (Liao et al., 2014a). Liao et al. (2014b) used *degree centrality* and *betweenness centrality* to assess the actors' roles in authorising and controlling information in the safety communication network. *Network density*, centrality measures, *clustering coefficient*, *average path length*, and *modularity* also proved to be useful in the evaluation of safety performance and system resilience by preventing risks using simulated agent-based modelling. *Modular* was used to divide the network into different community structures for observation. Cluster groups that reflected the teams' existence on the site were identified through the *clustering coefficient*. Higher *degree centrality* of the upper management indicated that they were influential and that more responsibility for safety was entrusted to them. A high betweenness and low closeness bridged the gap and encouraged communications flow. Low *closeness centrality* and *average path length* also revealed a connected safety network that had a low incident rate (Wehbe et al., 2016).

For accident networks, a higher *out-nodal degree* indicated the cause of an accident that triggered more accidents. Zhou and Irizarry (2016) used the *clustering coefficient* to identify the causes of accidents with similar characteristics. The *diameter* and *average path length* were used to identify the distance of a cause of an accident from another. Causes of accidents with similar *average path lengths* in a random network were deemed to have a *small-world* attribute that was difficult to control as they exhibited faster propagation than that of a regular network.

4.7 Discussions and Conclusions

This review has systematically combined 38 SNA metrics and concepts in 9 complex project management knowledge areas. Fig. 4.2 illustrates the 39 most frequently occurring keywords extracted from the 65 referenced papers which were related to SNA applications in complex project management. The bigger the font size of the keywords, the more frequently it appears in the references of this study. Here, "centrality," "connected," "communication," "risk," and “stakeholder,” are the underpinned keywords adopted in the reviewed papers which reflect the common applications of SNA. It also shows the connection among complex projects keywords, such as “different,” “emergence,” “difficulty,” “dynamic,” and “evolution” and complex project management knowledge areas, such as “risk management,” “procurement management,” “stakeholder management,” “communication management,” “quality management,” “schedule management,” and “resource management” with the SNA common keywords, suggesting that SNA is a useful tool for analysing complex project networks.

Figure 4.2 Keyword co-occurrence network: 1998 to January 2017



The demonstration of the application of SNA using UCINET software as in Table 4.4 provides a practical example to practitioners and researchers on how SNA can be applied in their case studies. While there are many SNA software products available on the market, UCINET was selected as this program is specially designed for the users who are not technically oriented but who require a tool that features many SNA metrics to characterise the overall networks and the positions of nodes within networks (Borgatti et al., 2014).

From a practical perspective, the SNA metrics and concepts such as *brokerage, boundary spanners, homophily, reciprocity, transitivity, giant component, small-world, modularity,* and *partitioning*, identified in the study, can be used as practical tools for analysing the complex relationships among stakeholders and to determine new relationships for engineering projects and construction organisational strategic planning. For instance, *giant component* can be applied to existing client and contractor hierarchical structure networks to improve the transmission efficiency, and the *small-world* properties of consultation networks can be used to improve interdisciplinary interactions that lead to technology innovation and reduced engineering errors (Lin, 2014). Risks arising from technical, organisational, and environmental complexity can be analysed using SNA to investigate the interrelationships between risk and accidental factors, as described in Li et al. (2016), Mohammadfam et al. (2015), Yang and Zhou (2014), and Zhou and Irrizary (2016). Additionally, the uses of SNA are not limited to social studies for analysing trust, communications, and other social structure networks, but the practitioners can also extend the uses of SNA to broader complex project management areas that involve interdependencies between activities and resources. This is evident from work conducted on project trade networks (Wambeke et al., 2012; Wambeke et al., 2013), defect causes networks (Aljassmi et al., 2013), project practices networks (Pishdad-Bozorgi et al., 2016), highway data-information-decisions networks (Woldesenbet et al., 2015), traffic networks (El-Adaway et al., 2016), water distribution networks (Dunn and Wilkinson, 2013), risk networks (Li et al., 2016; Yang and Zou, 2014), and accident networks (Zhou and Irrizary, 2016).

SNA could be a useful tool for analysing the structural complexity of complex projects. As demonstrated by the work of examining essential flash track practices for successful project execution (Pishdad-Bozorgi et al., 2016), one of the fundamental advantages of SNA is its ability to examine the dependencies between tasks and identify the interrelationships between them. SNA is applied to quality management for tasks such as the analysis of job-site networks to discover underlying problems (Lin, 2014) and the investigation of the task and organisational network interdependence to identify misalignments that impede project effectiveness (Chinowsky et al., 2011), which could promote lean practices in complex project management. Reciprocal complexity issues arising in complex projects have led to serious interface problems between different project disciplines (Baccarini, 1996). This includes problems such as project participants belonging to different linguistic and cultural backgrounds, which affects the trust level among them (Bosch-Rekveldt et al., 2011). SNA can also be integrated with inter-organisational systems to select team members who share common values and trust and who could cooperate to ensure the successful implementation of projects (Zhang et al., 2016). In the same context, SNA can be used to analyse cross-cultural interactions among global project participants (Di Marco et al., 2010; Di Marco et al., 2012), and examine team coordination (Hossain, 2009a; Hossain, 2009b; Hossain and Wu, 2009).

The review also reveals that SNA could be potentially used as an effective tool to examine the uncertainty and dynamic change of complex project networks. SNA could identify the construction trades associated with the variation and support decision-making in targeting trades to reduce that variation (Wembeke et al., 2014). Risk factors that interlink with project stakeholders (Yang and Zhou, 2014; Li et al., 2016) could be used to determine the stakeholders' risk factors and evaluate the effect of these risks from the network perspectives. In terms of organisational context, SNA is revealed as a powerful tool for examining the dynamic change of inter-organisational collaborative relationships. It could be used in conjunction with an agent-based modeling to simulate various collaborative behavior (Son and Rojas, 2011) for determining a strategic relationship.

The application of SNA to complex projects should not only be limited to social boundaries but should go beyond to address more uncertainty issues and dynamic interaction relationships across different project management knowledge areas to improve the performance of complex projects. Future research should advance the SNA model that influences the dynamic nature of complex projects, particularly those related to the fragmentation of organisations and the spread of risks. Note that the present study did not consider aspects such as the formulas and parameters of SNA metrics, static or dynamic analytical paradigms, and the factors that influence the accuracy of SNA metrics. Some of the SNA metrics and concepts discussed in the selected publications may also have been overlooked.

Chapter 5

Enhancing BIM Performance in EPC Projects Through Integrative Trust-Based Functional Contracting Model[4]

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Abstract: Delivering Building Information Modelling (BIM) requires a certain level of trust to make it more effective. However, the Engineering, Procurement, and Construction (EPC) approach, which conventionally adopts transaction law, encourages each party to protect their legitimate interest. Consequently, EPC contracting parties operate within their own goals and procedures, in which trust is not a fundamental contracting strategy. In addition, distrust—which is commonly perceived as detrimental to the relationship—should receive more attention when examining the beneficial outcomes of the relationship. Contract research has emerged from focusing on the safeguarding of contract transaction and is currently moving towards coordination and contingency adaptability for its success. In this context, this paper proposes an integrative trust-based functional contracting model that describes how trust can enhance BIM performance in EPC projects. Thus, this paper contributes to new knowledge of the proper use and harmonisation of contract functions and provides significant insight for the construction industry to think beyond the traditional EPC contract setting for effective use of BIM.

Keywords: Trust model; Distrust model; Contract functions; Building information modelling (BIM); Engineering, Procurement, and Construction (EPC).

5.1 Introduction

Engineering, Procurement, and Construction (EPC) contracting enables a contractor to be responsible for all works associated with the design, procurement, erection, and testing of a facility (Steinberg, 2017). Thus, it provides benefits that enable the contractor to plan and execute projects successfully with greater flexibility (Lampel, 2001). Nevertheless, natural resources and infrastructure projects that typically adopt the EPC approach consistently experience cost and schedule overrun (Singh, 2010). This makes it essential that EPC projects accept new ideas for performance improvement. In the construction industry, Building Information Modelling (BIM) is not only a revolutionary technology (Chong et al., 2017b); but it should be described as a set of interaction processes, procedures and technologies that requires a system to manage the digital project data of key building design throughout the building's life-cycle (Succar, 2009). Hence, a multi-disciplinary collaborative platform is required to implement BIM (Singh et al., 2011) at a different level of trust between the contracting parties (Pishdad-Bozorgi and Beliveau, 2016).

Traditional contracting is grounded in the transactional contract law approach, which does not recognise cooperative relationships (Williston and Lewis, 1920). Transactional contract law refers to a set of contract law practice which involves an agreement between two or more persons, who focuses strictly on the transaction itself, legal rules and what happens when one of the parties decides not to follow through on the agreement (Harper et al., 2016). Transactional contracts specify the formal obligations of each party, which could sanction an opportunistic trading partner (Dyer, 1997). An opportunistic behavior brings destructive and devastating impact on the performance of contractual relationships (Parkhe, 1993) and trust (Morgan & Hunt, 1994). When the transaction becomes more complex with higher uncertainty and asset specificity, the higher the risk that one or both partners will engage in opportunistic actions (Williamson, 1991). This encourages firms to use more complicated and detail contracts (Poppo and Zenger, 2002) to safeguard the firms' transactions. The stronger the safeguard mechanisms imposed in a transaction, the more it reduces trust and cooperation behaviors between the contracting parties. Ghoshal and Moran (1996) argued that the use of formal control has a pernicious effect on cooperation. EPC contract is one of the typical transactional contracting approaches. The balance of certain degrees of trust and distrust during initial stages of cooperation could benefit the later stage of collaboration (Vlaar et al., 2007). When fear and skepticism are minimised through distrust-related contract provisions, only trust can produce positive impacts on the transaction. Construction contract research has focused heavily on trust research but ignored the positive influence of distrust in improving project efficiency. Contract research has also started to move from a narrow safeguarding function approach to multifunctional contracting, which also includes coordination and contingency adaptability (Schepker et al., 2014). The multifunctional approach has been used to examine the effects of coordination and contingency adaptability on cooperation in construction projects (Quanji et al., 2017). To improve business performance through trust, there should be a move away from the framework of minimising transaction costs towards a focus on learning and innovation (Sako, 2006). To improve transaction efficiency, in addition to the safeguarding function, coordination and contingency adaptation are necessary to foster learning and knowledge sharing (Parmigiani and Rivera-Santos, 2011).

To date, various BIM contract protocols have been established for administering contracts (Chong et al., 2017a), but the Chartered Institute Of Building (CIOB) contract for complex projects (CCP, 2013) seems more appropriate for facilitating BIM implementation in EPC projects. Most of the BIM contract protocols such as ConsensusDocs 301 (2008) and AIA E203TM-2013 (2013) tend to be used in accommodating the common design-bid-build approach or certain relational contracting methods such as Integrated Project Delivery (IPD). To cater for the complex practice in EPC projects, CCP (2013) provided more specific explanations on how the Contractor partly or wholly contributes to the design as well as other necessary obligations and rights when collaborating with the Owner. Construction research focuses substantially on how trust can be incorporated into relational contracting, but the trust research that focuses on the ambit of traditional contract setting is rather limited. Drawing upon the theory of trust, distrust, and various contract functions, we develop an integrative trust-based functional contracting model to describe how trust can deliver BIM effectively in an EPC contract. This paper not only contributes to the theoretical development of trust and distrust through harmonisation of various contract functions but also serves as an important reference in the design of BIM contracts to improve trust between EPC contracting parties.

5.2 Trust and distrust in contracting

Trust is widely accepted in the construction industry as the willingness of contracting parties to share information such that both parties can honor their commitments (Cheung et al, 2011).Trust is well known as a *"psychological state which comprises the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another"* (Rousseau et al., 1998, p.395). However, this definition should be extended to include confidence of positive expectations of trust and negative expectations of distrust regarding another's conduct (Lewicki, 2007; Lumineau, 2017). Trust and distrust in inter-firm contracts should be viewed as two distinct constructs because an existing study has proven that a high level of trust is distinguished from a low level of distrust (Connelly et al., 2012). Trust and distrust activate dissimilar brain areas and have different reactions in the neurological process (Dimoka, 2010). Moreover, trust does not necessarily bring benefits as it also has its dark side. The dark side of trust occurs when there is an excessive trust investment of a party in a relationship. The excessive trust could lead to (a) blind faith that increases the risk of malfeasance and impoverished quality information transfer to another party; (b) complacency and passivity in the face of inadequate outcome from a relationship; and (c) over-embedded relationships loaded with unnecessary obligations between the parties, trapping them into inadequate exchange schemes and consuming resources without bringing the associated benefits (Gargiulo and Ertug, 2006). Distrust is not necessarily detrimental as it produces beneficial outcomes (Lewicki, 2007). Distrust arises from an inconsistent perspective between an organisation's values and those of its partner, which creates doubt that a partner will act opportunistically (McConelly et al., 2012). Conceptualising trust and distrust as two different constructs provide insights into how institutions promote trust, as positive motives can be anticipated without significant monitoring (Rousseau et al., 1998).

Roles of trust operate differently at interorganisational and interpersonal level (Qi and Chau, 2013). Interorganisational trust is defined as an organisation's expectation that another firm will not act opportunistically (Bradach and Eccles 1989) whereas interpersonal trust results from repeated interactions with individuals (Rus and Iglic, 2005). Trust at both levels are interrelated. Interorganisational trust enabling the partner exchanges personnel and shared decision making (interpersonal trust) which leads to improved performance (Zaheer et al., 1998). Contracts can influence trust and distrust through calculative and non-calculative judgments (Lumineau, 2017). Calculative judgment describes interorganisational trust as emerging through rational perspectives when a firm regards another firm's actions that are with clear benefits to the transaction (Kadefors, 2004). Calculative trust tend to occur at the early construction stage when the owner and the EPC contractor are usually unacquainted with each other; but both firms scrutinise their interests and risks (Jiang et al., 2016) and consider whether each other is equipped with cognitive capabilities to perform their obligations (Zaghloul and Harman, 2003). Whereas, non-calculative judgment is influenced by intuition, gut feeling, and perceived notions (Fiske and Taylor , 2016). It tends to affects personal feelings, which are based on various categories such as age, sex, race, geographical origin, friendship, kinship, or belonging of managers to the same alumni network or professional association (Lumineau, 2017). Overall, this may distinguish some degree of differences of the interorganisational and interpersonal level trust and their effects on collaboration for EPC contracting parties."

5.3 BIM performance in relation to beneficial outcomes of trust and distrust

BIM performance metrics can be used to determine how BIM could deliver effectively (Succar et al., 2012). However, the positive expectations generated by trust and the confidence gained from negative expectations of distrust are intangible and it is difficult to measure their impacts directly from the BIM deliverables. Moreover, the lack of a remarkable relationship between trust and performance should not devalue the role of trust in inter-organisational relationships (Auklah et al., 1996). Hence, this paper argues that both trust and distrust influenced by contracts can deliver BIM effectively in the EPC approach through their beneficial outcomes that can enhance BIM performance, such as trust increasing satisfaction (Bulvik and Rofsen, 2015) and distrust supporting the monitoring of vulnerabilities by anticipating the earlier action (Kadefors, 2004). Table 5.1 summarises the trust and distrust expectations identified from the literature that can relate to improved BIM performance.

Table 5.1 Trust-based BIM performance

Expectations of trust and distrust	**References**
Securing critical resources	Connelly et al., (2012)
Higher commitment	Bulvik and Rofsen (2015); Chow et al. (2014); Gad et al (2016); Yiu and Lai (2009)
Better teamwork	Bulvik and Rofsen (2015); Cheung et al (2011); Fong and Lung (2007); Gad et al (2016)
Knowledge sharing improvement	Bulvik and Rofsen (2015); Fong and Lung (2007); Gad et al (2016)
Better communication	Cheung et al (2011); Cheung et al. (2013); Gad et al (2016)
Higher satisfaction	Bulvik and Rofsen (2015); Cheung et al. (2011); Chow et al. (2014)
Relationship improvement	Cheung et al (2011); Gad et al (2016)

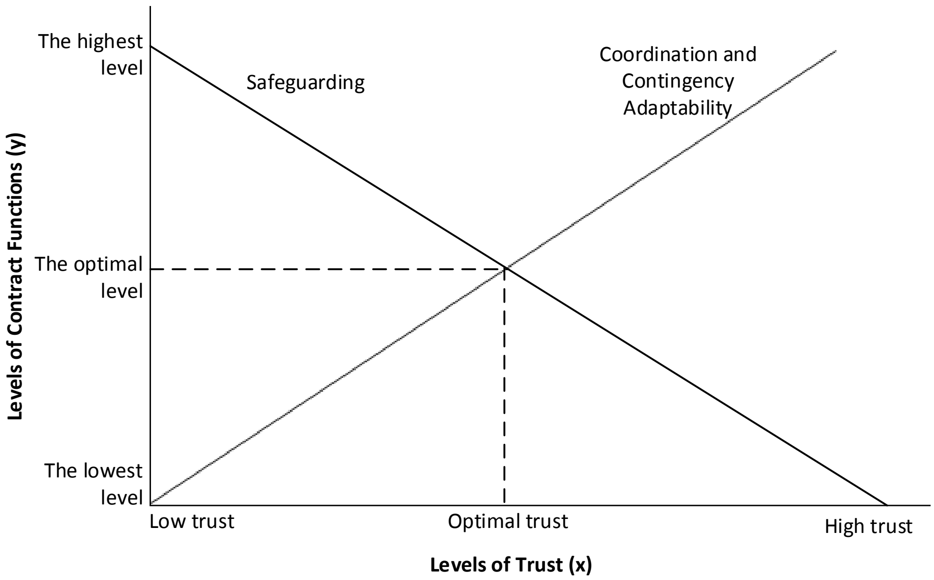
Performance improvement	Cheung et al. (2013); Fung and Lung (2007); Gad et al. (2016)
Easy negotiation	Cheung et al (2011); Gad et al (2016)
Time saving	Gad et al (2016); Yiu and Lai (2009)
Cost saving	Cheung et al (2011); Chow et al (2012); Gad et al (2016); Zaghloul and Hartman (2003)
Improve cooperative behaviour	Gad et al (2016); Yiu and Lai (2009); Zhang et al (2016)

5.4 Contract functions

The content of clauses in a contract has multiple functions (Woolthuis et al., 2005). When the uncertainty and complexity of a transaction increase, more sophisticated contractual governance is required (Segal, 1999), in the form of safeguarding provisions to bring about adherence to a desired behavior and outcome. The safeguarding provisions define transaction obligations (Benaroch et al., 2016), enforce obligations and penalties in case of breach of contract (Eckhard and Melewight, 2005), specifying what is allowed and disallowed, formalise performance, and control and monitor behavior (Faems, 2008). Coordination provisions are less enforceable than safeguarding provisions (Echkard and Melewight, 2005). They formalise procedures and processes (Schepker et al., 2014) that enable the accomplishment of a collective task (Benaroch et al, 2016). They also clarify the mutual expectations of parties (Eckhard and Melewight, 2005). The contingency adaptations function is a result of instability arising from the transaction environment (Gulati et al., 2005). This function is subjective; it consists of safeguarding and coordination elements, but is mainly used to adapt to the changes due to unforeseen circumstances. Examples of clauses of this function include the provisions pertaining to procedure changes (Mayer and Argyres, 2004) and adjustments for price fluctuation (Crocker and Reynolds, 1993).

5.5 Trust-based functional contracting model to enhance BIM performance in EPC projects

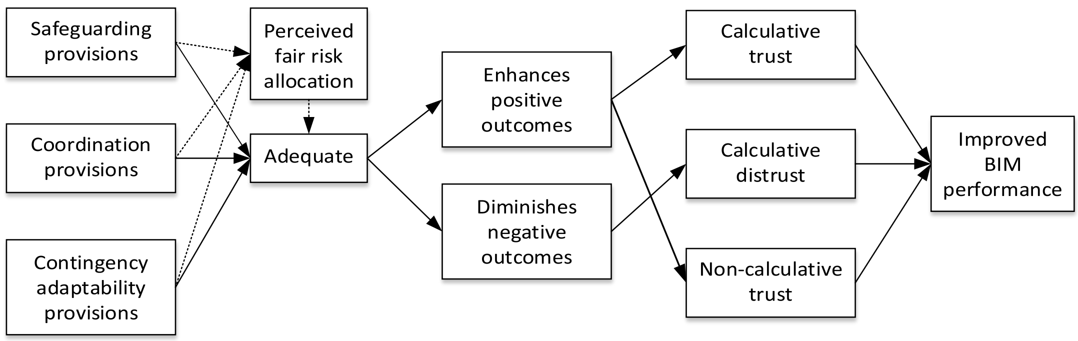
Figure 5.1 Contract functions by levels of trust



Trust and control in an inter-organisational relationship are complementary (Das and Teng, 1998). Figure 5.1 shows that the lower the level of safeguard and the higher the level of coordination and contingency adaptability between the firms, the higher is the level of trust between the firms. A high level of control is correlated with a low level of trust (Faukner, 2002), whereas a discretionary working environment that emphasises learning and coordination can increase trust relations (Choudhury, 2008). The optimal threshold in Figure 5.1 signifies the amount of damage the trustee could inflict on the trust if s/he decides to behave opportunistically (Gargiulo and Ertug, 2006). It is achieved when the trustor does not over- or under-invest trust in the trustee (Wicks et al., 1999). Optimal trust can lead to lower information processing costs, greater satisfaction between the partners, and lowers the amount of uncertainties in the transaction. Too little trust results in parties investing higher cost in the transaction for elaborate protections to guard against opportunism. Conversely, excessive trust leads to blind faith, complacency, and access obligations as discussed in the previous section (Gargiulo and Ertug, 2006). On the other hand, Lumineau (2017) stated that an excessive coordination function with too much information sharing and confidence may enhance the detrimental outcomes of trust and distrust. This implies that too much of a certain contract function may bring detrimental effects to the trust and distrust level between parties, which leads to reduced performance. Furthermore, the contractual terms that specify the expectations, rights, and obligations coupled with fair risk allocation could lead to higher trust (Wong et al., 2008) and facilitate cooperative behavior (Zhang et al., 2016). An adequate level of contract functions also could be achieved through perceived fair risk allocation between the contracting parties.

Considering the discussions above, this paper develops an integrative trust-based functional contracting model that discusses an adequate level of contract functions that can lead to optimal trust, and thereby result in a better BIM performance, as illustrated in Figure 5.2.

Figure 5.2 Integrative Trust-based functional contracting model



Safeguarding provisions promote calculative trust between parties as they develop a party's confidence that the other will act responsibly (Gulati, 1995). They enable parties to assess the risks and payoffs of the other party not fulfilling its expectations (Lui and Ngo, 2004). In other words, they support risk taking and trust behavior. BIM contracts that define an EPC contractor's intellectual property rights in designing the works and the owner's right to use the design are examples of safeguarding provisions. These provisions enhance the trust between the owner and the EPC contractor as they enable both parties to make a calculative judgment on their potential loss and gains when using BIM. On the other hand, safeguarding provisions that concern expectations of things feared, such as clauses that stipulate what must and must not be done and inflict penalties for the violation of behaviors (Lumineau, 2017), can curb the opportunistic behaviors of partners. For example, a distrust provision that requires an EPC contractor to compensate the owner for any loss suffered by the owner caused by infringement of copyright in the contractor's design can develop the confidence of parties working with BIM. This provision enhances the efficiency of rational evaluation made by the owner to draw inferences about the EPC contractor. An adequate level of safeguarding for distrust provisions is thus a level that can foster healthy suspicion in securing the parties' critical financial resources against potential loss.

Coordination provisions that enhance trust through the calculative judgments of parties are clauses that state the timeline of BIM deliverables, describe the clear procedures, processes, and timing of submittals, and determine the roles of the design coordination manager and the data security manager in maintaining the BIM database and model security, respectively. These coordination provisions overcome the cognitive limitations of parties (Vlaar et al., 2007) when using BIM, and specifying the goal and the ways to achieve that goal (Woolthuis et al., 2005) can lead to higher trust. The adequate level of coordination provisions should only be limited to the clauses that involve the facilitation of information processing sufficient for operating a project because too much information sharing will lead to the reverse effect (Lumineau, 2017). On the other hand, coordination provisions such as clauses that require regular formal BIM coordination meetings and information exchange to resolve design, planning, and project control conflicts shape the emergence over time of informal process that aid coordination, such as group conventions and a common language. Further, informal communication channels can enhance non-calculative trust between the parties as the relationships develop (Puranam et al., 2006). Through enhanced learning about the partner, coordination clauses promote the beneficial outcomes of trust (Lumineau, 2017). The coordination provisions can reduce barriers between the owner and the EPC contractor firms that rely on calculative judgments.

Although various technical solutions have been provided to resolve the potential conflicts due to the interoperability issues of BIM, it is still possible for errors to occur during the coordination process. Too little or excessive contingency adaptability arising from the rational judgment of parties can lead to detrimental trust effects. Too little contingency adaptability refers to a provision that states that no party shall be liable for any data corruption except failure to comply with the protocol. This shifts the risk to the owner, who is not responsible for the BIM execution but may have to bear the cost arising from the BIM use. Excessive contingency adaptability provisions refer to the provisions that state that the EPC contractor shall remain solely responsible for the suitability and integrity of the selected software and any information, drawings, specifications, or other information extracted from any model. Technical errors arising from use of BIM may occur as a result of external factors that may be out of his control. Hence, it is unfair to load all the risks onto the contractor. An adequate level of the contingency adaptability provision should award the party in charge of the BIM model, such as the EPC contractor, extension of time to resolve the conflicts or technical errors.

5.6 Conclusions

The model proposed in this paper suggests that an adequate level of safeguarding, coordination, and contingency adaptability provisions can optimise trust between the owner and the EPC contractor for improved BIM performance. It also provides useful references for enhancing trust between the contracting parties when drafting BIM contracts in relation to EPC project delivery. This paper has broadened the focus of the construction industry to look beyond the conventional EPC contract setting to a place where safeguarding is no longer the only domain to secure the parties' resources but it should also emphasise an adequate level of coordination and contingency adaptability in improving the BIM deliverables and the overall EPC project performance.

The content of chapter 6 has been removed due to copyright restrictions.

This chapter explained how data was collected and analysed. It also described the results of the analysis and how the effects of trust-based functional contracting on BIM-enabled EPC projects were predicted. The content of this chapter is under review and pending for acceptance by a journal.

Chapter 7

Conclusions and Recommendations

7.1 Introduction

As the research findings and contributions have been discussed at the end of each paper from chapter two to chapter six, this chapter concludes the overall aim, summarises how the objectives were satisfied, highlights the limitations and makes the recommendations for future research.

7.2 Conclusions

The aim of this research is to develop a complementary contractual approach to EPC BIM-enabled oil and gas projects. Various research methods had been used to develop the approach. At first, a systematic review on academic and vendor publications had been conducted and 36 DMAT uses and BIM uses had been streamlined. This enabled oil and gas project stakeholders identified the potential use of BIM in the oil and gas projects. However, to use BIM in the oil and gas projects, it is important to identify the legal issues and its solutions associated with BIM. Throughout a critical review of academic publications, the important legal issues of BIM and the existing solutions in dealing with the issues had been identified. To develop a complementary contractual approach to BIM-enabled EPC oil and gas projects, it is also important to identify the prominence social network measures that could affect the collaboration of project stakeholders. The key social network measures that influence the project stakeholders' networks in oil and gas complex projects had been identified through a critical review of academic publications. By consolidating the findings from the three macro level reviews, at a micro-level, an integrative trust-based functional contracting was proposed. The influence of the model on BIM-enabled oil and gas project performance had been empirically investigated through a data collection from the survey and data analysis using PLS-SEM. This research had successfully developed an integrative trust-based functional contracting, and its influence on the BIM-enabled project performance had been uncovered.

7.3 Satisfying Research Objectives and Research Contributions

7.3.1 Streamlining DMAT and BIM uses for the oil and gas projects

The first step which involved the macro-level review was streamlined the DMAT uses in the oil and gas projects and BIM uses in the AECO projects. This objective has been satisfied by discovering 38 BIM uses, 32 DMAT uses, and 36 both DMAT and BIM streamlined uses. The synergy between DMAT and BIM uses provides significant insights into oil and gas stakeholders to identify the area of project improvement. From there, the stakeholders could reduce the unnecessary investment cost and work process by streamlining the common DMAT and BIM uses, thereby reducing the waste in production. In addition, the synergy between DMAT and BIM uses allows the interaction of functionality between them, which potentially improve their existing function. For example, the existing condition modelling which is typically used to model an existing infrastructure of a potential site could be applied to model existing conditions of potential oil and gas plant. Similarly, the raceway analysis which is typically used to design an oil and gas plant could be used to optimise the mechanical and electrical layout of a domestic factory or science building. The streamlined DMAT and BIM uses has bridged the existing knowledge gap that DMAT shall be distinguished from BIM. The research outcomes suggested that although there are some distinctions between DMAT and BIM, they have the common attributes in terms of its philosophy and functionality.

7.3.2 Critically reviewing the legal issues and solutions associated with BIM

While DMAT in the oil and gas industry aims to increase productivity through the use of PLM and other associated technologies, BIM in the context of AECO industry enables more collaborative approaches among the multi-disciplinary team which leads to the innovation in contracts and project delivery systems. Therefore, the second step of the macro review focused on critically reviewing the legal issues and solutions associated with BIM which is perceived as one of the main constraints of BIM implementation in the oil and gas projects. 55

academic publications ranging from 2007 to 2017 were reviewed and analysed. The objective has been achieved by critically appraising the key legal issues and the solutions involved in BIM.The review provided a solid knowledge foundation on a need to develop a complementary contractual approach and the importance of contractual practices that should be adopted in delivering BIM in the oil and gas projects. In terms of knowledge contribution, this research makes clear the legal issues and its solutions in different regions. In terms of practical contribution, it uncovers the potential alteration in the professional standard of care of BIM project participants which required further attention from practitioners who involved in BIM-enabled projects. More importantly, it reveals some important and valuable contractual practices which are worth to be considered by project participants in BIM-enabled projects.

7.3.3 Social network measures in complex project management

As implementation of BIM in the oil and gas projects require the effective collaboration of multi-disciplinary team, the third step of the macro review focused on critically reviewing the social network measures and determine the prominent social network measures used in complex project management. This review has essentially reviewed the social network measures and identified the network properties that significantly influence the social capital in oil and gas projects, which are complex in nature. The research has made several theoretical contributions by (1) extending an existing knowledge to clarify the interpretation of SNA metrics , (2) discovering the influential SNA measures that are of significance in strengthening the collaboration of the multi-disciplinary team in the BIM-enabled oil and gas projects, and (3) revealing the uses of SNA in non-social structures of complex networks. It broadens the perspective that SNA is only limited in human applications.

7.3.4 Development of an integrative trust-based functional contracting model

By synthesising the macro review, at the micro level, the researcher has achieved the objective by identifying the potential of using an integrative trust-based functional contracting in improving BIM-enabled EPC oil and gas project performance. Most of the BIM contracting research focuses on collaborative contracting such as Integrated Project Delivery, Project Partnering, or Project Alliance (Ma et al., 2018; Rowlinson et al., 2017; Maskil-Leitan and Reychav, 2018). This research contributes to the knowledge that BIM can still deliver its benefits in the presence of EPC, which is a type of conventional contracting methods. The integrative model proposed in this research provides good references for contracting parties to use contract functions adequately in delivering BIM. It deepens the knowledge of the construction industry practitioners to look beyond EPC contract setting, where safeguarding/control is no longer the main domain to secure contracting parties' resources, but emphasising coordination and contingency adaptability could also potentially improve BIM-enabled EPC project performance.

7.3.5 The influence of integrative trust-based functional contracting on BIM-enabled EPC project performance

The last research objective has satisfied by empirically showing that an integrative trust-based functional contracting, which was applied in the context of the EPC contracting framework, could influence BIM-enabled oil and gas project performance. Prior construction research tends to use functional contracting in examining cooperative behaviours. For instance, Wang et al. (2017) examined the effects of contractual control, coordination, and adaptation on relational elements such as prior interactions, standard levels of cooperative behaviour, and voluntary cooperative behaviours, which refer to the behaviours beyond the standard roles of descriptions as prescribed in the contract. Similarly, Quanji et al. (2016) studied the influence of contractual control, coordination, and adaptation on the obligatory and voluntary cooperation of the transaction partner. None of the prior research considers integrative trust-based functional contracting could be a powerful contractual approach which could be used to complement EPC contracting in order to influence BIM-enabled oil and gas project performance. This research makes new theoretical contributions to the functional perspectives of contracting by extending its usefulness in influencing BIM-enabled project performance and providing explanations of how it influences BIM-enabled EPC oil and gas project performance through perceived fairness and interorganisational trust.

In addition, the common beliefs of effective network governance rely heavily on social control and coordination such as reputations and collective sanctions instead of formal governance (Jones et al., 1997). Formal contracts are commonly perceived as insufficient with regard to accommodating the dynamic evolution of transactions (Ring and Van de Ven, 1992), in addition to restraining the establishment of relational norms or ruining existing relationships between the parties (Malhotra and Murnighan, 2002). The research outcomes showed that combining the three contract functions in formal contracts could influence EPC BIM-enabled oil and gas project performance through calculative and relational trust. This indicates that the effective governance of the EPC oil and gas project stakeholders' network could also be affected by the three formal contract functions. Formal contracts and relational governance could complement each other to improve transaction performance (Ryall and Sampson, 2009).

7.4 Recommendations, limitations and future research directions

The formal contract framing is typically premised more on controlling and monitoring the parties to reduce opportunistic behaviours and resolve disputes in a BIM working environment. The research has empirically shown that contract functions, which comprise contractual control, coordination and contingency adaptability, could influence project performance through interorganisational trust. This suggests that the EPC conventional contract framing development should be restructured to balance and fulfil the functionality of contractual governance. This is particularly important for BIM-enabled EPC oil and gas projects where more coordination and adaptation are required among project stakeholders to deliver BIM successfully.

EPC formal contracts that grounded in the transaction law approach (Williston and Lewis, 1920) and TCE approach typically emphasise contractual control to safeguard the parties' interest (Williamson, 1985). The empirical research outcomes showed that combining the use of three contract functions in delivering BIM could have implications for interorganisational trust, thereby influencing EPC project performance. It means that these three contract functions are of importance in influencing project performance. From practical perspectives, it could provide an important guideline for oil and gas project stakeholders to focus effort in combining the three specific contract functions for the purposes of solidifying project planning and operation without devaluing any one of the functional aspects of the formal contracts. The research outcomes provide a new insight to practitioners, in that formal contract is not merely a mechanism that used to safeguard the parties' interest; instead, it should be treated as a tool for obtaining calculative trust and relational trust between the parties for realising a goal of a project. To obtain the calculative trust, the fairness of BIM provisions must be considered in the context of the contract as a whole. As the trust-based relationship is established through contracting, the mutual confidence between the project stakeholders would be increased which, in turn, would influence the project performance. One of the main factors contributing to cost and schedule overrun of the oil and gas projects is a lack of integration of downstream subcontractors (Jergeas, 2008). Jergeas (2008) also found that the data provided by the downstream project stakeholders (subcontractors, vendor etc.) have negative implications on the engineering progress which results in an ineffective three-dimensional model. Although this research focuses on investigating the roles of contract functions in influencing BIM-enabled project performance between the owner and EPC contractor, the model was also applied to contract between the EPC contractor and downstream subcontractor/vendor. BIM requires not only input from upstream project stakeholders, such as project owner and EPC contractor, but also requires input from downstream project stakeholders to reduce rework and increase model reliability. The focus on integrative functional contracting could foster tacit knowledge sharing and thereby strengthen the collaboration among EPC project stakeholders to deliver BIM effectively.

Several limitations found in this research. Although this research has empirically proven that the integrative functional contracting could impact project performance significantly through the mediators, it does not take a further stage to investigate how the integrative functional contracting could influence inter-organisational trust and distrust dynamically during a project lifecycle. Both interorganisational trust and distrust emerge from the beginning of the projects until the projects are handed over. Social network analysis could be conducted to examine how combinations of the three contract functions, namely, contractual control, coordination and contingency adaptability could influence the informational relationship among project participants in a BIM working environment. Besides, BIM transaction attributes have an influence on contractual governance (Lee et al., 2018c). For instance, high asset specificity in BIM may lead to more stringent contractual control (Williamson, 1981). On the other hand, parties who involved in high asset specificity of BIM may more reliant on one another's cooperation (Coff, 1993). This research does not take BIM transaction attributes into consideration by determining its relationship with contractual control, coordination and contingency adaptability. Future research is required to investigate whether BIM increases asset specificity, environmental and behavioural uncertainty or not, and how the transaction attributes influence each contract function. Future research is important as it allows appropriate contract strategies to be undertaken based on the identified BIM transaction attributes. PLS-SEM is an exploratory data analysis method to predict a theory which fits the case in this research. This method is different from CB-SEM, which uses strict measures of confirmatory factor analysis to validate a developed theory. As such, PLS-SEM may suffer certain inaccuracies due to less stringent measures were used. Furthermore, inter-organisational trust predecessors, such as communication and reciprocity, may strengthen the relationship between joint contract functions and inter-organisational trust. This research does not consider the antecedents of inter-organisational trust when evaluating the model. If the influences of these predecessors are proven, appropriate strategies could be adopted to enhance these aspects when devising the BIM contracts.

7.2 Summary

This chapter summarised the works in this research. More specifically, it has articulated the overall research contributions, limitations, recommendations, and future research directions.

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Appendix A

Basic Information of Respondents and Projects

Item	Indicators	Proportion (%)
The last EPC oil and gas project involved	Less than 2 years ago	58%
	2-5 years ago	21%
	5-10 years ago	11%
	More than 10 years ago	10%
Type of firm	Owner	44%
	EPC Contractor	56%
Years of operation of the firm	0-10 years	8%
	10-20 years	11%
	20-30 years	14%
	30-40 years	10%
	40-50 years	11%
	>50 years	46%
Project location	Offshore	29%
	Onshore	71%
Projects by continent	Africa	12%
	Asia	36%
	Europe	9%
	North America	23%
	Oceania	17%
	South America	3%
Project category	Drilling and Production Platform	15%
	FPSO	7%
	FLNG	4%
	Plant (other than those	45%
	mentioned above)	29%
	Other facilities	
Contract value	>US$500 mil	26%
	US$500 mil – 1 billion	18%

	US$1 – 2 billion	17%
	US$2 – 3 billion	4%
	US$3 – 4 billion	11%
	US$4 -10 billion	9%
	US$10 – 20 billion	8%
	US$20 – 30 billion	2%
	US$30 – 40 billion	4%
	US$40 – 50 billion	1%
	US$60 – 70 billion	1%
Project duration	<2 years	17%
	2-5 years	59%
	>5 years	25%
3D modelling used	3D model (without sharing of information among project participants)	18%
	3D model (the shared information model among project participants without digital fabrication)	40%
	3D model (the shared information model among project participants including digital fabrication)	32%
	None of the above	10%
nD modelling used	4D (construction sequencing)	30%
	5D (cost estimation)	16%
	6D (asset lifecycle management)	8%
	None of the above	46%
Gender	Male	96%
	Female	4%
Age	20-30 years old	0.4%
	30-40 years old	19%

	40-50 years old	31.8%
	>50 years old	48.8%
Years of working experience	0-5 years	3%
	5-10 years	5%
	10-15 years	12%
	15-20 years	15%
	>20 years	64%
Role	Project manager	37%
	Construction manager	12%
	Contract manager	13%
	Information manager	7%
	Engineering manager	13%
	Project control manager	6%
	Other roles	13%

Appendix B

Measurement of key constructs

No.	Variables/ Code	Reflective Measurement Items	Modified from Referred Sources
1	**Contractual Control (CON)**		
	CON_ 1	The contract specified right to audit for compliance with the creating, using and maintaining BIM.	Lumineau and Henderson (2012)
	CON_ 2	The contract stipulated damages against the party who failed to conform to the obligations of creating, using and maintaining BIM.	Lumineau and Henderson (2012)
	CON_ 3	The contract provided provisions for controlling and monitoring BIM deliverables.	Lumineau and Henderson (2012)
	CON_ 4	The contract specified resolution for nonconformance to the terms and conditions of creating, using and maintaining BIM.	Lumineau and Henderson (2012)
2	**Contractual Coordination (COR)**		
	COR_ 1	The contract delegated duties to create, use and maintain BIM.	Lumineau and Henderson (2012)
	COR_ 2	The contract provided operational coordination for parties to discuss the necessary adjustments that need to make	Lumineau and Henderson (2012)

	on BIM upon completion of the model review.	
COR_ 3	The contract provided strategic coordination for parties to sharpen the second-stage specific objectives of BIM development through mutual consultations after completion of the first-stage BIM development.	Lumineau and Henderson (2012)
COR_ 4	The contract provided dispute resolution provisions to deal with the conflicts arising from developing, using and maintaining BIM.	Lumineau and Henderson (2012)

3 Contingency Adaptability (COA)

COA_ 1	The contract provided provisions that required revisions/updates of BIM in conjunction with the variations/changes to the works.	Wang et al (2017)
COA_ 2	The contract provided principles or guidelines for handling unforeseen circumstances arising from developing, using and maintaining BIM.	Wang et al (2017)
COA_ 3	The contract provided solutions for responding to various contingencies arising from developing, using and maintaining BIM.	Wang et al (2017)

	COA_ 4	The contract specified procedures for changes made in BIM.	Quanji et al (2016)
4	**Calculative Trust (CAL)**		
	CAL_ 1	Considering risks and rewards, we believed the other party would behave honestly in dealing with us.	Poppo et al (2016)
	CAL_ 2	Taking into account the high cost of misconduct, we believed the other party would behave trustworthily in performing the works.	Poppo et al. (2016)
	CAL_ 3	We believed the other party would act professionally and competently in performing the works.	Poppo et al. (2016)
	CAL_ 4	We expected the relationship with the other party would continue for a long time.	Wu et al (2017)
5	**Relational Trust (REL)**		
	REL_ 1	Both of us were confident that our interests would be protected because we shared a common identity.	Poppo et al (2016)
	REL_ 2	We believed the other party would act effectively for us because we shared the same understanding of what matters.	Poppo et al (2016)

REL_ 3	We believed the other party would be willing to share information with us given that both of us shared the common objectives.	Poppo et al (2016)
REL_ 4	Both of us would be willing to look for a joint solution to a problem arising in the project because we shared the common objectives.	Poppo et al (2016)

6 Calculative Distrust (DIS)

DIS_ 1	We believed monitoring of vulnerabilities (e.g. potential leakage of valuable knowledge) would safeguard our interest in the project.	Lumineau (2017)
DIS_ 2	We believed healthy suspicion of the other party would protect us against potential opportunism.	Lumineau (2017)
DIS_ 3	We supported vigilance against the other party.	Lumineau (2017)
DIS_ 4	We believed constructive scepticism of the other party enabled us to work more confidently in the project.	Lumineau (2017)

7 Perceived Fairness (PF)

PF_ 1	Our remuneration was commensurate with our ability, effort, input, and experience.	Lim and Loosemore (2017)
PF_ 2		Lim and Loosemore (2017)

	PF_ 3	We were provided with adequate resources to execute our work effectively.	Lim and Loosemore (2017)
	PF_ 4	The risks that we were required to bear were equitable and commensurate with our capability to cope with them.	Lim and Loosemore (2017)
		We were paid equitably for the job that we completed.	
8	**Project Performance (PP)**		
	PP_ 1	In general, the project team members were very satisfied with their work.	Thompson et al (2007)
	PP_ 2	The project outcome added value to the business operations of our firm.	Thompson et al (2007)
	PP_ 3	The rate of the project met the schedule as compared to other projects.	Thompson et al (2007)
	PP_ 4	The rate of the project met the budget as compared to other projects.	Thompson et al (2007)
	PP_ 5	The rate of the project met the quality of the produced work as compared to other projects.	Thompson et al (2007)
	PP_ 6	The rate of the effectiveness of team members' interactions as compared to other projects.	Thompson et al (2007)
	PP_ 7	The rate of the project met the health and safety expectations as compared to other projects.	Suprapto et al. (2016)

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I, Cen Ying Lee, contributed abstract, introduction, BIM and DMAT uses, review methodology, findings, analysis and discussions, conclusions, recommendations and references significantly to the paper/publication entitled "**Streamlining Digital Modeling and Building Information Modelling (BIM) Uses for the Oil and Gas Projects.**"

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Dr. Heap-Yih Chong

__________________20-09-2018___________________

Prof. Xiangyu Wang

____

APPENDIX G

Statement of Author's Contributions

To Whom It May Concern

I, Cen Ying Lee, contributed abstract, introduction, review methodology, findings of legal issues surrounding BIM, associated solutions, discussions, conclusions and references significantly to the paper entitled "**A critical review of legal issues and solutions associated with building information modelling**."

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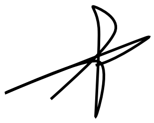

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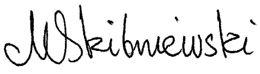

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To Whom It May Concern

I, Cen Ying Lee, contributed abstract, introduction, literature review complex project management knowledge areas, review methodology analysis of SNA application in complex project management, discussions, conclusions and references significantly to the paper/publication entitled "**Critical Review of Social Network Analysis Applications in Complex Project Management**"

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Assoc. Prof. Pin-Chao Liao

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Appendix I

Statement of Author’s Contributions

To Whom It May Concern

I, Cen Ying Lee, contributed abstract, introduction, trust and distrust in contracting, BIM performance in relation to beneficial outcomes of trust and distrust, contract functions, trust-based functional contracting model to enhance BIM performance in EPC Projects, conclusions and references significantly to the paper/publication entitled “**Enhancing BIM Performance in EPC Projects through Integrative Trust-Based Functional Contracting Model**.”

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